ОБЩЕСТВО НА ТРИБОЛОЗИТЕ В БЪЛГАРИЯ

SOCIETY OF BULGARIAN TRIBOLOGISTS

ТЕХНИЧЕСКИ УНИВЕРСИТЕТ – СОФИЯ

TECHNICAL UNIVERSITY OF SOFIA

ТРИБОЛОГИЧЕН ЖУРНАЛ БУЛТРИБ

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БУЛТРИБ '12

Научен отчет по проект CEEPUS III-BG-0703-01-1213

"Modern Trends in Education and Research on Mechanical Systems - Bridging Reliability, Quality and Tribology"

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ВСТЪПИТЕЛНО СЛОВО

Мара КАНДЕВА
Председател на Обществото на триболозите в България

Уважаеми колеги, скъпи гости на конференцията БУЛТРИБ'2012,

За мен е голямо удоволствие да Ви приветствам с добре дошли на международната конференция БУЛТРИБ'2012!

БУЛТРИБ'2012 е посветена на 80 годишния юбилей на проф. дтн Нягол Манолов – създател на българската школа по трибология, на Обществото на триболозите в България (ОТБ), на Балканската трибологична асоциация (БТА) и на Интердисциплинната гражданска академия (ИНГА).

БУЛТРИБ'2012 се провежда съвместно с работната среща на партньорите от проекта CEEPUS III-BG-0703-01-1213 „Съвременни тенденции в обучението и научните изследвания върху механични системи – връзка между надеждност, качество и трибология", обединяващ 19 университета с водещ координатор Университет по химична технология и металургия – София. Мисията на този проект е да разработи функционална контактна мрежа на триболозите в Централна и Югоизточна Европа.

БУЛТРИБ'12 се провежда съвместно с международната научна конференция AMTECH'2012 с домакинството на Машинно-технологичен факултет при Техническия университет-София.

БУЛТРИБ'12 е първата конференция, която се провежда на територията на новооткрития модерен Библиотечно-информационен комплекс при ТУ-София.

Благодаря на нашите скъпи гости от Гърция, която в момента управлява Балканската трибологична асоциация с председател проф. Константин Бузакис, на колегите от страните членки на БТА – Румъния, Сърбия и Турция.

За всички нас е особена чест присъствието н такива изявени международни триболози като Акад. Дмитрий Гаркунов и проф. дтн Валентина Бабел от Москва, Акад. Кирил Войнов от Санкт Петербург, проф. Станислав Питко от Краков и много други наши колеги и приятели.

Настоящата конференция е събитие, което разширява функционалното научно-технологично и образователно пространство на лабораторията по трибология към МТФ като национален координационен център за България.

Използвам случая да благодаря на ръководството на Научно-изследователския сектор при ТУ-София за безрезервното съдействие и финансово осигуряване на конференцията в рамките на форума „Дни на науката на ТУ-София-2012".

Накрая лично и от името на Обществото на триболозите в България изразявам дълбока признателност към нашия учител проф. дтн Н. Манолов и му пожелавам добро здраве и творчески успехи!

Обявявам 9-тата Международна конференция БУЛТРИБ'12 за открита!

19 октомври 2012 г. София

OPENING SPEECH

by ***Mara Kandeva***
President of the Society of Bulgarian Tribologists

Dear colleagues, dear guests to the 9th Conference BULTRIB'12,

I am honored to welcome you to the International Conference BULTRIB'12!

The Conference BULTRIB'12 is dedicated to the 80th anniversary of Prof. DSc. Nyagol Manolov – originator of the Bulgarian school in tribology, of the Society of Bulgarian Tribologists, of the Balkan Tribological Association and the Interdisciplinary Civil Academy in Bulgaria.

BULTRIB'12 is held along with the Workshop of the partners in the first Tribology Network Project CEEPUS III-BG-0703-01-1213 "Modern Trends in Education and Research on Mechanical Systems - Bridging Reliability, Quality and Tribology", unifying 19 universities of 10 European countries. Leading coordinator is the University of Chemical Technology and Metallurgy in Sofia. The mission of the Project is to develop a functional contact network of the tribologists in Central and South-East Europe.

BULTRIB'12 is held along with the 10th International Scientific Conference AMTECH'12 - the scientific forum of the Faculties of Machine Technology and Machine Building, with host the Faculty of Industrial Technology at the Technical University - Sofia.

BULTRIB'12 is the first conference held in the modern new Library and Information Complex at the Technical University - Sofia.

I would like to express thanks to our colleagues from Greece, which is authorized with the present 3-years chair of the Balkan Tribological Association under the presidency of Prof. Dr. Konstantinos-Dionysios Bouzakis, to our colleagues of the member countries of the Balkan tribological Association – Romania, Serbia and Turkey.

We are all honored by the presence of the eminent tribologists like Acad. Prof. Dmitrii Garkunov and Prof. Valentina Babel from Moscow, Acad. Prof. Kiril Voinov from Sankt Peterburg, Prof. Stanislaw Pytko from Krakow, Prof. Andrei Tudor from Bucharest, Prof. Hakan Kaleli from Istanbul, and to many other colleagues and friends.

The present conference is an event which expands the functional research and educational space of the Laboratory for tribology of the Faculty of Industrial Technology - Sofia making it a national coordination center for Bulgaria.

I take this opportunity to express our gratitude to the managing body of the Research and Development Sector in the Technical University – Sofia, for their unreserved assistance and financial support for the conference in the frames of the Forum "Days of Science in the Technical University – Sofia, 2012".

Finally, I would like to convey in my name and in the name of the Society of the Bulgarian Tribologists, our profound thanks to our teacher Prof. DSc Nyagol Manolov, wishing him good health and further achievements in his work!

I open the 9th International Conference BULTRIB'12 and I wish all delegates fruitful and beneficial participation at the Conference and pleasant stay in Sofia!

Sofia, October 19th, 2012

International Tribology Council

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September 2012

MESSAGE TO BULTRIB '12 and CEEPUS WORKSHOP

18 – 20 October 2012

by

PROFESSOR H PETER JOST CBE DSc DTech DEng

Greetings to the Chairman, Members of the Organising Committee and all participants of BULTRIB '12 and CEEPUS Workshop for a successful, instructive and enjoyable venture, especially as it is linked to one of Tribology's International Greats, Professor Nyagol Manolov.

The importance of the subject of tribology and especially those of its aspects in which Professor Manolov has internationally distinguished himself, has gained considerably, not only in engineering design and operation, but energy and materials saving and improvement of the environment.

The conservation of Energy and the protection of the Environment have become prime objectives of tribology to help to ensure the continued existence of our way of life. Hence the birth of Green Tribology, its aim being to save energy and materials and enhance the environment and the quality of life.

Energy in all its forms, has a vital part to play in endeavours to keep our planet fit for future generations. We know that tribology is all pervading, because friction is all pervading. If it were not for friction we could not exist, yet over 30% of generated energy is wasted in industry. The control of friction is an important facet in the area of energy, which brings us back to Professor Manolov and to the aims of this Conference.

I hope that all participants will benefit not only from the contents of the papers presented and from their discussions, but that they will also enjoy the Conference and return to their places of activity, wherever they are, as banner bearers of tribology in general and of Green Tribology in particular.

With these thoughts, I send greetings to all of you engaged in this International Conference, with particular good wishes to Professor Nyagol Manolov on the eightieth anniversary of his birth, which he and all tribologists will celebrate.

H Peter Jost
President

LABORATORY FOR MACHINE TOOLS AND MANUFACTURING ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
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Your Reference	Our previous References	Our Reference	Date
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Subject: Wishes

Dear Colleague Manolov!

Please accept my apologies that insuperable professional obligations hindered me to be with you in Sofia, on the occasion of your 80th anniversary. Therefore, by this brief note, my Collaborators and I would like to wish you good health, every happiness for you and your family and to encourage you to continue to be active, successful and productive.

Dear Professor Manolov, the Balkan Tribological Association (BTA) is your child, born in Sofia twenty years ago. BTA is meanwhile a mature and well known Institution, with significant activities and own journal, included in science citation index. Please be sure, that all our colleagues will continue your efforts for improving BTA, which represents an important link among the tribologists of all Balkan Countries.

Last but not least, I also would like to wish a successful and fruitful BulTrib'12 Conference conduct and all my best to the participants.

Prof. K.-D. Bouzakis

President of the Balkan Tribologiscal Association

До
професор дтн Нягол Манолов

Уважаеми професор Манолов,

Бих искал от името на академичната общност на Техническия университет - София и лично от свое име най-сърдечно да Ви поздравя по повод Вашия 80-годишен юбилей.

Това е достатъчен повод да изкажа благодарност на създателя на една цяла школа от преподаватели в катедра „Механика", на дългогодишния ръководител на Лаборатория по трибология, на основателя на Обществото на триболозите в България и Балканската трибологична асоциация.

Вие можете да се гордеете със своите талантливи възпитаници, постигнали висок професионализъм и допринесли за повишаване авторитета на висшето инженерно образование не само у нас, но и далеч зад пределите на Родината ни. Вярвам, че те ще продължат традициите, създадени от Вас, и в новите обществено-икономически условия, в които живеем и работим, винаги ще си спомнят с най-хубави чувства за своя професор!

Уважаеми професор Манолов,

От името на Академичното ръководство на ТУ - София искам да изразя нашето най-голямо уважение към Вас и Вашата дългогодишна дейност в областта на образованието и науката, да Ви пожелая здраве и лично щастие.

ЧЕСТИТ 80-ГОДИШЕН ЮБИЛЕЙ!!!

октомври 2012 г.
гр. София

РЕКТОР:
проф. д-р инж. Марин Христов

До
професор дтн Нягол Манолов

Уважаеми професор Манолов,

От името на Научноизследователския център при Техническия университет - София и лично от свое име най-сърдечно Ви поздравявам по повод Вашия 80-годишен юбилей.

Ползвам се от случая да изкажа благодарност на един от забележителните, авторитетни и достойни за уважение български специалисти в областта на трибологията, отдал повече от 40 години от живота си на активна научноизследователска, преподавателска и ръководна дейност.

Уважаеми господин професор,

Вие можете да се гордеете със своите научни постижения и разработки, оставили следа в развитието на инженерната наука и допринесли за повишаване авторитета на българските специалисти не само у нас, но и далеч зад пределите на Родината ни.

От името на ръководството на НИС при ТУ - София искам да изразя нашето най-голямо уважение към Вас и Вашата дългогодишна дейност в областта на образованието и науката, да Ви пожелая здраве и лично щастие.

ЧЕСТИТ 80-ГОДИШЕН ЮБИЛЕЙ!!!

октомври 2012 г.
гр. София

Зам.-ректор по НПД:
доц. д-р инж. Иван Кралов

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ОСЕМДЕСЕТ ГОДИШНИЯТ ЮБИЛЕЙ НА Проф. дтн НЯГОЛ МАНОЛОВ

Проф. дтн Митко МИХОВСКИ

THE 80TH ANNIVERSARY OF PROF. DSC NYAGOL MANOLOV

Prof. DSc Mitko MIHOVSKI

Проф. дтн Нягол Манолов, академик на интердисциплинната гражданска академия (ИНГА), е роден на 28.10.1932 г. в с. Мъдрец, Старозагорско.

След завършване на средното си образование постъпва в СУ „Кл. Охридски”, където през 1954 г. завършва специалност „Физика”. От 1954 до 1958 г. е учител по физика в Симеоновград и Хасково.

От 1959 г. започва неговата педагогическа дейност като преподавател и ръководител на катедра „Техническа механика” във ВНВУ „В. Левски” в гр. Търново (1959 – 1963).

От 1959 г. до пенсионирането си през 2000 г. работи последователно като асистент, доцент и професор в ТУ – София в катедра „Механика”.

Във ВМЕИ „Ленин” младият асистент Н. Манолов работи под ръководството на проф. Г. Данов, който го ориентира към проблемите на механиката на контактните взаимодействия в сформираната през 1963 г. лаборатория по „Контактна механика”.

През 1966 г. проф. Питър Джост в Лондон формулира основните задачи на трибологията и необходимостта тя да се структурира като отделна част от „Механиката”. Аргументира се необходимостта, че процесите на триене, износване и мазане имат самостоятелно и съществено значение за развитието на световната икономика. Процесите, протичащи при относителното движение на телата, повърхностното взаимодействие и разрушаване, неизбежно са вплетени в механизмите и процесите, пораждащи материални, енергийни и екологични кризи по места и за цялото общество като цяло.

През 1990 г. трибологията заема в България своето място в класификацията на научните направления. На този етап трибологията се определя като наука и технология за контактното взаимодействие на телата при релативното им преместване.

През 1966 г. младият асистент Н. Манолов насочва своите търсения в тази нова област. И така вече 46 години той е утвърден учен, изследовател и теоретик на трибологията в България и в световната практика.

Значително влияние върху формиране на научната насоченост на изследванията на Н. Манолов оказват контактите му с такива известни специалисти в областта на механичния контакт – проф. Д. Гаркунов, проф. Г. Флейшер и проф. Г. Полцер. Особено място в живота на Н. Манолов като учен заема Александър Сергеевич Ахматов, един от колосите на руската и световна наука и научен ръководител на Манолов в Москва.

Н. Манолов подчини творческите си научни амбиции без остатък на трибологията. От наука за техническите контакти той успя да развие трибологията като фундаментална наука за контакта като универсален функционален елемент във всички контактни системи в природата и обществото.

Въз основа на изследванията и резултатите си в областта на трибологията на техническите контакти Н. Манолов създава нов онтологичен модел, наречен от него „триализъм”, формулира, обоснова и разработва „модел за функционалния атом” и „контактен подход”.

Контактът като функционален обект в системите изпълнява три фундаментални функции – защитна, активна и творческа, които са свързани с обмяна на вещество, енергия и информация между телата. Той е реален обект с физическо, социално или духовно измерение, което прави системите открити, а светът в своето развитие – единен.

В областта на науката трийерархическото ниво доведе до нивото на комплексните науки, върху които се гради развитието на научното познание днес – информатиката, кибернетиката, екологията, наукознание, трибологията.

През седемдесетте години на 20 век във ВМЕИ като основно интересно и перспективно научно направление се очертава използването на ултразвуковите вълни за безразрушителен контрол и въздействие върху някои технологични процеси. Н. Манолов се ориентира към използването на ултразвуковите вълни за оценка на контактните взаимодействия. Теоретичното и експриментлно изследване, в рамките на първата му дисертационна работа, се съпътстват с получаването на авторски права върху този метод, и с увереността му в значителното бъдеще на тематиката на изучаването на третото тяло.

Неговите изследвания в областта на ултразвуковия контрол на контактните взаимодействия в следващите години бяха развити в теоретичен план и в създаването на специализирани уреди в Института по металознание (в България), в ИОПГ – Варшава, ТРТИ – Таганрог и на други места.

Н. Манолов осъзнава необходимостта от интензивно развитие на трибологичните изследвания и през 1974 г. - неговите усилия се реализират в създадената лаборатория, а по-късно в Национален координационен център по трибология, (през 1986 г.), когато на държавно ниво е приета и разработената от него и неговите сътрудници „Концепция за развитие на трибологията в България".

Наред с тази организционна дейност той израства и в научно отношение като последователно са му присъдени научните звания „доцент" и „професор", и защитава дисертация за научна степен „доктор на техническите науки" . В Координационния център по трибология се подготвят под ръковдството на Н. Манолов и първите доктори в областта на трибологията: Е. Асенова, инж. Ал. Янков, инж. В. Тенчев, инж. М. Кандева, инж. Л. Йорданов, инж. С. Кавалджиев, инж. М. Теофилова и др.

Основните научни направления, по които се работи в Центъра по трибология, са:

- изследване на контактни състояния на твърди тела;
- изследване на контактни взаимодействия и процеси между твърди тела;
- взаимодействие на еднофазни и многофазни структури и потоци с твърди тела;
- дисперсни трибосистеми.

От по-важните постижения на Н. Манолов и неговата научна школа трябва да се посочат:

- ултразвуков и пневмо-хидравлични методи в трибологи ята;
- формулиране на закон за контактното взаимодействие на телата с отчитане на комуникационния потенциал на контакта;
- нова трипараметрична форма на закона за триене, износване, деформиране и преработка на трибосъединенията;
- формулиране на ефекта на пневмо-хидравлична непроницаемост;
- разработки на калибровани пневмо-хидравлични дросели.

Изследванията на проф. Н. Манолов са публикувани в 300 научни статии, 20 монографии и 3 учебника. Автор е на 40 изобретения и патенти.

Проф. Н. Манолов развива наред с научната и активна педагогическа дейност. Разработва учебни програми за подготовка на специалисти – триболози в транспорта, машиностроенето, екологията. Включва елементи на трибологията в учебния процес по механика в ТУ – София. Създава необходимото оборудване за осигуряване на учебния процес. Разработва специалност за следдипломна квалификация на триболози. Подготвени са значителен брой дипломанти, научни сътрудници, 10 докторанти, 8 хабилитации, 5 докторантури и 2 професури с неговото активно участие и ръководство.

Проф. Н. Манолов е основател и първи председател на Обществото по триболозите в България (1993 г.) и на Балканската трибологична асоциация (1993 г.). Основател е на международното списание JBTA (Jornal of the Balkan Tribological association с импакт 0.182) (1994 г.), на списанието „Контакти". Организатор е на научни конференции на ОТБ и ИНГА, (повече от 35).

Особено следва да се отбележи дейността му по формирането на гражданска академия ИНГА през 1999 г. Интердисциплинарна гражданска академия (ИНГА) проведе за периода до 2012 г. повече от 450 заседания.

Активната му гражданска позция е високо оценена. Н. Манолов е почетен член на ФНТС, НТСМ, ОТБ и ИНГА. Носител е на отличията на ФНТС „Проф. Асен Златарев" и на наградата „Акад. А. Балевски" на НТСМ.

Днес когато приближава 80-тия рожден ден на проф. Н. Манолов той отново е пълен със сили да твори, да се бори и да утвърждава трибологичната наука в България, да се радва на едно чудесно семейство, грижовна съпруга, деца и внуци, да се радва и на своите ученици и колеги, с които той извървя този дълъг и ползотворен път в науката.

На юбиляра от все сърце!

За много години, дълъг живот с хората, които Ви обичат, уважават и ценят!

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THE COOLING-LUBRICATING LIQUID WITH Cu COMPLEXES FOR STEELS MACHINING

Stanisław PYTKO, Paweł PYTKO

Abstract: *The aim of the work was to elaborate a composition of a cooling-lubricating fluids, based on versenate complexes containing such metals as Cu, intended for application for finishing machining of steel and cast iron. In the paper the authors present the composition of aforementioned liquids. In the presented, new method, the elaborated process parameters provide the increase of the cutting tools life. The cooling-lubricating conditions provided by the elaborated method, lead to the constitution of 1μm thick metal coating, which can serve as a substrate layer for further processing e.g. electrolytic no etching-chromium plating. The abstract should be in 10pt Arial, Italic, Justified – not more than 6 lines long, summarising the work and placing it in an appropriate context.*

Key Words: *cooling-lubricating fluids, steel cutting. ecological chromium plating*

1. INTRODUCTION

The processes taking place during steel cutting are inseparably connect with sliding friction and relevant thermal and physical - chemical phenomena. The results of processes are:
- release of large quantity of heat, electrons and photons,
- increase of surface defects density and chemically activated centres, on machined surface.

Aforementioned processes, in connection with the cooling-lubricating fluid properties, have a significant influence on surface layer properties such as following:
- geometrical- correlated with surface stereometry,
- structural- resulting from fluid composition and a grade steel element machining,
- physical- connected with elastic and plastic deformation of substrate layer.

2. TRIBOLOGICAL- THERMAL PHENOMENA

Cutting edge and machined material create in cutting process, a friction pair operating in very hard tribological conditions [1]. For instance, in steel turning process, the resulting force F (Fig.1) depends among others, on cutting parameters and mechanical properties of a material. Forces evolved during cutting, result in stresses concentration in small area of friction contact, which is, in this case, in the area of the tool edge vicinity (Fig.2,3).

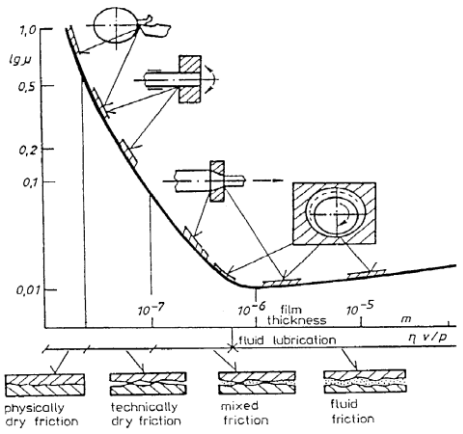


Fig.1. The relation between element-cutting tool friction and cutting fluid film thickness: μ-coefficient of friction, p-pressure, η-coefficient of viscosity, v-speed

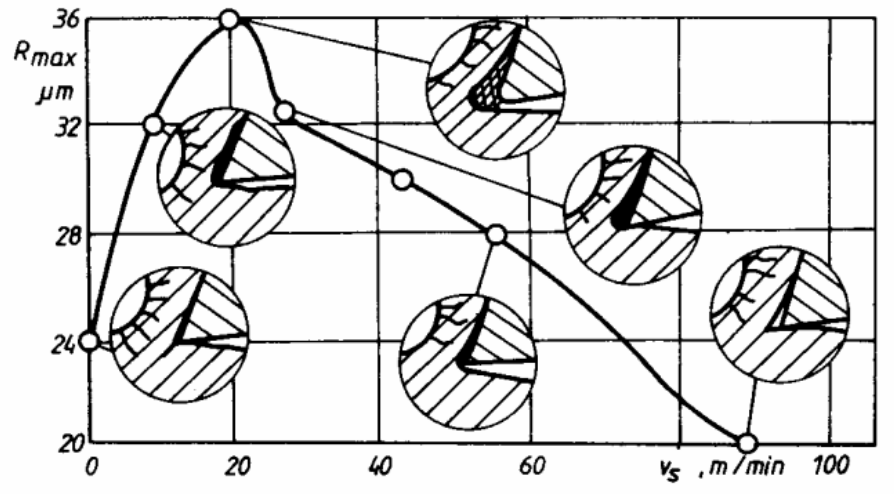


Fig.2. Geometry of tool- material contact zone

In one of the cases the crack of the material takes place ahead of the edge of the tool (see Fig.2), which is particularly important because the crack reveals a very clean surface of the machined material (steel), practically surrounded by temporary vacuum.

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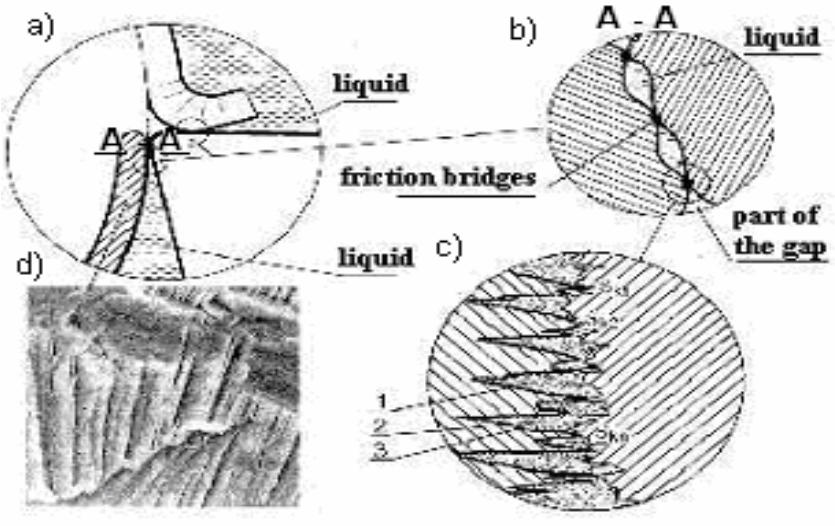


Fig.3. Geometrical character of the contact between the edge, cooling-lubricating liquid and the chip: a) contact of the cutting edge with metal, chip and fluid in macro scale, b) hypothetic contact of the tool surface asperities and machined steel in micro scale, c) contact of the edge with real surface with asperities filled by fluid, d) microscopic image of machined surface: magn.5000

Stresses accumulation in the cutting edge area 1 in Fig.4, may exceed 1000 MPa [2,3] and causing elastic deformation followed by plastic deformation and finally after exceeding of machined steel strength, may lead to break and tear of cutting layer in the form of chips. Friction force accompanying the process, resulting from adhesive friction T_{adh} and deformation friction T_{def} , are defined by the known formula:

$$T = T_{adh} + T_{def} \quad (1)$$

In the cutting process a part of energy is transformed into heat as a result of external and internal friction in the material itself. The heating of machined surface and chips, in contact with a tool surface is observed to be non-uniform. The heat is generated in a very short time, depending on cutting velocity, and in a small area. Local temperatures in the area of cutting edge may achieve value above 1000 K in a very short time i.e. 10-.5 - 10-.3 s.

Isotherms run perpendicularly to the cutting surface and their maximum values are at a certain depth below the surface. About 90% of produced heat energy is concentrated in the area close to the surface of machined material.

The heat from this area penetrates by conduction, convection and radiation, increasing vibration energy of structural elements, particles of machined steel and the solution (Fig.4). The higher temperature in the area of steel cutting, the higher is the vibration amplitude of atoms in the surface layer and in cooling- lubricating liquid. Thereby, ions and atoms diffusion into plastic deformated-area of an element is easier. The heat generation in the surface layer also leads to thermal stresses initiation and melting of the micro zones of the machined element.

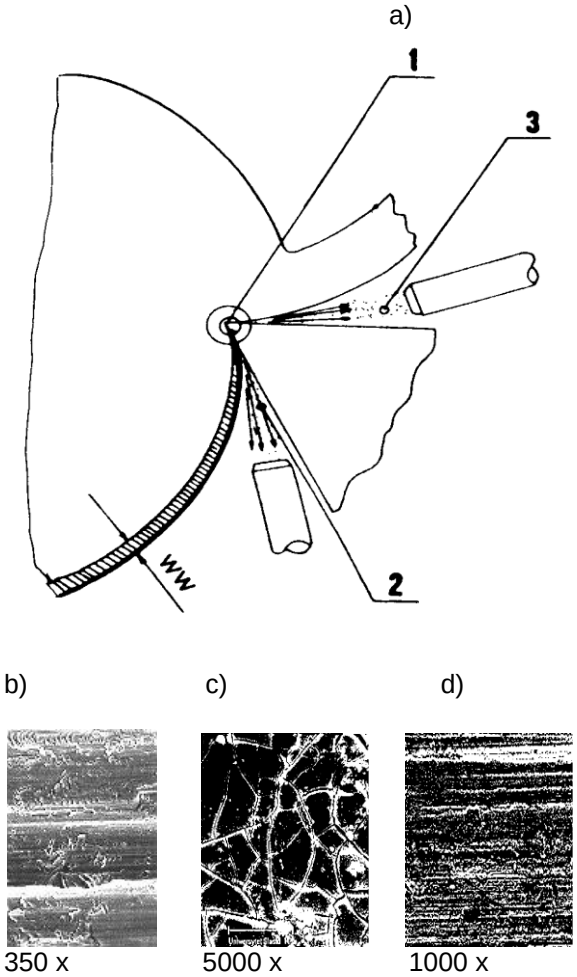


Fig.4. Phenomena in cutting area:
a) 1- area of tribological phenomena, 2- area of electron emission, 3- cooling- lubricating fluid with complex of Cu, b) layer after turning without liquid, c), d) layer after turning with used liquid (Cu)

3. CHARACTERISTICS OF WATER SOLUTIONS BASED ON COPPER COMPLEXES

Presented fluids protected by patent (being under patent proceedings) [4] (Marzec, Pytko, Zochniak 1995) are versenian and tartrate copper complexes. In the reactions of complexes formation, the coordinative properties of metal cations were utilized. The process of complexes formation by disodium versenate with copper cations can be expressed by the following equation:

$$Me^{+2} + H_2\,Y^{-2} \Rightarrow MeY^{-2} + 2H^{+} \qquad (2)$$

where: Me^{+2} - metal ion (Cu^{+2}),

Y - binegative anion of versene acid ($C_{10}\ H_{12}\ N_2\ 0_g^{-2}$).

An exemplary structure of a complex with copper cations is presented in Fig.5.

The 90 % of the cooling-lubricating fluid composition is water, moreover, the solution contains also:

The basic component of these fluids is water, being 90% fraction.

- versenate and tartrate copper complexes,
- compounds improving physical - chemical properties of a fluid,
- pH control agents,
- anticorrosion agents,
- friction depressants,
- brighteners, and others.

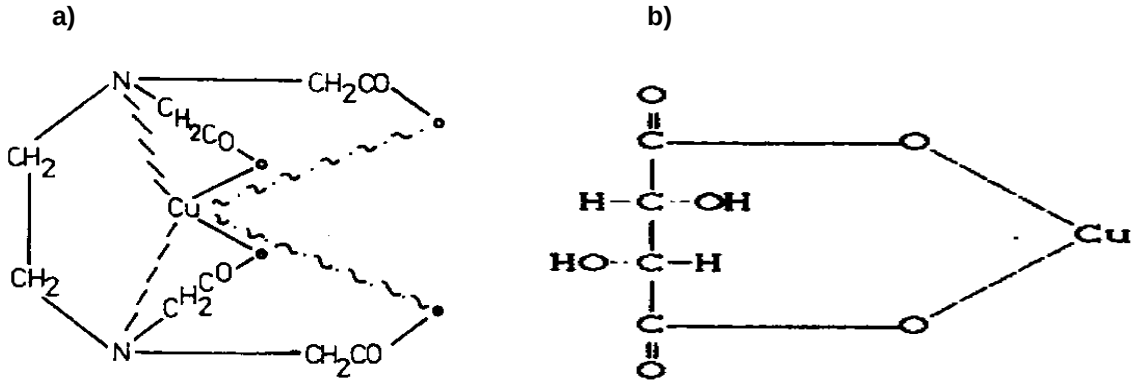


Fig.5. The structure of copper complexes: a) versenate, b) tartrate

Effectiveness of such compounds action operation depends on, among others:

- kind and composition of a complex,
- kind and number of reductants,
- reactivity of the active sites on machined surface.

Water solutions of versenate and tartrate copper complexes are stable, transparent, clear fluids, without foaming tendency and pH in the range from 2.5 to 5.0. Some modifications are required due to the low value of some properties e.g. pH, viscosity and others.

3.1. The pH control agents.

The pH value in tested fluids is a decisive factor in the process of surface layer constitution, thus the authors have analysed the effect of various factors on pH change. In publications [5] pH values from 8.5 to more than 9.0 are recommended for cooling fluids.

Undesirable processes of microbiological destruction are delayed when pH is kept above 9.0. The elaborated fluids, modified by liquid glass, ethylenediamine and other compounds, achieved pH higher than 10.0, which is shown in Fig.6 and Fig.7.

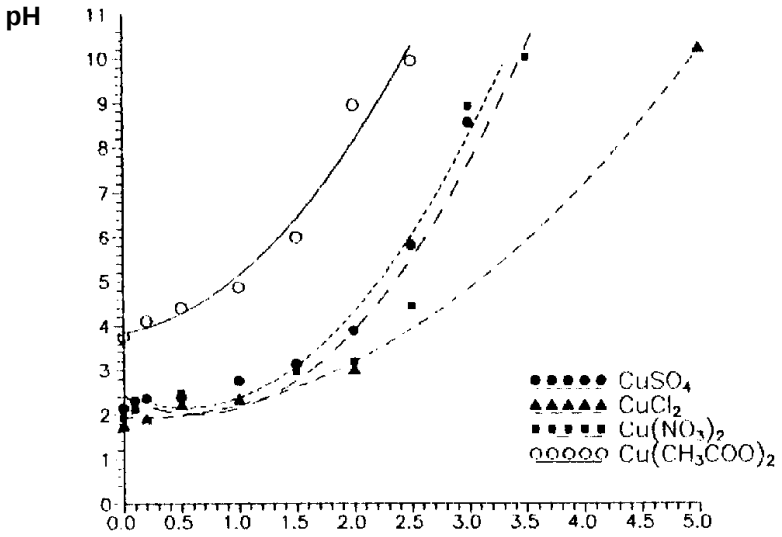


Fig. 6: The influence of liquid glass content on pH of versenate copper complexes based fluid

Diagram presented in Fig.6. shows that up to 1.5% of liquid glass content in fluids, only a slight increase of pH value is observed, however, above this level of concentration the pH increases rapidly. When the content of liquid glass exceeds 2.5% of volumetric share, the 24 hour gelatinization occurs, making the fluid useless in cutting process.

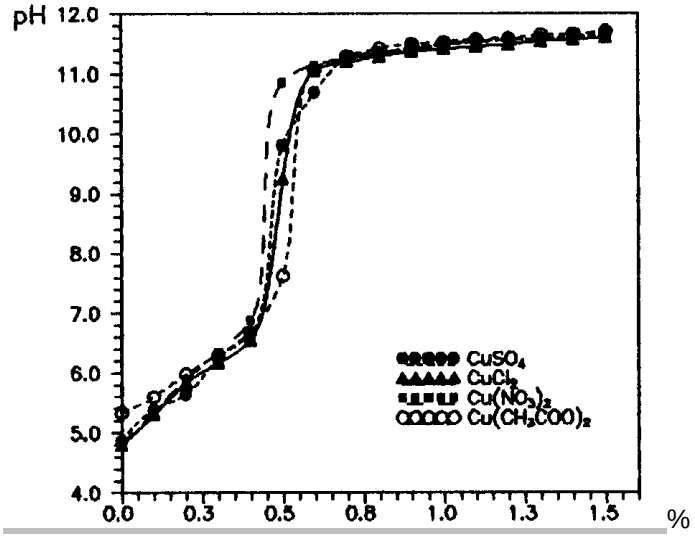


Fig. 7: The pH value vs. ethylenediamine content for tartrate copper complexes. The influence of ethylenediamine content on pH of tartarate copper complexes based fluid

Diagram presented in Fig.7. shows a rapid growth of pH value for the ethylenediamine volumetric fraction from 0.4 to 0.6% .

3.2. Tribological properties of tested fluids.

Cooling- lubricating fluids, commonly used in metal machining processes, are water emulsions with about 3-5% of mineral oils concentration.

The welding load of the four-ball friction joint lubricated with aforementioned fluid is approximately 160 daN, on the other hand, in the comparative tests with cooling-lubricating fluids with 2.5-10% of E-42 emulgator concentration, the welding load of 126 daN was obtained.

Versenate complexes based on various copper salts without modifiers have various welding loads, shown in the Table 1.

Adding of water glass into cutting fluid with copper complexes up to 1% of concentration, results in increase of welding load from 400 to 500 daN. Below 0.5% of water glass concentration, the welding load stays at level of 400 daN (Fig. 8).

Table 1. Welding load (Pz) of copper complexes ased fluids without modificators [6].

Complex on the basis of				
	$Cu(CH_4C00)_2$	$CuS0_4$	$Cu(NO_3)_2$	$CuCl_2$
Pz [daN]	200	200	250	400-500

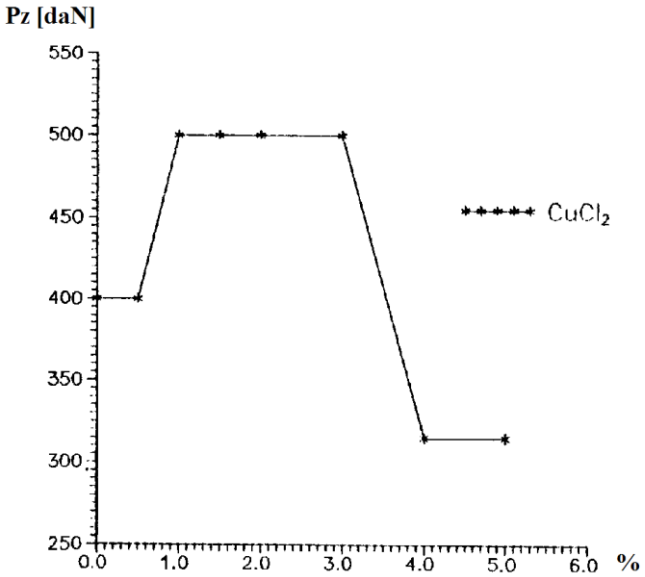


Fig. 8: The Pz values vs-liquid glass content in a fluid based on $CuCl_2$

The Pz value is held on the same level up to 3.0% of liquid glass in fluid volumetric share. Above this concentration, welding load declines to 315 daN, probably as a result of copper versenate complex stabilization with a termination of metalic copper deposition.

During the Pz tests, the surfaces of the test balls were covered with metal copper layer. Properties of constituted layer depend on structure of reacting compounds, their energetic state, a way of activity and the condition of surfaces which–physically and chemically cooperate against each other. The control agents such as liquid glass, phosphates, ethylenediamine and others compounds, introduced simultaneously, increase welding load to 800 daN.

The wear properties were measured according to ASTM test method. The diameter of wear scars on the balls, vary depending on the composition of solutions and modifiers.

Table 2. The results of wear tests under lubrication conditions of copper chloride based complex.

Solution	1	2	3	4
Scar width [mm]	1,75	1,60	1,35	1,25

where:

1.- solution without additives,

2.- solution with ethylenediamine,

3.–solution with ethylenediamine, nitrilene-trimetylenephosphonite acid,

4.–solution with ethylenediamine, nitrilene trimethylene-phosphonite acid, disodium hydrophosphate.

4. THE EFFECT OF TRIBOLOGICAL PHENOMENA ON SURFACE LAYER STATE AND FORMATION OF A COATING

The authors propose for cutting processes the special cooling - lubricating liquids according to their own patent [4]. Introduced liquids are based on versenate complexes of following metals: Cu, Zn, Cr, Mo and others. Water is used as the carrier of aforementioned complexes and additives. In cutting process, with such liquids used, the components with uncovered steel surface, react with metal complexes form the solution resulting in formation of metal coating on machined surface. The process can be described by the following chemical equation:

$$Fe^0 + Cu^{++} \Rightarrow F^{++} + Cu^0 \downarrow \quad (3)$$

The liquid participates in cutting and penetrates into cutting area due to vacuum caused by material cracking a head of the edge.

As a result of the temperature increase and the shock in the cutting area, the liquid defunds with ease into steel.

For the process of metallic coating constitution, it is important to provide such conditions, in which the cooling-lubricating liquid will be able to get close to the tip of the cutting tool edge, where the cut material cracks revealing the pure steel surface. As a result of surface discontinuity, microcapillary properties expose, creating a conditions of solution penetration into the plastically deformed zones of bulk material. In the Fig. 9. there is presented a mechanism, of the constitution of the coating containing metals, which were transferred on the machined element from the cooling-lubricating liquid.

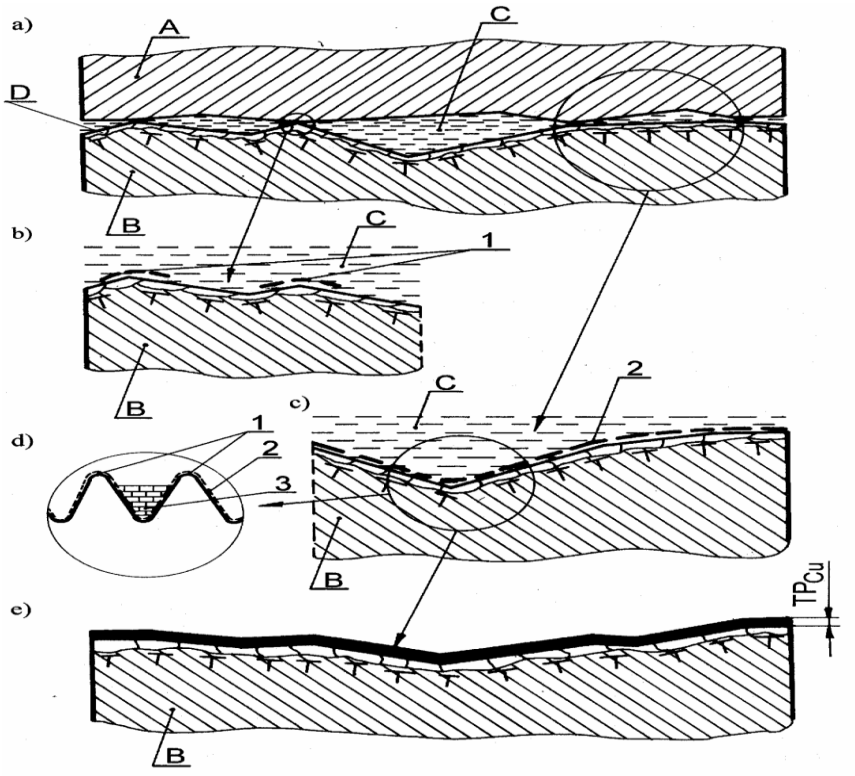


Fig. 9. Physical-chemical phenomena presenting the constitution of copper coating: A- surface of lathe tool edge ; B- surface of machined element; C- cooling-lubricating fluid; D- the plastically deformed layer; 1- area of reactions on cut element asperities; 2- the constitution of copper coating in the area of pits; 3- filling of the pits with copper

Deposition of a metal from lubricating- cooling liquid on the surface, proceeds in the following way:

- metal nuclei radical are formed, then they grow and form microcrystal. The shape of a crystal nucleus grains depends on the substrate on which the crystal is formed on,
- the crystals grow in the tangential and perpendicular directions in relation to the substrate and after aforementioned process, a stress state is constituted in the coating as a result of cooling process.

Investigations were carried out to determine residual stress state in the newly formed coating.

A complex solution of T_o ambient temperature, receive the heat from the machined surface having T_1 temperature, which leads to increase of solution temperature to the level of T_2. The process of the solution heat receiving is described by Newton's low, which says that the heat flux density is proportional to the deferences between the solid body temperature T_s and the solution temperature

$$T_p - q_s = \alpha (T_s - T_p) \quad (4)$$

The considered temperature difference leads to explosive evaporation of certain components from the cooling-lubricating fluid.

5. FINAL REMARKS

On the bases of performed investigation the following conclusions can be drawn:

- formation of a coating from metal from the cooling- lubricating liquid at cutting process, is influenced by the thermal shock accompanying this process,
- the coating thickness depends on carbon quantity in machined steels,
- the tested solutions that cool and lubricate in cutting process, lower the friction coefficient, thereby, diminish the residual stresses in respectively: the surface layer of a machined element and in the coating.

Investigations of the formation of the coating and the coating properties, -formation process were both caused by introduction of a new technology of machined elements chromium plating with no preliminary etching.

At present another investigations are carried out concerning the deposition of trivalent chromium on substrate layers according to the technology presented above.

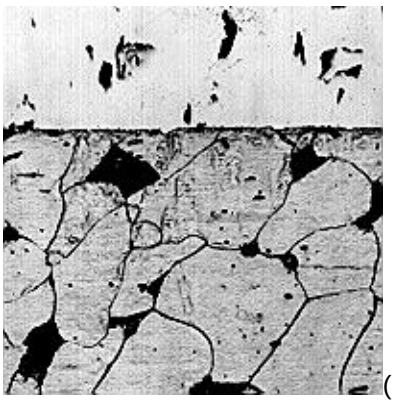


Fig.10. The coating (1) of chrome (VI) on steel (2) after turning under conditions of lubrication of fluid containing copper complexes- steel 10

From ecological and technological points of view, the solution of the problem is of high importance, because chromium plating process is shorten and etching is eliminated.

The sections of steel 10 with chromium coating deposited by the above presented technology is shown in the Fig.10.

After two years, the authors have not observed corrosion between chromium layer and coatings with Cu.

The Cr (III) plating process of covering subsurfaces during the course of machining, is significantly simpler, lower in cost and more environmental firandly than traditional chromium plating, which is noticible i.e. in the number of required process oparations:

Traditional chromium plating

1. Mechanical machining
2. Fat elimination with $H_2SO_3 + H_2O_2$
3. Cleaning
4. Etching
5. Cleaning
6. Cyan copper plating
7. Cleaning

8. Nickel plating
9. Cleaning
10. Cr(VI) plating in the bath

Ecological chromium plating

11. Mechanical machining
12. Finishing in presence of the solution of metal complexes
13. Over-etching in the H_2SO_3 + H_2O_2 solution cleaning
14. Nickel plating
15. Cleaning
16. Cr(III) plating in the bath

The advantages of the new method which is presented in the paper, is the elimination of substances which are extremely hazardous to live organisms, simplification of the process and reduction of the costs of savage utilization.

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HOW TO DIMINISH THE WEAR FOR CHAINS WHICH ARE TIGHT ON THE SPROCKETS

Kirill VOINOV

Abstract: *This article is going about the standard bush-roller chain for bicycle, machine-tool or for conveyor. And the chain can be settled in the different spatial position. In all these cases we have to stretch the chain periodically because of wear during the operation. For this aim the people apply different contact methods: spring-loaded rollers, flat springs (as a pair of friction), stretchers and so on. But here we describe a new way how to stretch the chain constantly and without any additional pairs of friction at all.*

Key Words: *Bush-roller chain, magnet, pairs of friction, wear, sprockets*

INTRODUCTION

In up-to-date machines, mechanisms, different equipments there are various working elements or the whole junctions which during many years didn't have any alterations in their design, very likely, with the exception of technology to manufacture the parts. For example, let's take the standard bush-roller chain for bicycle or for conveyor. It is stretched and put on the sprockets. In practice the next important and main characteristics can be changed: the long of the chain, pitch, mass, the distance between sprockets, diameters, number of tooth and members, number of the lines, power and high-speed factors, peculiarities of tension and lubrication.

As a tradition way of the relative position for sprockets is their vertical strengthening on the axis. In the capacity of the tension device (stretcher) we usually use the spring-loaded rollers mounted on their axis with frictionless bearings or sprockets, and seldom they are the flat springs. Moreover we can draw a chain by means of the spiral working principles which are accommodated in the special grooves. In these cases it demands for the most of these mechanisms the manual adjustment by means of the transference of the stretchers in the slots.

Although these named principles have been using for a long time, they are rather complicated during manufacture, have not high reliability for operation, forms the additional pairs of friction and wear out the chains [2,3,4].

During operation process a chain always has its natural wear and tear, the chain becomes longer that's why the angle of the girth for the tooth will be smaller. It reinforces the vibration and oscillations. In its turn this situation changes the distribution of efforts and strains both in chain and in tooth of sprockets. If the tension for the chain will be too weak, the chain can jump off the sprockets at all. In this case it brings to damage or even to fracture of our mechanism.

And what is more in practice we have a large problem with chains if they are placed in a horizontal position. In this case the wear for chain and sprockets grows repeatedly and essentially. The point is that in such situation the sagging of chain doesn't useful both for chain and for the tooth of sprockets because of their intensive wear. Our practice in operation of many chains shows that the wear and tear we can see not only on the surfaces of tooth but on the "body" of sprockets also.

1. METHODOLOGY OF EXAMINATION

That's why the described situation it is needed to consider as the great problem. In this article we show the new and very simple/effective method [1] how to solve it (Fig. 1, *A, B*).

As it was mentioned above, if there are special rollers or sprockets to stretch the chains we use bearings in a design, apply lubricant in which any abrasive can get in it during operation. It leads both a spoiling for lubricant and wear for bearing.

The same negative pictures we can see if we use in the design the spring plates.

In my way the all named negative moments connected with chains and sprockets accommodated in various space position (vertical, horizontal or with a slope) were deleted in full.

For example, at the vertical arrangement of the chain (Fig. 1, *A*) the effective tension for the links of chain we reach by means of constant magnet *4*. The presence of the block with a screw helps us to regulate the position of our (constant or even electrical) magnet both in vertical and in horizontal disposition because the block is placed in a guide.

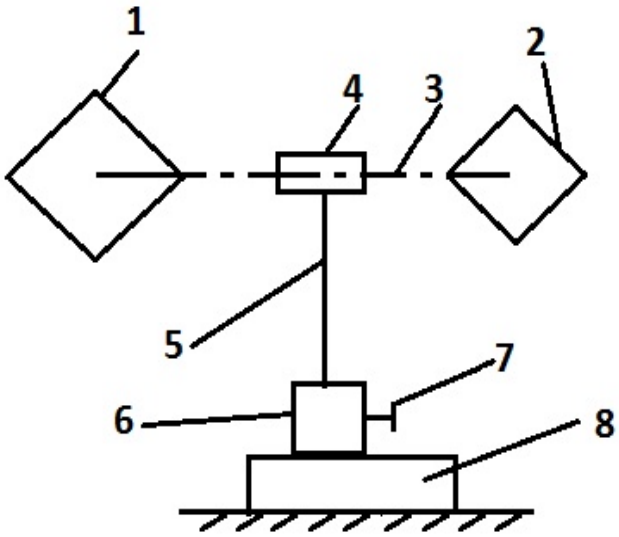


Fig. 1, A. Example how to realize the pull for the chain without any contact with it: 1 and 2 – sprockets; 3 – chain (for example, bush-roller); 4 – magnet; 5 – vertical support; 6 – block; 7 – keeper screw; 8 – basis

If the chain is very long, we can set up two magnets on the definite distance between two sprockets. In any case the magnet makes for the larger girth of sprockets tooth; automatically and constantly tighten the chain during operation deleting all negative aspects named above.

If the chain has the horizontal disposition we use two magnets once again but set up magnets quite near to the sprockets above of the two lines of a chain. By this way we raise slightly the two lines of a chain at the same time and hold the chain in such position constantly. Using this way we axise both chain and sprockets and it is very important! In this position our mechanical system will work without any distortion (Fig. 1, *B*).

In our experiment we have used the standard bush-roller chain for bicycle. The distance between axes of sprockets was 570 mm. To take into account the velocity/speed of a chain, weight, mass and another factors we can apply the definite shape and power of a magnet and assemble it in the definite position. Because of the direct contact between magnet and chain is absent so by this simplest way we eliminate any wear in this place completely.

Using such method of assembly for chains we decrease wear of chains and sprockets, vibrations, strain in parts, and the design becomes cheaper and has high reliability in operation. Moreover the experiment shows that the sagging of the chain doesn't take place at all in a position for magnets near the sprockets. So in this case the coefficient of sagging will be 1 (instead of 6 for horizontal transmissions and 3 if the slope has $\leq 40^{o}$).

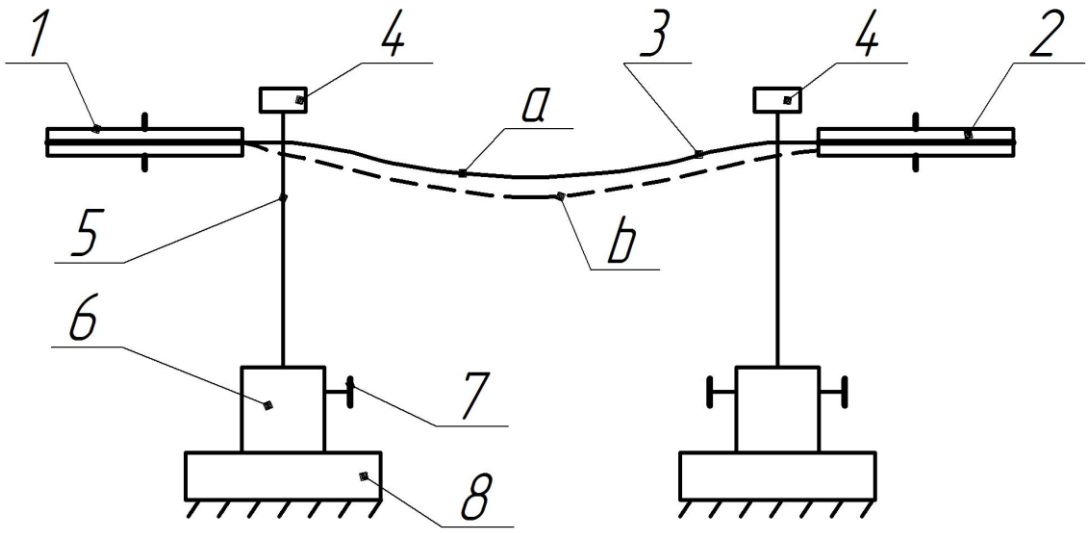


Fig. 1, B. Schematic version of a distribution sprockets and magnets which raise slightly the two lines of a horizontal chain simultaneously: the numerical symbols are the same as in Fig. 1, A; a – the disposition of a chain if we use magnets; б – sagging of a chain if the magnets are absent (the old traditional/standard sketch of assembling)

For the preliminary tension F_0 of chain from the excessive sagging they use the next formula:

$$F_0 = K_f qag, \quad \text{(N)},$$

where K_f – is the coefficient of sagging;
q – mass of 1 m for chain, kg/m;
a – the distance between axes of sprockets, m.;
g – acceleration (9,81 m/c^2).

Thus, in our case if we have got the horizontal position, the chain and sprockets raise slightly, and the coefficient of sagging will be 1 (as in a vertical position for chain and sprockets).

What kind of picture we can observe if the chain and sprockets have the vertical position? Put our magnet in the space between of the two lines of chain (Fig. 2). In this case the both lines of chain have been attracting by magnet to each other constantly during the all cycle of operation and they encompass of sprockets better.

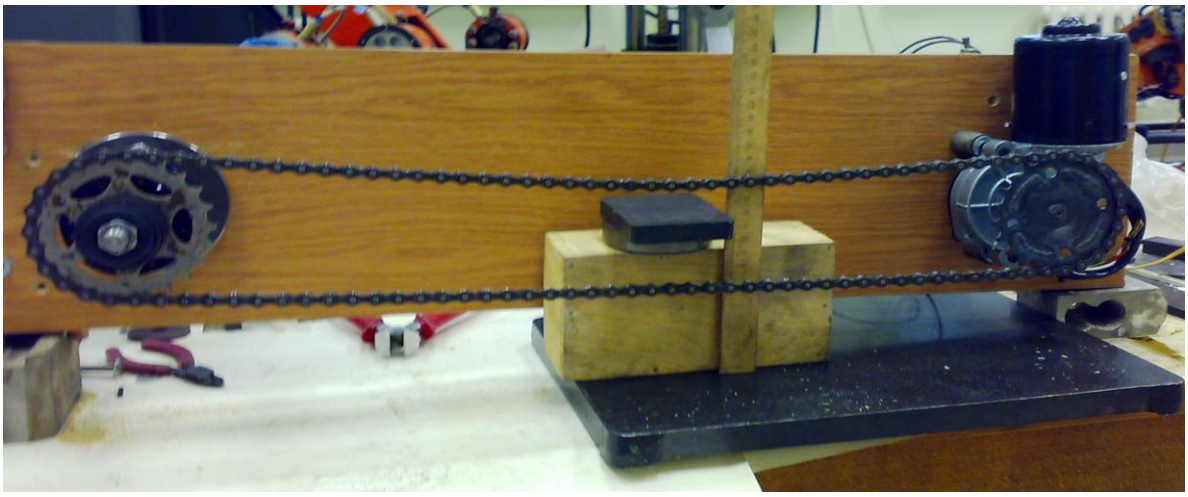


Fig. 2. The demonstration of setting for the magnet using special test bench

In the process of deterioration both the chain and sprockets, and stretching or lengthening of a chain our magnet will always attract both lines of chain. Another positive result of my observation in this case is the next: about one additional tooth will be encompassed by pitch of the chain, that's why it works much better with magnet. The rapprochement for the two lines of chain was about 15 mm.

If the distance between sprockets are big, set two or three magnets between the lines of chain. They will calm the vibration of the oscillation, too.

Now here it is the picture which demonstrates us the real shape of chain and sagging in a horizontal position with sprockets (Fig. 3 and Fig. 4). We made the experiment using special test bench.

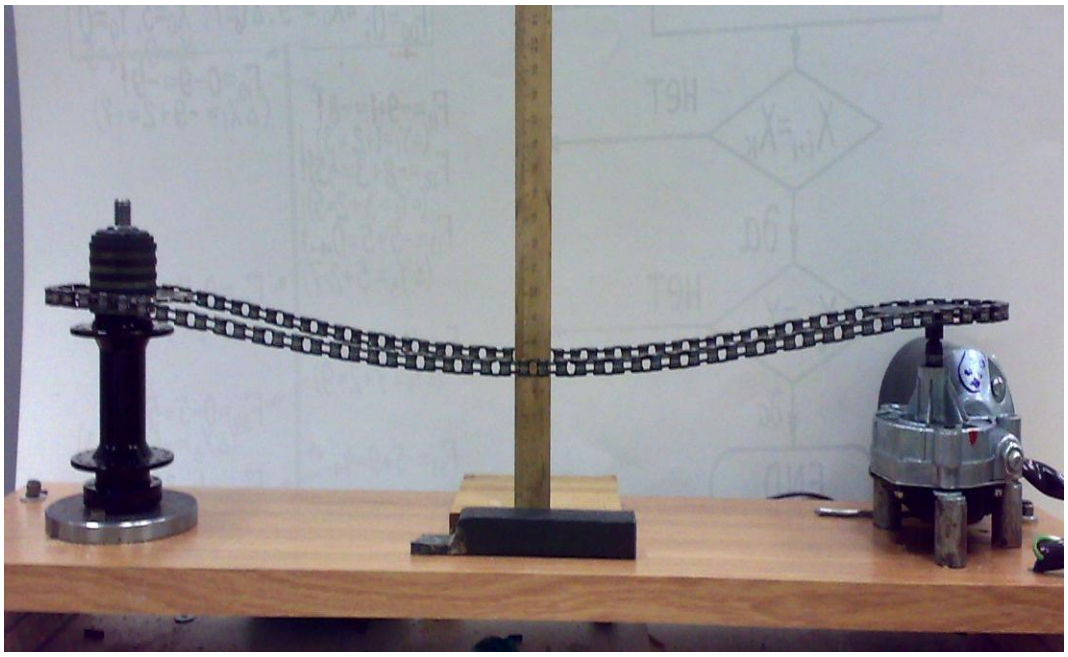


Fig. 3. Laboratory stand to investigate chains and sprockets if they have a horizontal Disposition

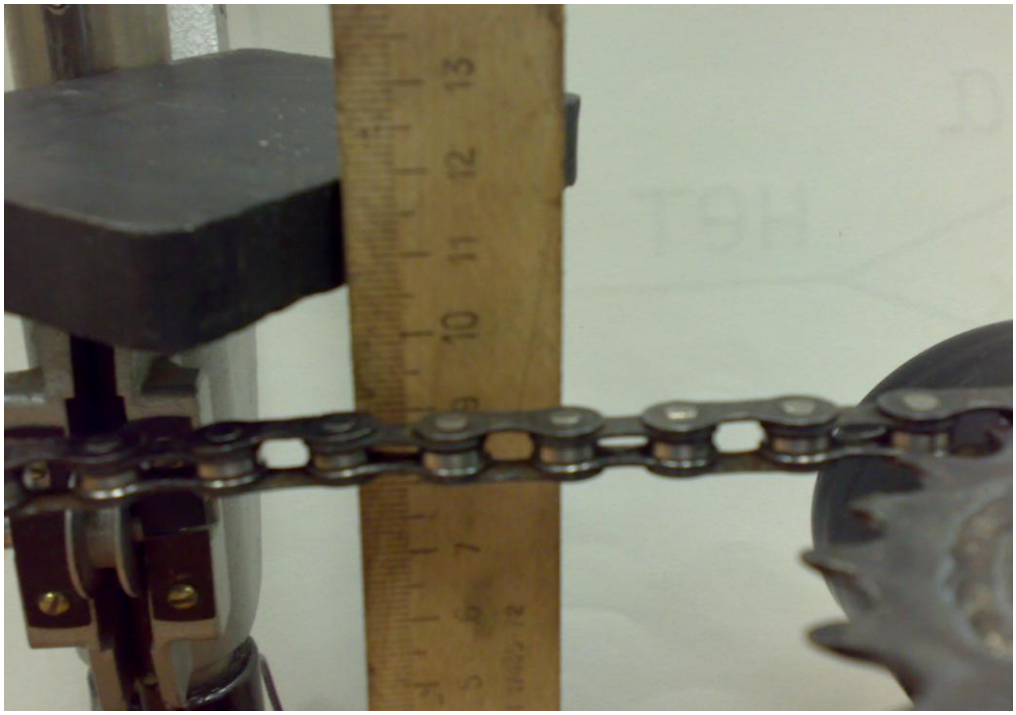


Fig. 4. Other foreshortening when we can see as the magnet raised slightly the line of the chain and put it in one plane with sprocket

2. EXAMINATION RESULTS AND CONCLUSION

So, we have got the new way to decrease essentially wear and tear for chains and sprockets in their different space disposition (vertical, horizontal or with a slope). This way helps to increase the reliability and durability both for chains and sprockets during their operation.

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NEW ORGANIC LUBRICANT

Kirill VOINOV

Abstract: *There is information about the new organic lubricant (not liquid) which is the cheapest at the present day in the world. It can be effectively used in different mobile junctions in machines and mechanisms. The first investigation using programme MathCad in personal computer with new lubricant is given, too.*

Key Words: *organic lubricant, hair, beard, moustache, wear*

1. COMMON INTRODUCTION AND INTRODUCTION

A very new organic lubricant is described in this paper. It didn't apply anywhere before as we think and presuppose. It is the cheapest lubricant in the world as it seems to me. Really, if we want to take any lubricant (oil, grease, fat, chemical structure and so on) we need to prepare it (grow, make in laboratories or in works). But in this case we don't produce it by means of special technical or technological procedures (using plants, oil, chemical industry and so forth). That's why a new organic lubricant can be realized in practice for pairs of mobile junctions. As you certainly know, to prepare some amount organic or synthetic lubricant we need to expend the definite efforts. For example, if we want to get organic oil we cultivate plants, fruits, vegetables, trees or animals (pigs, sheep, fish,…). Periodically we can get such kind of oil from the nature directly and at once. The next action is to keep this lubricant or work overtime the initial material. It takes from us many hours, days or even months sometimes. Moreover we consume time and much money. So, what kind of organic oils do we usually have? They are, for example: butter, vegetable oil, rape oil, olive oil, and many others.

Among the synthetic lubricants we can refer to both Russian and foreign chemical compositions: axial lubricant for axle-box in railway transport, VNIINP, for all-seasons, Castrol, Mobilux, Multi–Purpose Grease and so on. It is well known, in order that to improve the technical characteristics of lubricants the specialists try to include the different additives which must positive change the lubricant properties.

But we must remember and negative moments connected with lubricants. Namely:

- liquid lubricants (especially) under the load (in the contact "body-counter body") try to destroy the upper layer of surface where there are roughness, micro-defects and usually maximum strains. These types of oils try to break the thin cracks and surface defects intensively;
- at the beginning of motion for body we have to apply more power to get moving it if there is oil or any grease on the surface in a contact zone;
- we must have plants/works and especial equipment to produce lubricant, to pack it up into the packaging;
- we have to utilize old and worked out lubricant, keep it against fire and explosion or renew initial characteristics and properties…and so on.

All these factors demand our efforts, labour/work, time and money. That's why it will be the very useful fact if the lubricant can't destroy both roughness and upper layer of surface.

2. METHODOLOGY OF EXAMINATION

To measure the stress on the cross side of surface for asperity we made physical macro model in a view like pyramid. Five sensors were stuck on the cross side of the pyramid and into the model we poured out different lubricants and water by turns. After that the thin and strong film was put on the each kind of liquid and further a load was laid on the film. Personal computer fixed the stress from signals got from five sensors.

During experiments we have got the next important and interesting result, namely: if we apply lubricant which has forms as the small parts like balls, macaroni or sausages, then the stress on the surface of physical model diminishes from 30% till ten times.
What's the reason of such great positive effect? I suppose that the situation which was discovered is owing to forms of the applied lubricants. It turned out that small and springy elements of the lubricant can't penetrate very deeply into the small cracks or in the mouth of asperity. It decreases the stress essentially on the physical model.
This experiment graphically shows and prompts us the way how using such forms of lubricant we can raise in operation the reliability for different pairs of friction. Moreover these lubricants in forms as small balls, macaroni or sausages give the definite type of friction – not so much a sliding friction but more as a rolling friction.
These discovered facts helped us to find the similar organic lubricant which has approximately the same small form for elements. Maybe it will be rather strange but our hair (for example, beard and moustache) are shaved by means of electric razor give that result which we needed. Moreover the structure of hair consists of the fat (grease) which helps us to protect surfaces against wear and tear during the mobile contact for body and counter body (pair of friction). So, now we must verify this statement by experiment using test bench (Fig. 1 and Fig. 2).



Fig. 1 – Created test bench with the electric drill (as a drive) to investigate the effect if we use in a capacity of lubricant a new organic lubricant (small elements of hair)



Fig. 2 – Gathered small parts of hair (left) and specimens (as body) prepared for test (right)

In a capacity of counter body we made the cylindrical steel washers with fenders. On the surfaces of steel specimens the curve grooves were made (look at the picture Fig. 2, right). It helps to catch practically constantly our new organic lubricant which was put up between two contact surfaces (rotary body and motionless counter body). The electrical drill (brand FINCH Industrial Tools FIT^{TM} Serial NO: ID 04 1 0298) has the next characteristics: 220 V, the speed of rotation from 0 to 1410 per minute (rpm).

After testing we can see the next surface (Fig. 3) on the specimen.



Fig. 3 – The profile of the specimen (rotary body) with grooves and new organic lubricant on the surface

Fig. 4 shows us the curves of wear for two cases, namely, with dry surfaces (1) and with our new organic lubricant (2 and 3).

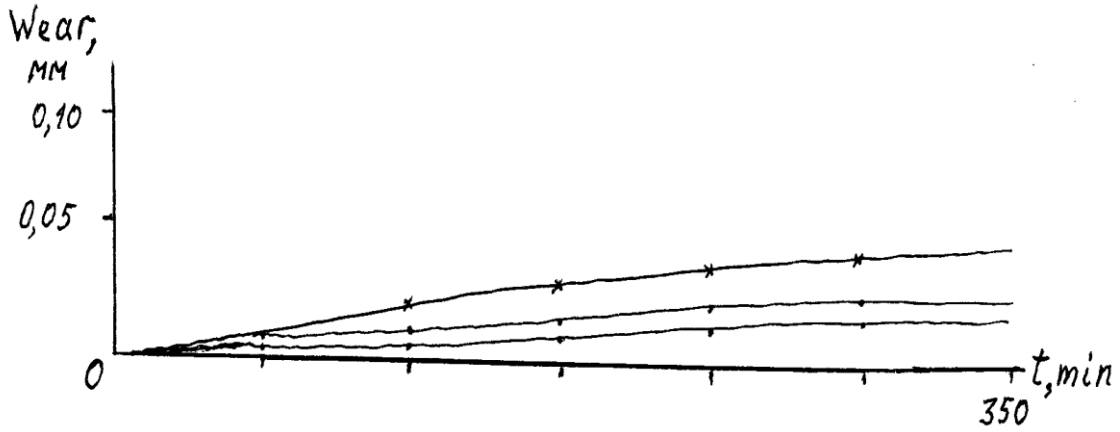


Fig. 4 – The character of wear for dry steel surfaces (number 1) and for surfaces with new organic lubricant (number 2 and 3)

Now we apply the programme MathCad to describe two of our curves connected with wear and tear.

Conventional signs:
x_0 is the mean proportional for time t;
x_i is the present variable for time t;
h is the step of observation;
H_1 and H_2 – are constants.

$$i := 1 .. 7 \qquad n := 7 \qquad h := 110$$

$x_i :=$ $y1_i :=$

x_i	$y1_i$
0	0
110	0.01
220	0.022
330	0.029
440	0.036
550	0.039
660	0.04

$x_1 := 0$ $x_n := 660$ $M := \frac{n+1}{2}$ $M = 4$

$y_0 := \sum_i \frac{y1_i}{n}$ $y_0 = 0.025$ $x_0 := \frac{x_1 + x_n}{2}$

$H_1 := n \cdot \frac{n^2 - 1}{12}$ $H_2 := n \cdot \left(n^2 - 1\right) \cdot \frac{n^2 - 4}{180}$

$$a1 := \frac{1}{3 \cdot H_2} \cdot \left[3 \cdot \left[\sum_i \left[y1_i \cdot (i - M)^2 \right] \right] - \frac{n^2 - 1}{4} \cdot \sum_i y1_i \right] \quad a1 = -1.071 \times 10^{-3}$$

$$c1 := y_0 - \frac{H_1 \cdot a1}{n}$$

$$b1 := \frac{1}{H_1} \cdot \sum_i \left[y1_i \cdot (i - M) \right] \quad b1 = 6.857 \times 10^{-3}$$

$c1 = 0.029$

This is the first equation (W1).

$$W1_i := a1 \cdot \frac{\left(x_i - x_0\right)^2}{h^2} + b1 \cdot \frac{x_i - x_0}{h} + c1$$

The second equation (W2) is the next:

$$W2_i := a2 \cdot \frac{\left(x_i - x_0\right)^2}{h^2} + b2 \cdot \frac{x_i - x_0}{h} + c2$$

At last the third equation is $W3_i := a3 \cdot \frac{\left(x_i - x_0\right)^2}{h^2} + b3 \cdot \frac{x_i - x_0}{h} + c3$

As a result:

$$1 - W1 = -1.071 \cdot 10^{-3} * (x_i - x_0)^2 / h^2 + 6.857 \cdot 10^{-3} * (x_i - x_0) / h + 0.029;$$

$$2 - W2 = -5.238 \cdot 10^{-4} * (x_i - x_0)^2 / h^2 + 5.071 \cdot 10^{-3} * (x_i - x_0) / h + 0.02;$$

$$3 - W3 = -3.81 \cdot 10^{-4} * (x_i - x_0)^2 / h^2 + 4.286 \cdot 10^{-3} * (x_i - x_0) / h + 0.017.$$

And the total graph is given in Fig. 5.

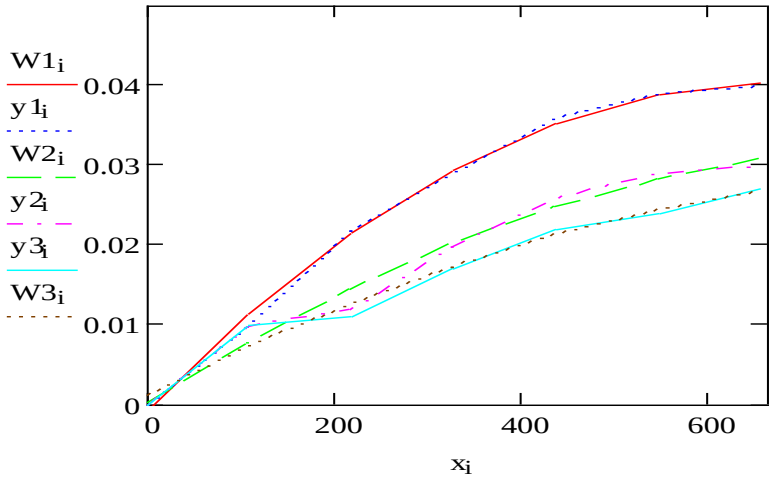


Fig. 5 – The total curves of wear

3. CONCLUSION

So, the new organic lubricant can be applied in practice.

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METHODOLOGY AND FRAGMENT OF LONG DURATION SAVING IN MEMORY THE BASIC STATUTES OF THE DISCIPLINES WHICH ARE TAUGHT

Kirill VOINOV

Abstract: *In this paper we show the new effective method of teaching and its main result, namely, how to get the stable and long duration accomplishments for those essential positions which were given to listeners (for example, students, post-graduate students, probationers, teachers, workers, employees, pupils and so on). New methodology of teaching can be effectively applied to different disciplines.*

Key Words: *teaching, long term, memory, different disciplines*

1. COMMON AND IMPORTANT METHODOLOGY PROBLEMS

Introduction

One of the very important problems in education on the whole and in the high education in particular is the low level of knowledge of those basic positions in different subjects which were given listeners by teachers some months or years ago. The main reason of such negative situation is the rather long period when listeners didn't repeat the heard material any more, the constant practice is absent or it takes place too seldom. That's why they often forget formulas, laws, terms, rules and others main factors which were given them before. Such negative example we can represent right now. The English language in many Russian high schools /institutes/universities is given during two years only. After this period for three years students didn't learn or have any earnest practice (before their diploma). In this case they can't remember many heard materials. The analogous pictures take place with tribology, the highest mathematics, the strength of materials, physics, chemistry and so forth.

In this article the author has given the material which was rewarded with grant of G. Soros. Furthermore, the new methodology of teaching had the positive success during the congress in Dusseldorf in Germany.

By opinions of the two competent medical specialists we have to repeat the same fragment several times (from 4 to 7 for the average intellectual level of human maturity). Only in this case a man can learn the material practically by heart as a good poem/rhyme or the multiplication table. In this situation we shall know this material till our pension and even more!

2. The essence of the methodology and fragments of the long duration saving in human memory the basic statutes of the disciplines/information

This human peculiarity connected with memory we'll use in our case. In a capacity of the experimental disciplines we took the next ones appropriating them conventional numbers I-IX. The numbers which are standing after the sign **/** show us, namely, how many essential questions the pedagogues / connoisseurs want to check up on the listeners/persons' memory. This information I'll give here only in brief:

applied mechanics (I/13**), parts of machines and the bases of constructions (II/**12**), firmness of materials and constructions (III/**11**), theoretical mechanics (IV/**11**), the highest mathematics (V/**14**), chemistry for engineers**
(VI/11**), descriptive geometry and drawing (VII/**10**), foreign language (English,** for example**) (VIII/**11**), tribology (IX/**13).

The note: the general amount of the important questions in each discipline we see after the oblique strokes.

The leading collaborators of the definite chairs gave these minimum questions to check up the memory of listeners. The same collaborators gave the answers for these questions, and the members of the exam commission can put the questions at the end of teaching (in the defence of diploma).

These key questions and explanations pedagogues will be use not less than 6 times in a whole period of teaching for students (listeners).

The most laborious work is the next: how to connect the work of different chairs in this plan? If it is realized in practice we'll get the brilliant result. Namely, our listeners will remember the all key states for a long time.

Below there are only several short fragments of our methodology which are represented [1, 2]. In italics we give the answers.

2.1 Questions and answers for applied mechanics:

1) What is the main aspect which we learn in this discipline? *Movement and the work for mechanisms / machines, ways to calculation of the firmness and wear.*
2) What's a machine and designate its main parts? *Machine is the working principles which transform the energy, facilitate the human labour (as motor, robot, crane and so on). The main parts in a machine usually are motor/engine, driving gear (reducing gear, for example) and executive mechanism (lift, canter,…)…*

13) Cinematic pair in mechanism? *It is a junction for two links which permits for these pairs to accomplish the relative movement.*

2.2 Questions and answers for parts of machines and the bases of constructions:

1) What must we learn when we'll listen to this discipline? *They are the next: basics of calculation, constructions and reliability for hardware in mechanical engineering.*
2) What does it mean "a part/component"? *It is an article made from the homogeneous by the name and by the trade-mark of material when any assembly actions don't take place (for example, a pinion, a pulley, a flask).*
3) Give examples of a group which has in assembling many parts. *They are the next: bearings, train of gears or toothed gearing, gear-box.*

12) What do they mean "tribology" and "tribo-technique"? *The first is the science of friction, and the second term stands for its practical application.*

2.3 Questions and answers for firmness of materials and constructions:

1) What is the main object which we'll study in the strength of materials? *It is a prismatic pivot having the straight axis.*
2) What does it mean "deformation"? *It is the alteration in the disposition for the particles (small parts) of body and as a final result is the change both for dimensions and a form/configuration.*

11) What kind of the surface elements has the extremum? *It will be on the surfaces which have a slope at the 45^o to the main surfaces.*

2.4 Questions and answers for theoretical mechanics:

1) Moment of the force $\vec{P}$ with regard to the axis z? *It is the projection on this axis for the moment $\vec{M}_O$ of the force with regard to the arbitrary point O which is on the axis z:*

$$M_{Oz} = \vec{M}_O.\vec{k} = M_O \cos\alpha ,$$

where α is the angle between the vector $\vec{M}_O$ and the axis z.

2) What is the centre of gravity? *It is the imaginary point C and the radius-vector of it is the*

$$\vec{r}_C = \frac{\sum_i \vec{r}_i G_i}{G}$$

where $\vec{r}_i$ is the radius-vector i-part of body; G_i is the weight for i-part of body; $G = \Sigma G_i$.

11) Write the differential equation for the free oscillations of the mechanical system with one degree of freedom and without any forces of resistance. *The answer:*

$$\ddot{q} + k^2 q = 0,$$

where $k = \sqrt{\frac{c}{a}}$ *is the cyclical (own) frequency of the free oscillations; a and c are coefficients of inertia and stiffness of this system accordingly.*

2.5 Questions and answers for the highest mathematics:

1) If two vectors are perpendicular then to what is the result of their scalar product? *Answer is 0.*
2) What is the module of vector, if we know its coordinates a_x, a_y, a_z? *Answer:*

$$|\bar{a}| = \sqrt{a_x^2 + a_y^2 + a_z^2}\ .$$

14) Is the calculation right for this integral $\int_0^1 x^2 dx = \frac{x^3}{3}\Big|_0^1 = \frac{1}{3}$? *Answer: Yes.*

2.6 Questions and answers for chemistry for engineers:

1) Name the main factors which influence on the velocity of the chemical reaction. *Answer: they are the nature of the chemical matters/substances, the temperature, the concentration of matter and the presence of the catalyst.*
2) Name the two ways to protect a metal against corrosion influence. *Answer: the anode covering when the potential of the protected metal is bigger than the potential of covering. Moreover in this case the covering will be destroyed in the course of time; the cathode covering when the potential of the protected material is less than the potential which the covering has.*

11) What does it mean *pH* and what values of it do you know? *Answer: the hydrogen index pH shows the amount of free ions of hydrogen in the solution. Common range for pH can be from 0 to 14.*

2.7 Questions and answers for the descriptive geometry and drawing:

1) Give the way of writing for the surface determinant. *Answer:* φ *is a surface; its presentation are* φ *(Г) , [A], where the (Г) is the geometric part and the [A] is the algorithmic part of determinant.*
2) How can you show the straight line on a diagram? *Answer: by a projection of two dots, as a section/piece, by own projections.*

10) What is the track of plane? *Answer: it is the line of intersection for the plane with the projection plane.*

2.8 Questions and answers for the foreign language (English, *for example****):***

1) Name the two versions of the Russian verb «хотеть» and give examples. *Answer: want and to be after. What is he after? = What does he want? I wanted to eat. = I was after to eat. They want to go. = They are after to go.*
2) What is the structure for The Past Perfect Tense and examples? *Answer: the structure is the next: had and the third form of the main verb. We hadn't cleaned our room for weeks. Had you visited your friend yesterday? I had done it before he entered the flat.*

11) Show the structure and give examples for The Passive Voice. *Answer: this house <u>was built</u> in 1985. The new hotel <u>will be opened</u> next year. The room is being cleaned at the moment. The experiment <u>was being made</u> when I arrived.*

2.9 Questions and answers for the tribology:

1) What does it mean "Tribology"? *Answer: it is a science about friction, wear, lubricant and interaction for surfaces in the mobile contacts.*

2) Name some models of friction. *Answer: external (in a zone of contact between body-counter body, internal (among the small parts inside of the body), friction of the rest, friction of sliding, and so on.*
3) Stages of friction? *Answer: running-in, stable period, catastrophic rate of wear and tear.*
4) Intensity of the deterioration? *Answer: it is the ratio of the wear quantity to the way on which such wear took place or to the volume of work which was made.*
5) What does it mean wear and tear? *Answer: it is the result of wear which can be estimated both in significances of length (mm, for example) and in the meaning of mass (as the weight).*
6) Varieties of lubricants? *Answer: gas, solid, liquid, mixed, plastic, half-liquid.*
7) Roughness of the surface? *Answer: it is the aggregate of the micro-irregularities with a small step which create the wear surface relief.*

13) What is the main tribology law and the notion as the third body? *Answer: the force of friction equals the sum from adhesion tie/coupling and the mechanical component connected with the failure of roughness. The third body is a possibility of any lubricant or films on the surfaces of friction.*

2.10 Now the common arrangement of questions-answers in interactions for different disciplines

(Sketch of collaboration for the examined disciplines)
I; II; III; IV; V; VI; VII; VIII; IX

I: for **II/** 6,7,8,11,12; for **IV/** 1-5; for **V/** 1,3, 5, 6,9,11,12; for **VI/** 1,2,3,4; for **VII/** 1-10; for I**X/** 1-13.

II: for **I/** 1-13; for **III/**1-9; **IV/** 1-5, 7-9, 11; **V/** 1,2,3,4, 5-14; **VI/** 1-11; for **VII/** 1-10; **IX/** 1-13.

III: for **II/** 1-12; for I**V/** 1-11; for **VI/** 5-11; **VII/** 1-10; for **IX/** 1-13.

IV: for **I/** 1-13; for **II/** 1-5, 10-12; for **III/** 1-11; **V/**1-14; for **VI/** 1-11; for **VII/** 5-10; for **VIII/**1-8.

V: for **I/** 1-6, 13; for **II/** 1-6; for **III/** 5-11; for **IV/** 1-8, 10, 11; for **VI/** 1-5; for I**X/**1-13.

VI: for **I/** 1-6, 13; for **II/** 6-12; for **VII/** 1-10; for **VIII/** 1-11; for I**X/** 1-13.

VII: for **I/** 1-4; for **II/** 1-5; for **III/** 1-11; for **IV/** 1-9; for **V/** 6-14; for **VI/** 3-11.

VIII: for **I/** 1-9, 11,12, 13; for **II/**1-5;7-12; for **V/** 12-14; for **VI/** 3-11; for I**X/** 1-13.

IX: for **I/** 7-13; for **II/**1-7; for **III/**5-11; for **IV/** 1-6, 8-11; for **VI/** 3-11; for **IX/**5-13.

3. CONCLUSION

1. We show the effective new method of teaching when listeners can memorize the key and important factors in different disciplines for a long time.
2. In this system of teaching all chairs help each other very effectively to prepare specialists/engineers with the highest level of knowledge.

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AN EROSIVE WEAR MODEL FOR AERSPACE APPLICATIONS

Danuta GRAD, Andrei TUDOR, Valeriu DRAGAN

Abstract: *The goal of this paper is to develop and implement a complex analytical model for erosive wear in aerospace components such as helicopter or turbo machinery blades. The methodology implies both an analytical model for the wear intensity and a computational fluid dynamics analysis to implement the said model. A simple airfoil is tested and a user defined flow field is generated which illustrates the erosive intensity around the perimeter of the airfoil. Results indicate the most erosion prone arias and provide a quantitative indication which can be useful in the material choice for designing a real blade.*

Key Words: *erosive wear, solid – gas flow, aerospace applications, analytical wear model, user defined flow field.*

1. INTRODUCTION

One of the aims of this study is to provide a simple, easy to use algorithm for determining the erosion rate of airfoils. – in particular for the airfoils used in helicopter main rotors such as the IAR 330 Puma. The erosion rate is of great interest in such aeronautical applications because of the composite nature of the helicopter blade. That is to say, incidents such as the one presented in **[1]** show how an apparent small erosion dammage can lead to the rapid in-flight deterioration of the entire rotor.

In order to accomplish the task of estimating which parts of the airfoil are more pre-disposes to erosive wear we must first:

1. determine the flow pressure coefficient (and implicitly the velocity distribution) near the airfoil using a computational fluid dynamics method
2. After establishing the flow parameters we move on to using the erosive wear equations based on the relative angle of attack of the impinging particles and the friction coefficient, which we will see in the following moments

By combining the two we can obtain a full picture of the airfoil erosion.

1.1. The wear model

The erosive wear equations are demonstrated in [2], therefore we will only summarise the mathematical relations:

$$I_{er} = \frac{m_{uz}}{m_{ab}} = \frac{V\,\rho_m}{\frac{4}{3}\pi\, r^3 \rho_{ab}\, n_{ab}} \tag{1}$$

where

ρ_m – density of the worn surface's material;

r – spherical radius of abrasive particle;

ρ_{ab} – density of abrasive material;

n_{ab} – the number of sand solid particles that hit the respective surface.

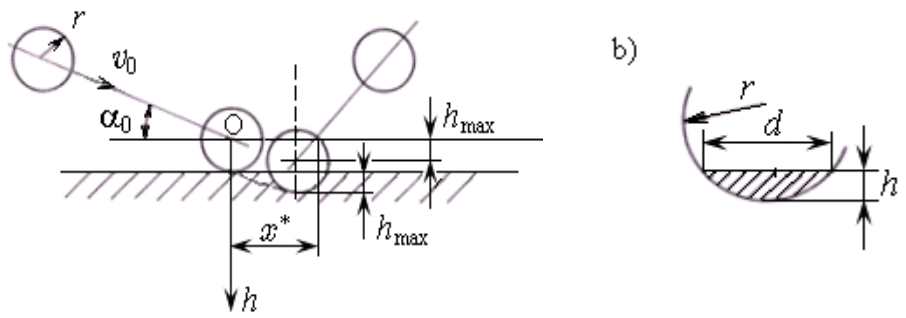


Fig. 1. The interaction between the sand solid particle and the surface worn through erosion.

The diferential equation of the paticle during the impact:

$$m\frac{v_{oh}^2}{2}-\frac{m}{2}\left(\frac{dh}{d\tau}\right)^2=\int_0^h F_n\,dh \tag{2}$$

The differential equation of the particle trajectory

$$d\xi=\left(\mu\pm\frac{\operatorname{ctg}\alpha_0-\mu}{\sqrt{1-\varepsilon^{5/2}}}\right)d\varepsilon \tag{3}$$

The integration limit is determined on the basis of the observation that in the particle's "exit" moment from the surface's material, which is elastically deformed,

$$v_X=\frac{dx}{d\tau}=0 \tag{4}$$

thus, it results:

$$\frac{dh}{d\tau}=h_{\max}\frac{d\varepsilon}{d\tau}=\pm v_0\sin\alpha_0\left(1-\varepsilon^{5/2}\right)^{1/2} \tag{5}$$

1.2. The Wear Intensity for an oblique impact wear model

From Hertz's classic relations and from the condition of plasticity, it can be deduced the maximum elastic impact velocity in any given point of the helicopter's blade, characterized by the αo angle,

$$v_{ocr}=\frac{0.798}{\sin\alpha_o}\frac{\left(\sigma_c\theta\right)^5}{\left(\rho_{ab}\theta\right)} \tag{6}$$

where σ_c is the flow resistance of the blade material.

For example, for the leading edge material with the yield strength σc = 750 N/mm²,
Young's modulus E_m = 1500 N/mm²,
v_p = 0.3 at the impact with sand particles with the density of 5 400 kg/m3,
From this we deduce the maximum velocity (m/s) for which the impact is elastic.

1.3. The Wear Intensity for plastic contact

For the plastic contact, the wear intensity can be calculated by

$$F_n = \pi\, r\, h\, \sigma_m \tag{7}$$

and

$$F = \mu\, F_n$$

where σ_m is the blade material's resistance at the plastic impact. This strength is considered variable with the temperature *T* and the hardening, evaluated through the *n* exponent

For the rebound coefficient, Stack's solution is accepted:

$$e_r = \frac{1.36 H_s^{\,0.625}}{E^{0.5} \rho_{ab}^{\,0.125} v_o^{\,0.25}} \tag{8}$$

For the tangential component of the impact

$$I_{ero} = \frac{0.052}{\left(T_t - 436\right)^{0.75}} \frac{(n+1)\frac{\mu}{\mu_c}\left(2 - \frac{\mu}{\mu_c}\right) v^2 \cos^2 \alpha}{2^{2-n} C_p n} \tag{9}$$

where

$$\mu_c = \frac{1}{(1+e_r)\tan\alpha} \tag{10}$$

is the critical friction coefficient , defined as the value above which the spherical particle begins to roll over the blade.

2. THE COMPUTATIONAL FLUID DYNAMICS TEST

For the aerodynamic test, a simple NACA airfoil was used. However, as oposed to the previous paper [2], the airfoil is no longer considered to be symetrical and also has an angle of attack of its own. This makes the flow calculation more difficult and demands for the use of more sophisticated computational means since boundary layer separation can be expected to occur. In order to be able to forsee this phenomena, the k-omega SST **[3]** and Reynolds Stress Model **[4]** were used.

The k-omega SST is the most advanced (standard) viscosity model that uses the turbulent viscosity hypotesis as it is a blending of the classical Wilcox k-omega model – which offers the best results near the wall- and the robust k-epsilon model which is considered to be the best for far field.

On the other hand, the RSM 5 equation model, is largelly considered to be the most physically sound RANS (Reynolds Averaged Navier Stokes) model. Its use is only limited by the long time it requires for the solution to converge.

Both methods show comparable results in calculating the pressure coefficients across the airfoil surface.

For the computational grid, we opted for a C-mesh with structured submaping, which was then refined using the Winslow scheme. The structured grid has also a boundary-layer type mesh near the airfoil surface in order to facilitate the convergence of the solution and also to improve the quality of the results.

Figure 2 presents the discretisation of the C-mesh used.

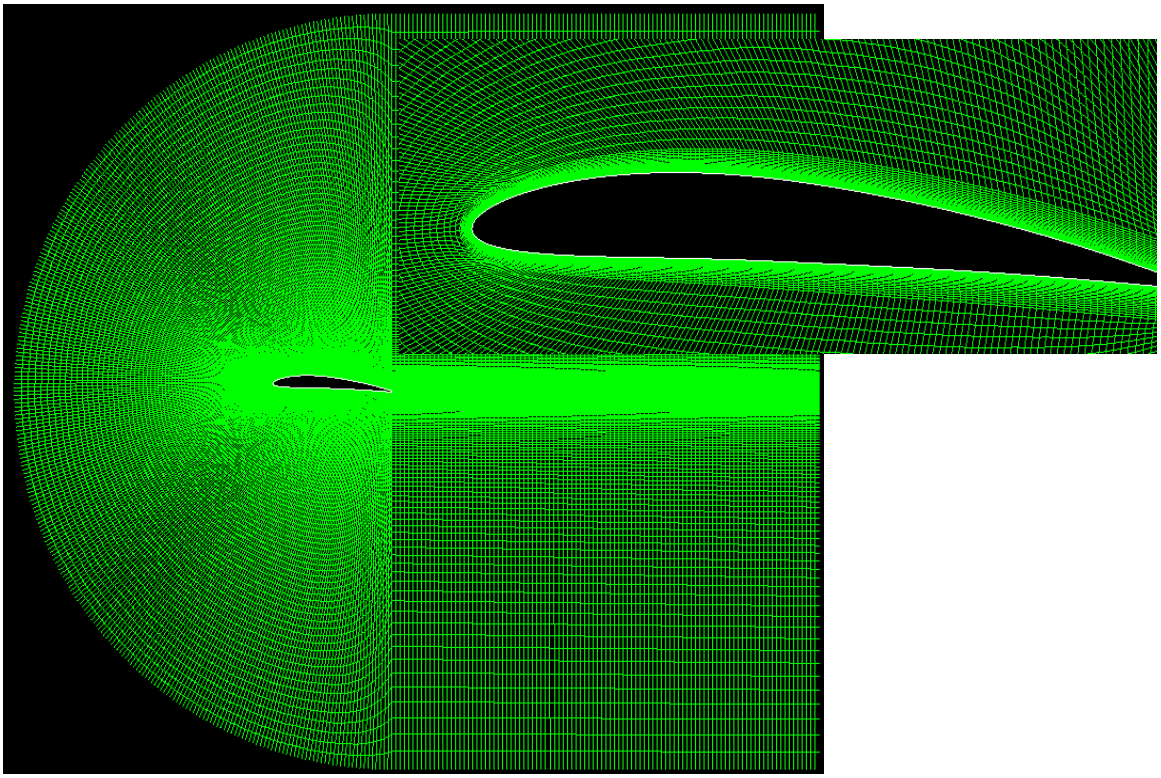


Fig. 2. The computational mesh used

The static pressure profiles calculated are presented in Fig.3 plotted against the direction vector to the surface of the airfoil.

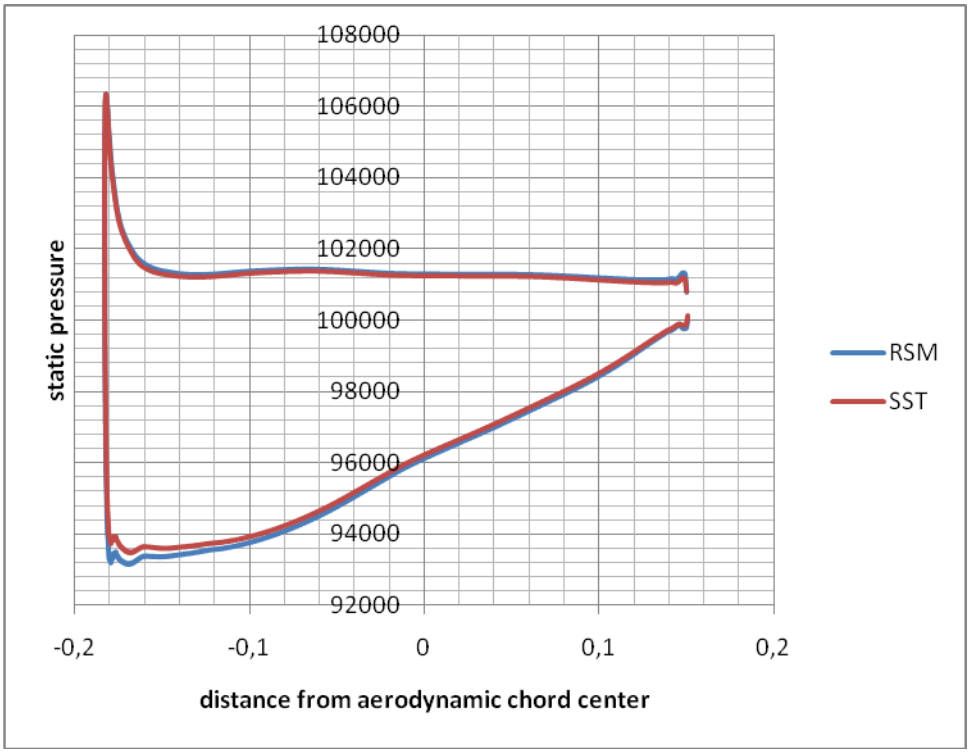


Fig. 3. The static pressure profiles calculated by the two above mentioned methods

Because the boundary layer is calculated in a more complex manner, the same analysis used with the panel method cannot be employed directly. This is because, the theory states the velocity of

the fluid near the wall must always tend to zero. In order to by-pass this problem, we can derive a near-wall velocity (outside the boundary layer) trough a user defined flow field. This UDFF holds identical results to the velocity plot but with the advantage that the velocity near the wall is equal to that directly outside the boundary layer –which alowes us to apply the methods used in the previous paper. Figure 4 shows the user defined flow field used.

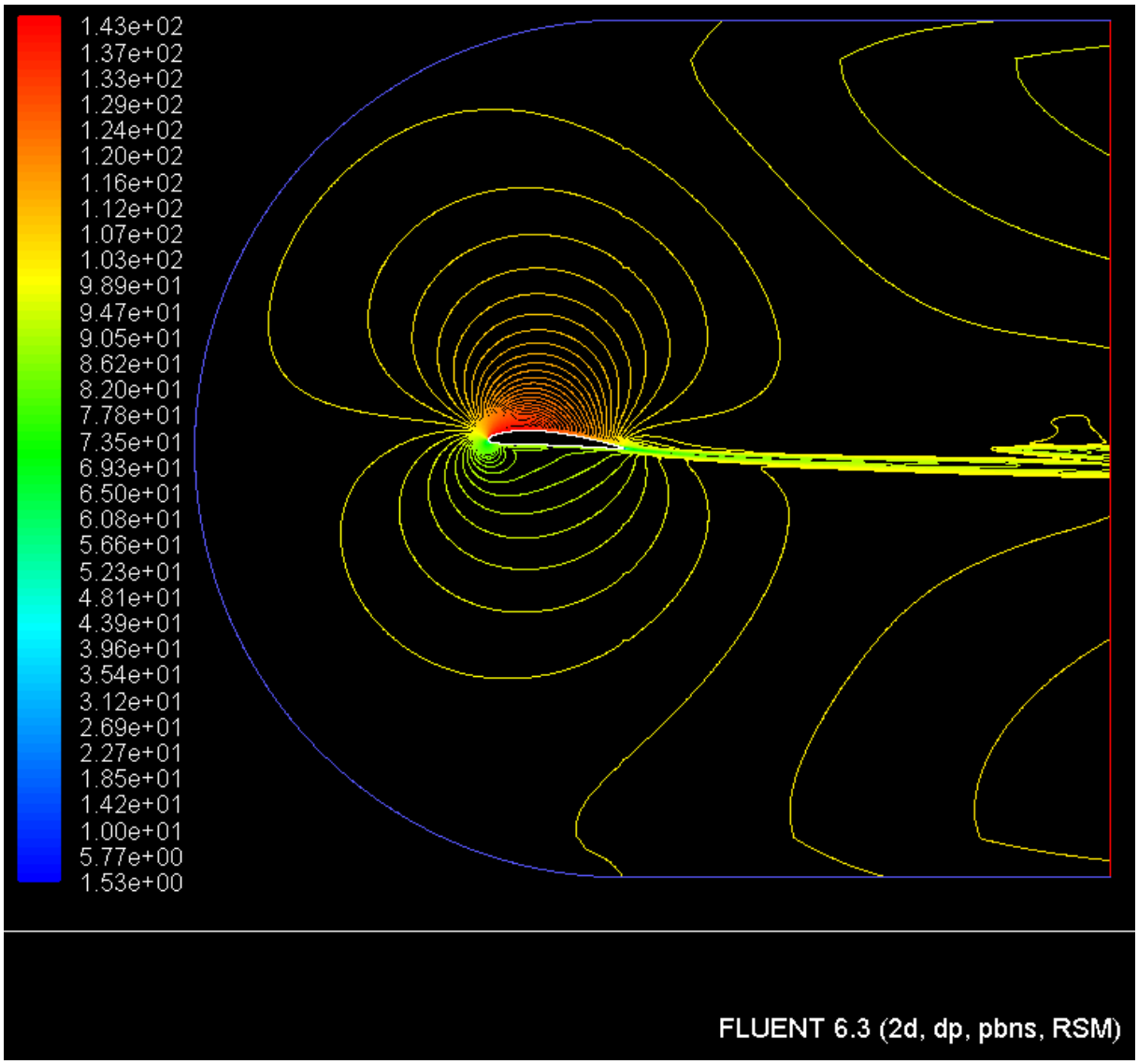


Fig. 4. The user defined flow field for velocity near the wall

In Fig. 5 the scatter plot shows the velocity outside the boundary layer for every location across the surface of the airfoil.

We note that the velocity distribution reveals a much lower boundary layer maximum velocity than the velocity calculated in the far field region. This is a new finding and has a significant impact on the erosion magnitude.

Since the intial velocity of the free stream is 100 m/s, every point across the airfoil for which the maximum boundary layer velocity is below this value can be considered under the influence of erosion. This is because for the airspeed to drop, one has to assume an impinging phenomenon.

Two interpretations can be made from this:

1. The velocity of the impact particle is lower than the one calcuated with the more rudimentary panel method.

2. The velocity distribution across the airfoil shows that the upper side is subject to erosion almost as much as the underside. This is in good aggreement with the empirical findings in [1].

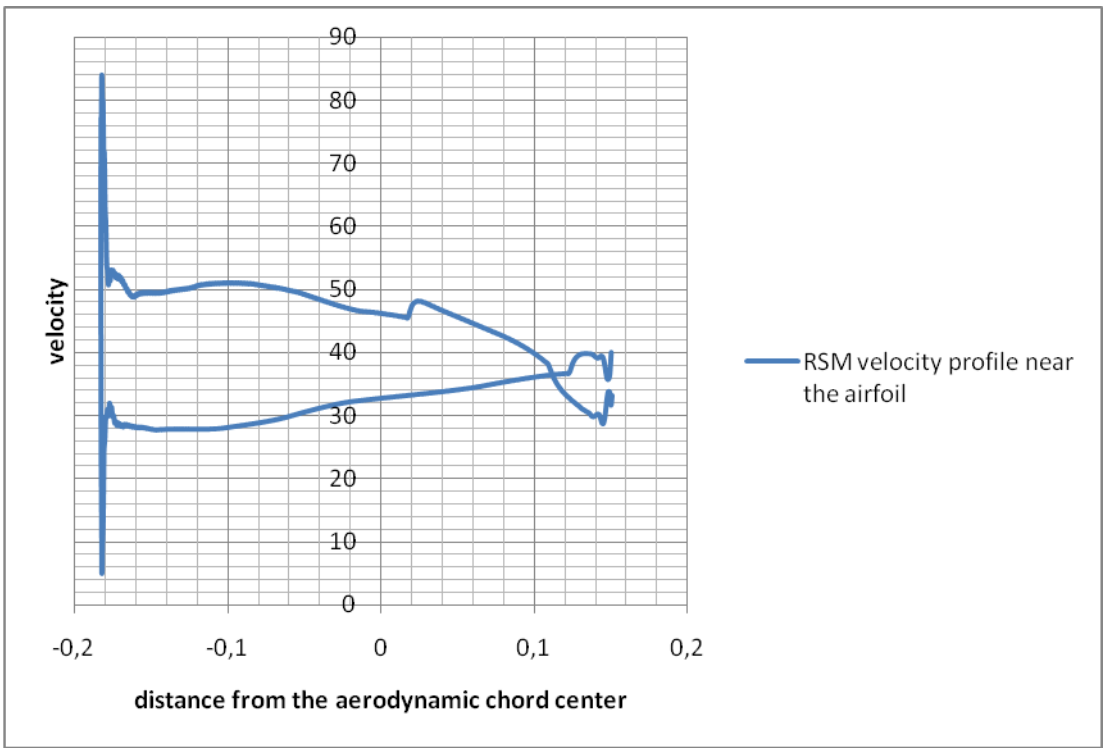


Fig. 5. The user defined flow field for velocity near the wall ploted across the airfoil span

3. CONCLUSION

The paper presents a continuation of the work previously made in describing an analytical model for erosive wear on aerospace applications and in particular on helicopter blades.

A more complex computational fluid dynamic analysis is performed in order to assess the pressure and velocity distribution across a more complicated airfoil which has also a positive angle of attack. Two of the most accurate RANS methods are used: the Menter k-omega SST and the Reynolds Stress Model, both in good aggreement to each other.

In order to obtain the necessary data for the compete erosion calculations a user defined flow field was generated for calculating the maximum boundary layer velocity. This is an approach to determine the near wall behavior of the entrained particles. The necessity of this UDFF lyes in the boundary layer theory which states that the velocity of air on the wall is zero. Bearing this in mind, a velocity distribution could never be obtained trough the classical velocity flow field deffined by the solver developer.

The findings reveal that the velocity distribution near the airfoil is significantly different from that outside the boundary layer and also different from the one that could be calculated with less sophisticated CFD models. The current analysis shows how the erosive wear is likely to occur also on the upper side of the airfoil – which is a known fact that could not be verified trough the panel method CFD model.

Further work will include the boundary layer velocity profile which can be derived both analyticaly and numerically. Also, the boundary layer lift and drag exherted on the particles could be included in order to assess the impact of the different shaped particles.

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ABRASIVE WEAR BEHAVIOR OF LASER CLAD AND FLAME SPRAYED - MELTED NiCrBSi COATING

D. Petrescu, N.N. Antonescu

Abstract: *This paper looks to examine the influence of the processing condition on the microstructure and abrasive wear behaviour of the powder tip NiCrBSi hard facing alloy. The hard facing alloy was applied in the form of coating onto a mild steel substrate (Fe-1,5%C) by different technology: laser cladding (LC) and the flame spraying (FS) combined with surface flame melting (SFM). In both cases, the appropriate selection of process parameters enabled high-quality, defect-free NiCrBSi coating to the obtained. The microstructure of the coating was analyzed by scanning electron microscopy (SEM), with attached energy dispersive spectroscopy (EDS) microprobe, and by X-ray diffraction (XRD). Their ethnological properties were evaluated by micro-scale ball cratering abrasive wear test, using different abrasive: diamond, SiC and WC.*

Micro-structural characterization showed both coatings exhibit similar phases in the microstructure, but the phases present differences in morphology, size distribution and relative proportions from one coating to another. Despite these micro-structural differences, the wear tests showed that in three-body abrasive condition the wear behaviour is comparable for both coating. Conversely, in two-body wear conditions with diamond particles as the abrasive, it was observed that the specific wear rate of the material is micro-structural changes. The fact is particularly apparent in laser cladding (LC) coatings, in which the zones of the layers with higher proportions of very small particles present a lower wear resistance. The result proves that it is important to have good micro-structural control of this material, in order to obtain coatings with an optimized and homogeneous tribological behaviour.

Key words: *Laser cladding, Plasma spraying, Wear, Hard-facing alloys*

1. Introduction

Nickel-based alloys a unique combination of properties that enables them to be in a variety of special purpose applications. In particular, the Ni-Cr-B-Si-C colmonoy alloys provide adhesive wear and corrosion resistance at ambient and high temperature similar to that of Co-based satellite-type alloys [1]. Moreover, these Ni/boride-based alloys also exhibit excellent resistance to abrasive wear, because of the boride and carbide dispersions within their microstructures [1]. Therefore, NiCrBSi coatings are widely employing emend to improve the quality of the components whose surface is subjected to severe tribological conditions such as coal-fired boilers, heat exchangers, turbines, tools, extruders, plungers, rolls for rolling mills, agriculture machinery etc. [2]

The alloys can be used in the form of the protective coating and lead to improved tool life and performance.

Therefore, nowadays, the use of thermal spraying theologies for the type of alloy's application in the form of coatings has increased enormously [3,4,5,6]. Nevertheless, despite the introduction of new deposition methods such as high-velocity oxy-fuel spraying and high—velocity air fuel spraying, thermal - some results show that sprayed Ni- based coatings have low to moderate adhesion to the substrate and show porosity and formation of oxide interlayer's. [7], witch impair the properties of the coatings. As a result, subsequent melting can be necessary in order to reduce the porosity and improve their tribological properties.

The use laser cladding can provide an alternative solution for components' or products with added value or with smaller functional areas. In fact, a large number of works have shown that laser cladding enables the production of dense coatings, metallurgical bonded to base material with minimum dilution of the clad layer [8,9,10].

However, it is well known that the processing techniques (and also the processing parameters) can affect the microstructure of the coatings and that dramatic changes can be observed within coatings of the same alloy processed differently. Regarding laser technology, previous works showed that, in general, the drastic solidification condition normally achieved result in micro-structural refinement and in partial or total dissolution of the second phase reinforcement particles, in iron-based alloys [11], cobalt based alloy [12] and Ni-based alloys [13].

In general, these micro-structural changes lead to the modifications of the mechanical properties of the material and, consequently, to the modifications of its wear behaviour. Therefore, particular attention must be shown to the relations between processing conditions, microstructure and the wear resistance of the material [14,15,16]. Also, since the wear resistance depends on the overall conditions of the tribological system (such as size, shape, roughness and hardness at the basic material, loading conditions, sliding speed and environment), further understanding of the relation between the properties of the material and its wear behaviour, under a given set of working conditions, is essential for the design and selection of the materials for any tribological application.

In our research, we are comparing the abrasive wear behaviours of NiCrBSi coatings applied by thermal spraying and by laser cladding in order to establish relations between the tribological response of the material and the microstructures that result from the different deposition processes.

2. Experimental researches

2.1. Materials and deposition processes

The material studied in this work was applied as a coating on a mild substrate (0,15%C) by two different techniques: laser cladding (LC) and flame spraying (FS) combined with surface flame melting (SFM). Ni/boride-based alloy powders, whose composition is shown in Table 1, were used to produce the coatings. The powder consists of spherically shaped particles with an average diameter of 66μm. Cladding was performed using a CO_2 laser, operating at a power of 1900W. Thus, for producing the laser clad, there were selected a power density on the surface of the piece of 5400W/cm^2, a beam scanning speed of 200 mm/min and a powder feed rate of 9 g/min. By 6 means of successive scans, with a 50% overlap, the surface of the substrate was clad with a coating approximately 1,9 mm thick.

The flame sprayed coatings were produced with an oxygen pressure of 170 kPa, an oxygen flow rate of 1,7 m^3/h, an acetylene flow rate of 0,93 m^3/h, a spray distance of 175-200mm and a feed rate of 9,1 kg/h.

Table 1. Chemical composition of the powders

Cr (wt.%)	B (wt.%)	Si (wt.%)	Fe (wt.%)	C (wt.%)	Ni (wt.%)
15,7	3,35	4,27	4,08	0,81	Bal.

After spraying, the material was subjected to flame melting at 1025^{o}C. The final thickness of these coatings was approximately 1,5 mm.

2.2. Micro-structural and hardness characterization of the coatings

The microstructure of the coatings was analyzed by optical and scanning electron microscopy (SEM), with an attached energy dispersive spectroscopy (EDS) microprobe. X-ray diffraction (XRD) analysis of the original powder, laser cladding (LC) and surface flame melting (SFM) coatings were carried out in order to identify their phase composition, and also to investigate the micro-structural modification brought about by the heat treatments in both coated layer. $Cu_{K\alpha}$ radiation with goniometer in Bragg-Brentano configuration was used in the X-ray diffraction (XRD) analysis.

Vickers micro-hardness measurements were performed with a 100g load sections perpendicular to the deposition direction, making a vertical profile from the coating surface to the base steel.

2.3. Wear and hardness tests

The tribological properties of the coatings were evaluated in detail by free ball micro-abrasion wear tests. Two types of tests were performed: abrasive slurry, and dry sliding abrasion. For both conditions, the tests were performed by a microscale ball caterings abrasive wear testing machine [17], schematically represented in Fig. 1.

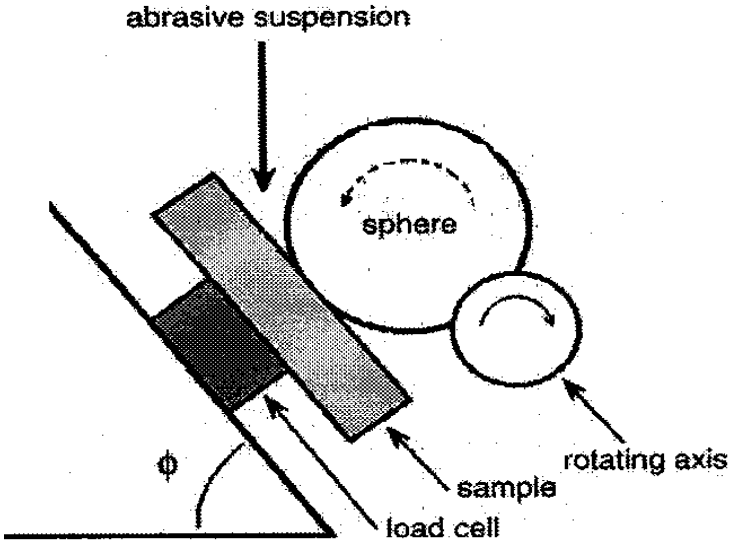


Fig. 1. Schematic view of the microscale ball-cratering abrasive wear testing machine.

Prior to the wear tests, the surface of the samples was polished to a final average surface roughness (R_a) less than 0,5 µm. In the abrasive slurry wear tests a 25,4 mm diameter sphere, made of quenched and tempered AISI 440C tool steel (approximately 800HV), was used to carry the load and the abrasive particles to the samples contact region. While the ball rotated against the surface of the sample to be tested, an abrasive suspension was fed, drop by drop, into the contact region. Two abrasive slurries wears used a suspension of diamond particles in alcohol (12 vol. % abrasive) and the suspension of SiC particles in distilled water at two different concentration: 0,09g/cm^3 (12 vol.% abrasive) and 0,35 g/cm^3 (45 vol.% abrasive). The SiC and diamond abrasives have mean particle diameters (?) of 4,25 and 6,00µm, respectively. The slurries wear agitated continuously throughout each test to prevent settling of the abrasive particles. In dry sliding abrasive wear condition, a 20mm-diameter WC sphere (approximately 2500HV) was used as counter-body and, obviously, no abrasive slurry was fed into the contact region. All tests were carried out with a sliding speed of 2 35 mm/s, a normal load of 0,2 N, and a total sliding distance of 90 m.
Since the sphere rotates freely on the sample's surface in the type of tests, the wear of the counter-body has not been localized. Therefore, the change in the curvature radius of the counter-body caused by its own wear is negligible, and the wear volume of the sample can easily be easily by using the following geometrical equation, previously established by Rutherford and Hutchins [17].

$$V = \frac{\pi d^4}{64R}, \qquad (1)$$

Where: R and d are the ball radius and, respectively, the wear crater.
The calculated wear volume in the average of 5 tests for each set of testing conditions.
After that, the specific wear rate was obtained by dividing the volumetric wear loss by the sliding distance and the contact load.
The worn surfaces were observed by SEM.

3. Results and discussion

3.1. Micro-structural characterization

3.1.1 LC coatings

SEM micrographs which show the typical microstructure of a section longitudinal to the laser scanning direction are presented in Fig.2. The absence of porosity and micro-cracks shows that the processing parameters selected in this study have ensured a high quality of laser-clad coatings. It can be observed that the clad zone has a not-homogeneous microstructure, most probably because of the local changes in the solidification conditions [10,12].

Fig. 2, shows the change of the microstructure from the substrate/clad interface to the top surface of the clad layer at the edge of a laser track. Similarly, Fig.2,b shows the micro-structural variation from the edge to the middle point of the total length of a laser track at the coating surface. It can be observed that solidification starts with a planar front solidification region.

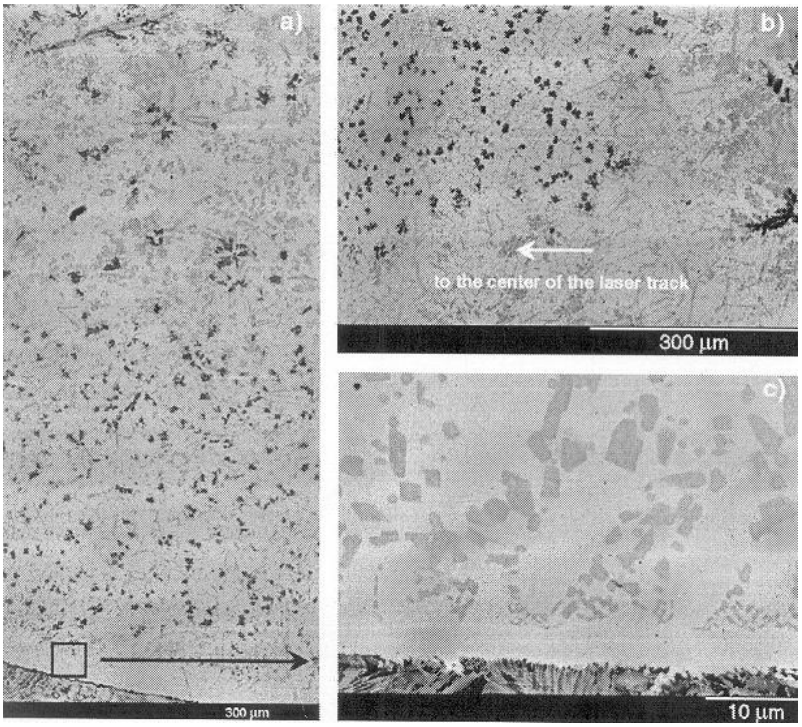


Fig. 2. Back scattered electron images of a section longitudinal to the laser scanning direction of the Ni-alloy:
a- microstructure changes from the interface to the top surface: b- micro-structural variation from the edge to the centre of the laser track at the coating surface; c- magnification showing the planer crystallization region.

This is formed because the substrate at the interface acts as a heat sink, while the temperature gradient (G) is fairly high and the solidification velocity (V) is very slow. With a sufficiently high G/V ratio, planer crystallization is obtained [18]. Immediately above this, a zone with eutectic morphology can be observed, where a grey phase appears (Fig. 2,c).

From this point to the top surface of the clad, a complex microstructure ca be observed, formed of phases heterogeneously distributed across the metallic matrix. Observation of this region at the central area (the middle point of the thickness and the length) of laser track at higher magnifications (Fig. 3, a, b, c), shows a dendrite structure formed of different phases, suggesting changes of the primary solidification mode during solidification (Fig. 3, a, b). An interdendritic eutectic can also be clearly observed in some regions of the clad (Fig. 3,c). The EDX analysis of this microstructure indicates that the Ni solid solution is rich in Si and Fe and poor in cr. The darker phase (see a in Fig. 3, a, b) has a blocky morphology and contains a high concentration of Cr. The grey phase shows several morphologies: eutectic, blocky and needle-like structure and mainly contains Cr and Fe (see B in Fig. 3,a,b,c).

X-ray diffraction pattern of the clad coating is shown in Fig. 4. It reveals that the microstructure of the LC coating consists mainly of γ-Ni, $(Cr, Fe)_7C_3$, CrB and Ni_3B and Ni_3B. Therefore, the XRD and SEM results strongly suggest that the blocky black phase is CrB-type chromium boride.

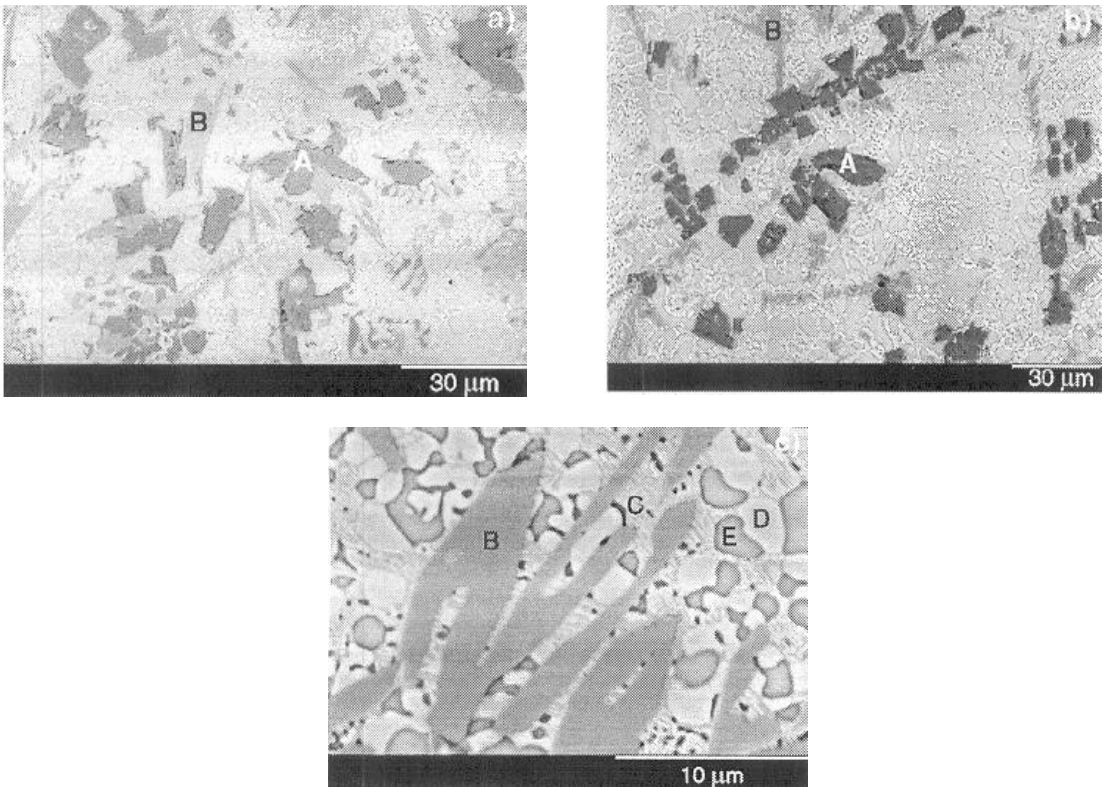


Fig. 3. Micro-structural details at the central area (middle point of the thickness and the length) of a laser track (back-scattered electron images) : a- diverse phases existing; b- another view of the phases; c-c magnification showing interdendritic eutectic morphology and grey phase.

Fig. 3,b suggests that the formation of this phase may possibility take please by primary solidification. On the other hand, the grey phase could be determined as a complex chromium-iron carbide, and its formation could occur by a local change of the primary solidification mode (Fig. 3,b). the formation of carbides and borides, during laser cladding of this group of colmonoy series alloys, has been previously reported by several authors [1,19,20,21,22]. Moreover, it has been found that, during the solidification of the clad molten pool, it is inevitable that large amounts of eutectics form, such as the lamellar eutectic shown in Fig. 3,c. Previously published work [19,20] and the XRD results suggest that the interdendritic lamellar eutectic is, most certainly, the γNi+Ni_3B lamellar eutectic (see C in Fig. 3,c).

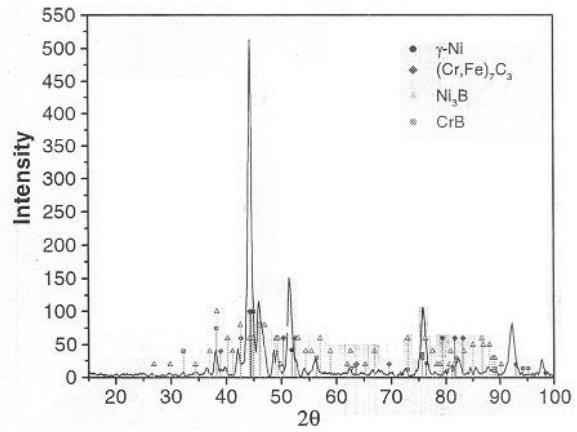


Fig. 4. XRD spectra of the LC layer.

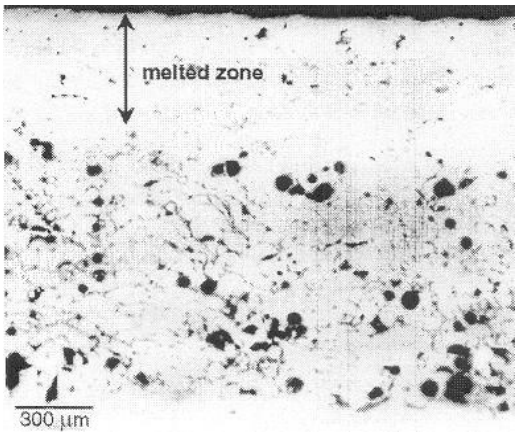


Fig. 5. Cross-sectional micrograph of the SFM coating.

Finally, and according to the microstructure observed, the white dendrite phase can be identified as the Ni_3B phase and the darker interdendritic zone as the γNi solid solution (see D and E, respectively, in Fig. 3,c). However, it is realistic to state that using other analytical techniques, such as transmission electron microscopy (TEM), it should be possible to find other interdendritic eutectics, as well as other compounds based on chromium carbides and borides or even amorphous phases along grain boundaries. In fact, although the chemical compositions of the clad materials used by the investigators are similar, there are differences in the final microstructure of clad layers obtained, perhaps due to the different process parameters used in each case.

3.1.2. SFM coating

Fig. 5 shows a cross-section of SFM coating. As can be observed, the flame melting was superficial and penetrated about a third of the coating thickness. As a result, the under-melt coating shows large unclosed inter-particle voids and a metallurgical bond between the steel substrate was not achieved. The SEM observation shows the micro-structural aspects of both these regions (Fig 6). As-sprayed coatings have small size phases and high magnification is necessary to observe them (Fig.6,a). The surface flame melted area shows larger phases, which can achieve several micrometers in size (Fig. 6,b). X-ray analysis shows the existence of γ-Ni, $(Cr, Fe)_7C_3$, CrB and Ni_3B phases in both flame sprayed and flame sprayed-melted regions, as well as in the original Ni alloy powder (Fig. 7). The differences between the diffraction peaks of the powder, FS, FSM and LC coatings (see Fig. 4) are hardly noticeable. However, a similarity in pairs can be appreciated: FS spectrum is more similar to that of the powder and LC spectrum is more similar to that of the FSM coating. From comparisons between the FS and powder spectra, the flame spraying process seems not to produce obvious changes in the phase composition of as-sprayed particles. However, the relative pea intensity of Ni_3B and CrB phases in these spectra is slightly lower than that for the LC and FSM spectrums (see the peak of Ni_3B at about $2\theta=39^o$ and that of CrB at $2\theta=46^o$). This would indicate that flame melting and laser cladding treatments lead to reactions within the Ni matrix, which result in a major formation of Ni_3B and CrB compounds. This explains the micro-structural differences between the as-sprayed and the flame sprayed-melted areas.
On the other hand, comparing LC with FSM spectra, it can be observed that the relative peak intensity of the SFM decreases slightly with respect the LC, witch can result from the higher porosity and poorer quality of the SFM samples compared with the LC ones. Moreover, the diffraction peaks of the LC clad are slightly shifted to the left, which can be an indication of an increase in the lattice parameters due to super-saturation of alloying elements during the LC process [20].

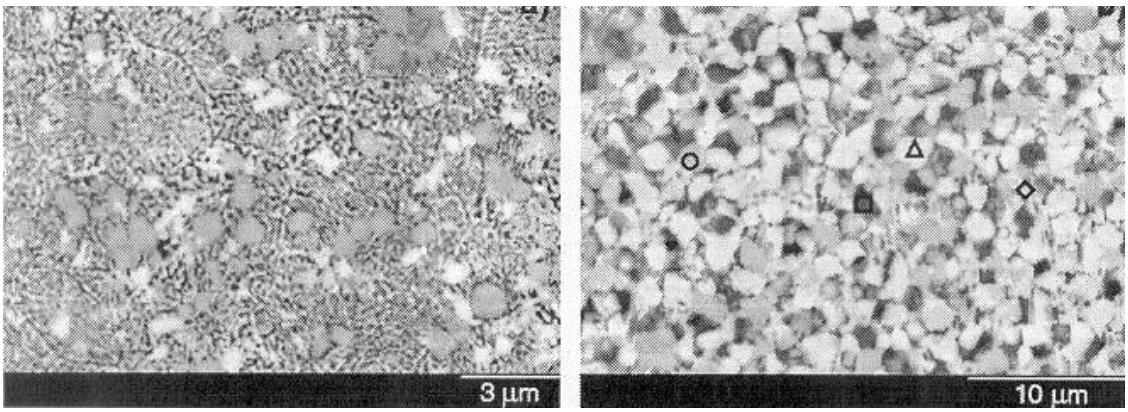


Fig.6. Cross-sectional back scattered electron images of the microstructure of the SFM coating: a- as-sprayed; b-sprayed+melted region, symbols: o-$(Cr, Fe)_7C_3$, □- CrB, ◇ - Ni/Ni_3B, Δ-Ni_3B.

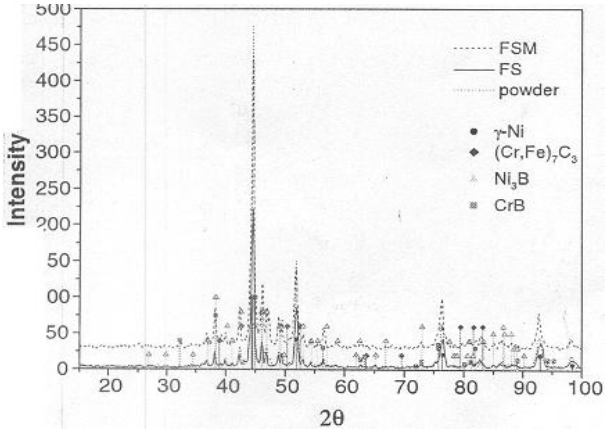


Fig. 7. XRD spectra of the SFM layer

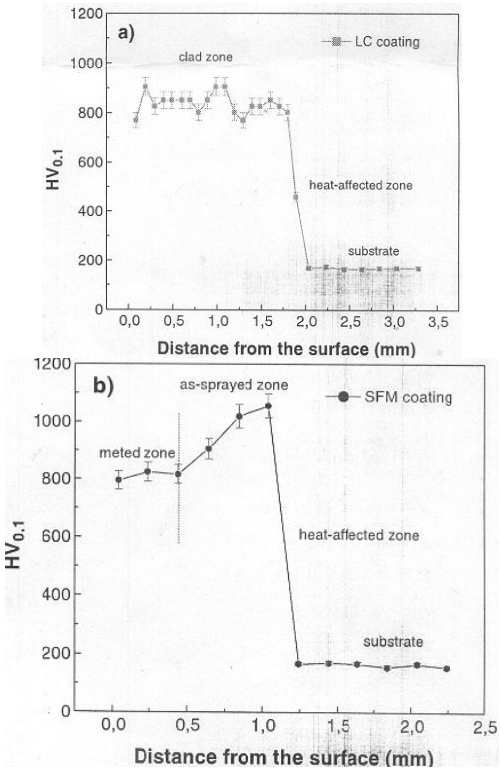


Fig. 8. Cross-section micro-hardness profile for:
a- LC coating; b- SFM coating

The microstructure of the SFM layer is composed of borides and carbides with blocky morphologies uniformly distributed in the Ni solid solution, Ni/ Ni_3B compound (see symbols in Fig. 6, b and the corresponding figure caption). In contrast, as mentioned above, the microstructure of laser cladding the same phase type with different distribution, morphologies and size. From the grain size microstructure, it is evident that carbide and boride phases in the laser clad are noticeably larger than that in the SFM. Nevertheless, the other phases exhibits the fine microstructure expected from laser cladding process. This unexpected high phase size is, most certainly, dependent on local compositions and cooling rats, which determine the uncertainty of the phase formations and its growth, especially in the laser clad.

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3.2. Micro-hardness profiles

Fig. 8 shows the micro-hardness profiles along the cross-section in the LC and SFM coated layers. It can be observed that the surface hardness of both coatings is similar, reaching values higher than 800 $HV_{0,1}$. Three distinct regions can be distinguished in the hardness profile, corresponding to clad zone, heat-affected zone and substrate, respectively. The hardness values remain practically constant in the clad zone and decrease to 180 HV when the bulk of base metal is reached (Fig. 8,a). In the case of the SFM coating, it is interesting to note that the hardness of the as-sprayed region is higher than the melted region (Fig. 8,b). This can be explained by considering that the microstructure itself in the as-sprayed zone is finer than that of melt zone. Another reason is that load of hardness measurement is small enough not, but also, to cover the effect of coating porosity of the as-sprayed region (100g).

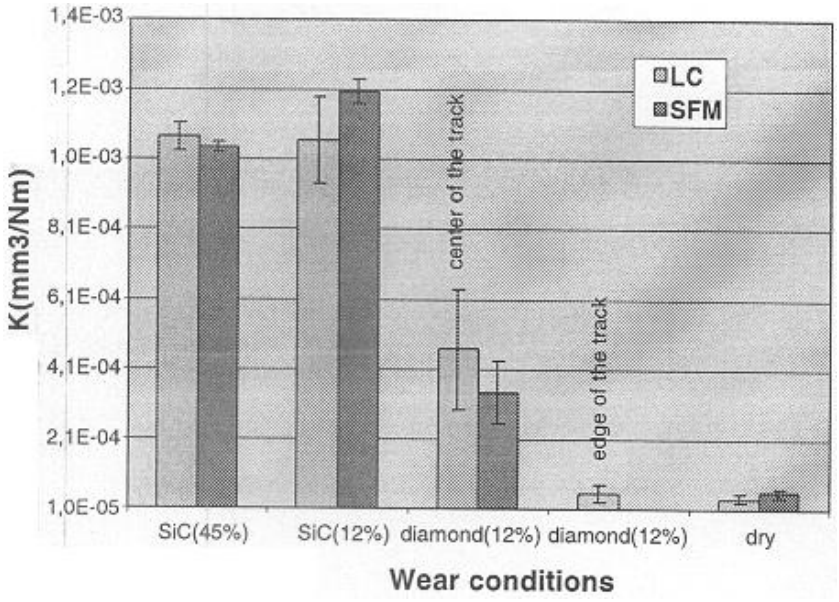


Fig. 9. Wear rates of the material for the different testing condition

3.3. Wear behavior

Fig. 9 shows the specific wear rate (defined by the volume of the wear crater divided by the sliding distance and the normal load, e.g. [23]) for the different coatings and testing conditions. The vertical scatter bands that are plotted are the standard deviation of the five wear tests performed in each series of tests.

As expected, in dry sliding, the wear rate of the material was the lowest, and the wear rate values are similar for booth SFM and LC coatings.

Concerning the tests with abrasive SiC slurry, it can be observed that, for both deposition techniques and using the SiC abrasive, the wear rate of coatings is practically the same. Moreover, a decrease of the slurry concentration from 45% to 12% dose not result in a decrease of the wear rate of the material, indicating that, in the case, the decrease of slurry concentration does not result in a transition from three-body to two-body abrasive wear [24].

Surprisingly, for the harder diamond abrasive, the wear rate of the material is significantly lower then for the SiC abrasive. A heterogeneous behavior can also be observed in the case of the LC layers, when diamond is used as the abrasive: the central area of the laser tracks exhibits a lower wear resistance than the edge of the tracks. Hence, two different wear rats could be obtained (see Fig.9) corresponding to regions in which the sample has different micro-structural characteristics (see Fig.2).

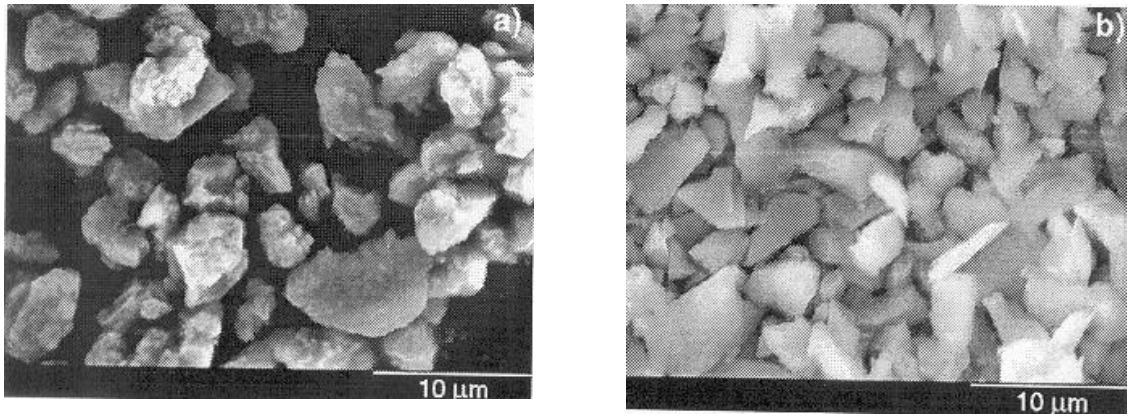


Fig.10. Morphology of the abrasive particles used: a- diamond particle; b- SiC particles.

Considering the higher hardness of the diamond particles compared with the hardness of SiC particles ($HV_{diamond}$= 6000-10 000, HV_{SiC} = 2800-3000), the lower wear rate found with diamond slurry is

unexpected. However, it is impossible to isolate hardness completely from other features, of the particle such as its shape. Fig.10 shows the morphology of diamond particles (Fig.10,a) and SiC particles (Fig.10,b). It can be observed that the average particle size of both abrasive slurries is very similar, but that SiC particles exhibit a sharper shape, consisting of flat areas joined by corners with a small curvature radius. This sharp morphology is highly aggressive in terms of wear, since it increases the cutting efficiency of the abrasive particle [25].

Conversely, the diamond particles are relatively blunt with a mostly curved surface. On the other hand, Trezona et al. [26] have pointed out that changes in the morphology of the abrasive particles can lead to transitions from three-to two- body abrasive wear(or vice versa) in micro-scale abrasion tests, thereby leading to unexpected changes in the wear rates.
Observation of the worn surfaces of the samples enables classification of point.

3.4. Wear mechanisms

In am attempt to identify the wear mechanisms taking place in the different test conditions, the worn surfaces by SEM were examined.

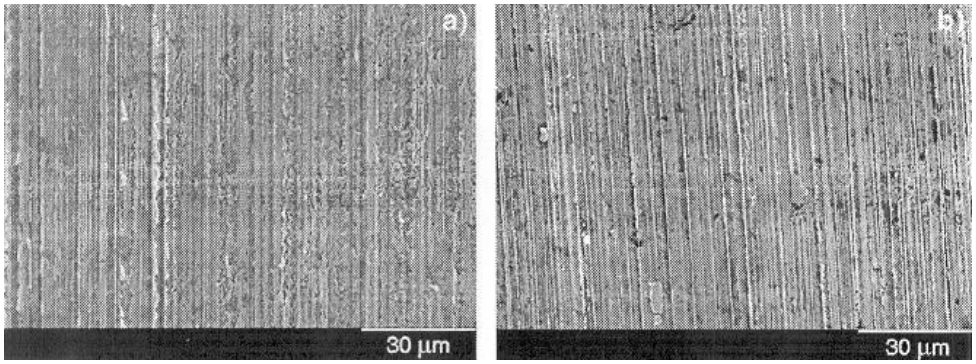


Fig. 11.Worn surfaces generated by the microscale abrasion with diamond slurry (SEM-secondary electrons): a - LC layer; b - SFM layer.

It could be observed that the type of abrasion changes with the type of abrasive suspension used. In the case of the diamond slurry, and for both deposit coatings, the craters produced by the diamond suspension show deep parallel scratches, with plastically deformed edges, caused by the hard diamond abrasive particles (Fig. 11,a, b).

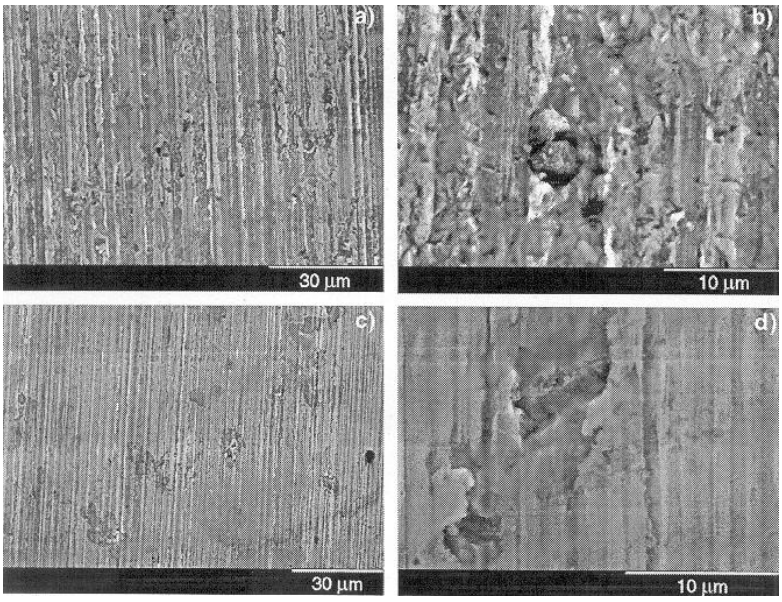


Fig. 12. SEM images of the worm surface of the LC layer with a diamond slurry: a – aspect of the wear craters formed at the centre of laser track; b- detachment of the smaller phases by the particle/matrix interface; c- aspect of the wear craters formed at the edge of the laser track; d- brittle fracture of the bigger phases.

The process occurs when a significant proportion of the slurry particles embed into the surface of the ball bearing and act as fixed indenters, causing the so-called two-body abrasion (or grooving) wear mode [26].

Furthermore, the observation of the worn surfaces indicates that the grooves are steep-side and correspond well in size to the abrasive particles, showing that, in this case, cutting and ploughing were the main abrasive wear the main abrasive wear mechanisms (see Fig. 10,a,b). Some differences in the wear performance of both coatings related to micro-structural aspects could be observed. As previously mentioned, the LC layer has a heterogeneous distribution of carbide and boride phases along the track responsible for the different wear rates found.

The surface areas with a major proportion of small hard phases show a lower wear resistance because these phases are easily extracted from the matrix, in general, by the interface between the particle and the matrix, being incapable of resisting the action of the hard abrasive diamond particles (Fig. 12, a, b).

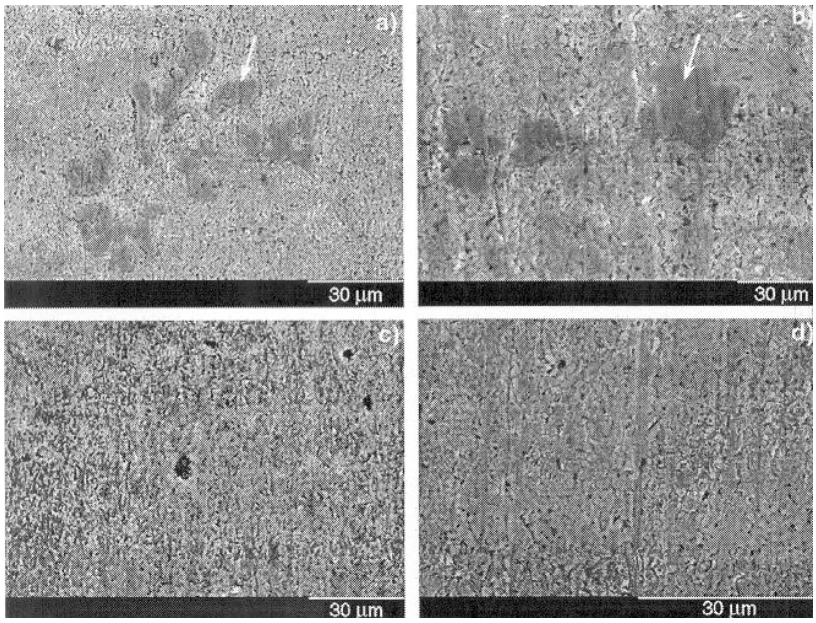


Fig. 13. SEM images of the worn surfaces of the NiCrBSi coatings with SiC slurries: a, b- morphology of the wear scar formed on the LC layer with an abrasive concentration of 45 vol.% and 12 vol.%, respectively; c, d – morphology of the wear scar formed on the SFM layer with an abrasive concentration of the 45 vol.% and 12 vol.%, respectively;

Moreover, these extracted hard particles can become trapped the sliding surfaces and increase the wear of the matrix, thereby increasing the whole wear rate. On the other hand, the regions containing a higher amount of large compounds exhibited superior wear resistance (Fig. 12, c), since these wear not as easily extracted from the matrix as the smaller ones. However, the larger phases, witch are not extracted from de matrix, suffer, in some cases, brittle existing in the LC layer, the whole surface of the coating showed a similar wear resistance. The could be explained by considering that the low directionality existing under rolling abrasion conditions decreases the influence of the phase size on the wear process of the NiCrBSi coatings. The region of the abrasive particle in contact with the wearing surface is continually changing, so the extraction of the small phases from the matrix is not as helped as in grooving abrasion. SEM observation indicates that there is a preferential wear of the matrix, witch is removed by micro-ploughing and micro-cutting mechanisms, leaving the hard phases exposed on the surface of the track (arrows in Fig. 13, a,b). Finally these phases detach from the matrix. The decrease of the slurry concentration from 45 vol.% to 12 vol. %, neither changed the mechanism nor the wear rate of the material (see Fig. 13 and 9, respectively). A few parallel scratches, characteristic of two-body abrasion, can be seen for the lowest concentration, but the dominant wear, mode was rolling wear, as can be deduced from the multiply indented crater surface shown in Fig.13,c, b.

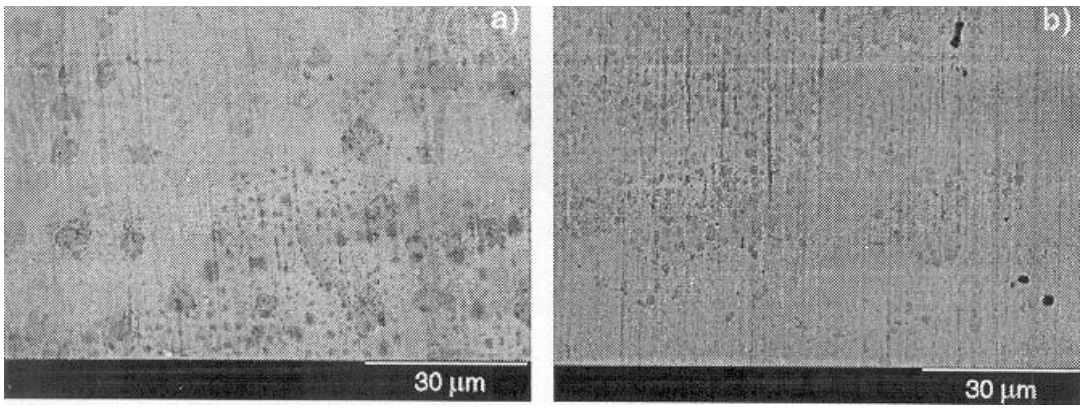


Fig. 14. Worn surfaces in dry sliding wear tests (SEM- secondary electrons): A - LC-coating; b - SFM coating.

The extend of damage in the worm surfaces of the samples subjected to dry sliding wear against a WC sphere counter-body is much smaller than in the slurry-fed abrasive wear conditions. The scratches are not as deep and sharp and most of the phases resist to the abrasion of the counter-body asperities without-being extracted (Fig. 14,a,b).

4. CONCLUSIONS

1. The appropriate selection of laser cladding parameters allows high-quality NiCrBSi LC coatings to be obtained on a mild steel substrate. The LC coatings obtained are defect-free and are metallurgical bonded to the substrate. Although the quality of the SFM coatings is acceptably good, new processing conditions can be tested in order to decrease their porosity even more and to obtain a metallurgical bond between the coating and the substrate.
2. Comparison of the microstructure of the laser clad and the flame melted reveals a similar phase composition in the both coating, but different distribution, morphology, and size of phases. LC shows a heterogeneous distribution of different size phases across the Ni solid solution as the SFM exhibits similar size phases homogenously distributed. Despite these micro-structural differences, both coating showed analogous wear behavior, which, critically, depended on the tribological conditions used. Under abrasion wear condition, the morphology of the abrasive particles influences strongly the wear rate and wear mode of the coatings.
3. Despite the higher hardness of the diamond particles in comparison with the SiC particles, the highest wear rate was obtained with the SiC slurry, duo to its extremely sharp shape.
A two-body (grooving) wear mechanism occurred with the diamond slurry, while the wear proceeded with a tree-body (rolling) wear mechanism with the SiC abrasive. The high directionality existing under grooving abrasion conditions increased the influence of the phase size on the wear process of the coatings. For that, reason, using a diamond abrasive suspension, LC coating showed a heterogeneous wear rate as a result of its non-homogeneous microstructure.
4. In the present research, it has been demonstrated the influence of the microstructure on the wear response of the material, under a given set of working conditions.The knowledge of the co-relation between processing conditions, metallurgical and mechanical properties and wear behavior, is essential for the design and selection of any tribological system.

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CONCEPTUAL ASPECTS OF THE CEEPUS PROJECT "MODERN TRENDS IN EDUCATION AND RESEARCH ON MECHANICAL SYSTEMS - BRIDGING RELIABILITY, QUALITY AND TRIBOLOGY"

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Abstract: *In the current paper are presented the main educational and scientific aspects of the first CEEPUS project in the field of reliability, quality and tribology. Here are described the specific contributions of all partner institutions and planned activities to ensure successful dissemination of knowledge and competencies.*

Key Words: *CEEPUS, education, research, tribology*

1.WHAT IS CEEPUS?

CEEPUS is an acronym for "Central European Exchange Program for University Studies".

Current member countries: Albania, Austria, Bosnia and Herzegovina, Bulgaria, Croatia, the Czech Republic, Hungary, Macedonia, Moldova, Montenegro, Poland, Romania, Serbia, the Slovak Republic and Slovenia. Prishtina/Kosovo is also participating.

CEEPUS is based on lean management. The highest ranking decision making CEEPUS body is the Joint Committee of Ministers that meets once a year and takes all strategic decisions. Coordination, evaluation, program development and advertizing are the main tasks of the Central CEEPUS Office – Vienna, Austria. Each country has a National CEEPUS Office in charge of national implementation.

The main activity of CEEPUS are university networks operating joint programs ideally leading to Joint Degrees, esp. Joint Doctoral Programs. CEEPUS covers mobility grants for students and teachers in this framework.

The main objectives are:

- Focus on joint PhD programs.
- Promote cooperation in the framework of the EUSDR.

2.INTRODUCTION

2.1. Project overview

Tribology: a way to reliability and quality

Mechanical engineering is one of the oldest and most diverse branches of engineering and supports industrial development in such areas as manufacturing and production, energy generation and conversion, chemical engineering, transportation, automation, robotics, etc. Nowadays, the existence of general crisis enhances the increasing and continuous need for improved methods of determining the reliability and predicting the lifetime and quality of elements, machines and production systems. This is especially valid for the European countries, particularly in Danube region, and in Central and East European regions. Attention will be turned to the role of **tribology** for the large and complex scope of reliability engineering and the different tribology-related methods to improve reliability and quality, such as reliability design, component lifetime, condition monitoring, and diagnostics.

What is the **key to improved reliability and quality of mechanical systems**?

Machinery and mechanical equipment can break down for a large variety of reasons, and frequently the tribological components, i.e. bearings, gears, seals, couplings, etc. are the source of the problem.

The reason why tribological components tend to fail before other parts of the machine, can be readily understood by thinking about their function. A bearing is required to carry a substantial load,

while allowing e.g. rotary motion with very low friction. Typical friction coefficients for continuously rotating bearings are 0.01 or less. It does not require very much to go wrong to cause this friction coefficient to rise by a factor of 10 or more. When this happens, there is suddenly a large amount of heat generated in the bearing, leading to melting and destruction of surrounding materials. The cause may be something quite small: dirt or water in the oil; external shock loads and vibration; or thermal distortions during warm-up, are just some possibilities.

One of the tasks of tribology is to study and find the advantages from a full investigation of industrial failures, and using tribological knowledge and understanding to establish the causes and the ways of healing them. It is frequently possible to improve reliability and quality substantially by not so complex procedures, once the real cause of the mechanism of the failure is revealed and understood.

An illustration can be given in the following consideration. What is wear? The tribological interactions of a solid surface's exposed face with interfacing materials and environment results in loss of material from the surface. The process leading to loss of material is known as **wear**, one of the most menacing tribological processes. Major types of wear include abrasion, friction, erosion, corrosion. Wear can be minimized by modifying the surface properties of solids by one or more of surface engineering processes or by use of lubricants. Engineered surfaces extend the working life of both original and recycled and resurfaced equipments, thus saving large sums of money and leading to conservation of material, energy and the environment. Methodologies to minimize wear include systematic approaches to diagnose the wear and to prescribe appropriate solutions. Important methods are: the systems approach, where appropriate material is selected by checking properties against tribological requirements under operating environment; the interdisciplinary engineering and management techniques used to protect equipment and machinery from degradation; the asset management by material prognosis. Good health monitoring systems combined with appropriate remedies at maintenance and repair stages have led to improved performance, reliability and extended life cycle of the assets.

The mostly used definition is that **Tribology** is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication, wear and other process between contacting surfaces. This definition is related to the origin of the tribological science as a separate knowledge given by Prof. H.P. Jost 45 years ago.

Looking at tribology from the modern point of view we could say that **Tribology** is the name given to the scientific concept with embraces processes at surfaces and interfaces, as friction, wear, lubrication, tightness in the contact zone, called also contact body or third body, generally revealing the interaction in contact. There are recently basic reasons for the growing importance of tribology: the control of friction and wear leads to economical, ecological advance and sustainable development in industry, very large energy saving factor, and as one of the most important practical issue – improvement of the **reliability and quality**, becoming thus a recognized topic acknowledged during the last thirty years as an important educational, scientific and technological conception.

Let us **look in the future**. The roots of tribology are in the nature of things. However, tribology is much broader than the physical, natural world. Physics, chemistry, etc. individual sciences are no more enough. There are sciences located on the contact between each other – the interdisciplinary sciences, involving new concepts not found in the traditional sense. Viewed in this larger sense, tribology is extremely healthy and is contributing to our society economically, culturally, and intellectually.

Being deep and worldwide, the present crisis of our society embraces in unity economic, political and spiritual crises. The missing thing for the way out of the crisis is an adequate preparation of human thinking, with turning point embedded in the **education**. The present state of science, education and knowledge is basic element of the global crisis of humanity. We have to consider the actual problems of the crisis in engineering education and knowledge on the basis of the interdisciplinary paradigm and the European strategy of sustainable development, while integrating in a unity the assessment of the three components of education: erudition, cognition and teaching.

Let’s have one more glance in the current crisis with accent in the engineering education. Finding one way out of the crisis in industry could be to teach how to introduce the application of **tribological knowledge** as instrument for **improving reliability and quality** of our material assets, as well as of our culture and life. **Tribology** is an **interdisciplinary approach** to the solution of problems in the engineering sciences and technology creating complex tools for the solution of problems. In the interdisciplinary look at the wholeness, is the biggest chance for spreading our horizon, moreover in different aspects: scientific, cultural and political-economical.

Educational aspects of the project

The educational processes required to create experts whose expertise would meet the requirements set by the objectives mentioned. This is why design of adequate curricula enriched by the most recent scientific knowledge, created on problem based learning and active participation of

students in all teaching processes is of utmost importance. The proposed network would provide possibilities for exchange and transfer of teaching and research experience and know-how in the field of Mechanical Engineering, particularly in the topic Reliability and Quality set forth by Tribological knowledge, by enhancing student and teacher mobility, as well as by development, improvement and harmonization of curricula, and preparation of Joint programs. It will instruct the students and young scientist the important didactic topic to be engaged in decision-making, policy-making and planning.

Scientific aspects of the project

Hence we face the increasing role of tribology in the large and complex scope of reliability engineering, the different tribology-related methods to improve reliability, and finally the scope of tribology covering technical and scientific problems from nanoscale, through microscale up to macroscale. One of the tasks of tribology is to study the advantages from a full investigation of industrial failures, and using tribological knowledge and understanding to establish the causes and the ways of healing them. It becomes frequently possible to improve reliability and quality by using tribological knowledge. This knowledge can be improved and concentrated to essential knowledge in the integrated research interactions in the frame of the Joint Programs of the project, as well as brought to awareness and application of the academic staffs of the partners.

Thus, the **main goal** of the CEEPUS project is to create a Network for integrating the partners in education and scientific research in the field of reliability, quality and tribology of mechanical systems.

3.PARTICIPATING INSTITUTIONS IN THE FRAMEWORK OF THE CEEPUS PROJECT - RESEARCH AND EDUCATIONAL CONTRIBUTIONS

3.1. University of Chemical Technology and Metallurgy (UCTM), Department of Applied Mechanics, Sofia, Bulgaria

UCTM will develop web portal for the CEEPUS network on reliability, quality and tribology. Topics of education and research for the current project are:

• Tribology: - Hydrodynamic and Elastohydrodynamic Theory of Lubrication /effects of: inertia forces; contact surfaces deformations; lubricant's non-Newtonian properties; turbulence, etc./; - Stability of Journal Bearings /static and dynamic characteristics; dynamic coefficients; stability criteria/; - Contact Problems;

• Modeling and simulation: - Mathematical modeling and computer simulations of mechanical and HD processes /ANSYS Classic and ; Workbench & ANSYS CFX/; - Original Program codes of mechanical processes' simulations; - Algorithms for analysis and synthesis of mechanical systems with matrix methods; - Variational Methods for Technological Processes Control;

• Mechanics of materials: - Mechanics and mechanisms of the materials behavior /relation between composition, microstructures and properties of materials/; - Composites /mechanical properties, homogenization, damage, failure, rheology - modeling and characterization/; - Mechanical behaviour of materials in aggressive mediums;

• Nonlinear mechanical systems – identification methods. Vibrations. Inverse Problems in Technics;

• E-Learning.

3.2. Technical University of Sofia, Faculty of Machine Technology, Bulgaria

The long term ideas that this partner institution is willing to develop within the CEEPUS network focus on:

• Tribology of wear-resistant coatings;

• Application of infrared thermography in the qualifying of tribological processes in mechanical systems;

• Influence of micro- and nanoparticles on the wear-resistance materials;

• Ecological investigations and tribotechnologies for improvement the resource of filters in the automotive transport;

• Effects of selforganization, selective transfer of materials and hydrogen wear in contact systems;

• Application of the contact approach in mechanical systems modeling.

3.3. Technical University of Sofia, Branch Plovdiv, Faculty of Mechanical Engineering, Bulgaria

The contribution to the project will be in the following scientific and educational areas:

• Research and modeling of friction in machine tools guides – new theoretical models with its experimental evidence;

• Research and modeling of the wear in tribosystems – at various coatings on the contact surfaces;

• Methods and tools for reducing the friction and wear of friction surfaces;

• Improving the static and dynamic behavior of the machine tools.

3.4. University of Belgrade, Faculty of Mechanical Engineering, Serbia

The main topics for education and research work of this partner will be in the field of:

• Friction and wear characteristics of materials (metals, polymers and ceramics) and their improvements – coatings and composite materials;
• Lubricants – application, recycling and monitoring;
• Lubrication systems and failure diagnostic of tribomechanical systems;
• Tribological characteristic calculation for basic machine elements according to the new methods and standards;
• Wear resistance of welded coatings;
• Tribological characterisation of coatings and their improvements;
• Development and characterization of: Metal Matrix Composites; hypereutectic Al-Si alloys;
• Development and characterization of the hypereutectic Al-Si alloys obtained with t he rheocasting process;
• Vegetable (sunflower)oil base lubricants as an alternative and ecological lubricant solution.

3.5. University of Novi Sad, Faculty of Technical Sciences, Serbia

Education and research in the field of:

• All branches of Machine elements, Machine design and Product design;
• Implementation of proper products' management and design;
• Design of unconventional machinery and development of mechanical automotive systems - with focus on solutions with low energy consumption and environment protection;
• Reliability and quality of the systems.

3.6. University of Nis, Faculty of Mechanical Engineering, Serbia

Research and educational topics:

• Methods of mechanical systems (MS) design: Stages of MS creation; Evaluation methods and indicators of quality; Basic principles of quality management;
• Technology of mechanical systems: Technological rating; Technology of elements developed by casting process and deformation process; Technology of elements created by welding; Technology overhaul of elements of MS;
• Welded machine construction: Application of welding in the function of mechanical structures; Design of groove shape in the function of the load; Calculation of reliability of welded joints and structures; Design of mechanical structures of welding technology;
• Testing the quality of welded joints: Inspection of welded joints by non destruction techniques; Testing the welded joints with the destruction of the material;
• Modern welding techniques: Welding method FSW (Friction Welding Sear); Application of WSF methods, Thermal characteristics of FSW;
• Technical diagnostics of mechanical systems: systems for monitoring and protecting of mechanical systems; Predictive maintenance systems; Proactive maintenance systems;
• Application of microcontroller in the technical diagnostics: PIC Microcontrollers in machine vibration diagnostics, Control of PIC microcontrollers signals.

3.7. "Dunarea de Jos" University of Galati, Faculty of Mechanical Engineering, Romania

Topics of education and research work:

• Oil testing - determination of: extreme pressure and anti-wear properties of fluids (four ball method); viscosity using glass capillary viscosimeters, shear stability of oils and other technical fluids; flammability characteristics for fluids in contact with hot surfaces;
• Mechanical and tribological characterisation of advanced materials;
• Analysis of tribological behavior in laboratory tests (pin-on-disc, pin-on-plate, block-on-ring, shoe-roller) in dry and lubricated regimes;
• Study of superficial layer behaviour during indentation or indentation by sliding, free rolling or different relative sliding levels;
• Study of wear in free rolling or sliding at low or high temperatures;
• Friction and wear of composite materials with lubrication or without lubrication;
• Engineering metrology and diagnostics of surface;
• Surface analysis by 2D and 3D profilometry;
• Assessment of the influence of geometrical surface structure on friction and wear;
• Fatigue resistance characteristics for materials;
• Fatigue tests in corrosive environment.

3.8. University "Politehnica" Bucharest, Department of Machine Elements and Tribology, Romania

Educational and research topics:

• Machine elements and Mechanisms; Tribology; Mechanical transmissions; Finite element analysis; Computer aided design;
• Rheology of lubricants (oil, greases, biodegradable lubricants, technological fluids etc.);
• Tribological properties of coatings materials (mechanical properties, adhesion of coatings and engineered surfaces, process-structure-property interrelationships, property/performance mapping);
• Reliability and durability of mechanical components (damage accumulation model for various machine elements, vibration and noise of gears and gearboxes, flexible product development for machine elements);
• Biotribology (tribology of human joints and prothesis, rheology of sinovial fluid);
• Tribological behaviour of materials in dry and boundary friction (Stribeck curve, friction and wear processes and phenomena).

3.9. University "Stefan cel Mare" of Suceava, Faculty of Mechanical Engineering and Mechatronics, Romania

Education and research in the field of:

• Optimization of manufacturing technologies and technological equipments;
• limproving the characteristics of materials by heat treatment and other processes;
• Elastohydrodynamic lubrication and physics of lubrication;
• Contact mechanics - micro and nanocontact;
• Tribology of contacts with dry and boundary friction;
• Dry friction in multibody systems with impact phenomenon;
• Biomechanics - interactive damage processes in biomechanical fatigue; influence of initial stresses on biomechanical fatigue; Innovative bioorthopedic methods for bio-joint reconstruction; effects of initial stresses in dental biocontacts.

- ***Slovak University of Technology, Faculty of Mechanical Engineering, Bratislava, Slovakia***

Research and educational topics:

• Production and manufacturing technology – CNC and machining;
• PLM, environmental production, machine vision in production systems;
• Tribological processes in machining and milling of several materials used in automotive industry – influence of cutting fluids on the cutting force;
• Power consumption monitoring using several cutting fluids while maintaining appropriate properties of the process and outputting product.

- ***Technical University Kosice, Faculty of Manufacturing Technologies in Presov, Slovakia***

Topics of education and research work:

• Standard mechanical manufacturing technologies, progressive technologies and computer support of manufacturing technologies;
• Manufacturing cutting processes, plasma cutting processes;
• Manufacturing tribological processes;
• Tribotechnical diagnostics;
• Modelling and simulation of the technological processes;
• Technology of virtual technologies and virtual manufacturing;
• Rapid prototyping processes.

- ***Warsaw University of Technology, Institute of Micromechanics and Photonics, Poland***

Education and research in the field of:

• Microtribology and Tribology – Scale problems in tribology, Tribometry in macro and micro /nanotribology;
• MEMS (Micro Electro Mechanical Systems) Devices – design, fundamental techniques of fabrication, micromechanical sensors and actuators, metrology, tribological problems, applications;
• Micromechatronics – metrology and quality evaluation, friction/stiction and reliability of micromechatronical devices;
• Micro/Nanotechnology;
• Micro/Nanotribology; Micro/Nanomechanics; MEMS/NEMS;
• Surface and interface studies of Micro/Nanosystems – surface topography and energetic studies in micro/nanotribological behavior of the micro/nanotribological systems;

• Materials used in Micro/Nanotechnologies – in particular in the form of ultrathin films (with nanometer thickness);
• Use of advanced test instruments and elaboration of new test devices and tools.

- ***Technical University of Radom, Institute of Vehicles and Machines Maintenance, Poland***

Research and educational topics:
• Tribological investigations of sliding friction pairs;
• Examination of selective transfer phenomenon;
• Investigation on influence of lubricating and cutting oils modification with addition of nanostructures (e.g. metal nanoparticles) on sliding friction joints tribological properties;
• Examination of tribological processes effects on friction surfaces state (investigation with use of: optical an electron microscopy, X-ray spectroscopy, surface roughness analysis);
• Examination of protective coatings generation in tribological processes with metal nanoparticles use;
• Formation of polymer coatings with nanofillers (kind of nanofiller selection, optimization of nanofiller quantity, design of application technique);
• Multicriterial investigations of polymer coatings quality (investigation with use of: optical an electron microscopy, X-ray spectroscopy, IR spectroscopy, DMA analysis, surface roughness analysis);
• Investigations of operational factors influence on polymer coatings reliability;
• Multicriterial prediction of durability of polymer coatings used in different conditions.

- ***Poznan University of Technology, Department of Metrology and Measurement Systems, Poland***

Education and research in the field of:
• Nanometrology - Measurement with Atomic Force Microscope, Measurement with optical profilometer;
• Roughness and surface topography measurement - investigations on 3D surface topography measurement: accuracy of contact and non-contact topography measurement, its application in the unconventional production processes and technologies, fast measurement of topography with spiral sampling method;
• Thermal diagnostics - analysis of the thermal picture of workpiece in order to reveal structural defects, correction of the accuracy dependent on emissivity coefficient, thermal diagnostics of machine tools and unconventional devices, diagnostics of the prototypes of devices and of final products;
• Air gauging - especially non-contact measurement: improvement of static and dynamic metrological properties, application in in-process control, untypical measuring heads, non-contact form deviation measurement;
• 3D coordinate measurement (contact & non-contact) - accuracy of measurement of complicated shapes (irregular surfaces, gears, corpses etc.), calculation and simulation of form deviations, simulation of single-flank gear tests and calculations of dynamic deviations of transmission, digitalization of surface, digital modeling and Reverse Engineering, reproduction accuracy.

- ***Budapest University of Technology and Economics, Department of Machine and Product Design, Hungary***

Topics of education and research work:
• Numerical modelling of friction mechanisms, wear and lubrication;
• Modelling of sliding and rolling friction of rubber/glass, rubber/metal, polymer/metal, polymer composite/metal and metal/metal sliding pairs;
• Numerical modelling of frictional heat generation and coupled thermo-mechanical problems;
• Mechanical behavior of polymers, rubbers, rubber-like materials and polymer composites;
• Modelling and characterization of surface roughness.

- ***Technical University of Moldova, Department of Machinery and Production Systems, Chisinau, Moldova***

Research and educational topics:
• Tribology of Technical Systems – critical temperatures of oils in limit regime of lubrication; wear resistance of tribosystems materials, in sliding or rolling regime;
• Tribological couples with usage resistant electrolytic coating behavior
- Research and obtaining of electrolytic coatings (iron basis) resistant to usage;
- Electrolytic coatings (Fe, Fe-Ni, etc) and coated machines elements with auto-lubrication properties;
- Restore of machines and structures with galvanic usage resistant coatings, utilizing resonance phenomena;

- Hardening and reconditioning of machines elements with electrolytic coatings, usage resistant;
- Electrocorrosives effects in unconventional technologies;
• Machines and Systems of Production.

➢ ***University of Banja Luka, Faculty of Mechanical Engineering, Bosnia and Herzegovina***

Education and research in the field of:
• Development of technological processes, design of cutting tools and products;
• Modeling and simulation of cutting process;
• Programming of CNC tool machines;
• Design, reconstruction and modernization of production systems,
• Application of robots in manufacturing and robot programming;
• Machining of heavy machinability material;
• CAD/CAPP/CAM techniques in field of metal machining;
• Cutting tool wear monitoring;
• Machinability determination of new construction materials;
• Model development to define the universal machinability of materials;
• Prediction of output parameters of the process using artificial intelligence (neural networks);
• Identification of dynamic parameters of tool machines.

➢ ***University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture, Croatia***

Topics of education and research work:
• Design and simulation of tribosystems;
• Heat treatment and surface engineering of metallic materials;
• Deep cryogenic treatment of tool steels;
• Tribological properties testing (abrasion, adhesion, erosion);
• Testing of lubrication properties by ferrography and four ball method;
• Application of material characterisation methods;
• Developing and testing of new lightweight materials (metal foams and sandwiches);
• Sol gel surface techniques;
• Developing, application and characterisation of ceramic layers.

➢ ***Vienna University of Technology, Institute for Sensors and Actuator Systems, Austria***

Education and research in the field of:
• Methodology and design of sensors in triboengineering, such as microfluidics, microsystems, materials, sensor technology and nanotechnology in research projects in different areas where sensing solutions are needed;
• Modelling of solids and tribosystems on various length scales, coupling of models (FEM, BEM, MD, etc.);
• Preparation of surfaces by a variety of methods ranging from thin film technology to industrial production processes;
• Modification and tribological investigation of polymer materials, embedding of lubricants, technology issues, compatibility of components, ageing behaviour;
• Chemical characterisation of tribosurfaces and of organic lubricants by various techniques. Imaging and profiling mass spectrometry and electron spectroscopy as well fluorescence imaging will be used and new analytical concepts and methods will be developed, especially for the characterisation of lubricants;
• Use of state of the art radio-chemical methods for the detection of wear in the nanometre range and design optimised detection systems;
• Optimisation of the efficiency of drivelines by reduction of friction and wear. Investigations with engines and vehicles on engine test benches and roller test bench. Vehicle operation - Fleet test, Data analysis and interpretation, modelling and extrapolation.

4. BASIC AIM OF THE PROJECT

Each of network partners units is specialized and excellent in different scope of our domain, the Mechanical Engineering. We will make an effort to utilize the individual experience of the partners in a **synergy effect**. Synergy corresponds to the mutual work of two or more partners working together to produce a result not obtainable by any of the partners independently. Accordingly, it is suitable to utilize the research and educational experience, resources and achievements of the individual partners in their mutual work for the functioning of the entire network. The mobility and integration of students and teachers will enable to achieve results in education and research on a higher level.

Therefore the **basic aim** of the proposed project is to improve the international cooperation in education and research, increasing the mobility in the Danube region, the Central and East European regions and giving the possibility to the students and teachers to have access to the achievements of other universities in the interdisciplinary area of **tribology, reliability and quality** of the engineering domain. The way to the completion of the aim will be development of new Joint Programs awarding manifold support for developing and finishing of PhD theses. The Joint Programs will be a good tool for utilizing in a unity the excellent and the specific methods of education and research in engineering elaborated by the individual partner institutions. A good opportunity is the existence of previous active cooperation in the considered topics between most of the partners. The creation of the new network will consolidate the synergy effect for improving the level of educational and research area, increasing flexibility of students and teachers, and improving cooperation between network partners.

5. PLANNED ACTIVITIES

The CEEPUS Network will be focused on the following **main activities**:

- Exchange of students and teachers – lectures; finishing of diploma theses and PhD theses; work in laboratories;
- Organization of conferences; workshops; seminars;
- Implementation of Joint programs and Joint degrees;
- Preparation of study materials (books; scripts; lectures) in English language for Joint programs;
- Development of e-platform /e-learning; WEB based teaching; etc./ for study in partner universities.

The main activities will be realized successfully on the base of elaboration of following **particular tasks**:

- To develop joint program for PhD study “Design and simulation of tribosystems”;
- To support joint theses supervision (common elaboration of PhD thesis).

The **other planned general activities** are as follows:

- Exchanging students and teachers between the partner universities;
- Lectures of academic staff during their mobility - on the topics of their research activities and in accordance with the special contribution of each institution; /NOTE: The workload for teacher mobility will be at least six (6) teaching hours per week in accordance with CEEPUS III Agreement./
- Preparation of study materials - will include: reviewing the existing teaching materials and proposing new ones based on common syllabuses in the frame of the developed joint program;
- Implementation of electronic activities in the area of the joint program regarding electronic presentations, virtual laboratories, e-books, etc. by means of e-learning through an appropriate learning management system;
- Laboratory work - students and researchers will be able to carry out measurements and experimental research work for their master theses and dissertations in outstanding laboratories at partners’ institution participating in the network;
- Taking part in diploma examinations for MSc and PhD;
- Organizing intensive seminars for PhD students - will be based on common schedule of exchange visit during teachers and short-term students mobility, on topics defined jointly;
- Organizing workshops for PhD students working on their theses – special issue “Research Report” with selected lectures of teachers and PhD students will be published;
- Organizing the annual scientific conference on tribology “Bultrib” in Sofia, BG with participation of the partners cooperating in this CEEPUS network;
- Organizing symposium about diagnostics and prediction in mechanical engineering systems with topics related to reliability, quality and tribology – in Galati, RO with participation of the partners cooperating in this CEEPUS network;
- Publishing of the proceedings of each of above mentioned conferences;
- Publishing of an annual report concerning tribology state of art in the partner’s universities;
- Creating and regularly updating of the database containing the publications, diploma works, MSc-PhD works and scientific work elaborated at the partner institutions;
- Developing a web portal for the CEEPUS network on Reliability, Quality and Tribology.

Dissemination of knowledge will be carried out as follows:

1. It will be published special issue “Research Report” from the workshops - with selected papers/lectures of teachers and PhD students. The publication will be presented in textual and also in electronic form on Internet.

2. It will be be published the papers in Proceedings of the conferences and symposiums. The proceedings are good basis for study of advanced methods of industrial engineering and mechanical engineering for undergraduate, graduate and PhD students in all partner institutions.

The University of Chemical Technology and Metallurgy of Sofia and Dunarea de Jos University of Galati will develop web portal for the CEEPUS network. The planned content on this **e-platform** will be as follows:

- information on all partners included in the network;
- study plans of partner universities, curriculums;
- information oriented on new methods in the area of tribology;
- presentation of selected diplomas and PhD theses concerned with Tribology, Reability, Quality, Maintenance and Machine Design;
- presentation of the scientific and educational area of the network universities;
- other important material concerning the topics of the project,
- e-learning platform oriented on topics of joint programs;
- discussion forum for selected topics of the overall topics of network;
- information about all incoming and outgoing mobilities;
- information about all prepared conferences, symposiums, workshops and seminaries in partner institutions.

6. NETWORK COOPERATION: A CRUCIAL PROBLEM OF THE PRESENT DAY

The coordinator of the project has been partner in the frame of other CEEPUS networks and the gained experience in the cooperation among partners represents one of the motives for creation of a new CEEPUS network in Mechanical Engineering, especially in the domain of Reliability, Quality and Tribology. In the frame of the new network with the common efforts of all partners will be made a base for development and improvement of educational and research activities for students and teachers in the partner universities.

The network assures an efficient possibility for students and teachers mobility that enhances mutual acquaintance, contacts and important educational and research programs development. Exchange of knowledge, experience and various information is crucial for each university teacher and student, as well for university progress. Creation of Joint Programs of study and PhD works are also significant. It is also possible that students and young scientists participate at scientific seminars and conferences, as well as at workshops especially organized in the frame of the network.

One main advantage of the developed new network is that almost all involved partners know each other. They have been collaborating with each other, though not always formally, for a number of years. Some of the partners participate in other networks, others are new for CEEPUS, but they all have mutual scientific and teaching cooperation from conferences and official meetings in the previous years. A profit of importance for each partner in this network of CEEPUS III program is also the possibility to create new beneficial partnerships and relationships.

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COST OPTIMIZATION OF ABRASIVE WATER JET CUTTING USING GA

Miroslav RADOVANOVIC

Abstract: *This paper presents the development of mathematical model for cost optimization of abrasive water jet cutting. Mathematical optimization model includes the manufacturing cost as the objective function, the traverse rate for separation cut as the cutting performance function, and constraints. Outputs of the mathematical model for optimization are the values of orifice diameter, focusing tube diameter, traverse rate, water pressure and abrasive mass flow rate when the manufacturing cost is minimal. Genetic algorithms are used to find optimal process parameters.*

Key Words: *abrasive water jet cutting, cost, optimization, genetic algorithms*

1. INTRODUCTION

Abrasive water jet cutting (AWJC) is one of the most recent developed advanced non-traditional technologies used in industry for material processing. Almost any material can be cut. Mix high pressure water jet with abrasives gives an effective tool to cut metals and non-metals. Abrasive water jet (AWJ) can cut a wide range of thickness. Maximum thickness is 100 mm for stainless steel, 120 mm for aluminum, 140 mm for stone, 100 mm for glass, but not limited. AWJ makes it possible to cut random contours, very fine tabs and filigree structures. AWJC is capable of producing high precision parts that usually requiring no further processing. Tolerances of ±0.1 mm can be realized in metal cutting. AWJC is cold slitting process. There is no thermal effect on the workpiece. AWJC produces very little lateral force, eliminating the need for accessories to hold the workpiece.

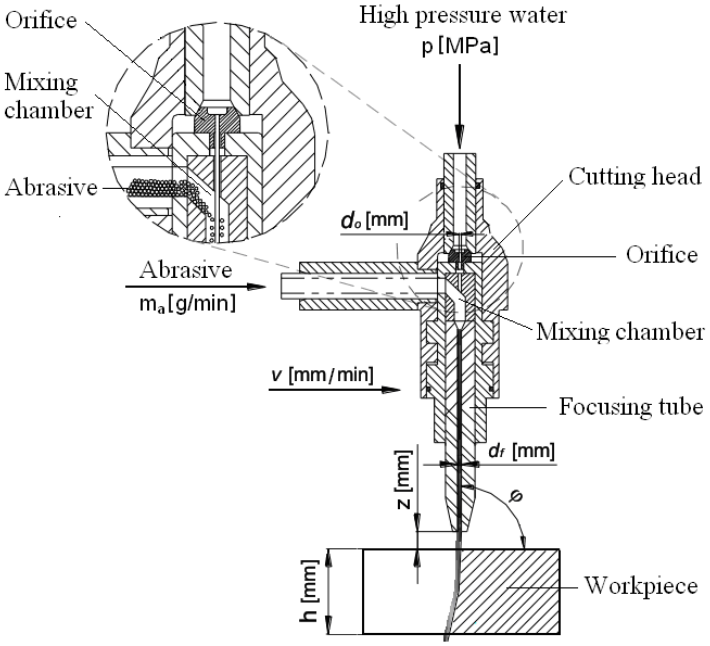


Fig. 1. Scheme of abrasive water jet cutting

AWJC process is like grinding, except that abrasive particles are moved through the material by water jet rather than by a solid wheel. Scheme of abrasive water jet cutting is shown in Fig. 1 (adapted from [8]). Most theories explain AWJC process as a form of micro erosion. By AWJC the high

pressure pump produces the water pressure up to 400 MPa. A high pressure supply line directs the pressurized water from the pump via accumulator to the cutting head. Cutting head consists from orifice, mixing chamber and focusing tube. Orifice is made of sapphire, ruby or diamond. Orifice is with diameter of 0.15 to 0.35 mm. Focusing tube is made of hard metal. Focusing tube is with diameter of 0.54 to 1.1 mm and length of 50 to 100 mm. Water is pressed out of the orifice in form of jet at a speed of approximately 900 m/s – nearly three times the speed of sound. Result is a very thin, extremely high velocity water jet. Solid abrasive particles are added and mixed with the water jet in the mixing chamber of the cutting head and then focused by a focusing tube. High speed of the water jet creates a partial vacuum in the mixing chamber so that abrasive particles are sucked in and flushed away by the water jet. This is known as the injector principle. Focusing tube focus and direct the abrasive water jet to the workpiece. Abrasive water jet attack and cut workpiece along the programmed contour guided by the cutting head.

Intensity and the efficiency of the AWJ cutting process depend on several categories of process parameters (Momber and Kovacevic, 1998) [2]. AWJ process parameters can be classified into categories that relate to: workpiece (material type, thickness, chemical structure, hardness, toughness, grain size), high pressure pump (pump pressure, water flow rate, water purity, accumulator volume), abrasive (material type, hardness, particle diameter, particle shape, particle size distribution, humidity), cutting head (orifice diameter, orifice material, focusing tube diameter, focusing tube length, focusing tube material), motion system (precision, accuracy, stiffness, working conditions) and process parameters (water pressure, traverse rate, abrasive mass flow rate, standoff distance, impact angle, traverse direction). AWJ cutting performances can be divided into four categories: process performances (orifice wear, focusing tube wear, temperature, noise, vibration), quality performances (form deviations, dimension deviations, cut quality: surface roughness, burr, depth of cut, kerf width, kerf taper), productivity performances (machining time, productivity), and economy performances (manufacturing cost, power consumption).

2. MATHEMATICAL MODEL OF TRAVERSE RATE

Traverse rate is necessary data for NC program of CNC AWJ cutting machine. Traverse rate selects based on the quality of cut and tolerance of parts. In many cases manufacturers use separation cut, i.e. traverse rate at which the abrasive water jet can cut through material. In this case the productivity is the maximum. For material type and thickness, it is necessary to know traverse rate of separation cut. Traverse rate changes according to changes in process parameters and can be determined using design of experiments. Relationship between traverse rate and process parameters is commonly approximated by analytical function. In developing the traverse rate models there are three main modeling approaches: dimensional analysis, regression analysis, and artificial intelligence based modeling. Artificial intelligence based models are developed using artificial neural networks, fuzzy logic and genetic algorithms.

Zeng and Kim (1993) [1] developed a widely accepted AWJ traverse rate prediction model and give cost analysis in abrasive water jet cutting operations. They use the traverse rate to estimate manufacturing cost, via the required cutting length and layout. Model to estimate manufacturing cost for the AWJ cutting process is presented and by Kramar and Junkar (2000) [4]. Predictive model for the depth of cut in abrasive water jet cutting of alumina ceramics using a dimensional analysis technique has been developed by Wang (2009) [7]. An empirical model for the prediction of depth of cut in abrasive water jet cutting of stainless steel using regression analysis has been developed by Selvan and Raju (2011) [9]. Predictive model for the depth of cut in abrasive water jet cutting using a hybrid approach combining fuzzy logic principles and genetic approach has been developed by Chakravarthy and Babu (2000) [3]. Predictive models for the traverse rate, water pressure, abrasive mass flow rate and focusing tube diameter in abrasive water jet cutting using a neural network approach has been proposed by Parikh and Lam (2009) [6].

In this paper predictive model for traverse rate of separation cut in abrasive water jet cutting has form of multiple power function:

$$v_s = c_0 \frac{d_o^{c_1} p^{c_2} m_a^{c_3}}{h^{c_4} d_f^{c_5}} \tag{1}$$

where are v_s - traverse rate of separation cut, h - material thickness, d_o - orifice diameter, d_f - focusing tube diameter, p - water pressure, m_a - abrasive flow rate, c_i - coefficients.

Key parameter that affects the traverse rate is the orifice diameter or, indirectly, the cutting water flow rate. Other two parameters that greatly influence the traverse rate are the water pressure and the

abrasive mass flow rate. However, the optimum values of these parameters are not independent. Optimum abrasive flow rate can be related to the water flow rate.

3. COST OF ABRASIVE WATER JET CUTTING

Three categories make manufacturing cost of abrasive water jet cutting: investment cost, operating cost, and labor cost. Investment cost is associated with the equipment purchase. Operating cost is associated with operating the process, including electrical energy consumption, water consumption, abrasive consumption, wearing parts consumption, and maintenance and repair. Labor cost is associated with running the machine, including the time to handle raw material, finished parts and remnants, and attending the machinery while it's running. Cost per meter of cut in abrasive water jet cutting can be calculated using the equation [5]:

$$C = \frac{1}{v}\left(C_i + C_e + C_w + C_a + C_r + C_m + C_p\right) \tag{2}$$

where are C (EUR/m) – cost per meter of cut, v (m/h) – traverse rate, $C_i=I/DL_a$ (EUR/h) – investment cost, I (EUR) – capital investment cost of water jet cutting machine, D (year) – depreciation period, L_a (h/year) – machine utilization, $C_e=c_e \cdot E$ (EUR/h) – cost of electrical energy, c_e (EUR/kWh) – unit cost of electrical energy, E (kW) – electrical power consumption, C_w (EUR/h) – cost of water, $C_a = c_a m_a$ (EUR/h) – cost of abrasive, c_a (EUR/kg) – unit cost of abrasive, m_a (kg/h) – abrasive mass flow rate, C_r (EUR/h) – cost of wearing parts, C_m (EUR/h) – maintenance cost, C_p (EUR/h) – labor cost.

Cost of water can be calculated using the equation :

$$C_w = c_w \cdot m_w = \frac{\pi \psi c_w}{2\sqrt{2\rho_w}} \cdot d_o^2 \sqrt{p} \tag{3}$$

where are c_w (EUR/m^3) – unit cost of water, m_w (m^3/h) – water consumption, ψ - velocity coefficient of the orifice, ρ_w (kg/m^3) – density of water, d_o (mm) – orifice diameter, p (MPa) – water pressure.

Cost per meter of cut, according equations from (2) and (3), can be calculated using the equation:

$$C = \frac{1}{v}\left(C_1 + \frac{\pi \psi c_w}{2\sqrt{2\rho_w}} \cdot d_o^2 \sqrt{p} + c_a m_a\right) \tag{4}$$

where is $C_1=C_i+C_e+C_r+C_m+C_p$.

4. MATHEMATICAL OPTIMIZATION MODEL

Machining optimization provides optimal or near-optimal solution to the overall optimization problem formulated, and subsequently implemented in actual cutting process. Procedure of the optimization has four phases:

- Mathematical modeling of AWJ cutting process performances,
- Mathematical modeling of optimization problem,
- Selection of optimization methods for solving optimization problem, and
- Solving optimization problem and determine the optimum process parameters.

Mathematical optimization model consists of the objective function and constraints. The objective function of the optimization model when cutting with abrasive water jet is the cost per meter of cut given by equation (4). For a given combination of workpiece, cutting head and machine tool, the cutting condition becomes optimal when the machining cost is minimal, subject to constraints on the process parameters.

Mathematical optimization model has the form:

- Objective function

$$\min C = \frac{1}{v}\left(C_1 + \frac{\pi \psi c_w}{2\sqrt{2\rho_w}} \cdot d_o^2 \sqrt{p} + c_a m_a \right)$$

- Constraints

(a) $v \le v_s$ (Constraint on the traverse rate of separation cut)

(b) $v_{min} \le v \le v_{max}$ (Constraints on the available traverse rate)

(c) $v_{t,min} \le v \le v_{t,max}$ (Constraints on the technological traverse rate)

(d) $d_{o,min} \le d_o \le d_{o,max}$ (Constraints on the orifice diameter)

(e) $d_{f,min} \le d_f \le d_{f,max}$ (Constraints on the focusing tube diameter)

(f) $p_{min} \le p \le p_{max}$ (Constraints on the water pressure)

(g) $m_{a,min} \le m_a \le m_{a,max}$ (Constraints on the abrasive mass flow rate)

For cutting aluminum alloy 6061-T6 plate thickness of 8 mm by abrasive water jet cutting machine with high pressure pump of 37 kW, maximum water pressure of p_{max}=400 MPa and water mass flow rate of m_w=3.73 l/min, data is: investment cost of water jet cutting machine I=120,000 EUR, depreciation period of machine D=5 years, machine utilization L_a=4000 hours per year, electrical power consumption E=45 kW, unit cost of electrical energy c_e=0.105 EUR/kWh, unit cost of water c_w=0.5 EUR/m^3, unit cost of abrasive c_a=0.7 EUR/kg, cost of wearing parts per hour C_r=0.858 EUR/h, maintenance cost C_m=1.25 EUR/h, personnel cost C_p=5 EUR/h, density of water ρ_w=999.13 kg/m^3, velocity coefficient of the orifice ψ=0.7, abrasive Garnet mesh 80, minimum abrasive mass flow rate $m_{a,min}$=100 g/min, maximum abrasive mass flow rate $m_{a,max}$= 1800 g/min, available traverse rate of 0 to 20000 mm/min, minimum technological traverse rate $v_{t,min}$= 160 mm/min, maximum technological traverse rate $v_{t,max}$= 2000 mm/min.

Mathematical model for the traverse rate of separation cut when cutting aluminum alloy 6061-T6 has the form:

$$v_s = 0.21 \frac{d_o^{1.58} p^{1.83} m_a^{0.39}}{h^{1.15} d_f^{0.71}} \tag{5}$$

where are v_s (mm/min) - traverse rate of separation cut, d_o (mm) - orifice diameter, d_f (mm) - focusing tube diameter, p (MPa) - water pressure, m_a (g/min) – abrasive mass flow rate, h (mm) - material thickness.

Equation is valied for intervals of material thickness h=6-10 mm, water pressure p=360-400 MPa, orifice diameter d_o=0.25-0.33 mm, focusing tube diameter d_f=0.9-1.1 mm, abrasive mass flow rate m_a=300-400 g/min, and abrasive Garnet mesh 80.

Mathematical optimization model for this data takes the form:

- Objective function

$$\min C = \frac{1}{v}\left(297.22 + 0.74 d_o^2 \sqrt{p} + 0.7 m_a \right)$$

- Constraints

(a) $v \le 0.019 \frac{d_o^{1.58} p^{1.83} m_a^{0.39}}{d_f^{0.71}}$

(b) $0 \le v \le 20000$

(c) $160 \le v \le 2000$

(d) $0.25 \le d_o \le 0.33$

(e) $0.90 \le d_f \le 1.10$

(f) $360 \le p \le 400$

(g) $300 \le m_a \le 400$

where are C (EUR/m) – cost per meter of cut, v (mm/min) – traverse rate, p (MPa) – water pressure, m_a (g/min) – abrasive mass flow rate, d_o (mm) - orifice diameter, d_f (mm) - focusing tube diameter.

5. COST OPTIMIZATION USING GENETIC ALGORITHMS

Genetic algorithms (GAs) are known under the name of evolutionary algorithms, and belong to a group of powerful tools for optimization of functions that can more easily locate the global optimum. GAs use only objective function to search for optimal solution. GAs seek an optimal solution in the space of solutions starting from groups of points instead of one starting point. The basic construction of genetic algorithms is the population of individuals. Certain number of strings is called population, a population at a certain point of time generation. The main operators, reproduction, crossover and mutation, are used to search for solutions of the population. Reproduction of some selected chromosomes is a process in which certain binary strings are transformed and passed to the next generation. The aim of crossover is creation of new strings by exchanging information between the strings. The crossover is the main operator, which generates new strings with better fitness values. After crossover, mutation is to provide certain randomness in the new chromosomes. Mutations can lead to degenerative solution or to a completely new solution. This process creates a new population, which is estimated according to predefined criteria. The procedure repeats until the stopping criterion is satisfied. In practice, genetic algorithms stop after a certain number of generations or after a certain time interval. In this case the genetic algorithms were used for cost optimization of the abrasive water jet cutting. Minimization of the manufacturing cost and determination of the optimal process parameters were performed by MATLAB genetic algorithm toolbox.

Table 1. The best tuning parameters for the GA procedure

Iteration	Generation	Population	Reproduction	Crossover	Migration
5	20	20	2	0.8	0.2

Optimal cutting conditions for a minimal cost per meter of cut when cutting with abrasive water jet were achieved for the following tuning parameters: number of iterations is 5, number of generations is 20, population size is 20, and reproduction elite count is 2. Genetic operators, crossover and migration, were used was 0.8 and 0.2 respectively. Obtained fitness value decreasing through generations and for the fitness function values through generations is shown in Fig. 2.

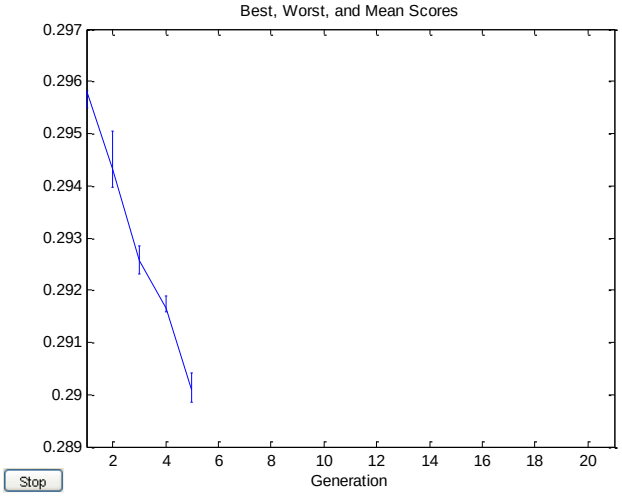


Fig. 2. Fitness function values through generations

Genetic algorithms provide the following optimal parameters values: d_o=0.319 mm, d_f=0.916 mm, p=397 MPa, m_a=303 g/min, and v=1762 mm/min. For these values, minimum cost per meter of cut is C=0.28985 EUR/m. With increasing traverse rate decreases the cost per meter of cut directly. Traverse rate increases with increasing orifice diameter, water pressure and abrasive mass flow rate, while decreases with increasing focusing tube diameter. Water pressure has a dominant influence on the traverse rate. Influence of water pressure on the traverse rate is much greater than the influence of abrasive mass flow rate. In the selection of process parameters is necessary to choose the maximum available water pressure to get the maximum traverse rate and choose the minimum abrasive mass flow rate to get the minimum cost. For the available values of orifice diameters d_o=0.30 mm and 0.33 mm, focusing tube diameters d_f=0.9 mm and 1.10 mm, water pressure p=400 MPa, and abrasive mass flow rate m_a=300 g/min, the values of traverse rate and cost per meter of cut are:

a) For d_o=0.30 mm, d_f=0.9 mm, p=400 MPa, m_a=300 g/min are:

v=1633 mm/min and C=0.311 EUR/m

b) For d_o=0.30 mm, d_f=1.10 mm, p=400 MPa, m_a=300 g/min are:
v=1416 mm/min and C=0.359 EUR/m
c) For d_o=0.33 mm, d_f=0.9 mm, p=400 MPa, m_a=300 g/min are:
v=1737 mm/min and C=0.293 EUR/m
d) For d_o=0.33 mm, d_f=1.10 mm, p=400 MPa, m_a=300 g/min are:
v=1646 mm/min and C=0.309 EUR/m

Approximately optimal values of process parameters are d_o=0.33 mm, d_f=0.9 mm, p=400 MPa, m_a=300 g/min, and v=1737 mm/min. For approximately optimal parameters values, at the cost per meter of cut, fixed costs has the greatest impact with 58.36%, then the consumption of abrasives with 41.30%, while consumption of water has the neglecting impact with 0.34%.

6. CONCLUSION

Cutting with abrasive water jet costs less than other cutting methods. At cost per meter of cut consumption of abrasives has the greatest impact, then the fixed costs, while consumption of water has the neglecting impact. With increasing traverse rate decreases the cost per meter of cut directly. Traverse rate increases with increasing orifice diameter, water pressure and abrasive mass flow rate, while decreases with increasing focusing tube diameter. Water pressure has a dominant influence on the traverse rate. Influence of water pressure on the traverse rate is much greater than the influence of abrasive mass flow rate. In the selection of process parameters is necessary to choose the maximum available water pressure to get the maximum traverse rate and choose the minimum abrasive mass flow rate to get the minimum cost. Cost of abrasive water jet cutting is minimized by using genetic algorithms. Approximately optimal values of process parameters for the presented data are d_o=0.33 mm, d_f=0.9 mm, p=400 MPa, m_a=300 g/min, and v=1737 mm/min.

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OPTIMIZING CUTTING PARAMETERS IN TUBE TURNING USING TAGUCHI METHOD

Miroslav RADOVANOVIC

Abstract: *Optimizing cutting parameters based on specific cutting energy in tube turning of S235 G2T steel by coated carbide tool using Taguchi method is proposed in this paper. Three cutting parameters namely, cutting speed, feed and depth of cut are optimized with consideration of specific cutting energy. Experiment was conducted as per Taguchi's L_9 orthogonal array. Orthogonal array, measured values of cutting force components, calculated values of specific cutting energy, signal-to-noise ratios, and analysis of variance are applied to optimize the cutting parameters.*

Key Words: *tube turning, specific cutting energy, optimization, Taguchi method*

1. INTRODUCTION

Turning is a complicated process, where the performances depend upon a number of cutting conditions. Researchers have focused on improving the performances of turning operation with the aim of minimizing time and costs or maximize quality. Knowledge about the energy necessary for cutting may help the manufacture of machine tools to estimate the power requirement. Lower specific cutting energy gives better efficiency of the machining power. Finding process parameters that optimize specific cutting energy is an important task towards enhancing efficiency of machining process. There are some studies regarding optimization of cutting parameters based on performances related to specific cutting energy such as machining power, power consumption, and specific cutting force in turning operation using Taguchi method. Davim in [1] was presented a study of the influence of cutting conditions on turning metal matrix composites. Objective was to establish the correlation between the cutting speed, feed and cutting time with tool wear, power required to perform the machining operations and surface roughness in workpiece. L_{27} orthogonal array and the analysis of variance are employed to investigate the cutting characteristics of metal matrix composites using PCD cutting tools. Aggarwal et al. in [2] were presented an experimental investigation of the effects of cutting speed, feed, depth of cut, nose radius, and cutting environment on power consumption in CNC turning of AISI P-20 tool steel. Response surface methodology and Taguchi's technique have been used to accomplish the objective. L_{27} orthogonal array and face centered central composite design have been used for conducting the experiment. Suresh et al. in [3] were presented a study on hard turning of AISI 4340 steel using multilayer coated carbide tool. An attempt has been made to study the effects of process parameters on machinability aspects using Taguchi technique. L_{27} orthogonal array is employed to investigate the effects of cutting speed, feed and depth of cut on tool wear, specific cutting force, machining power and surface roughness.

In this paper is applied Taguchi method for optimizing cutting parameters based on specific cutting energy in tube turning of S235 G2T steel by coated carbide tool.

2. SPECIFIC CUTTING ENERGY

Machining operation requires energy for removal material from workpiece. Specific cutting energy plays an important role in evaluation the machinability of materials. However, because many parameters can be varied in the cutting process that change the energy consumed, this energy value is usually normalized by dividing by the volume of removed material. Specific cutting energy is defined as energy per unit volume. Specific cutting energy can be calculated and as cutting power per material removal rate or as force per cross-sectional area of the cut.

$$u = \frac{E}{V} = \frac{W}{V} = \frac{P \cdot t}{MRR \cdot t} = \frac{P}{MRR} \tag{1}$$

where is u - specific cutting energy, E – energy to form chip, W – work done by cutting force, V – volume of chip, P – cutting power, t – cutting time, MRR – material removal rate.

Specific cutting energy in the process of turning can be expressed in the form:

$$u = \frac{P}{MRR} = \frac{P_c + P_f}{MRR} = \frac{F_c \cdot v_c + F_f \cdot v_f}{a_p \cdot f \cdot v_c} = \frac{F_c}{a_p f} + \frac{F_f}{a_p f} \cdot \frac{v_f}{v_c} = u_c + u_f \quad (2)$$

where is u_c - part of specific cutting energy related to main cutting force in MJ/m^3, u_f - part of specific cutting energy related to feed force in MJ/m^3, F_c - main cutting force in N, F_f - feed force in N, a_p - depth of cut in mm, f – feed in mm/rev, v_c - cutting speed in m/min, v_f - feed rate in m/min (v_f=f·n/1000, n – spindle speed in rev/min)

3. DESIGN OF EXPERIMENT

Taguchi method of design of experiments [4, 6] is a relatively simple and powerful tool for analysis and optimization of the machining process. Taguchi method includes selection of parameters, experimental design, conducting an experiment, data analysis, determining the optimal combination of parameters, and verification. Taguchi method uses a special design of orthogonal arrays where the experimental results are transformed into signal-to-noise (S/N) ratios as the measure of the quality characteristic. Orthogonal array and signal to noise (S/N) ratio are two major tools used in Taguchi method. Depending on the criterion for the quality characteristic to be optimized, the S/N ratio characteristics can be divided into three stages: smaller-the-better, larger-the-better, and nominal-the-better. The larger S/N ratio corresponds to the better performance characteristic. The optimal levels of parameters are the levels with the highest S/N ratio. Optimal levels of parameters are determined using analysis of means (ANOM) and analysis of variance (ANOVA). Confirmation experiment is the final step in Taguchi method and is used to verify the optimal combination of parameter settings.

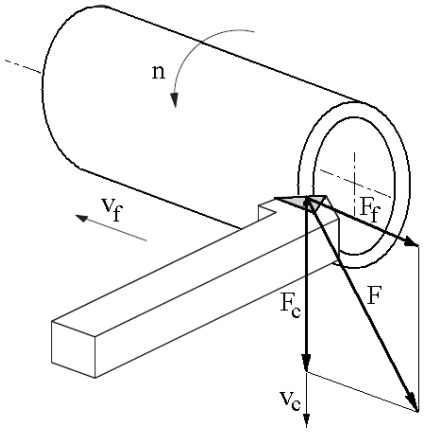


Fig. 1. Cutting force components

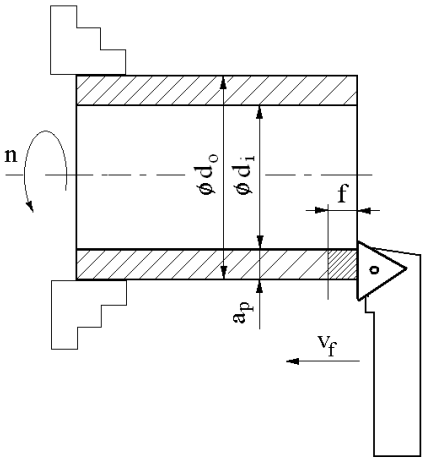


Fig. 2. Conditions of the tool's engagement

Tube turning of S235 G2T steel by coated carbide tool was performed on universal lathe. For cutting method is used tube turning in the aim to eliminate the impacts of passive force (radial force) and tool noise radius on the cutting force, Fig. 1. The workpiece is in the form of round tube and in the cutting process only the main cutting edge of the tool is in contact with the workpiece. Depth of cut is equal to the thickness of the round tube wall. For this cutting method of turning passive force does not exist. In applying cutting method, cutting force F can be decomposed in coordinate system of the machine in two components: main cutting force (tangential force) F_c, acting on the rake face of the tool in the direction of the cutting speed, and feed force (axial force) F_f, acting on the tool in the direction of tool movement. Main cutting force acts in direction tangential to the revolving workpiece and represents the resistance to the rotation of the workpiece. Feed force acts in the direction parallel to the axis of the workpiece and represents the resistance to the axial (longitudinal) feed of tool.

Workpiece material used in the experiment is S235 G2T steel. The chemical and mechanical properties of this steel are: C=0.17%, Si≤0.35%, Mn≥0.40%, Cr<0.30%, P≤0.05%, S≤0.05%, yield stress Re=240 N/mm^2, strength Rm=480 N/mm^2, and strain A=25%. Experiment was conducted with a sample in the form of tube with diameter 51 mm on a universal lathe “Potisje PA-C30” (power of 11kW, spindle speed of 20 to 2000 rpm, and longitudinal feed of 0.04 to 9.16 mm/rev) under dry

condition. Cutting tool was SANDVIK Coromant tool holder PTGNR 3225P22 with insert TNMG 220408-PM4225. Tool geometry was cutting edge angle of 90°, rake angle of -6° and corner radius of 0.8 mm. Cutting parameters were set by three levels of depth of cut (1.75; 3.50; 7.00 mm), three levels of feed (0.049; 0.107; 0.214 mm/rev) and three levels of cutting speed (78.54; 142.94; 314.16 m/min) respectively three levels of spindle speed (500; 910; 2000 rpm). Insert style, geometry, carbide grade and cutting conditions are corresponded with the material and hardness of workpiece. Sample was cleaned by removing the 0.5 mm depth of cut from the outside diameter. For the experiment working outside diameter was 50 mm. Condition of the tool's engagement is shown in Fig. 2. Main cutting force F_c and feed force F_f were measured with a three-component force dynamometer Kistler type 9441, mount on the lathe. Charge signal generated at the dynamometer was amplified using amplifier Kistler type 5007A. Amplified signal is acquired and sampled by using computer Hewlett Packard HP 9000/300. Experiment was conducted using Taguchi method. Taguchi method involves selection of control factors, response factors and an orthogonal array. Three control factors selected for the present investigation are cutting parameters: cutting speed v_c, feed f and depth of cut a_p. Cutting parameters ranges were selected based on machining guidelines provided by manufacturer of cutting tools SANDVIK Coromant. Control factors and their levels are illustrated in Table 1.

Table 1. Control factors and levels

Control factors	Control factors	Levels		
		1	2	3
A	Cutting speed, v_c (m/min)	78.54	142.94	314.16
B	Feed, f (mm/rev)	0.049	0.107	0.214
C	Depth of cut, a_p (mm)	1.75	3.50	7.00

Response factors selected for the experiment are main cutting force F_c and feed force F_f. Values of specific cutting energy u were calculated. Three cutting parameters with three levels are arranged in L_9 orthogonal array. Table 2 shows standard L_9 (3^3) orthogonal array and experimental results. Left side of the table includes coding values of control factors and real values of cutting parameters. Right side of the table includes the results of the measured values of main cutting force F_c and feed force F_f, each experiment with three repetitions, and calculated values of specific cutting energy. Orthogonal array, measured values of cutting force components, calculated values of specific cutting energy, signal-to-noise ratios, and analysis of variance are employed to study the specific cutting energy.

Table 2. Plan of experiment and results

No.	Control factors			Main cutting force			Feed force			Specific cutting energy			u (MJ/m^3)	η_u (dB)
	A	B	C	F_{c1} (N)	F_{c2} (N)	F_{c3} (N)	F_{f1} (N)	F_{f2} (N)	F_{f3} (N)	u_1 (MJ/m^3)	u_2 (MJ/m^3)	u_3 (MJ/m^3)		
1	1	1	1	356	367	366	289	285	294	4245	4268	4257	4256,67	-72,5814
2	1	2	2	1155	1163	1164	941	952	950	3090	3111	3114	3105,00	-69,8413
3	1	3	3	3640	3614	3642	3247	3279	3237	2433	2416	2434	2427,67	-67,7038
4	2	1	2	559	557	564	473	487	483	3270	3258	3229	3252,33	-70,2440
5	2	2	3	1625	1626	1614	1196	1207	1183	2171	2172	2156	2166,33	-66,7146
6	2	3	1	895	898	905	530	539	536	2395	2403	2422	2406,67	-67,6284
7	3	1	3	1266	1250	1255	1055	955	975	3692	3645	3660	3665,67	-71,2832
8	3	2	1	505	508	504	376	340	368	2702	2719	2697	2706,00	-68,6466
9	3	3	2	1515	1510	1526	837	874	860	2024	2018	2039	2027,00	-66,1372

4. ANALYSIS OF EXPERIMENTAL RESULTS AND CONFIRMATION TEST

The aim of the experiment is to optimize the cutting conditions for turning S235 G2T steel with regard to the minimum specific cutting energy. Used smaller-the-better characteristic is defined as:

$$S/N = \eta = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \quad (3)$$

where is S/N - signal-to-noise ratio, n - number of repetitions of the experiment, y_i - measured values of quality characteristic.

To analyze the effect of cutting parameters on specific cutting energy a main effect plots were generated. Main effects plot for S/N ratios of specific cutting energy with respect to the factor levels is presented in Fig. 3. S/N ratio increases (i.e. the specific cutting energy decreases) as the depth of cut and feed increase. When the cutting speed increases S/N ratio first increases and than decreases (i.e. the specific cutting energy first decreases and then increases). Verticality of the line indicates that the feed is factor which has more influence on the specific cutting energy. Depth of cut is of little significance because the verticality of line is small.

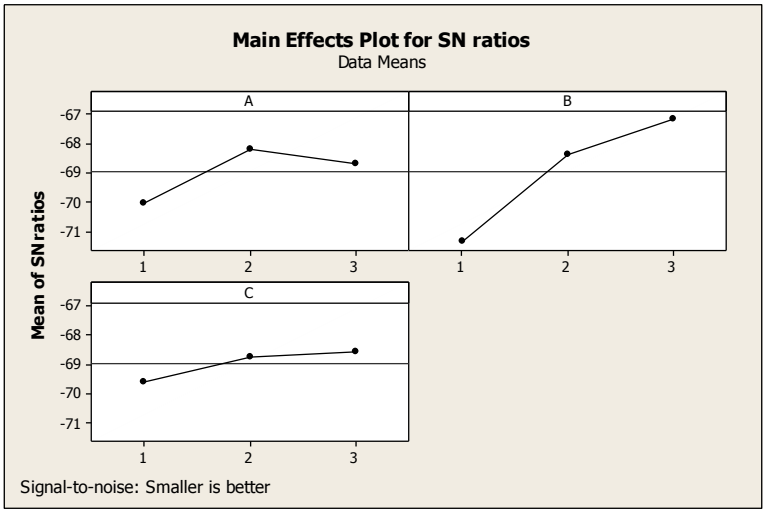


Fig. 3. Main effects plot for S/N ratios

Analysis of means (ANOM) is a statistical approach of estimating the mean S/N ratios for each parameter and each of its levels. Response table for S/N ratios of specific cutting energy for each level of control factors is shown in Table 3. Table 3 shows the rank of factors, in the first place is the feed, in the second place is cutting speed, and in the third place is depth of cut. The results from Table 3 suggest that the optimum values of control factors are given by $A_2B_3C_3$, i.e. the optimal cutting parameters are: the cutting speed of 142.94 m/min, the feed of 0.214 mm/rev and the depth of cut of 7.00 mm. This combination gives the lower specific cutting energy within the range of experiments.

Table 3. Response table for S/N ratios

No	Factors	Code	Level average			Max-Min	Rank
			1	2	3		
1	Cutting speed, v_c (m/min)	A	-70,04	-68,20*	-68,69	1,85	2
2	Feed, f (mm/rev)	B	-71,37	-68,40	-67,16*	4,21	1
3	Depth of cut, a_p (mm)	C	-69,62	-68,74	-68,57*	1,05	3

* Optimum level

Analysis of variance (ANOVA) is a statistical technique, which is used to estimate the relative significance of each process factor. It is also required for estimating the variance of error. In ANOVA, the ratio between the variance of the factor and the variance of error is called Fisher's ratio (F). It is used to determine whether the factor has a significant effect on the quality characteristic by comparing the F test value of the factor with the standard F table value (F_α) at the α% significance level. Greater the F-ratio more significant is the process parameter. Fowlkes & Creveling (1996) suggest a simple set of criteria based on the size of the F ratio:

- F ratio < 1: Control factor effect is insignificant (error effects outweigh control factor effect).

- F ratio ≈ 2: Control factor has only a moderate effect compared with experimental error.
- F ratio > 4: Control factor has a strong (clearly statistically significant) effect.

ANOVA was carried out to find the relative effect of cutting parameters on the specific cutting energy. Table 4 shows analysis of variance for S/N ratios. From the ANOVA, it can be seen that cutting parameters, feed and cutting speed have a strong (clearly statistically significant) effect on specific cutting energy. Depth of cut has only a moderate effect compared with experimental error. Percent contribution of source to the total variation defines parameter sensitivity. Depth of cut, feed and cutting speed affect the specific cutting energy with contribution of 94.94%. Feed is the most significant parameter affecting the specific cutting energy with contribution of 75.18%, followed by the cutting speed with contribution of 14.66%. Depth of cut has little effect with contribution of 5.10%.

Table 4. Analysis of variance for S/N ratios

No	Factors	Code	DOF	SS	MS	F	p	%
1	Cutting speed, v_c (m/min)	A	2	5,484	2,7421	2,90	0,257	14.66
2	Feed, f (mm/rev)	B	2	28,112	14,0559	14,86	0,063	75.18
3	Depth of cut, a_p (mm)	C	2	1,907	0,9535	1,01	0,498	5.10
	Residual error		2	1,892	0,9460			5.06
	Total		8	37,395				100

DF - degree of freedom, SS - sum of square, MS - mean square, F - variance ratio, p - probability value and % - percent contribution

Optimal value of specific cutting energy (μ_{SE}) is predicted by selection of cutting parameters $A_2B_3C_3$. Predicted optimal value of specific cutting energy can be calculated as:

$$\mu_{SE} = \overline{A}_2 + \overline{B}_3 + \overline{C}_3 - 2\overline{T}_{SE} = 2608 + 2287 + 2753 - 2x2890 = 1868\ \mathrm{MJ/m^3} \quad (4)$$

$$\overline{T}_{SE} = \frac{1}{9}(4256.67 + 3105 + 2427.67 + 3252.33 + 2166.33 + 2406.67 + 3665.67 + 2706 + 2027) = 2890\ \mathrm{MJ/m^3}$$

$$\overline{A}_2 = \frac{1}{3}(3252.33 + 2166.33 + 2406.67) = 2608\ \mathrm{MJ/m^3}\ ,\ \overline{B}_3 = \frac{1}{3}(2427.67 + 2406.67 + 2027) = 2287\ \mathrm{MJ/m^3}$$

$$\overline{C}_3 = \frac{1}{3}(2427.67 + 2166.33 + 3665.67) = 2753\ \mathrm{MJ/m^3}$$

Where is $\overline{T}_{SE}$ - overall mean of specific cutting energy, $\overline{A}_2$ - mean effect of parameter A at level 2, $\overline{B}_3$ - mean effect of parameter B at level 3, $\overline{C}_3$ - mean effect of parameter C at level 3.

In order to statistically judge the closeness of predicted to observed data, the confidence interval was determined. Confidence interval (C.I.) for the predicted mean can be calculated as [5]:

$$CI = \pm\sqrt{F_{\alpha(1,f_e)} \cdot V_e\left[\frac{1}{n} + \frac{1}{n_{ver}}\right]} = \pm\sqrt{18.5x64407x\left[\frac{1}{3.86} + \frac{1}{3}\right]} = \pm 840 \quad (5)$$

where $F_{\alpha(1;fe)}$ is the F value from the F-table at a required confidence level of 1-α = 0.95 at DF = 1, and DF of error f_e = 2, $F_{0.05(1;2)}$ = 18.5, V_e = 64407 is the error variance, n_{ver} = 3 is the validation test trial number, and $n = \frac{N}{1+\nu} = 3.86$ is the effective number of replications where N = 9x3 = 27 is the total number of experiments and ν = 2x3 = 6 is the total DF of all parameters.

The 95% confidence interval of the predicted optimal value of specific cutting energy is:

$$(\mu_{SE} - C.I.) < \mu_{SE} < (\mu_{SE} - C.I.) \quad (6)$$

$$1028 < \mu_{SE}(\mathrm{MJ/m^3}) < 2708$$

The predicted S/N ratio using the optimal levels of the design factors ($\hat{\eta}_{opt}$) can be calculated as:

$$\hat{\eta}_{opt} = \overline{\eta} + \sum_{i=1}^{p} (\overline{\eta}_{i,opt} - \overline{\eta}), \quad \overline{\eta} = \frac{1}{n_t} \sum_{i=1}^{n_t} \eta_i \tag{7}$$

$$\hat{\eta}_{opt} = -68.98 + (-68.20 + 68.98) + (-67.16 + 68.98) + (-68.57 + 68.98) = -65.97\text{dB}$$

$$\overline{\eta} = \frac{1}{9}(-72.5814 - 69.8413 - 67.7038 - 70.2440 - 66.7146 - 67.6284 - 71.2832 - 68.6466 - 66.1372) = -68.98\text{dB}$$

where is $\overline{\eta}_{i,opt}$ - mean S/N ratio for i-th parameter at the optimal level, $\overline{\eta}$ - total mean S/N ratio, *p* - number of parameters that significantly affect the quality characteristic, n_t - total number of trials, and η_i - S/N ratio in i-th trial in the OA.

Confirmation experiment is the final step in Taguchi method and is used to verify the optimal combination of the factor settings. For that purpose, a confirmation experiment was performed using optimal condition ($A_2B_3C_3$) for specific cutting energy. The predicted and the experimentally observed values of specific cutting energy at the optimum levels of the cutting parameters are shown in Table 5.

Table 5. Predicted values and confirmation test results

<table>
<tr><td rowspan="2"></td><td colspan="7">Taguchi optimal parameter settings</td></tr>
<tr><td>Prediction</td><td colspan="6">Experiment</td></tr>
<tr><td>Level</td><td>$A_2B_3C_3$</td><td colspan="6">$A_2B_3C_3$</td></tr>
<tr><td rowspan="2">Cutting force and feed force (N)</td><td rowspan="2">-</td><td>F_{c1}</td><td>F_{f1}</td><td>F_{c2}</td><td>F_{f2}</td><td>F_{c3}</td><td>F_{f3}</td></tr>
<tr><td>3415</td><td>2256</td><td>3422</td><td>2285</td><td>3424</td><td>2255</td></tr>
<tr><td rowspan="2">Specific cutting energy (MJ/m^3)</td><td rowspan="2">1868</td><td colspan="2">u_1</td><td colspan="2">u_2</td><td colspan="2">u_3</td></tr>
<tr><td colspan="2">2281</td><td colspan="2">2285</td><td colspan="2">2287</td></tr>
<tr><td>S/N ratio (dB)</td><td>-65.97</td><td colspan="6">-67.18</td></tr>
</table>

Since the prediction errors for specific cutting energy are within C.I. values, the combination of cutting parameter levels for optimization of specific cutting energy can be validated.

5. CONCLUSION

Experimental results showed that the Taguchi method of design of experiments is an effective method for optimizing cutting parameters based on specific cutting energy. Orthogonal array, measured values of cutting force components, calculated values of specific cutting energy, S/N ratios and ANOVA are applied to study specific cutting energy and to optimize the cutting parameters. Significant cutting parameters were identified and the optimal combination of cutting parameter values was determined. Optimal cutting parameter values, namely, cutting speed of 142.94 m/min, feed of 0.214 mm/rev and depth of cut of 7.00 mm give the lower value of specific cutting energy within the range of experiment based on smaller-the-better characteristic. ANOVA analysis showed that feed is the most significant parameter affecting the specific cutting energy with contribution of 75.18%, followed by the cutting speed with contribution of 14.66%. Depth of cut has little effect with contribution of 5.10%.

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THE FAILURE UNCEMENTED HIP REPLACEMENTS FROM FRACTURE STEM PROSTHESIS

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Abstract: *This research refers to a prosthesis made of CoCr with porous area "Madrepore macro", recovered during a revision surgical intervention due to femoral stem's fracture. Such a fracture appears to prosthesis distally well fixed, but proximally mobile, leading to fracture through stem's middle or proximal third. In the case of this prosthesis, object of the present study, the goal is to find the cause leading to the implant's failure. The macroscopic observations showed that the stem's fracture occurred on a transversal plan, proximally close to the distal area of the porous zone, due to bending efforts, not preceded by a plastic strain. Based upon microscopic observations, this research shows that this process manifested itself as a fragile fracture with ighlight on a pronounced trans-crystallization. In the fracture area and in its adjacency there were detected conspicuous oxidation aspects (corrosion). Therewith, during microscopic observation performed on both pieces (the femoral head being assembled through a shrinking-on process on the flange femoral stem) it was detected that they have the same type of microstructure, made of a solid solution δ, and a relatively coarse compounds network, wich represents the structure as it was casted. In the stem's marginal area as well as middle area, numerous casting defects were identified, like microporosities and microfissures. These defects communicated with the stem's exterior, and after the implant, they allowed body's organic components diffusion, which leaded to tribocorrosion. The present research highlights also the existence of a major casting defect around the tiredness efforts' action area, a defect that facilitated the stem's fracture.*

Keywords**:** *uncementless hip prosthesis, stem stability, porous implant surfaces, breakage.*

1. Introduction

Bone tissue ingrowth within the open porous microstructure leads to improvement of the transfer forces, avoiding at the same time stress concentrations, by producing a permanent secondary contact. One of the main parameters of the implant's surface is to establish the optimal pores dimension to facilitate bone growth. From a historical point of view, French researchers started by producing structures similar to cancelleous bone by means of a coarse structure made of a CoCrMo alloy. For example, the Judet prosthesis, with "porometal" (porous metal) surface, as well as many other models so-called "mandrapore" surfaces (coarse surfaces, with only one layer) produced through balls (coating), like in the case of Lord prosthesis.

Subsequently, these ideas were developed in Germanic countries and USA by replacing the unique layer with a multilayer structure, with open pores – an interconnected porous structure. For example, the LUBECK hip prosthesis surfaces made of spongy metal (spongy metal) and "mini-mandrapores" structures (resembling corals), retrievable in PCA prosthesis (Tab.1, Fig.1) [1].

As the use grew, microporous coating surfaces was also taken into account. In comparison with coarse porous surfaces and those resembling corals, for this prosthesis, it can be reached a growing rate of the contact surface of the bone several times higher. Casting processes, possible only for coarse structures and cobalt alloys, must face the comparison with the sintering processes which can be used for cobalt alloys as well as for titanium alloys.

New achievements (executions, performances) were obtained applying metal fibers and Ti balls on stems made of wrought titanium alloy, with the help of diffusion contacts. Moreover, prosthesis models with porous surfaces obtained through plasma and powder blasting were also tested.

Table.1. Implants' porous metal surfaces [1].

Porous covering (coating)	Material	Deposit technique	Pores' size	Porosity
1. a "Porometal" (porous metal) b." Spongy Metal"	Cast CoCr	Adhesion of spongy material on a wax model	0,5 ÷ 1,5 mm 400 ÷ 500 μm (ball	> 50 ÷75%
2. "Madrepore" macro (coarse , one layer) - "Madrepore" mini (fine, multilayer)	Cast CoCr Cast CoCr	Adhesion of plastic balls on a wax model Metal balls sintered in a mould	diameter approx. 1,5 mm) 200 ÷ 300 μm (ball diameter approx. 0,8 mm)	> 35 ÷50% approx. 35%
4. "Madrepore" mini/micro (one layer /multilayer)	Ti	Metal ball sintering on raw wrought stems	200 ÷ 300 μm (ball diameter approx. 0,8 mm)	approx. 35%
5. "Metal fibres"	Ti	Contact through diffusion of wrought alloy fibres	400 μm (ball diameter approx. 0,5 mm)	50%
6. "Plasmapore"	Ti	Deposits through plasma atomization of Ti powder on Ti wrought alloy	20 ÷ 200 μm	25 ÷ 50%

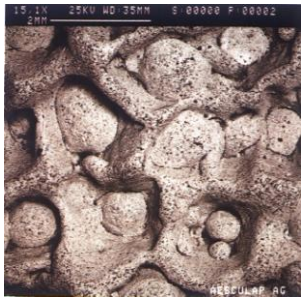
Microporous implant surfaces with active transfer processes are carried through plasma coating (for endoprosthesis). Pores' sizes afferent to the structures mentioned above enter the range of approximately 400 μm to 1.5 mm for macroporous surfaces with a porosity higher than 50%, between 200 and 400 μm for microporous surfaces and between 20 ÷ 200 μm for microporous surfaces with a porosity between 25 and 50%.

High expectations are expected from material engineering for porous coating of metal prosthesis. On one side, the coating material must be compatible and stable within the organism. Because of the surface growth, the corrosive products quantity, which toxic reaction may inhibit the formation of new bone, may increase. On other side, coating layers must adhere so well on the prosthesis body and it must be that stable so that it will not shatter and the particles will not detach themselves during press or after the contact with the bone. Mechanical characteristics of the prosthesis components under effort must not be significantly affected by the coating method. A peculiar importance has also the resistance to weariness.

If we follow the experiments on animals done in USA and in other countries starting with 1970, it results the necessity to take into account pores' size, porosity, bone growth kinetics, micro and macro movements and the contact resistance after a certain period, based upon histologic examinations and shearing stress measurements.

Hulbert experiments s.a., [2], performed on porous ceramic material made of calcium alumina with a pores' size varying between 11 μm and 200 μm, showed that:

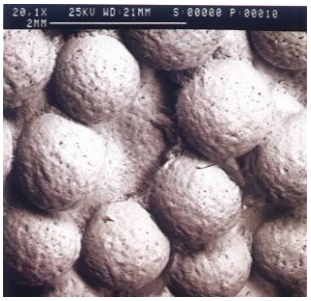
- There is a significant growth of the binding tissue only in the pores that have a dimension between 44 μm and 75 μm;
- The vascularization starts in the pores whose dimensions vary between 75 μm and 100 μm with un-mineralized bone formation within concentric lamella and with tissue calcification at the surface;
- Infiltration with mineralized bone starts in the pores having between 100 and 150 μm;
- Osteon formation takes place in the pores having between 150 and 200 μm.



a. Porous metal



b. Spongy metal



c. Madrepore macro (resembling coral)



d. Madrepore mini (resembling coral)



e. Metal fibres coating (armour)



f. Plasmapore

Fig.1. Images obtained through microscopy with electronic scan of certain porous metal coatings [1].

Hence, the conclusion that the minimum pore size to have a significant growth of the natural bone is approximately 70-100 μm.

These results are in accordance to those obtained by Klawitter s.a., [3], while using polyethylene with high molecular density, porous. He drew the conclusion that pores that have 40 μm allow the bone to grow, but the optimum growth speed is obtained when the size of the pores is between 100 and 135 μm, even trough for larger pores there is no significant growth acceleration. Cameron s.a., [4] reached the same conclusion.

There are few data in the specialized literature that rely on appropriate experiments referring to optimum porosity, particularly referring to the fact that pores' size and porosity are not independent one from another. According to Hahn and Palich [5], there is an ideal value, 20-40%, which allows the osteoblasts to grow. Below 20%, there is neither direct growth, nor blood circulation. Above 60%, the pores' growth becomes incomplete (Galante s.a. [6]).

Most authors accept the pores size as being higher than 200 μm. They investigated a large variety of materials (porous polyethylene, calcium aluminate, stainless steel, titanium, Ti fibers network). For example, Predecki's s.a. very detailed work, [9], tackles the kinetics of bone growth within deep cylindrical channels produced in ceramic materials with alumina and in titanium. Authors reached the conclusion that:

- Tissue calcification can be observed in channels with 95 μm diameter;
- A significant growth of bone tissue, with continuous growing process – for a long period of time– can be registered starting with 195 μm diameter.

Particularly it was demonstrated that:

- deep bone penetration takes place far more rapidly during the first 4 weeks for channels with 400 μm diameter than for those with diameters smaller than 400 μm, but
- the larger the channel's diameter, the less complete will be the filling

- growth speed decreases significantly after 8 weeks within the channels with diameters of 500 μm to 1000 μm. Many of these types of implants, after these 8 weeks, lost their bondage.

- on the other hand, bone growth was evidently accelerated after 8 or even 18 months in the case of implants with channels whose diameters decreased from 400 μm to 195 μm.

Cameron s.a., [4] and Pillar s.a., [10] verified the fact that new bone formation may appear during micro-movements that have a maximum value of 28 μm. For example, contrarily to such phenomenon only binding tissue can form itself during macro-movements of about 150 μm. In this sense, large interstitial spaces between implant and bone need extensive movements. For example, Harris' s.a. [11] experiment made on a pelvis model, determined that an interstitial space of 0.5 mm is already too large to ensure the implant's fixation into the bone. The importance of primary stability and of the surfaces in direct contact is also confirmed by the experiences related to fractures' healing. Damaging influence of the local interstitial spaces formation between implant and surrounding bone must be avoided by using the appropriate implant model, instruments used during implant and a very attentive operating technique. If the porous coating is in direct contact with the bone, it is highly expectable to have a firm anchorage of the implant after approximately 3 weeks and to reach the maximum critical shear stress of the area between the implant and tissue after 4 weeks. According to Heck [12], considering his animal experiments, when decreasing the stress that the implant is subject to, for 3 weeks in row, a positive effect on improvement of the biomechanical performances of the implants with porous coatings is registred, in comparison with the situation when implants are subject to maximum stress.

Looking at the measurements of the critical shear stress within dogs' cortex layer, on samples with mandreporous surfaces consisting of CoCr balls with groups of pores A: between 20-50 μm, B: between 50-200 μm, C: between 200-400 μm and D: between 400-800 μm, as they were carried out by Bobyn s.a. [13], they might lead to a maximum critical shear stress of 17 N/mm^2. Groups of pores between 50-200 μm as well as those between 200-400 μm register the fastest implant stabilization. Authors explain this fast stabilization through the plurality of the bone's contact points existing in the groups of pores A and B.

Stresses status of the prosthesis stem is dully described by six stress components. As a whole, the stress status is known as stress tensor. Even though components may vary according to the chosen specific references system, stress status remains the same. In other words, stress status along an object does not depend on the chosen references system (for example observer). It depends only on the load, geometry and features of the material. The simplest way to represent stress status is within the main references system and through three main stress components of normal stress. Structures bone/prosthesis often require information related to the "interface" loadings, where different materials are connected. These interfaces do not always align with the references external system, and generally, they do not align with the main directions of the loadings [14]. To reach this goal, the local system of coordinates at the interest points may be relatively introduced. Relate to it the normal interface and shear stresses are expressed – Figure 2.

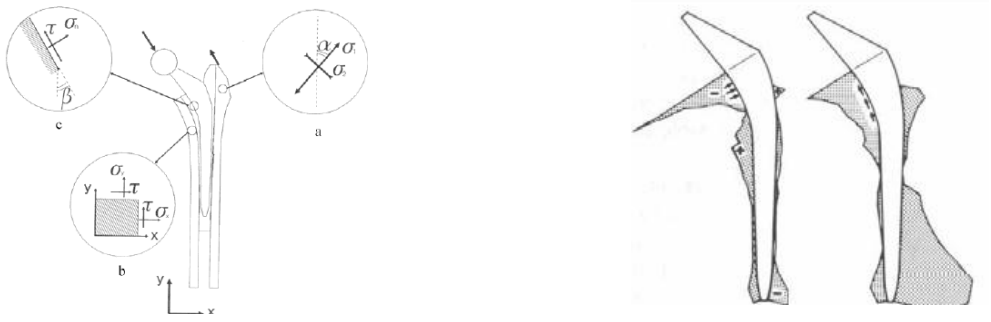


Fig. 2. (A) The illustration of three representation of the stress status and (B) the distribution of tension, compression and shearing stress at the interface stem / bone for a THA stem, simulated through a FE model. Left: normal efforts at the interface (tension / compression); Right: shearing efforts [15].

The three methods to represent the loading (coordinates, main efforts, and interface) are illustrated in Figure 2 (A), for a bi-dimensional example, where (a) main stress (σ_1, σ_2) in main direction α, relative to *x-y* coordinates system; (b) stress components (σ_x, σ_y and τ) within *x-y* coordinates system; (c) stress components (σ_n and τ) normal and parallel to a chosen surface, for example an interface at a β orientation towards *y* axis. The distribution of tension, compression and

shearing stresses at the interface stem/cement for a THA cemented stem, simulated though a FE model, is illustrated in Fig. 2 (B) [15].

Maximum stress (elastic limit) of a material is usually measured through uniaxial compression and tension tests or through shear test made on samples of material with simple geometries. The arising question is how to relate a stress status calculated in 2D or 3D, characterized through six components, to those resulted from the uniaxial tests in order to obtain an estimation of the failure probabilities. To reach such a goal, it is necessary to calculate an equivalent stress (or an effective stress) by using a particular resistance criterion.

For example the von Mises resistence criterion assumes that the material will fail (plastic deformation) when distortion energy will rise for a certain value. Von Mises stress can be calculated from the equation:

$$\sigma_m = \left\{ \frac{1}{2} \cdot \left[(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2 \right] \right\}^{\frac{1}{2}} \quad (1)$$

where σ_1, σ_2 and σ_3 are the main efforts in the interest point in the material. These values of the von Mises equivalent loadings can be simply compared to the values of failure effort obtained from samples of the same material, tested in laboratory for uniaxial stresses and compressions with the goal of obtaining an estimation of the failure probabilities. They offer reasonable predictions for isotropic materials. In the case of anisotropic elastic materials (as bone) or in the case of viscoelastic materials, such comparisons are less satisfactory. Nevertheless, they are often used for such materials as well [15].

The density of the deformation energy represents as well the deformation status of a material but it was not directly related to a failure criterion. This quantity can be calculated using the following equation:

$$U = \frac{1}{2} \cdot (\varepsilon_1 \cdot \sigma_1 + \varepsilon_2 \cdot \sigma_2 + \varepsilon_3 \cdot \sigma_3) \quad (2)$$

where ε_1, ε_2, ε_3, σ_1, σ_2, and σ_3 are the specific deformations and main efforts, respectively. This formula is valid only for isotropic materials where the directions of main forces and main efforts are parallel. The function of the density of the deformation energy is used usually to formulate constitutive equations of the non-linear elasticity. It is also used within the theory of bone remodeling that adapts to effort [15].

Most medical devices implanted serve their patients well, during the entire use period, which sometimes can be quite long (decades, in case of permanent implants, following certain accidents suffered by young patients). The performance of such a device when it is in use, can be evaluated only after it is retrieved from the organism, intervention performed if there is any damage suffered by the device or if the implant's duration has expired.

If the extraction is imposed by a certain type of damage (fracture, deformation, detachment) or by certain complications suffered by the organism, such an analysis of the damaged medical devices is absolutely necessary in order to explain the failure's causes. In the cases of implants for bone system, most clinic complications that can be indicated through the analysis of damaged medical devices can be grouped in a series of well-defined categories [15]: structural damage due to materials' degeneracy (wear; fracture; calcification; sectioning); adverse interaction of the local tissue (inflammation and infection; toxicity; tumors' formation; tissue overgrowth); migration (displacing of the entire device; embolism or lymphatic dispersion of material fragments); systemic effects or others (allergy).

The analysis performed may refer either to design and test processes, that potentially affect all devices of a certain batch, or to the particular conditions that damaged the device in the case of that particular patient. Determining the causes and mechanisms contributing to the damage of an implant or device following the retrieval and evaluation procedures of the implants may lead to a series of conclusions that might result in the following effects [16, 17]:

- patient management modification, by choosing a different type of prosthesis, modifying the existent one or modification of the medication dosage used during patient's therapy, patient closer monitoring through non-invasive therapy (bone scanning);
- revealing the vulnerabilities of a certain prosthesis type, of a manner or particular damaging mechanism, which in their turn lead to the intervention of regulating agencies, in the sense of retiring from usage of that type of prosthesis, detailed examination of a group of patients having that particular type of device, design modification, materials or production selection;

- influencing litigations regarding the liability related to the respective product, as an individual case or with the involvement of several patients.

Retrieved implants' analysis may accurately indicate several aspects of the damaging mechanism: presence of model deficiency; choosing inappropriate materials; damage that might appear due to the fact that preclinical tests of that device did not indicate certain manufacturing or material flaws, but which become evident after their clinic use on large-scale; the time when the defect appeared (in production or during the implantation); patient's physiological abnormal response to the implant (for example, hypersensitivity or blood clotting tendency).

Implant's evaluation without taking into consideration also the tissue represents an incomplete evaluation, without the understanding of the host medium's response. It may be anticipated that implants and new materials may impose the use of advanced techniques in the assessment of interactions between host medium and biomaterials, and the development of new analytical techniques for these particular situations [18].

2. Materials and methods

Protocols and analytical techniques to evaluate the implant can be specified only after appropriate consultation, cataloguing and identification, including a complete overview of the patient's medical antecedents, and after the radiography [16]. ASTM and ISO [19, 20], implants' retrieval standards, established an assessment approach in three stages. Stage I supposes the routine device identification and its description. Stage II of the assessment (more detailed, time consuming and costly) includes photographing and not destructive evaluation of the damage. The protocols for Stage I and II are identical for different types of materials, and can be found in ASRM F561-05a. Stage III protocols include destructive analytic techniques, a lot of them being specific for particular types of materials and they suppose separate techniques for metal, polymeric and ceramic materials. The combination of such protocols results in guides helpful in the analysis of different compounds and materials components. The assessment of an implant and its surrounding host tissue, when the implant is located into the bone, takes place in the conditions where around the implant there is grown bone, and the local tissue calcifies. There are a series of standards regulating the issues intervening during bone implants' analysis retrieved for assessment, such as: ASTM F561-05a: Standard Practice for Retrieval and Analysis of Medical Devices, and Associated Tissues and Fluids; ISO/NP 12891-1:2007 Retrieval and analysis of surgical implants - Part 1: Retrieval and handling; ISO 12891-2: 2005 Retrieval and analysis of surgical implants - Part 2: Analysis of retrieved metallic surgical implants; ISO 12891-3: 2005 Retrieval and analysis of surgical implants - Part 3: Analysis of retrieved polymeric surgical implants; ISO 12891-4: 2005 Retrieval and analysis of surgical implants - Part 4: Analysis of retrieved ceramic surgical implants

The techniques to assess the implant are in most cases typical destructive, which means that the implant or a part of it must be destroyed or modified in order to obtain the needed data in what its features or those of the material out of which the implant was manufactured [21] are concerned.

Stress analysis in solids' mechanics involves a particular structure with a given geometry, created for a certain material, whose elastic properties are known (Young modulus and Poisson coefficient). The structure is under the influence of external forces and/or moments and connected to the environment through a certain shape. The objective of a stress analysis is to determine the loading and forces field within the structure and to see whether the structure produces excessive deformations or loadings, which might cause the mechanical failure. Stress analysis may be achieved either numerical on a computer or using mathematic solutions. In the first case, a model simulated on the computer is used, for example the method with finite element. In the second case, the solution is obtained through explicit mathematic formulae. These solutions, with similar shapes, are available only for particular structures, with regulated shapes, such as prismatic bars and beams. Solutions with similar applicable shape are always preferred to the numerical ones due to their numerical results. They offer an understanding of the relationships between structural parameters, materials features, efforts and effort-force models. Finally, as a rule, all calculated loadings and forces must be verified through experiments. Forces acting on the surface of a structure can be experimentally determined either directly, through measurements, or indirectly using a testing model.

Mention must be made that the results of a stress analysis, experimental or analytical, depend very much on the model built to recreate the structure. The accuracy of the calculations of force and effort depend very much on the model's realism (for example geometry, constitutive equations for the material, material's coefficients, loading conditions and boundary conditions). Models are abstract forms of the reality and are used to simplify the current issue. The essence of modeling is that each model must include issue's main features, as close to its needs as possible. Complex models are not always better than the simple ones. There are no fixed rules regarding these modeling processes. The

questions are when is an assumed model real (almost never) and when a simplification is justified regarding the issue definition [15].

2.1. Surface bondage

To bond the femoral stem surface of a hip prosthesis is taken into consideration a very simple model of a solid layer (prosthesis) bonded on a sub-layer (bone) (Figure 3). It is assumed that both materials, taken separately, have uniform elastic properties and that the layer above it is rigidly bonded on the sub-layer. Figure 3 shows a von Mises model of stresses within the materials for the case in which the prosthesis is loaded through a force *F* that acts in only one place. For example, the resistance criterion von Misses supposes that the material will cede (plastic deformation) the moment when the distorting energy will increase above a certain value. Von Misses stress can be calculated from the equation (1)

Fig. 3.A presents the case in which the prosthesis has the same elastic properties as the bone ("isoelastic material"), while in Fig. 3.B the prosthesis is made of metal, assuming it is titanium, which is far more rigid than bone.

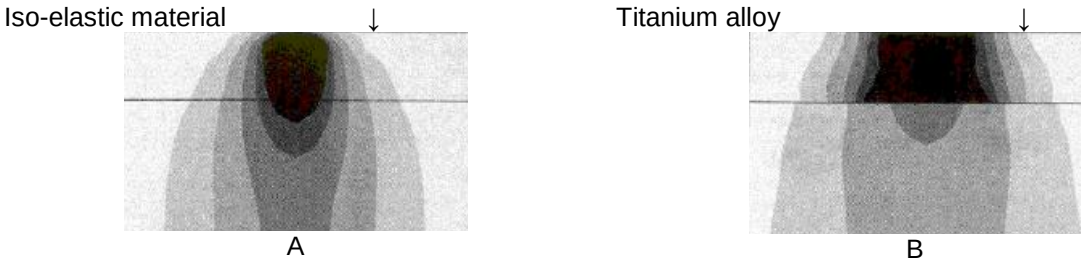


Fig. 3. Stresses distribution calculated for a FE simple model of an elastic sub-layer and upon which an F force acts. A: von Mises stresses distribution, equation 3, is presented for the case in which the layer from above (prosthesis) has the same elastic properties as its foundation (bone); B: von Mises stresses distribution for the case in which the prosthesis is made out of a more rigid material (ex. titanium) than its base (bone).

From these results we note the following characteristics:

1. Stresses are not essentially uniform, mostly concentrated on a central band within the structure, directly below the applied effort.

2. When the modules of the two materials are equal (Fig. 3.A), efforts are continuous along the surface; when materials are different (Fig. 3.B), stresses are discontinuous along the surface.

3. Stresses' models are more uniformly distributed in the case of rigid prosthesis (Fig. 3.B) in comparison with the case of soft prosthesis (Fig. 3.A). As a result, efforts' intensities are higher in the case of the prosthesis made of a softer material.

These characteristics are central for the understanding of the stresses' transfer during the surface_bondage. Normal stress (compression) σ_y at the interface must balance the applied force on direction *y*. Stress σ_y is not uniform and must satisfy the balance conditions. Thus, there is a simple relation, which establishes the link between the stresses' average and the current stress.

Even though the stresses' average may be used in certain situations, when there are doubts related to the existence of a number of loadings concentrations within the composite structure, the loadings average should not be taken as representative for the maximum stress value. As the stress distribution σ_y should always balance the applied force *F*, a composite structure that leads to the stresses distribution contraction will have a maximum value higher (Fig 3.A), than in the case of Fig. 3.B.

Such a situation indicates that, even though, according to the intuitive expectancies that a material having similar elastic properties with the bone might be ideal for implants, in fact it might not be the ideal choice from the point of view of stresses distribution.

Generally, stresses models of a surface bondage structure depend, not only, on the features of the articular stresses (amplitude, direction, contact area and contact area increment) but also on the bending rigidity (elasticity modules and component's dimensions), the elastic characteristics of the support bone and the characteristics of the joint type. The bending rigidity of the prosthesis is a design parameter that can be adjusted so that it influences the stresses models. It is the product of the elastic module and of the second module of inertia (proportional with width *x* depth). As well, the effects of rigidity onto the osseous sub-layer have to be taken into account, as, in general, they are not uniform [15].

As a rule, local concentration of efforts appears where the rigidity of the support bone is relatively high. Rigid area tends to attract the loading transfer, and the flexible area tends to become a shield against stresses. In fact, all mechanisms discussed above play a role in the stresses transfer within this composite structure. Because of the structure's complexity and bone's lack of homogeneity, they are not easily recognizable in the stresses models.

The principles of stresses transfer during the inter-marrow fixation rely on the participation of stresses and are very similar to the mechanism illustrated in Fig. 3. As simplified model, a metallic stem was chosen (femoral stem) fixed within a tubular bone. The stem is under stress through an axial force that has to be transferred to the bone. Once again, the transfer of loadings between stem and bone is carried out through shear stresses localized at the interface. In fact, the diagram of the stem's free body indicates that these shear stresses should balance the external loading. Therefore, the shear stresses average multiplied by the stem's surface area should be equal to the axial force. However, once again, these shear stresses are not uniformly distributed. Stresses concentrations appear in the proximal and distal zones.

When the stem suffers a bending stress, a mechanism appears which is similar to the stresses transfer. This time, the bending moment is transferred from the stem to the bone through the interface loadings (stress, compression, and tangential shear) that carry out this transfer of moment. These stresses are not uniform and are concentrated mostly in the proximal and distal zone.

2.2. Principles of the stresses transfer

The most important principles of the stresses transfer during the intra-marrow fixation for artificial articulations are:

1. The structure can be divided in three regions zones: medial zone where the stresses participation appears and two stresses transfer zones in the proximal and distal zone.

2. Within medial zone there is a pure participation of the stresses, while the stem carries $\varepsilon_n \times 100\%$ of the axial force or $\varepsilon_t \times 100\%$ of the bending moment; here ε_n and ε_t are the relative rigidities, axial and bending defined as:

$$\varepsilon_n = \frac{A_s \cdot E_s}{A_s \cdot E_s + A_b \cdot E_b} \tag{3}$$

$$\varepsilon_t = \frac{I_s \cdot E_s}{I_s \cdot E_s + I_b \cdot E_b} \tag{4}$$

where E, A and I represent the elasticity module, the plan areas and the second moment of stem's inertia (s) and bone's inertia (b).

3. In a normal situation the loading are taken over only by the bone, but in this case the loadings are taken over by stem and bone, the bone is protected against stresses by the stem. The higher ε_n and ε_t are the higher percentage of the stress taken over by the stem and the more extensive the stress shielding effect.

4. The higher is the percentage of stress taken over by the stem within medial zone the smaller will be the transfer within proximal zone and the bigger it will be in the distal zone and the other way round. The stress transfer in the proximal zone is proportional with $(1 - \varepsilon_n)$, respectively $(1 - \varepsilon_t)$ and the transfer in the distal zone is proportional with ε_n, respectively ε_t. Hence, the more rigid the stem is, the bigger the tensor of the proximal interface is.

5. The length of the distal and proximal areas of stresses transfer and the peak of the stresses interface on the distal and proximal zone, depend on the parameters λ_n and λ_t, and on the fixation exponents for axial and shear stresses. These parameters depend not only on the axial and bending rigidity of the stem and bone, but also, mostly on the elasticity modules and depth of the middle layer (acrylic cement and trabecular bone). A rigid middle layer (large module and /or thin layer) reduces the length of the efforts transfer zones, increasing in this way the gradients of the interface's stresses.

6. Stresses' peak at the interface is not necessarily reduces when the stem is longer. In this case, the notion "stresses is the loading on the available area" is erroneous. When the stem is longer, only the regions of the transfer of loading change. When the stem is shorter (shorter than π/λ_n or π/λ_t), the region in the middle disappears, and a further reduction of the stem affecting the interface stress.

7. If a collar in the proximal region of the stem is bonded to the proximal bone, the proximal region of the transfer of loadings is deviated. Hence, conceptually, none of the stresses will be transferred in the proximal part along the interface. The above considerations represent basic principles derived from a generalized simplified model, and they are actually very useful as an information data base for the prosthesis design. In reality the stresses transfer mechanism and stresses models are far more complex. The loadings do not appear as isolated axial compressions or bendings, stems are not usually straight, interfaces are not always bonded rigidly, and the bone has features and shapes far more complex than in this model.

Stem's rigidity plays a major role in inter-marrow fixation, and as such, it is an important parameter in the design process. The considerations about the major effects of the rigidity lead to the main design conflict for uncemented prosthesis (Fig. 4). When a stem is manufactured from metal (rigid stem in comparison to bone), in the bone appears a low stress value, possibly resulting, as a long-term effect, in a bone resorption (Fig. 4 A).

The stresses at the interface are relatively small (Fig. 4B). When the stem is manufactured from a flexible material (isoelastic material), the stress amplitude is only moderate but the proximal shear stresses are extremely high (fig. 4B), and in such case the dissolution of the bondages implant interface/ bone may appear. This will show again that a prosthesis material having the same elastic properties as the bone, cannot necessarily represent the ideal solution.

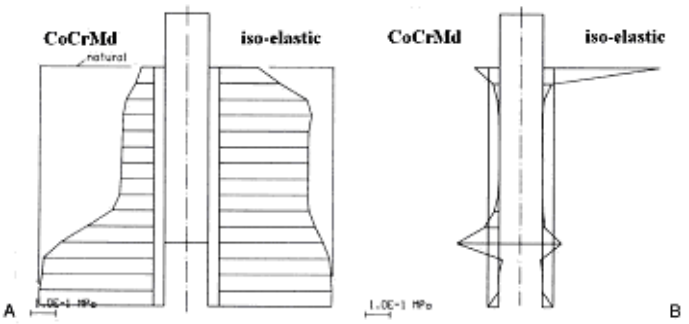


Fig. 4. Stresses models for a simple FE model of inter-marrow fixation that compares the effects of a CoCrMd stem (left) with those of a isoelastic flexible stem (right). A: Periostal osseous stresses compared to natural efforts. B: Interface shear's stressess. The stem suffers an stress while bending [15].

Finding the optimum design for the stem's shape and the right material that will protect the bone and guarantee the interface's long-term integrity represents a challenge in the contemporary design of artificial articulations [15].

2.3. Methods of morphological quantitative analysis

Artificial articulations' design is usually created in two phases. First phase is the conceptual design, when the specialist's philosophy is transformed into shape. The designer may be an engineer, an orthopedist or an entire team composed of engineers and surgeons. Second phase is very difficult to carry out and to analyze due to the difficulties that appear while trying to obtain samples of human tissue and due to the large variety of osseous shapes. The designer can use databases containing the most encountered osseous dimensions from different patients' populations. However, such situations are rarely available in the accessible literature. Some data may belong to implants' manufacturers. Anthropometric data retrievable in the specialized literature are, in general, limited in what the bones' extreme dimensions characterization is concerned, and it is not detailed enough to serve as basis for the prosthesis design.

The morphological quantitative analysis on large scale of the bones' shape and with a statistics basis is very important to develop the implantology, and for the moment, there are not very popular research projects in this field. Some researchers deployed extended geometrical analysis of the proximal femur with the help of digital analysis with *X* rays. They obtained few significant correlations for the femur, which is a very important step in the prosthesis design of THA. On the other hand, they managed to define dimensional classes for the endosteum shapes. Such a system based on dimensional classes can be used to code the essential geometric models to achieve an order within the large variation of bones' dimensions.

A more precise method of geometric analysis is achievable by sectioning the osseous samples and through the digital analysis of photos and radiographic contacts. Such tasks are dull in

comparison to conventional methods with *X* rays. Following this analysis, the first issue arising is the collection of a sufficient number of bones and to be sure that the collection represents a well-defined population. Second issue is to define an external reference system so that each osseous section can be reported to it. Due to it, the reference system can rely only on the very varied external geometry of the bone, which is not an easy task [15].

2.4. Analysis of the relative movements

Implant's micro-motions related to the bone in conditions of dynamic stresss prevents the bone to grow within the porous coatings. The same micro-motions may lead to bone resorbtion at the interface with the prosthesis stem and to the creation of a fibred tissue membrane. Therefore, it is important, in the case of uncemented stems, to have an adequate "initial stability". Micromotions can be measured experimentally in vitro by placing sensors on the prosthesis, in one or in several points, to measure its motions related to the bone [16, 17, 18].

Sometimes, only the particular components of the motion are measured, for example femoral stems' deformation in case of axial or angular stresses or rotary bending stresses. A complete evaluation of prosthesis motions is trivial. The rigid body motion of the prosthesis component towards the bone can be described through 3 translations of a chosen basic point (superior / inferior motion or deformation, anteroposterior translation and medial-lateral translation) and 3 rotations around the perpendicular axis, alternatively (axial rotation, flexion and varus/valgus rotation). To determine these 6 motions of rigid body, at least 6 relative motions of 3 points must be determined (the motion on *x, y* and *z* of a point, the motion on *x, y* and *z* of a second point, the motion on *z* axis of a third point). Often, the motions of a rigid body are not enough to define the prosthesis motions. At the physiological levels of stresses, certain components bear deformations, which cannot be neglected when they are under stress. For example, the femoral stem suffers significant deformation while bending [15].

2.5. Experimental analysis to determine the stress

The experimental analysis of stress is usually deployed on laboratory models, using osseous samples or osseous substitutes. In each case the deformation are measured, and then interpreted visually, or measurements are used to calculate the stress using the elasticity theory. The common methods used to measure deformations in biomechanics are the analysis with the extensometer, holography, photo-elastic analysis, etc.

The most used method is the analysis with the strain gauge, where this electric instrument is attached to a blank surface of an object. The instrument contains one or more filaments, which deform at the same time with the surface to which they are attached. Strain gauge functions according the following principle: a filament's deformation is proportional to its electric resistance modification. Thus, the force that acts over a material sample on the point where the strain gauge was applied can be easily measured by evaluating the difference of electric resistance. To determine the complete force status (two linear forces and a shear force) on a blank surface, a rosette-tensometer can be used. A rosette contains three filaments (usually oriented at 30-45^{o} one against the other) that measure three linear forces in the application point. These three linear forces can be used to calculate the complete force status as well as the values of main force and main directions. When the elastic features of an object are known, forces can be calculated by using Hooke's generalized law.

2.6. Finite element analysis

The finite element method (FEM) became a very used instrument in orthopedic mechanics. It represents a computerized simulation method used to determine stresses and forces in any given point within a structure with geometric complexity and a material's complexity arbitrarily chosen. The model relies on modeling constitutive accuracy of the material and on material coefficients (Hooke generalized law is the most used), 3D geometric data, stresses features and interface conditions. To develop a FEM model, the form and structure is divided in small finite elements. In case of 3D analysis, volume elements with particular shapes (parallelepipeds and tetrahedrons) are used and for 2D analysis, area elements with particular shapes (triangles and tetragons) are used. Each element has joint points, regular at the elements' corners. For each joint point three movement components and three force components are identified (in case of 2D analysis only two by two).

When there is a need of information about structures which are too small to be taken into account, in FE models, local model may be used instead of general one (Fig. 5).

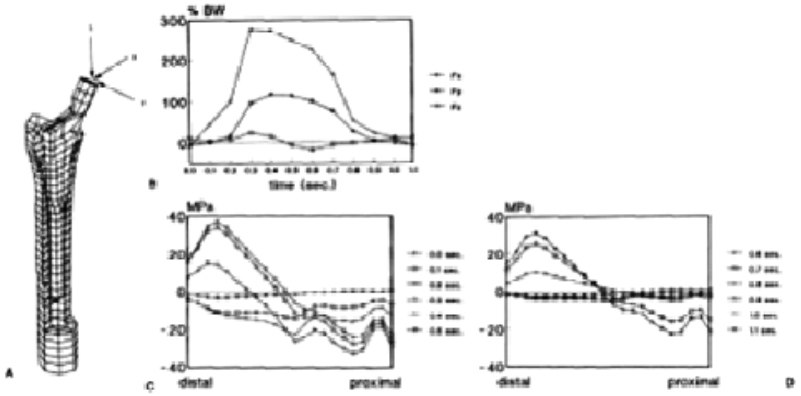


Fig. 5. A: a FE model of a composite structure femoral stem - bone. B: hip articulation forces are determined with an instrumented prosthesis in vitro. C and D: bending stresses distribution at the medial part of the frontal plan of the prosthesis, from 0 to 0.5 seconds and from 0.6 to 1 second.

In this case, a local region from the entire (global) surface is modeled in a secondary FE model, with a finer surface. Boundary conditions of the secondary model (stresses, motions) are then derived from the results of the global model. This secondary model needs boundary conditions independent of the micro-structural details that have to be analyzed. In other words, micro-structural details are small enough not to produce a notable effect on the mechanic behavior of a larger structure.

FE analysis demands numeric descriptions of external forces applied to the structure (application point, amplitude, direction). These loads are usually variable and not always accurately known, so the issue related to the FE analysis is often linked to the approach that has to be followed in order to obtain the necessary information. One consideration that is always helpful is that FE analysis is accessible for small parameters variations. Therefore, stresses may vary and studies' results may be defined in the idea of determining relations and situations of the "worst case scenario" type. Often the critical case configuration is initially selected in the case of different stresses. In such cases it is recommendable to investigate the stress modes sensitivity at small deviations of external forces. Fig. 5 shovs an example of variable stresses effect from hip joint during walking, at the bending stress modes from a femoral THA structure. A critical case loading for the proximal stem appears 0.5 seconds after the start of the walking phase. Anyhow, the distal stem's loading's will reach a maximum value of 0.3 seconds. This situation indicates that a critical case loading for one part of the structure does not necessarily imply a critical case loading for another part.

Another approach to select the efforts is to use the loadings representative cases. This approach is useful especially when the effects of the construction of a particular prosthesis design are to be studied in a comparative analysis, or when the stress transfer's mechanism is to be studied. For example, regarding the femoral component THA, the effects of the hip articulation force can be separated in those resulted out of axial force, and out of bending and rotary bending moments. The issue may be then analyzed from the point of view of the three perspectives or from the point of view of the main perspective. Finally, it is important to realize that most FE models of prosthesis structures use the linear infinitesimal elasticity theory and as such surfaces are perfectly bonded to their interface. For these models the superposition principle was used. Therefore, stress models resulting from the force application in the hip articulation together with muscular forces can be found by adding the results obtained from the separate approach of these forces [15].

When the interfaces are not bonded, meaning they are destabilized without friction or destabilized with friction, the issue becomes nonlinear and must be solved by using stresses increments. In order to achieve that, FE packages use the so-called "gap" elements to take into account the surfaces separation or untying. Load transfer for inter-marrow implants (femoral stems) are affected by the interface conditions more severely than by any other structural parameter, in particular when a completely bonded case is compared with a completely untied case (Fig. 6).

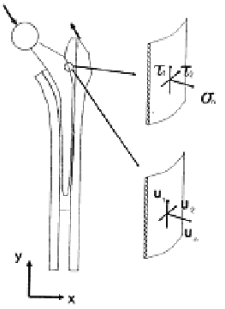


Fig. 6. Components of normal stress (σ_n) and shear stresses (τ_1 şi τ_2), transferred through the liaison interface; Normal (u_n) and tangential (u_1 and u_2) motion componentss are relative movements that may appear at the interface if it is not bonded.

This is the effect described previously due to the penetration of stem into the bone. When an interface is bonded, the compressive axial load acting on the stem is balanced by shear stresses from the interface. When the stem is unbonded and there is no friction, the shear stresses cannot exist. Stem should afterwards penetrate into the tubular bone developing a compression effort at the interface with the bone. The smaller the angle, the more necessary is to have a deeper penetration into the bone to balance the applied axial force. For a real stem, this mechanism is far more complex due to the stem's curve, ununiformed elastic features of the bone, and friction appearing at the interface.

2.7. Parametric analysis

There are two major benefits in using the FE analysis. Firstly, such analysis can be used to determine a stress, a force and a particular movement anywhere within the object, which otherwise, in theory, will be impossible to obtain by using other experimental or analytical methods. Secondly, this type of analysis can be used as an instrument for parametric analysis. This means that structural parameter can be modified and their results rapidly established. An example of such parametric analysis applied along the stem of a THA component is presented in Figure 7.

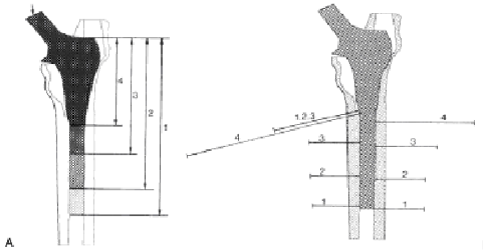


Fig. 7. A. Parametric analysis with a FE 2D model, lateral lamella of an uncemented femoral stem with variable stem lengths. B. Normal maximum (right) and the shear stresses (left) peak at the interface are presented for variations of the length. To be noted that differences are visible when the stem is very short (case 4).

The parametric analysis is useful not only during the design phase of the prosthesis, but also when defining experiments and explaining clinical observations.

The current research refers to a monobloc type prosthesis (Figure 8), whose femoral stem suffered a fracture during service time, surgery being necessary to remove and to replace it.



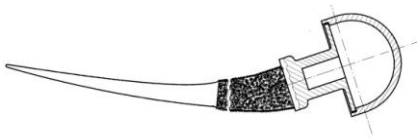


Fig. 8. Hip prosthesis submitted to investigation

3. Results and discussions

Investigations were performed in compliance with the international norms previsions ASTM F561-05a, Standard Practice for Retrieval and Analysis of Medical Devices, and Associated Tissues and Fluid [19]; ISO/NP 12891-1: 2007 Retrieval and analysis of surgical implants - Part 1: Retrieval and handling [20]; ASTM F1903-98(2003) Standard Practice for Testing for Biological Responses to Particles in Vitro [21]; ASTM F1904-98(2003) Standard Practice for Testing the Biological Responses to Particles in Vivo [22]; ISO 17853: 2003 Wear of implant materials - Polymer and metal wear

particles - Isolation, characterization and quantification [23]; ISO 17853: 2003 Wear of implant materials - Polymer and metal wear particles - Isolation, characterization and quantification [24]. In compliance with these standards, the investigations included three stages. During stage I, routine stage, of macroscopic inspection, the implant was identified as being a monobloc femoral prosthesis, with femoral head of 40 mm diameter (Fig 8). The femoral stem was manufactured through casting, and the proximal area covered with semi-spheres with 1.5 mm diameter, manufactured during casting, resembling to a coarse “Mandrepore macro” coating, presented in Fig. 1 c. The stem was fractured on a transversal plan on the porous area, at approximately 5 mm from its distal area.

During Stage II, non-destructive, digital photographs of the two prosthesis fragments were made, of the fracture, highlighting the fracture’s aspect, where a possible casting defect is indicated. The fracture was not preceded by a plastic deformation; it was a fragile fracture, indicating a pronounced trans-crystallization (Fig 9 a, and b). On the stem, in the fracture area, there were visible rust corrosion.



(a) (b)

Fig. 9. Photographs (a) and (b) of the two surfaces if the fractured femoral stem.

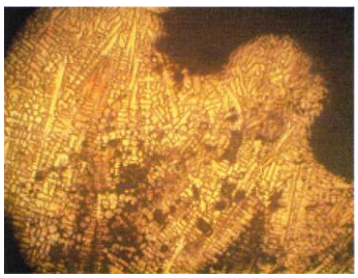
The fractured area of the femoral stem was submitted to microscopic investigation, indicating a casting defect near the middle of the area. Images from Fig 9 illustrate the sections of the two fractured stem pieces, where a casting defect can be observed almost in the middle of the fracture, of approximately 4 mm (natural size), but also reddish corrosion traces, from the contour towards the middle.

This evident observation proves that the femoral stem broke exactly where is the maximum bending (shear) stresses area (see. Fig. 2).

During the microscopic observation performed on both pieces (spherical head, and collar stem, shrunken-on), it was observed that they have the same type of microstructure, composed of a solid solution δ, and a network of relatively coarse compounds, rough casting structure.In marginal areas as well as in the middle of the stem, numerous casting defects were identified such as micro-porosities and fissures. These defects communicate with the piece’s exterior. They are illustrated in Fig. 10 a, b, c and d (x 50).



a b



c



d

Fig. 10. Casting defects, micro-porosities (a, and b) and fissures (c, and d). These defects communicate with the stem's exterior.

Mention must be made that the femoral head structure (Fig. 11) did not present any casting defects.

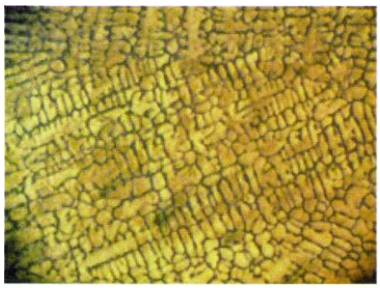


Fig. 11. Image of the femoral head structure, without casting defects

During stage III of the evaluation, femoral head as well as stem sections were submitted to hardness investigations. For the stem the following values were identified HV_{10} of 235; 232, the equivalent of ~ 21 *HRC*, that is an average resistance of R_m ~ 790 N/mm^2, and for the femoral head HV_{10} of 206 – 207 , the equivalent of ~ 18 *HRC*; R_m ~ 700 N/mm^2. The values of the stem's and femoral head's hardness are compliant with the range of values for different types of his endo-prosthesis.

4. Conclusions

Following theoretical studies and experimental investigations presented above, the following conclusions can be drawn:

- The prosthesis was manufactured from a stainless alloy (not magnetic) casted (CoCr), without further metallurgical processing.
- Glossy parts of the two components were carefully mechanically processed.
- The curved stem that is introduced in the marrow channel, with rounded prominences obtained through casting, presents a rusty aspect, due to the bio-tribo-corrosion within human organism.
- The entire stem presents numerous micro-porosities and fissures, where organic components diffused after the implant.
- The technological variant chosen to manufacture this prosthesis is not compliant, and as such the imposing action should be the manufacturing interdiction (and consequently its use).
- The fracture appeared most probably due to bending efforts that the stem was subject to, their maximum acting exactly in the area weakened by the casting defect highlighted during our investigations.

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A POSSIBLE NEW THIN COATING SOLUTION FOR SCRATCH RESISTANCE IMPROVEMENT OF FEMORAL HEAD OF TOTAL HIP PROSTHESIS

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Abstract : *We report on scratch resistance of femoral heads made of Co-Cr-Mo and Ti-6Al-4V alloys retrieved during the revision surgery and the evolution of the surface state influence on the wear of UHMWPE acetabular cups. Visual and optical microscopy analysis of femoral heads revealed numerous multi-directional scratches, deeper or less deep, tarnishing of the surface in the geometric locus of action of resultant force application point, micropitting and spalling on Co-Cr forged prosthetic femoral heads, coated with Co-Cr-Mo by PVD method. Scratches, pitting, spalling, and bio-tribo-corrosion on titanium nitride (TiN) coatings of Ti-6Al-4V femoral heads were also observed. AFM analysis revealed spectacular increase of average roughness (R_a) of the femoral heads, compared to the maximum value of 0.05 µm provided by ISO 7206-2. As an alternative, we realized TiN coatings by pulsed laser deposition (PLD) technique on cylindrical samples (22.5 mm in diameter and 10 mm in height), made of 316L stainless steel, with hardness of 150 HV_{30}. The number of applied laser pulses varied between 5000 and 20000 pulses. This work points out that TiN protective coatings deposited by PLD technique with the maximum number of pulses can represent an alternative technology to ensure adhesion and scratch resistance of TiN coatings on Ti-6Al-4V femoral heads. The success condition for such coating is to provide an optimal surface roughness of femoral head that serves as substrate for TiN coating.*

Key words**:** total hip prosthesis, femoral head wear, surface coatings, TiN, PLD.

1. AIMS AND BACKGROUND

Total hip prosthesis (THP) is the most success of the 20th century in orthopaedic biomedical engineering. If the insurance process of primary and secondary mechanical stability of THP takes less, stability loss of THP is a dynamic process that takes place throughout the life of the prosthesis. It depends on mechanical stress, movements and heat [1] that support artificial hip joint, bone-cement and cement-stem interfaces strength for cemented stems [2], on the growth of bone inside for uncemented stems [3], porous coatings efficiency of femoral stems [4] and acetabular shells, and on

the resistance to wear of femoral stems, acetabular cups and femoral heads of THP [5]. The most successful orthopaedic device proves to be a progressive bio-tribo-system due to request bills action and hostile environment specific to the human body. Co-Cr-Mo and Ti-6Al-4V alloys are the most used materials for femoral heads. With all the technological advances (coatings with mono or multi-thin films) femoral head damage remains a major problem in the THP.

This paper refers to the wear and scratching resistance of the femoral heads. Taking into account only the matting areas without deep scratches, R_a values 3 - 4 times higher were recorded. This increase in average roughness value leads to scratching of the inner surface UHMWPE of the acetabular liner, which adhere on the protective titanium nitride (TiN) coatings of Ti-6A-4V femoral heads. Hostile environment from the human body makes every crack on the TiN coating surface to become a focal point for development of tribo-corrosion, which finally leads to spalling of thin coatings areas and, in this way, to the formation of many particles that become embedded in the inner surface of the acetabular cup. In this way, the lubrication, supposed boundary or mixed, from the femoral head and acetabular cup is compromised.

Ti and its alloys are resistant to corrosion [6] and represent biocompatible materials widely used in orthopaedic implants because of their light weight and low elastic modulus [7]. However, the use of these materials in joint implants is limited by their high coefficient of friction and poor wear resistance. In order to improve their tribological properties, these materials have been submitted to surface modification treatments. Since TiN are hard biocompatible materials [7, 8, 9] of excellent abrasion resistance, many advanced processing methods have been developed aiming the production of a nitrided layer on the materials surface. In plasma nitriding [10], nitrogen atoms diffuse into the Ti matrix thus forming a top layer of TiN and Ti_2N compounds followed by a deeper diffusion layer. This layered structure produces a continuous hardness profile thus providing an adequate support of the protective layer [8, 11]. The physical properties of the treated surface, however, depend strongly on the plasma technique and processing parameters. The excellent corrosion resistance of the Ti alloys results from the formation of a very stable protective oxide film strongly adhered to the metal surfaces [12].

The wear and corrosion resistance of TiN, on the other hand, may be affected by its structural defects (pinholes, pores and small cracks) [10]. In fact, Meletis et al [13] showed that an adequately defect-free and dense structure of the TiN film can improve considerably the wear and corrosion resistance. The present work contributes to the investigation of how plasma nitriding affects the wear, scratching and corrosion behaviour of the Ti-6Al-4V alloy. The main differences to previous studies on this subject concern the nitriding and scratch resistance testing conditions.

In present work we report on the synthesis of thin films on steel substrates by pulsed laser deposition (PLD) method for improving the general performances and in particular the mechanical characteristics of the structures. The films were grown in reactive atmosphere using a TiN target. The substrate temperature during depositions was kept at 500ºC. Our samples were nitrided in a pulsed plasma reactor containing a gaseous nitrogen and wear and adhesion resistance of the coating on the sublayer was evaluated by scratching tests accompanied by Fourier Transform Infrared (FTIR) Spectroscopy, X-ray Diffraction (XRD), Optical Microscopy (OM), Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM) and scratch tests.

FTIR investigations proved the stoichiometric transfer of the material. XRD diffractograms showed that TiN coatings were polycrystalline, exhibiting reflections assigned to B1 cubic structure of TiN. We measured for the best TiN films by f(ψ) method high values (-10 to -13 GPa) of residual compressive stress. Using AFM, surface tribological parameters, such as maximum and minimum height, average roughness, surface skewness, were inferred. Graphic variation curves of scratch depths, depending on the applied normal loads were drawn. The surface of the sublayer did not present dislocations or other major structural defects. The increase of the surface hardness of the deposited TiN layer in respect with the thickness is discussed.

2. MATERIAL AND METHODS

2.1. PLD experiments

PLD experiments were conducted inside a stainless steel deposition chamber using a KrF* excimer source (λ = 248 nm, $\tau_{FWHM} \approx$ 25 ns, v = 10 Hz).

Cylindrical samples (22.5 mm in diameter and 10 mm in height), made of 316L stainless steel, with hardness of 150 HV_{30} were used as substrates. Depositions were made into deposition chambers (Fig. 1), with stainless steel reaction chamber (Fig. 2) to 5000, 10000 and 20000. The laser fluence was ~ 5 J/cm^2, at energy of 500 mJ.

The target-substrate separation distance was of 5 cm. The TiN target was ablated in a dynamic flux of N_2 constantly controlled using an MKS 400 mass flow controller. The pressure inside

the deposition chamber was ~ $2x10^{-3}$ Torr. In order to eliminate the micro-impurities, the steel substrates were cleaned using a laboratory procedure previously described [14]. During the deposition, the substrates were heated and maintained at 500 ^{0}C.



Fig. 1. Deposition Chambers



Fig. 2. Stainless steel reaction chamber

2.2. Characterisation of deposited thin films

Microstructure of TiN layers deposited by PLD was investigated using Grazing Incidence X - rays diffraction (GIXRD) technique.

Using a small incidence angle, this technique allows obtaining information from a small volume adjacent to the sample surface, the analyzed layer diffraction intensity being higher than that of conventional techniques. Therefore, the influence of substrate is reduced. Also, very important when analyzing films tension is the fact that the investigated depth remains relatively constant throughout the analysis interval.

Diffraction measurements were performed with Cu Kα radiation on Rigaku Ultima IV apparatus, equipped with parallel optics and vertical θ-θ goniometer. Divergence angle of the beam emitted by means of the multilayer mirror is about 0.05^0. This type of optics is suitable for thin films analysis, especially for measurements of residual stresses, due to strong beam's intensity and significantly reduction of the instrumental errors (position of diffraction lines is out of phase, shape and width of diffraction lines profiles are retained even at large angles of inclination) [15]. The diffractograms were purchased at a fixed angle of incidence $\alpha = 1^0$, in the angular range 2θ of 34^0 - 105^0, with step acquisition of 0.02^0 and counting time per step of 10s.

To determine the instrumental contribution, required for Rietveld analysis, it was used the standard material NIST SRM 660a - LaB_6. Diffractogram of standard material was acquired under the same conditions as the samples analyzed.

Microstructural analysis was performed with the help of FullProf specialized software developed by Juan Rodríguez-Carvajal that allows Rietveld analysis of the entire spectrum of diffraction. For modelling physical profile, pseudo-Voigt TCH function was used [16] which include Finger correction of axial divergence [17]. Determination of residual stresses was made using GIXRD. Assuming that the sample is subjected to biaxial tension with rotational symmetry ($\sigma_{11} = \sigma_{22} = \sigma_{\parallel}$, without dependence of φ, $(\sigma_{\perp} = 0)$, without shear stresses), condition usually satisfied in the case of thin films, dependence of the elastic deformation of the crystal lattice on the angle ψ can be expressed by the law $\sin^2\psi$ [18]:

$$\varepsilon_{\psi}^{hkl} = \left(2S_1^{hkl} + \frac{1}{2}S_2^{hkl}\sin^2\psi\right)\sigma_{\parallel} \quad (1)$$

where S_1^{hkl} şi S_2^{hkl} are elastic constants of the material. In this study, these were calculated starting from single crystal elastic constants [19] and using the elastic interaction model of Reuss crystallites.

In the case of residual stresses analysis at grazing incidence, there are measured absolute positions of all diffraction lines *hkl*, corresponding to the respective phase, presented in diffractogram.

The angle of inclination ψ for crystalline planes *hkl* is given by:

$$\psi = \theta^{hkl} - \alpha \tag{2}$$

where θ^{hkl} is Bragg angle, and α is the constant angle of incidence. For $f(\psi)$ method [20], elastic constants are included directly in construction of stress dependence on elastic deformation of crystalline lattice:

$$\varepsilon_{\psi}^{hkl} = f(\psi, hkl) \cdot \sigma_{II} \tag{3}$$

by

$$f(\psi, hkl) = 2S_1^{hkl} + 1/2S_2^{hkl} \sin^2 \psi \tag{4}$$

For materials with cubic structure, equation (3) can be reformulated in terms of network parameter *a*:

$$a_{\psi}^{hkl} = a_0 \cdot f(\psi) \cdot \sigma_{II} + a_0 \tag{5}$$

where a_0 is the unstressed network parameter. Gravity centers of the diffraction lines used in stresses analysis were determined by their filtering with split - Pearson VII functions. Using Bragg's law and the calculation relationship for the cubic structure, a_{ψ}^{hkl} network parameters were calculated.

Fourier Transform Infrared (FTIR) Spectroscopy investigations were performed on a Shimadzu 8400S device (Fig. 3) equipped with a Shimadzu AIM - 8800 infrared microscope (Fig. 4), in a single optical phase, in a wavenumber range of (7800-350) cm^{-1}.

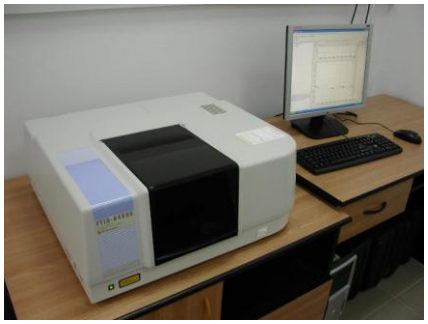


Fig. 3. Shimadzu 8400S FTIR apparatus



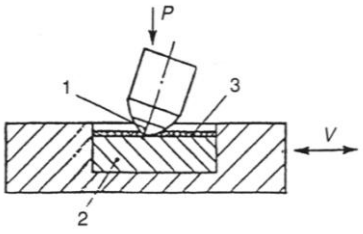
Fig. 4. Shimadzu AIM - 8800 infrared microscope

Optical microscopy (OM) and Atomic Force Microscopy (AFM) were carried on an optical microscope Epiquant, Carl Zeiss Jena GmbH, Germany and on an NTEGRA Probe NanoLaboratory NT - MDT, Moscow, Russia, respectively. Scanning electron microscopy (SEM) images were acquired with a FEI Microscope, up to a voltage of 20 kV at an inclination angle of 0°.

The adhesion resistance of the deposited layers was analyzed by scratch testing, with a tester Fig. 5(a), having a diamond tip. The applied loads were in the range of (2.5 – 125) N.



(a)



(b)

Fig. 5. Scratching tester with a diamond spherical segment. (a) General view; (b) 1 - natural diamond spherical segment; 2 - sample of tested material; 3 – lubricant (bovine serum). The plate has an oscillatory movement.

The use of a friction pair that involves natural diamond against the material to be investigated, allows considerable simplification of the test devices. The movement is, in this case, pure sliding, common in many tribometers with continuous or alternate motion and the tested body is a small circular plate. Fig. 5(b) presents a schema of a new scratching and fatigue wear tester.

The plate (2), made of the investigated material, has a unidirectional motion (for scratching tests), or oscillatory motion (for fatigue tests), respectively. The plate is loaded against a diamond spherical segment with a radius of 2 mm (1). The diamond can also be easily adapted to any wear-testing device with continuous or oscillatory moment. The plate is covered during the test with a thin layer (3) of lubricant (bovine serum).

Each scratch was analyzed by optical microscopy, AFM and SEM. Width and depth of the scratches were measured and graphic variation curves of scratch depth depending on the applied normal load were drawn.

3. RESULTS AND DISCUSSION

The hardness of 316L stainless steel samples before coating and microhardness of deposited TiN layers were determined. These hardness values were:

TIN/316L sample; 5000p: Basic material's hardness: 277; 299; 286 *HV* 5 kgf, HV_5; Medium hardness 287 HV_5; Layer's microhardness: 352; 345 *HV* 50 grf.; Medium microhardness: 348,5 HV_{50}.

- TIN/316L sample; 10000p: Basic material's hardness: 407; 429; 423 HV 5 kgf; Medium hardness 420 HV_5; Layer's microhardness: 532; 545 *HV* 50 grf.; Medium microhardness: 539 HV_{50}.

- TIN/316L sample; 20000p: Basic material's hardness: 453;473;466 HV 5 kgf; Medium hardness 466 HV_5; Layer's microhardness: 748; 727 *HV* 50 grf.; Medium microhardness: 728 HV_{50}

Average thickness of the coating, measured with optical microscopy was 0.0179 μm for 5000 pls., 0.0219 μm for 10000 pls. and for 20000 pls. was 0.032 μm.

Average thickness determined by AFM was 17.4 nm for 5000 pls., 21.4 nm for 10000 pls. and 27 nm for 20000 pls.

Average thickness determined by SEM was 0.8 - 1 μm for 5000 pls., 1.2 μm -1.4 for 10000 pls. and 1.5 - 1.6 μm for 20000 pls.

To investigate the microstructure of TiN layers deposited by PLD, were used X-ray diffraction techniques (XRD - GIXRD). Diffractograms with X rays were purchased at a fixed angle of incidence $\alpha = 1^0$, in the angular range 2θ of 34^0 - 105^0, with step acquisition of 0.02^0 and counting time per step of 10s.

To determine the instrumental contribution, required for Rietveld analysis, it was used the standard material NIST SRM 660a - LaB_6. Diffractogram of standard material was acquired under the same conditions as the samples analyzed.

Characteristics of the analyzed samples are presented in Table 1.

Table 1. Characteristics of the analyzed samples.

Cod sample	Target (coating)	Substrat	*d* (cm)	Energy (mJ)	Fluence (J/cm^2)	Frecvency (Hz)	Pressure (Torr N_2)	*T* (^0C)	No of pulses
5k	TiN	SS 316L	5	500	4,8	10	1.3×10^{-3}	500	5000
10k	TiN	SS 316L	5	500	4,8	10	1.3×10^{-3}	500	10000
15k	TiN	SS 316L	5	500	4,8	10	1.3×10^{-3}	500	15000
20k	TiN	SS 316L	5	500	4,8	10	1.3×10^{-3}	500	20000

3.1. Results of phase analysis

The recorded diffractograms in the analysis phase with X rays, at a fixed incidence angle α = 1°, are presented in Fig. 6 (a-d).

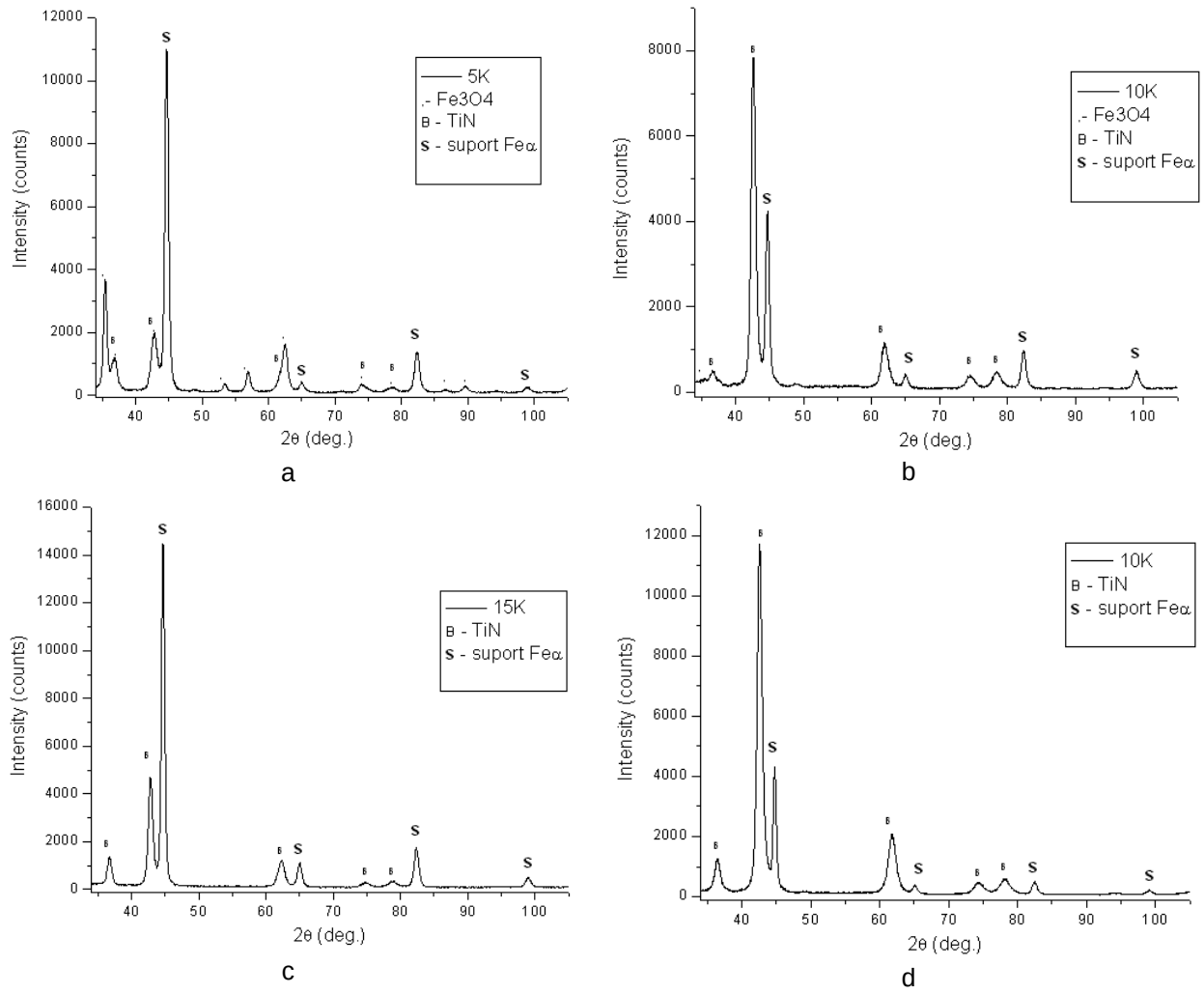


Fig. 6. Phase analysis. X-ray diffraction pattern of (a) 5k, (b) 10 k, (c) 15 k, and respectively (d) 20 k TiN thin films.

The micro-structural parameters obtained from Rietveld analysis are centralized in Table 2.

Table 2. Main parameters obtained from Rietveld analysis

Sample code	The average size of crystallites (Å)	Maximum mediated microdeformation (%)
5k	143.04	84.1698
10k	195.19	80.1921
15k	344.92	79.1179
20k	107.12	102.9714

3.2. Determination of residual stresses

Analysis of residual stresses of TiN layer for 5K sample was not possible because of strong overlapping diffraction lines corresponding to the two polycrystalline phases - TiN and Fe_3O_4. In Table 3 are presented the values of residual stresses and un-stresses network parameter, obtained using $f(\psi)$ method.

Table 3. Values of residual stresses and un-stressed network parameter obtained using $f(\psi)$ method

Sample code	σ_{II} (GPa)	a_0 (Å)
10k	-12.95	4.2155
15k	-10.06	4.2016
20k	-10.40	4.2299

In Fig. 7 (a – c) are presented linear dependencies of network parameters according to $f(\psi)$.

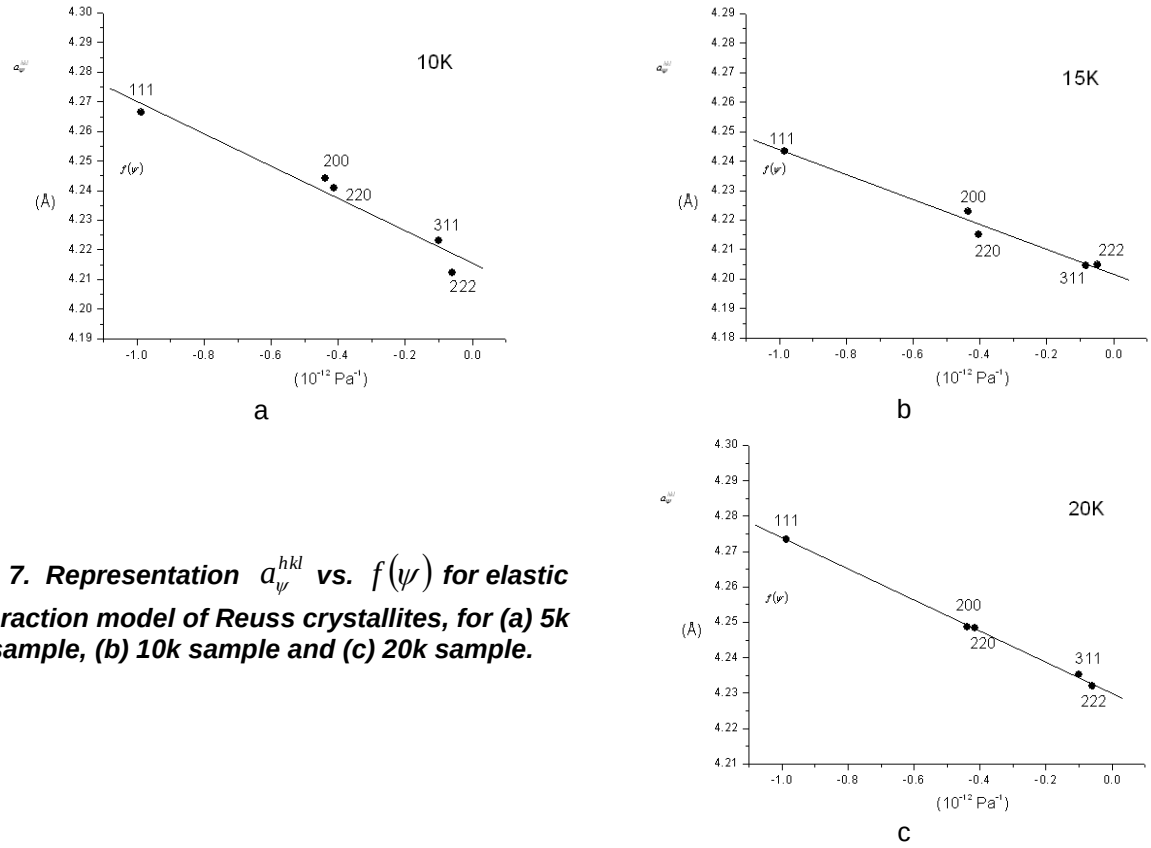


Fig. 7. Representation a_{ψ}^{hkl} vs. $f(\psi)$ for elastic interaction model of Reuss crystallites, for (a) 5k sample, (b) 10k sample and (c) 20k sample.

All analyzed samples are subjected to high compressive stresses. It can also be observed a tendency of layer to relax with thickness increasing.

3.3. FTIR investigations

FTIR investigations have been performed both in 10SPEC and 80SPEC geometry. The 10SPEC apparatus features a collimated beam that strikes the sample at a 10 degree angle of incidence. The 80SPEC technology is an 80 degree regular reflectance accessory. In Figs. 8 and 9 are presented FTIR records of TiN target and TiN thin films deposited in 80SPEC and respectively 10SPEC geometry.

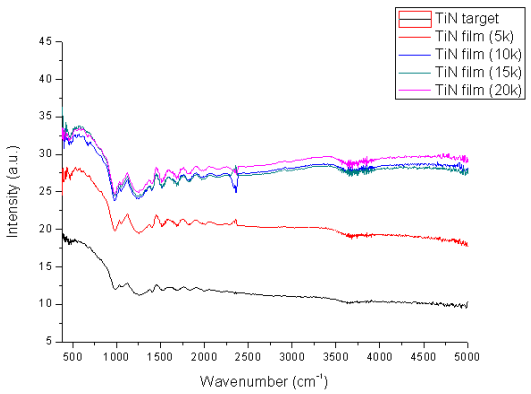


Fig. 8. FTIR of TiN target and deposited thin films (80 SPEC)

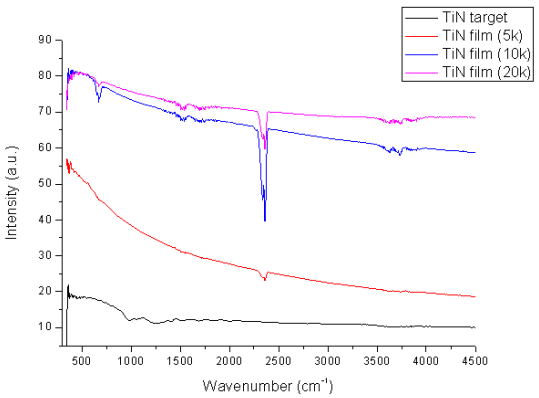


Fig. 9. FTIR of TiN target and deposited thin films (10 SPEC)

FTIR has been used in order to determine the molecular vibrational modes belonging to the main functional groups or to determine the nature. Spectrum matches identify constituent(s) in the sample. Generally, absorption bands in the range of 4000 – 1500 wavenumbers are typically due to functional

groups (e.g. – OH, C = O, N – H, CH_3, etc.). The absorption bands in the region 1500 – 400 wavenumbers are generally due to inter-molecular phenomena and are highly specific to each material.

3.4. Thickness of the deposited layers

By optical microscopy (OM) - Fig. 10 and SEM (Fig. 11) were measured widths of scratch traces and their depths were calculated and by calculation their depths. In order to determine the thickness of the deposited layers, OM, AFM and SEM investigations were performed on polished cross sections of specimens tested for scratch.

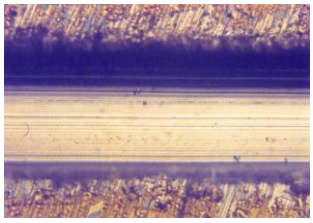


Fig. 10. Optical microscopy image: 5000 pls; 40 N; x 200.

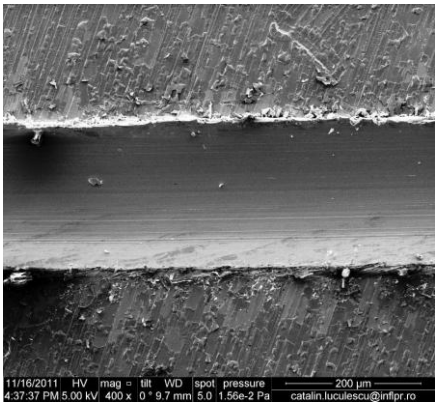


Fig. 11. SEM image: 5000 pls; 40 N: x 400.

On the OM images were measured in ten places scratch traces widths, then were calculated their depths *h* based on a simplified relationship (indent method), which takes into account the radius of diamond tip *(r)* and the medium value of measured widths of the indent *(l): h = l /8r*. Variation of scratching depth function of applied normal load is presented in Fig. 12. These curves show some "indenter drops" due to indentation on voids or other defects of coatings.

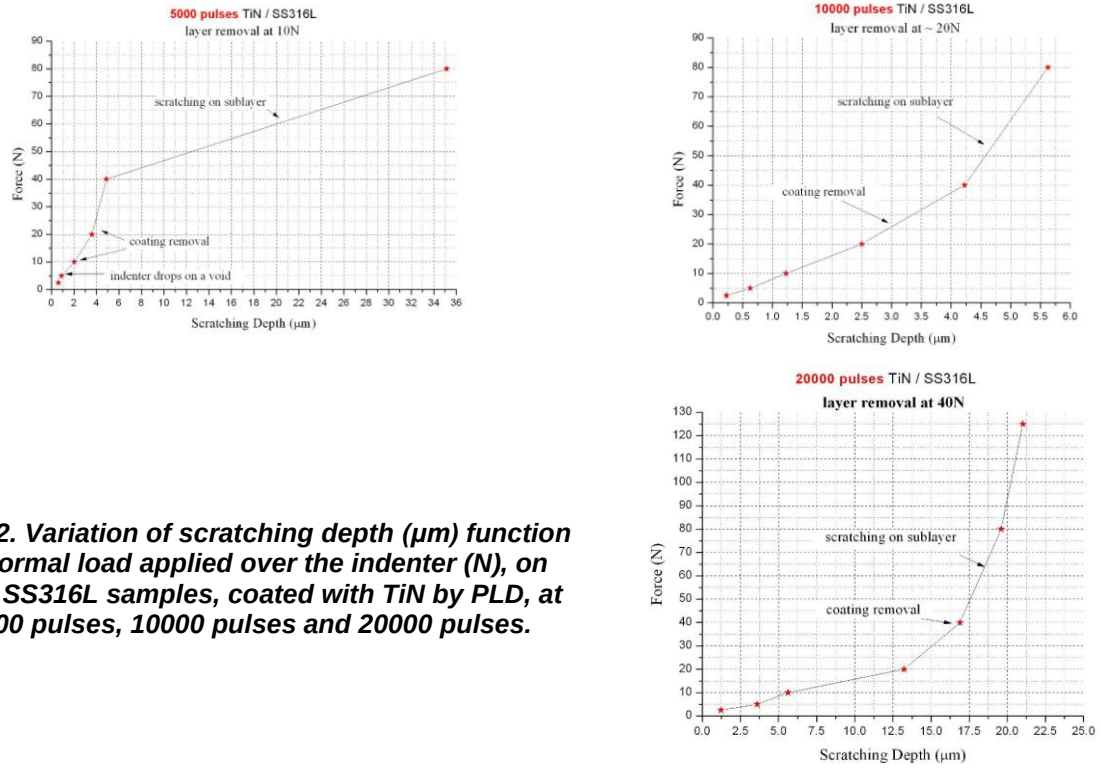
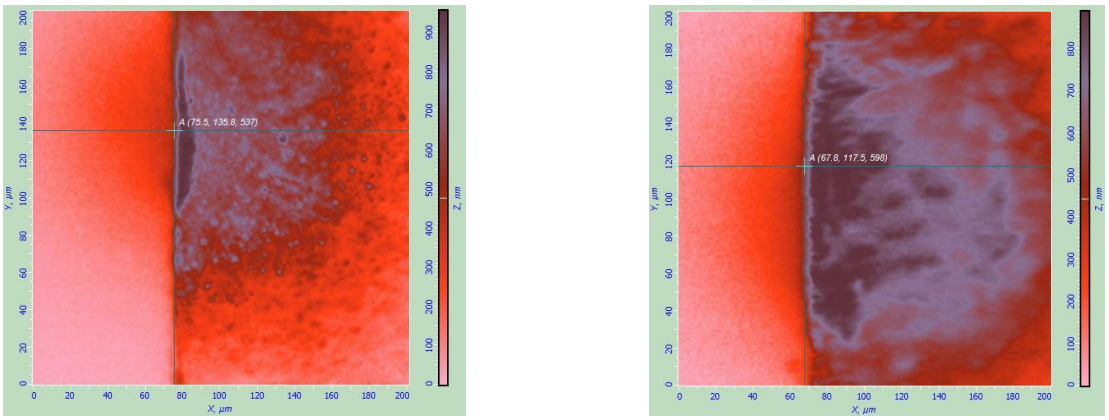


Fig. 12. Variation of scratching depth (µm) function of normal load applied over the indenter (N), on steel SS316L samples, coated with TiN by PLD, at 5000 pulses, 10000 pulses and 20000 pulses.

After OM investigations, the samples were cross-sectioned and after that polished with 400 and 600 grit sandpaper, and then inspected by AFM (Fig. 13).



(a) (b)

Fig. 13. AFM images of cross sections of SS316L steel samples coated with (a) 5000 and (b) 20000 pulses

The average depths of the layer resulted for 5k sample were of 13.25 µm (12 µm global and 12; 13; 14; 14 individual) and for 20k sample, of 65.1 µm (78 µm global and 58; 56; 65; 75 individual), respectively.

For comparison, measurements of thickness were also realized by SEM, at different magnifications (250X, 1000X and 2000X). The 250X magnification was considered optimal allowing an accurate view of the section of deposited layer.

In Fig. 14 are presented for comparison, the SEM images of TiN coatings thickness for 5k, 10k and 20k samples. All images were acquired up to a voltage of 20 kV at an inclination angle of 0°.

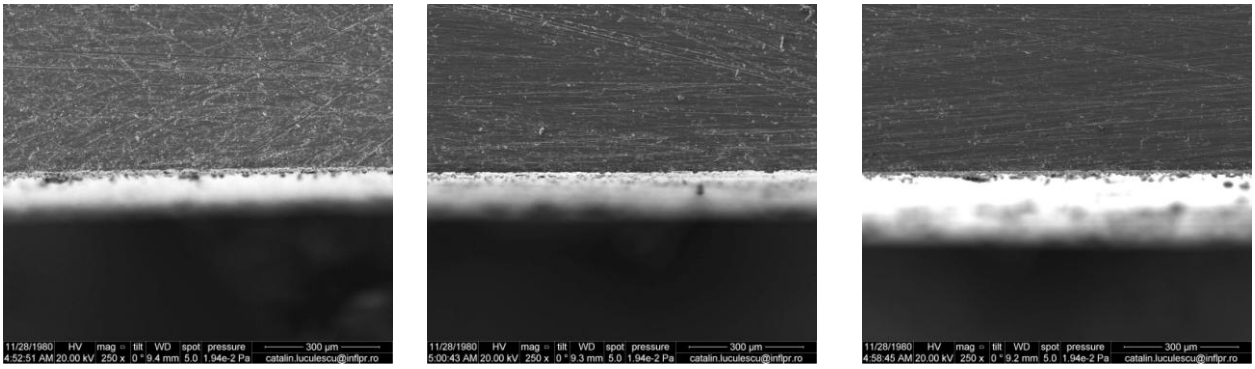
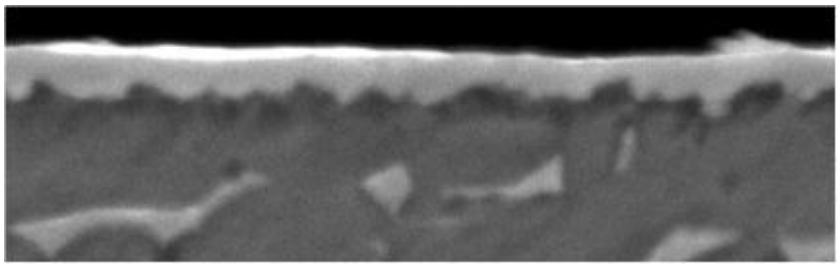


Fig. 14. SEM images of TiN coatings thickness for 5k, 10k and 20k samples.

From the SEM images presented in Fig. 14, one can calculate the thicknesses for 5k sample (~0.8-1 µm), 10k sample (~1.2-1.4 µm) and 20k sample (1.5-1.6 µm).

Before testing at relatively low voltages (10 kV) were recorded with images secondary electrons (SE) of surface topography (Fig 15) and of nitrated samples sections to minimize the edge effects in image formation of the free samples surfaces.

Fig. 15. SEM image of a cross section of Ti-6Al-4V plasma nitrided at 1048 K for 2h. Overall width of the image corresponds to 10µm. (0,5 cm = 1 µm)



SEM controlled characteristics, i.e. voltage, beam's diameter, scan time, amplification, remaining deviation and increasing were set to the same values in all images of morphologies of surfaces sections. One can clearly see irregular distribution of the input material on an enough large depth in the substrate material.

4. CONCLUSION

The recorded GIXRD patterns for TiN thin films, presented in Figs. 6 (a-d), shown that TiN coatings were polycrystalline, exhibiting reflections related to B1 cubic structure. Reflections corresponding to the substrate (Fe_α phase) were detected in all the X-ray diffraction patterns. In addition, in the 5000 pulses and 10000 pulses samples, Fe_3O_4 polycrystalline phase was present.

Phase qualitative analysis of TiN coatings showed the presence of three polycrystalline phases in samples analyzed:

- In 5000 pulses and 10000 pulses samples: TiN (B1 cubic structure), Fe_α (cubic structure) and Fe_3O_4 (cubic structure);
- In 15000 pulses and 20000 pulses samples (B1 cubic structure) and Fe_α (cubic structure).

Analyzing the residual stresses of the TiN deposited layers, presented in Table 3, it results that all the analyzed samples are subjected to high compressive stresses. It can also be observed a tendency to relax as the layer grows.

The paper points out that TiN protective coatings deposited by PLD technique with 20000 pulses can be an alternative technology to ensure adhesion and scratch resistance of TiN coatings of Ti-6Al-4V femoral heads. The condition for the success of such coating is to provide an optimal surface roughness of femoral head that serves as substrate for TiN coating.

Analyzing the overall experimental results it can be concluded that although the 20000 pulses layer is promising as alternative technology, further studies are necessary to determine the optimal roughness of the basic layer and fit it with the hardness and elasticity modulus of the coating. Perhaps that will be also necessary to realize biocompatibility studies of TiN layer.

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THE STICK-SLIP PHENOMENON REVISITED

Constantin Radu MIRESCU, Lucian CAPITANU

Abstract: *This paper claims to be a synthesis of some representative works concerning Stick-Slip phenomenon encountered in modern tribology. Facts from various research papers are first listed, concerning: sliding of rocks, adhesion force, Stick-Slip in general and on boundary lubrication films. Then some interpretations found in literature are mentioned together with models that make part of the actual paradigm highlighting some of their critics. Finally a new model for adhesion was proposed, a model that respects all the facts enumerated before and that address also the previous raised critics.*

Key Words: *Stick-Slip, adhesion, thermal activation, heat transfer*

1.INTRODUCTION

The most widely accepted definition for the Stick-Slip phenomenon is that of being an oscillation between the static and kinetic levels of friction [1].

Stick-Slip is strongly related with the noise and vibration between the sliding surfaces [2] being considered a phenomenon with bad consequences for engineering [3]; it is useful only when the noise is a desirable effect – as is the music produced by a violin.

The most common conditions to occur for Stick-Slip are dry friction at low sliding speed. It could be almost entirely avoided in industrial applications if the surfaces are lubricated by a thick lubrication film so we can conclude that Stick Slip is intimate related with the mechanics of dry friction being a function of friction and wear mechanism [1].

Both “stick” and the “slip” part seems to have important connection with other tribological observations. The “Stick” part appears to be strong related with the adhesion theory of friction. A true smooth sliding is almost impossible when the moving surfaces tend to adhere [1]. Concerning the “slip” part we have the fundamental cause of rolling friction is micro-slip between the contacting surfaces [1] and the fretting wear which is caused by the microslip at interface between two parts fixed together being subject of vibration in a corrosive environment [2].

Despite multiple efforts done in the last years the Stick Slip phenomenon remains to be clarified having many open questions related with:

- What is exactly the nature of Stick-Slip behavior? [1]
- Is there a general relationship between friction and adhesion?
- Is there a general energy-dissipation mechanism for friction? [4]
- What’s the mechanism behind the history related Stick-Slip behavior? [1]

This paper lists from the literature some representative experimental facts related with Stick-Slip phenomenon and also some representative interpretations and models making connections between them and adding a new light to the entire phenomenon. To make the final part a cursive one the facts, interpretations and critics of the models are labeled to be referred later.

2. FACTS

2.1 Facts from rock sliding experiments

In [5] referred paper are related some experiments of rock on rock sliding with some quite interesting results.

FACT1. The initial friction coefficient increase linearly with logarithm of stationary time and it's insensitive to normal stress. For intervals of approximately 1.0 seconds or less the friction coefficient is constant and no-time dependency is observed.

FACT2. When the velocity of slip was abruptly changed the frictional force didn't respond immediately: there was a distance d_c till the kinetic regime was encountered, this distance being

interpreted to represent the displacement required to eliminate the population of contacts characteristic of the previous velocity. Was found consistently that d_c was proportional with the surface roughness. The greater the surface roughness, the lesser is the tendency for stick-slip.

FACT3. “In chemically active environments surface hardness is at a maximum when the zeta-potential of the surface is near zero.” Rates of dislocation motion very sensible to ion composition of aqueous environment and are minimized when zeta-potential is 0 (that maximizes the micro-hardness).

FACT4. Investigating by microscope the wear produced during stick-slip sliding were observed grooves and micro-cracking of the surface by contrast with undamaged surfaces during smooth sliding.

INTERPRETATION-FACT4. Was suggested that enough load could produce wear and this wear will induce stick-slip, but, it is more correct to say that stick-slip induce wear since it is present for a vary domain of loads.

2.2.Facts from study of Stick-Slip friction on boundary lubrication films

A very well realized suite of experiments, on lubrication on thin molecule films, are atomic scale, is described in [3] and [4]. A surface forces apparatus (SFA) was used and in it were put two cylindrical mica surfaces – atomically flat, each of radius ~ 1cm and an optical technique using multiple interference fringes (FECO) was used to measure the radius of surfaces, distance between them, the contact radius and the film thickness between them with 1 Å precision. Some of the results are quite interesting too.

FACT5. The studies related with boundary lubrication states that the friction is strongly related with adhesion hysteresis.

There is no correlation between adhesion and friction force. Solid-state film exhibits high friction, less adhesion, wet surfaces exhibit low friction but high adhesion.

INTERPRETATION-FACT5. Mechanics for hysteretic behavior: diffusive interpenetration of chain segments via reputation and Rouse motion; reorientations of bipolar molecular groups; exchange of molecular species. For a surface is enough to plough only few Å in the opposing one to significantly increase adhesion. When two layers in this state is put in contact there will be more molecule to molecule interactions due to diffusive interpenetration and as a consequence more bonds to break and thus more friction.

CRITIC-INTERPRETATION-FACT5. The mechanism for adhesion hysteresis should be a general one and not depending of the shape of molecules or their electrical properties since this hysteretic behavior is quite general.

FACT6. For monolayers whose chains are not close packed and over a limited temperature range even molecularly smooth and chemically homogeneous surfaces presents adhesion that can be very hysteretic. For total frozen and liquid like state of a monolayer the hysteresis is low but for amorphous state – the intermediary state, it is high. The transition between liquid like, solid like and amorphous state was observed to produce stick-slip motion on a variety of surfaces and liquid layers between being actually the norm and not the exception.

Factors that favors hysteretic behavior: A) freedom of surfaces molecules to rearrange and interdigitate; B) increasing the load; C) increasing the time of contact. This is related with critical velocity; D) increasing the rate of unloading.

FACT8. To proper compare friction with adhesion hysteresis one should take in account the rates of loading (advancing) and unloading (receding), since the magnitude of the hysteresis depends on these rates.

Some experiments on boundary lubrication films were mentioned in [2] describing some facts related with the amorphous state transition.

FACT9. The system dilates at beginning of slip event despite the change in temperature is minimal. The dilation was reported in some experiments as being 10% large. This allows the atoms to slide past each other easier so the friction force is less.

FACT10. The Debye-Waller factor S(Q)/N drops at beginning of slip which means that the film lose its crystalline structure and become amorphous.

FACT11. Sliding is not related with atomic lattice step being much greater than it.

FACT12. The order of molecules remains after sliding stops

2.3.General facts collected from various tribological experiments

FACT13. When two surfaces are put in contact and then are separated by applying a repulsion force there appears always a sudden separation even when the repulsion force is increased in a very smoothly way. [2]

FACT14. Heating caused by frictional energy causes surface layers of a material to expand near the sources of heat. Assuming as the sources of heat the highest asperities which were in frictional contact with the other surface these asperities will expand become taller and wider and also more prone to plastic deformation due to rise of their temperature near the melting point. Thus the number of contact points will reduce and the surface will become wider. After the experiment the heated areas will reduce to their initial dimensions – except the plastically deformed areas. It is what is called in the literature as 'thermal mound' effect [1].

FACT15. The instant temperature is quite intense [could attain 1000 Celsius degrees] for a short period of time [< 10 micro seconds]. [2] Using dynamic thermocouple method – letting two dissimilar metals slide against each other were measured, on a random basis, for constantan alloy sliding on steel at 3 m/s, momentary temperature rises reaching 800°C but lasting about 0.1 ms [1]

FACT16. There was observed a triboemission of electrons – complex phenomenon observed at contact between sliding surfaces and not known in detail [1]. In [2] is cited a very impressive list of experiments regarding the localized electron clouds, referred by Simoi et al. (1968) as "exo-electrons."

FACT17. Stick slip disappears in many cases with lubrication [1]

FACT18. The friction coefficient (adhesion based) of metal in vide is much greater that the coefficient of friction between metals in ordinary atmosphere.

FACT19. For an experimental setup there is a critical temperature above which the Stick-Slip doesn't occur

FACT20. For an experimental setup there is a critical speed above which the Stick-Slip doesn't occur either. The static friction decrease with velocity but increase the frequency of Stick-Slip (see Fig.1)

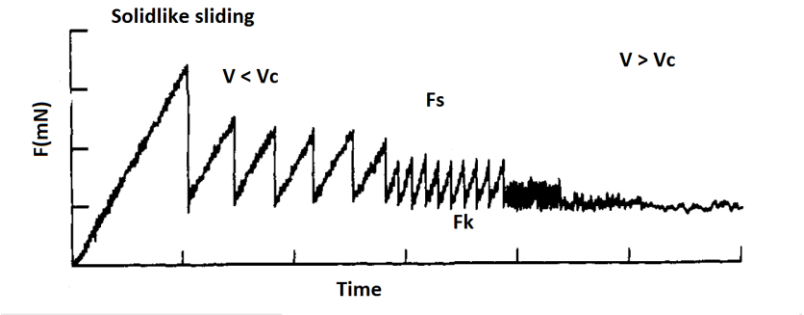


Fig. 1. Variation of friction force with sliding speed. Fs – static friction ; Fk – kinetic friction; Vc – critical velocity

FACT21. At least 95% of the energy dissipation occurs within the top 5 μm of the contacting bodies and most tribologists agree that nearly all of the energy dissipated in frictional contacts is transformed into heat [2]

2.INTERPRETATION AND MODELS

INTERPRETATION1. Energy lost and energy dissipated are unfortunate since the first law of thermodynamics states that no energy is every lost but it is transferred from one system to another. "It would be more correct to think of friction as arising from the transfer of energy between colliding molecules or between a moving and a stationary surface." [4]

INTERPRETATION3. "The similarities between the five phenomena of boundary friction, surfactant and polymer adhesion hysteresis, contact angle hysteresis, and polymer viscosity strongly indicate that the underlying molecular processes are also the same or related and that they all involve the transfer/dissipation of energy between interdigitated chain molecules" [4]

MODEL1. Tabor (and others) model of friction

Friction is proportional with the real area of contact [2]. It is the most accepted paradigm of friction, which respects the Amonton friction laws, and states that the friction is caused by a third body shared by adhesive bonds between the sliding surfaces and also by torn-off of the adhesive junctions

when the shear stress exceeds a critical value. The theory implies that plastic flow and surface destruction may occur at the moment of slip. The theory assumes the existence of a material third body in order to friction to occur. This material is composed by wear particles aggregated in lumps, and between the lumps belonging to the both surfaces there are interactions. Since the hardness of lumps are lesser than of that of the base material they could barely produce a pushing resistance – their structure should most probably be broken during interaction, so we think that the notion of lumps collision proposed in [1] is not quite an adequate concept, but instead we should consider that the lumps could produce a significant work based on adhesion – when the contact between lumps vanishes. This approach is taken in consideration also by the Stick-Slip Distance-Dependence model exposed in [2]

CRITIC1-MODEL1. The dislocation angle (see Fig.2)

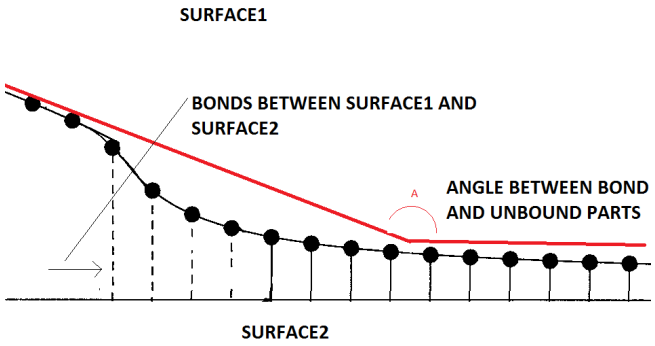


Fig. 2. Dislocation angle between 2 surfaces that were in contact

should be visible at macroscopic level and it is not. So it is more appropriate to think that we have a kind of bi-stable bond that it is not in any way related with the geometry (two atoms of the opposing surfaces are either bond or unbound) as was successfully proven by a frictional model which suppose that between two atoms, each from a different sliding body, could exists only two values of friction coefficient (k_s and k_d)

CRITIC2-MODEL1. One major limitation of this model is revealed by wearless friction phenomenon. There are situations where the friction is less on worn surfaces than on their previously perfect state as was reported by Israelachivili et al. on the sliding friction between mica surfaces during some SFA experiments [4]. Thus we have the evidence that friction is not necessarily related with the concepts of wear and plastic deformation. Even there is a strong relation – observed from industrial practice, between friction and wear, sometimes it is overestimated since were observed frequently in practice situations where friction remains quite high and wear rate is very small. There are industrial processes with high friction and near 0 wear.

MODEL2. Rough Surface Model – for Stick Slip

Rough Surface Model – it is essentially a noise-type fluctuations raised from surface imperfections than from the intrinsic interaction between surfaces.

CRITIC-MODEL2. This model could not explain the friction between atomically smooth surfaces.[2] The model implies the existence of a dissipation phenomenon because the motion of sliding body, once initiated, without a mechanism for dissipating the inertial energy being fed into the system, should continue indefinitely, rather than have to be continually maintained. On a smooth sinusoidal surface in a conservative field the sliding will work forever.

MODEL3. Velocity-Dependent Model for Stick-Slip

It is a descriptive model based on extensively experimental data collected.

CRITIC-MODEL3. This model doesn't address the basic question of the origin of friction and could not explain the increasing frequency of stick-slip with the sliding speed.

MODEL5. Phase transition model for Stick-Slip

Address the critical velocity that Velocity-Dependent models fail to predict.

CRITIC-MODEL5. It is a descriptive model too and not addresses the inner cause of friction. Besides it hides some of complexity behind a new notion – the nucleation time, a constant dependent of experimental conditions (so it's measurement and dependence law should be further explored).

MODEL6. The Tomlinson model.

This model provides a simplest type of intermittent motion for multistable regime ($\lambda > 1$) when energy is stored in the springs the atoms being trapped in metastable state, and converted to kinetic energy as they pop on the next metastable state. This behavior was confirmed by simulations and also by experimental measurements.[2]

CRITIC-MODEL6. In Tomlinson model energy dissipation is usually dealt by introducing a molecular dissipation factor (or friction coefficient). This does little to explain the origin of friction. [4].

This model and the others related with assume an elastic interaction between atoms (there is a used a concept like “force field” of an atom) and also some meta-stable states in which a given atom could arrive but provide no insight of the related physical phenomenon.

3. A NEW PERSPECTIVE

Friction – in the stick phase of stick-slip is caused by adhesion hysteresis [FACT5]. Since the adhesion based on the chemical structure of the contacting matter is not enough general [CRITIC-INTERPRETATION-FACT5], there should be a more common phenomenon at molecular level [INTERPRETATION3] to explain it.

Most experiments suggest that electrons cloud could place a role here [FACT16]. We know from Faraday observations that the free electrons goes to the external surfaces for metals. Thus we can explain the electromagnetic shielding effect. Some experiments by placing various things in a very strong electrostatic field that reveals the existence of hallow around the things. What about they have the free electrons placed around them as we have for metals? It sounds not quite odd.

Let’s start with some rock on rock sliding first. When the two bodies are put in contact the common outer electronic shield [ES] starts to be composed. What’s the intermediate state for shared free electrons (since they do not go instant to the boundary)? Here we have the first aspect of the model: every material entity [ME] (atom, molecule, group of atoms, group of molecules) has a ES around it which can interact with the neighbors fields. Most of the time this interaction between ES resides under the sign of repulsion (see Fig.3) even the resultant force between MEs could be an attraction one.

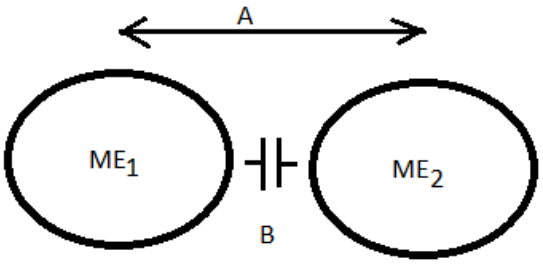


Fig. 3. External MEs interactions. A – attraction force B – electrical repulsion force between the two ESs belonging to the each ME

Sometimes this outer ES for 2 MEs could fusion (see Fig.4) and form a bigger ES around the 2 MEs (this affinity of electrons to belong to 2 MEs in the same time is not quite odd, a more common example being for electrons that belong to a covalent bond)

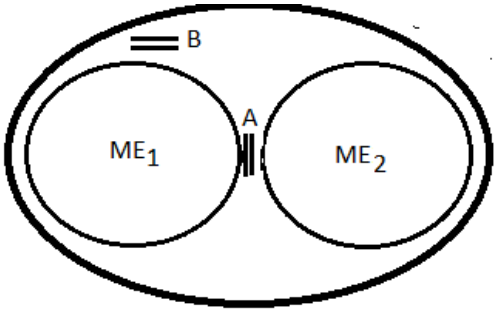


Fig. 4. “Internal” MEs interaction. Besides the attraction force between 2 MEs we have a repulsion force between the outer shield and ES of each ME (B) and a stronger repulsion force between ESs of the MEs (A). The ES for the MEs become thinner due to the fact that they borrow electrons from outer shield so the repulsion A force will be weaker than between 2 external MEs at the same distance.

A kind of potential energy is stored in this place, like in a spring – offering a way for modeling complex atomic interactions like in the Tomlinson model which names the spring as storing potential energy but offers no physical representations to them, addressing thus the [CRITIC-MODEL6]. Also in this way could be assessed the bi-stable bond mentioned in [CRITIC2-MODEL1].

This model for friction interaction could become more complex in respect with [INTERPRETATION1]. We could have movement, collision, adhesion – and cohesion of two material entities but the kinetic energy is stored as potential elastic energy beyond the bond which is contradiction with the current view for a collision: kinetic energy = plastic deformation + heat (no remaining potential energy stored anywhere).

The combination of 2 ME is more likely to occur when a load between them exists. When the load ends and a repulsive force is applied, then, at the moment when the outer shield is broken, the electrons go from it to the inner ESs where they came and thus, suddenly, the energy stored in the spring is augmented with extra repulsion and a significant repulsion force appears as is encountered in practice [FACT13].

The effect of combining of two electron shields could be spontaneous. In this way, we could image that third material entity appear at the boundary of 2 rocks. Now we address a contact point between the two rock surfaces (see Fig. 5).

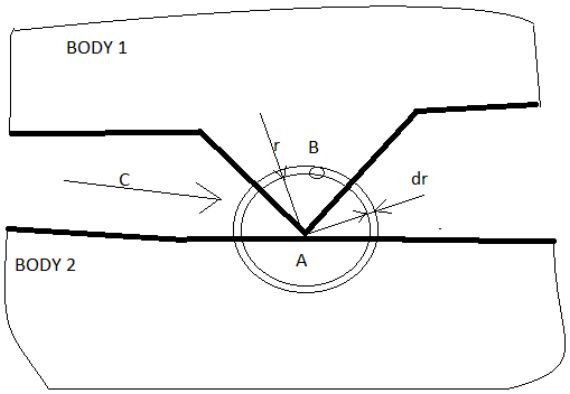


Fig. 5. Punctual contact between two rocks (point A). The ESs of two rocks begins to merge starting at the A point till the outside, implying more and more MEs belonging to the two rocks (one of them is shown as a small circle in point B). The C pointer identifies the space between the bodies in which a third party body could enter and destroy the growing ES formed

Let's assume that the speed of combining ES is small (let's say comparable with a millisecond).

$$r = a \cdot t \tag{1}$$

If consider tangential force F_t, at r expansion, composed by:

- a constant force F_{t0} proportional with normal force F_n (the Amonton law)

and

- a small increment due to forming of outer ES between MEs belonging to the two bodies (and thus making the adhesion between them stronger by making more atoms to contribute to it). This variation is proportional with

  - the normal force F_n: the stronger F_n is the more tight will be ESs on the strain direction and thus their interaction will be enhanced
  - the volume of contact with outer ESs - $4\pi r^2 dr$. This volume is the volume where extra electrons from external MEs are collected from: bigger this space then bigger the number of extra electrons will be.
  - the reverse of volume of the ES ($3/(4\pi r^3)$) – The new collected electrons need to cover all space of the outer shield so the more volume we have, the less electron "concentration" and thus the less ESs interactions will be.

Taking care of all of this we have:

$$dF_t = k \cdot F_n \cdot \frac{3 \cdot 4\pi r^2 dr}{4\pi r^3} = (\,from\,1) = 3kF_n \cdot \frac{dt}{t} \tag{2}$$

Given the fact that F_n is constant, to find the value of F_t at a given time moment t_n we will integrate from 0 to t_n the relation (2) and we will have

$$dF_t(t_n) = \int_0^{t_n} dF_t = \int_0^{t_n} 3kF_n \cdot \frac{dt}{t} = 3kF_n \cdot \log(t_n) \tag{3}$$

and we will arrive at

$$\mu_s(t_n) = \frac{F_{t0} + F_t(t_n)}{F_n} = \frac{F_{t0} + 3kF_n \cdot \log(t_n)}{F_n} = \mu_0 + A \cdot \log(t_n) \tag{4}$$

This result could be a demonstration for [FACT1].

When a third body enters the space C (see Fig. 3) and has high electrical properties (like an aqueous ionized substance) then the constructions of bigger ES around the contact will fail and we will have a strictly linear friction law, as was proven by [FACT3].

Let's go a bit further questioning about the properties of the ES. We can regard electrons as particles similar with material points that move on an orbit around the nucleus. Was the first model of atom that suggests such a vision. But our paradigm now is that every electron resides on its unique energy level around the nucleus and it is in a kind of stable state. Since the dimension of nucleus is quite small comparing with the dimension of the atom we can assume that the electrons – and also the free electrons that do not obey the covalence rules, are more related with the physical space of the material entity and with the physical properties too. Since we could not have a deterministic knowledge about the position and impulse of an electron at a given time (the Heisenberg uncertainty principle, and, to complicate more the things, we have also the dualism particle – wave for the electron too) there is here a space in which we can suggest properties that the ES could respect or not (by experiments). Because at quanta level we have uncertainty but at macroscopic level we have properties that almost all the materials have it is not quite odd to relate them with the properties of ES that all the materials have (the paradigm that matter is organized in atoms and molecules and that the atom is organized in nucleus and electrons is widely accepted).

In the following we want to introduce a property that ES could satisfy, namely, to store in its enclosed space heat, at atomic scale, like we use to "store" plasma in a given space (in industrial and research applications – of course, at macroscopic scale) using high electrical and magnetic fields.

Be dropping a molten drop of glass in an ice water was produced what is called a 'Prince Rupert's drop' which resists easily to massive amount of punishment, including repeated hammer blows but when the tail of the drop is broken the fracture will propagate through the drop at 2,000 miles per hour, releasing violently the inner tension, sometimes as an explosion with a flash of light. This experience is similar with pushing a trigger of a gun: it's not the energy of the trigger (or of the hammer that breaks the tail) that produce such an effect, but a stored energy is released, and we can say that for a Prince Rupert drop is obviously one strongly related with heat (in this case stored as internal tension).

As common experiences we know that the heat is stored by matter (see specific calorimetric capacity for each substance – there is a capacity of heat that each substance could absorb) and are common life phenomenon for which the model of thermal IR wave heat transfer doesn't work: the temperature gradients for an open flame which are so high (which not respect the first derivative of the thermal distribution); the convection currents; the reduction of density of the hot air.

Concerning our Stick-Slip investigation we can say that the great differences between instant temperature and bulk temperature on a sliding surface [FACT15] strongly suggest that the temperature distribution is not governed only by a continuous distribution function (such of a thermal IR wave propagation) as more or less a smooth gradient but, instead, we have also heat stored at atomic level, this being a quite adequate explanation for the highly localized energy layer [FACT21] and forming of thermal mounds [FACT14].

In the same manner could be explained for dilation of molecules in thin films even only a slight increase of sliding temperature was encountered [FACT9], resulting from this an explanation for all the odd things regarding the boundary films stick-slip experiments:

- the reducing the number of molecules per surface [FACT10] (the hottest ones will increase in volume and will push the others) and also

- the keeping of order during the Stick-Slip event [FACT12]. The dilation/contraction processes are reversible in contrast with the increase of entropy which is an irreversible process (once the disorder is produced there is no general mechanism to produce again order from it).

- why the amorphous state of the film is more hysteretic [FACT6] as we will see bellow, an important role being played by the MEs that store heat.

The first principle of Thermodynamics in the popular form states “the heat goes from the hot body to the colder one” so we can assume that when 2 corps become in contact the heat goes from the first one’s ES to the second’s one ES and the size of their ES are adjusted accordingly. We can assume that the ES has the tendency to uniform itself on their surface and that they will close equal (regarding “concentration” of the heat stored – which could be another name for temperature) after the thermal contact.

If we assume that this heat transfer between ES increase adhesion between them and thus “sticks” them we have here the intimate cause of the Stick part of the Stick-slip phenomenon (as common experiences we have the stick of open hand on a metal bar outside in cold winter, the stick of hand of a hot surface and the stick of the piece of butter thrown in a hot saucepan). After the transfer is done the stick disappears and the motion could continue in the slip phase.

Since friction force is proportional with adhesion hysteresis and this adhesion hysteresis is proportional with the load/unload rate [FACT6.D; FACT8] and the load/unload rate is proportional with heat generation (usually 4% of elastic energy is lost as heat in one cycle for many materials [2]) we have thus a strong suggestion that heat transfer is the cause of friction force in the stick phase.

As a first consequence this offers a base for sketching a dissipation mechanism that is missing from most of models (CRITIC-MODEL6; CRITIC-MODEL2; CRITIC-MODEL3).

The heat transfer is proportional with the number of contact points. For a rougher surface we will have less contact points and thus we will have a less tendency for Stick-Slip [FACT2].

When we have a third body between the 2 sliding surfaces the heat transfer will involve it and thus this third body will stick with one or another surface so the surfaces will not stick directly together and so we will have no Stick-Slip in this case [FACT17]. Also this could explain also the greatest adherence of metals in vide (where no third body exists) compared with the adhesion in ordinal atmosphere. [FACT18]

Since the heat transfer is governed by temperature gradients too, when the temperature of the coldest body will be close enough with that of the hottest body we will have little or no heat transfer so thus we will have a critical temperature at which Stick-Slip doesn’t occur either. [FACT19]

Due to the fact of very high temperature gradients we expect that the dimension of ES of the hottest body will be significantly larger than of the atomic lattice step and thus the heat exchange will not be affected by it [FACT11] and we could experiment adhesion without a third body between (the size of the thermal field inside ES will be big enough to cover the space between surfaces) addressing thus the CRITIC2-MODEL1.

Finally when the sliding speed is raised we will have less contact time between the sliding surfaces, less heat transfer so we will have less static friction force and a quicker cycle, an increase of frequency of stick-slip as was reported by experiments [CRITIC-MODEL5].

4.CONCLUSION

The new perspective sketched in chapter 4 makes many connections between various facts concerning Stick-Slip phenomenon and highlighted two physical phenomena as being related with the stick phase of the Stick-Slip namely the process of forming of outer electronic shield around a material body (based on this hypothesis an experimental formula was solved) and the process of heat transfer between bodies. Even these are not quite common studied we believe that a further investigation in this direction will add value to the understanding of this complex tribological process of Stick-Slip.

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INFLUENCE OF HOB MILLING TOOLS WEAR CRITERION ON MACHINING OF GEAR TEETH

Ivan SOVILJ-NIKIĆ, Bogdan SOVILJ, Ivan SAMARDŽIĆ, Sandra SOVILJ-NIKIĆ, Vladeta GAJIĆ

Abstract: *In metal industry, having of reliable parameters of machining is very important in order to get maximum efficiency of working equipment. Technological parameters have significant place. They influence on wearing of tools and, taking into consideration parameters for defining of process economy, they also influence on realization of optimal parameters for cutting speed.In this paper, the criterion of tool life on the basis of flank wear corresponding to maximal cutting tool capacity is defined.*

Key words: *hob milling, wear criterion, tool life*

1.INTRODUCTION

Hob milling process is one of the most important links in the chain of machining, because productivity, final geometric accuracy and machined surface of gear teeth are very dependent on it (Fig. 1). By development of technology of hob milling, it is successfully used in semi-rough machining as well as final machining of gear teeth [1, 2, 3]. For that reason, the demands for process optimum increase, both from the point of view of machined surface and from the point of view of productivity. Prerequisite for the successful optimum and adequate process control is its identification, respectively identification of occurrences originated during the hob milling [3, 4, 5].

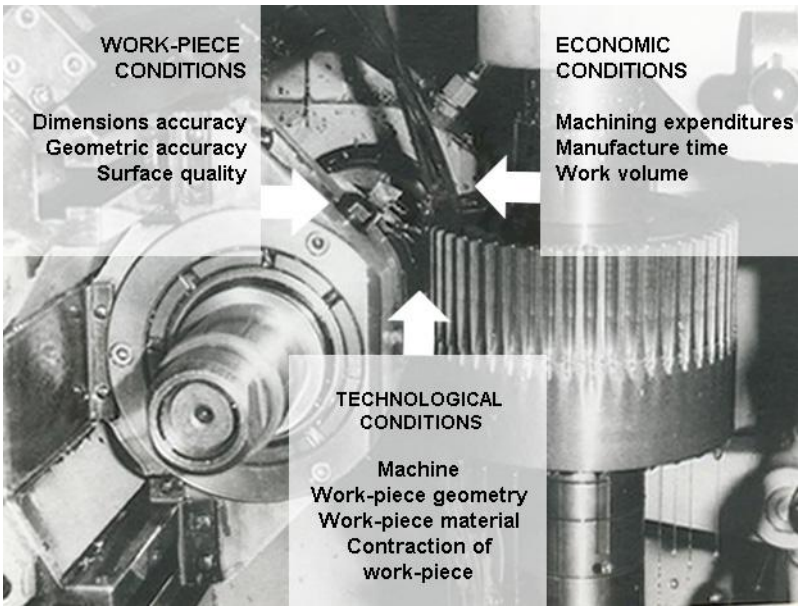


Fig. 1. Influential parameters on hob milling process

2.WEAR OF HOB MILLING TOOL

Development of tribological processes on the surfaces of teeth of the hob milling tool brings to deformation of their top and to change of their geometry[3, 6, 7, 8]. Critical wearing of the teeth of the hob milling tool presents the tool life criterion. Influence of the criterion of the hob milling tool dullness

on the tools costs. Working costs are very huge and, for that reason, in this paper a special attention is paid on its choice.

Wearing out is one of the very negative occurrences in the working processes. The wearing out of working elements of cutting tool develops continually also in every moment of contact, and in the some way under the all technological and cutting conditions of machining.

Development of wearing out on the particular tooth of the hob milling tool depends on the combination of the tool material and of the work piece, machine and used cooling agent and drawing compounds. On the other hand it depends on the machining conditions [7, 8, 9, 10]. Wearing out of gear teeth also depends on axial feed speed and on number of those displacements.

Cutting tool geometry, work piece geometry and milling methods also influence the wearing process of the hob milling tool [11].

3.MATHEMATICAL MODEL OF WEARING FUNCTION

By the wearing function of hob milling tool, the tribological state and behavior of the working process are described. Considering that this state influences directly on the most important output effects of the process, knowing of mathematical model of wearing function or its graph, in fact a curve of wearing, has a special practical importance.

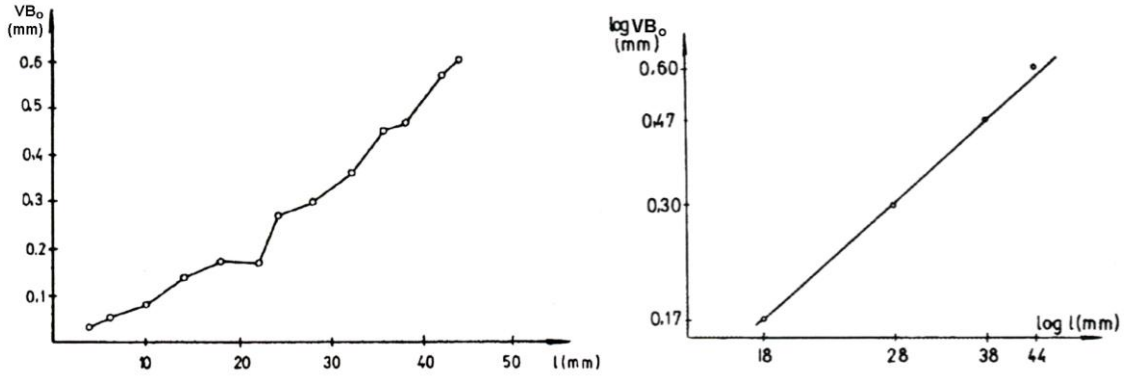


Fig. 2. Diagram of the function $VB = f(l)$ ***in*** $0lVB$ ***system (a) and in*** $\log l - \log VB$ ***system (b)***

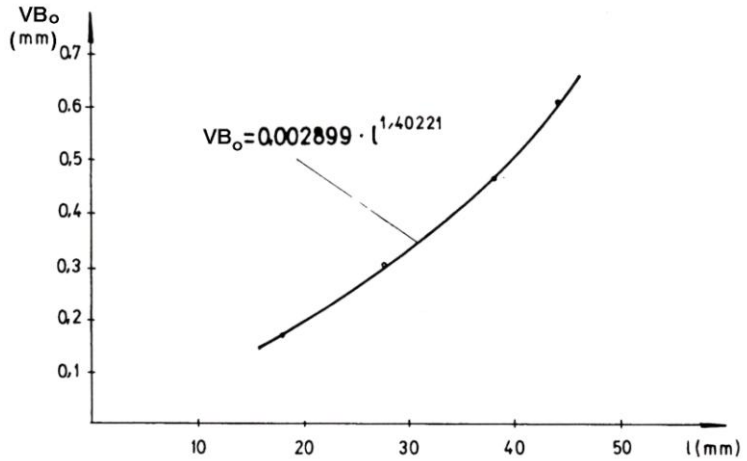


Fig.3. Forming of the wearing curve by a single regression $VB = b \cdot l^c$ ***at the hob milling of the cylindrical gears***

Mathematical interpretation of the complex form of the wearing curve $VB = f(l)$ can be simplified in production practice by separation of that part of the second phase (II) of wearing and encircles the area on the third phase (111) of wearing (Fig. 2). This area is also the most important for production practice. In the hob milling operation of the cylindrical gears with model hob milling tool by machining of steel 20CrMo5, regressive function:

$$VB = b \cdot l^c \quad (1)$$

in adequate way, mathematically describes the group of points $VB = f(l)$ (Fig.3)

4.DETERMINATION OF THE CRITERION OF WEARING WHICH CORRESPONDING TO MAX1MUM HOB MILLING TOOL CAPACITY

Rational determination of a wearing out value and a tool life function of the hob milling tool is not possible without reliable tool life criterions.

In the theory of machining of metals for determination of wearing out of some particular tool, among the others, there is a technological criterion. This criterion is very much used in production conditions. Wearing out time of a tool is that time of cutting when the tool wearing reaches the technological value of wearing parameters. Technological parameter which defines the wearing out may be, for example:

- roughness of machined surface
- accuracy of machining
- break up insufficient rigid and sensitive of tool.

The wearing criterion, based on maximum tool capacity, as a objective function, may be defined from the wearing curves of hob milling tools. This criterion can be achieved by the simulation method, if we know the character of wearing process of the hob milling tool (Fig.1) and an available width of tooth of hob milling tool for sharpening $M(mm)$. From the diagram, we can read the value of the length of gear teeth $l(mm)$ for which one sharp cutting edge corresponds to, after which $VB_{oo} = VB_o + 0.025$ is excluded.

For that reason, theoretical number of sharp cutting edge is:

$$i_{ot} = M / (VB_{oo} + 1) > i_{os} \quad (2)$$

where i_{os} is integer.

Total possible length of gear teeth machining to completely wearing out of the hob milling tool is:

$$L = \sum l_i \quad (3)$$

In order to define wearing criterion, many investigations are carried out in the laboratories of the Faculty for Technical Sciences in Novi Sad. Under the following conditions:

Working piece: cylindrical gear with straight teeth

- modul $m_n = 3(mm)$
- teeth number $z_2 = 45$
- length of rim $l_v = 54(mm)$,
- contact angle $\alpha = 20^\circ$
- working piece material steel 20CrMo5

Tool: single tooth hob milling tool, as a model for integral hob milling tool.

- diameter of the hob milling tool $d_g = 125(mm)$
- number of travels $z_1 = 1$
- number of grooves which is formed $n_i = 12$
- main tool material steel HS6-5-2
- coated tooth 9-79
- uncoated tooth 9-79

Coating of these tools has been made by TiN layer.

Machine tool: Hob milling machine MODUL-ZFWZ-250x5A producer VESTRAKSTROM - Anlagenbau, Karl Marx Stadt

- cutting fluid: emulsion 12% - CLETEX D
- cutting speed: $v_c = 98{,}125(m/\min)$
- feed $f = 2{,}0(mm/rev)$,
- axial displacement $a_d = 0{,}63(mm)$

Table 1. Wear parameters and tool life

VB_o	l_o	VB_{os}	i_{ot}	i_{os}	$i_{os}+1$	$\sum l_o = L$
0.10	10.25	0.125	96.00	96	97	991.35
0.15	15.00	0.175	68.50	68	69	1035.00
0.20	22.75	0.225	53.33	53	54	1227.50
0.25	23.50	0.275	47.20	47	48	1128.00
0.30	28.00	0.325	36.92	36	37	1036.00
0.40	34.00	0.425	28/.47	28	29	986.00
0.50	39.25	0.525	22.85	22	23	902.75
0.60	44.00	0.625	19.20	19	20	880.00

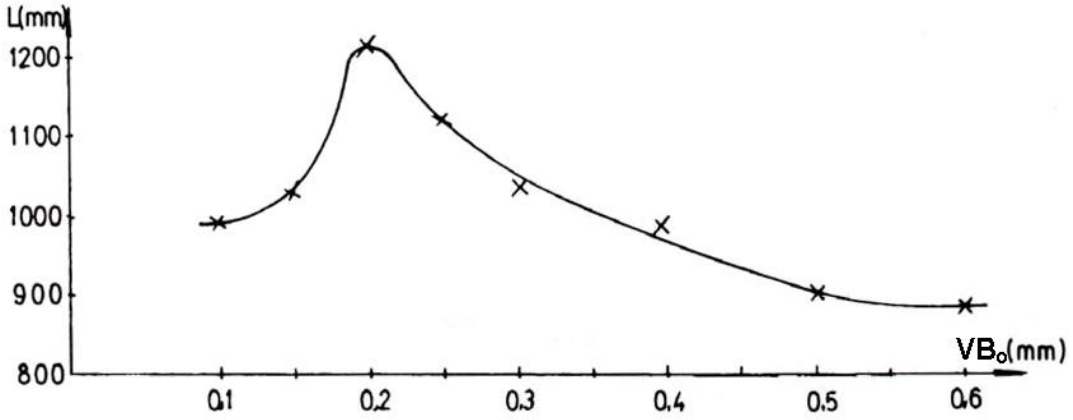


Fig. 4. Length of machined toothing (l) in the function of the parameters (VB_o) to wearing out of the hob milling tool

As it can be seen from the Fig. 4, the change of the whole length in function of the wearing criterion has an extreme for $VB_o = 0,2(mm)$, for which, maximum tool capacity corresponds to, respectively, under this value of the wearing criterion, the machining of the biggest number of the working pieces by one gear hob is made.

5.CONCLUSION

On the basis of presented, for analyzed machining conditions, flank wear land $VB_o = 0,2(mm)$ may be adopted, where maximum capacity of the hob milling tool and minimal tool cost in one operation are reached.

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STUDIES REGARDING SOIL INDUCED STRESSES IN BURIED STEEL GAS PIPES

Razvan George RIPEANU, Virgil METEA, Alexandru PUPAZESCU

Abstract: *There are few experimental results available for the gas transmission pipelines and no experimental data have been found for distribution pipelines backfilled by subgrade. Paper presents the determination of loads due to backfill and loads due to live loads induced in gas pipes respecting the standard EN 13480-6:2004 methodology and in experimental cases.*

Key Words: *soil, backfill, loads, gas pipes*

1.INTRODUCTION

The gas transport and distribution pipeline industry has long been interested in evaluating the effects of external loading due to fill and surface loads, induced by truck wheel loads or other heavy vehicles equipments, on buried pipes. These interests consist not only from the initial design of pipeline systems, but also from the need to evaluate changing loading conditions over the time-life of the pipeline.

The determination of critical loads for design of buried pipes requires consideration of the internal pressure of transported fluid as well as externally applied loads. The design of buried high pressure pipelines is often governed by the internal pressure of the pipe, compared to low pressure pipelines where external loads will be of significance.

Establishing the soil loads on pipes is often a difficult task because of the complex interaction between the pipe and soil in the vicinity. Under general operating conditions, these soil loads are mostly estimated using simplified semi-empirical formulae, but for example Smith and Watkins, [1] pointed out that the Iowa Formula was derived to predict the ring deflection of flexible culverts, and not as a design equation to determine the wall thicknesses of pipes. It is, however, widely used in stress calculations, and is part of the methodology used to predict the stresses in pipelines due to vertical loading in the ALA Guideline for the Design of Buried Steel Pipe. The use of the Iowa Formula to calculate the wall-bending stresses in a pressurized buried pipe is generally unrealistically conservative, and can, under certain circumstances, lead to results that behave strangely, particularly for high vertical loading, [2].

According to EN 13480-6:2004 the stresses in pipes are induced by:

- gas internal pressure;
- temperature;
- soil weight;
- traffic loads.

In gas distribution pipeline systems the operating pressures are usually smaller than 0.6 MPa and temperature variation along the year at burring pipe depth is smaller than 35^{o}C so the pipe stresses are mainly influenced by soil weight and traffic loads. Occasionally could appear vibration and soil displacements induced stresses, [3, 6].

Quantification of anticipated geotechnical hazards is a key consideration in assessing performance of pipelines under extreme loading conditions. Evaluation of the performance of pipeline systems under such hazards commonly uses equations based on simplified assumptions or sophisticated numerical modeling techniques, [2].

The pipeline performance against geotechnical hazards can be improved by avoiding/isolating from the hazard, redesigning the pipeline to accommodate the hazard of mitigating the hazard using ground improvement.

There are few experimental results available for the gas transmission pipelines and no experimental data have been found for distribution pipelines backfilled by subgrade. It has been

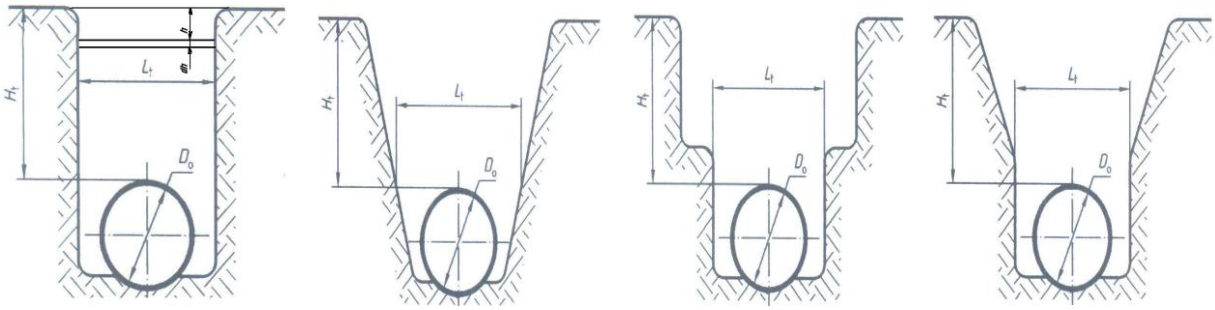
recognized that a major challenge is to perform the pipe/soil interaction simulation, which is critical in the calculation of the soil weight and heavy truck loads for buried pipes, [2, 5].

2.CALCULUS OF STRESSES IN BURIED PIPE DUE TO DEAD AND LIVE LOADS

2.1.Calculation of the load due to the backfill

Load induced by soil above buried pipe depends of, [6]:
- pressure created by soil in diametric pipe section;
- soil proprieties are constant along the pipe at a length grater than a calculus zone;
- the rapport between excavation width *B* and pipe diameter *D* is constant on analyzed length;
- the pipe weight is not considered.

According to Spangler theory presented in [4, 5, 7] is considered a soil elementary unit with d*h* high and unitary length unit (see Fig. 1).



a ***b*** ***c*** ***d***

Fig. 1. Types of soil piping

The load due to the backfill L_1 could be established with relation [7]:

$$F_1 = C_1 \gamma_t L_t H_t \tag{1}$$

were: L_t is width of the trench in the horizontal plane containing the top of the piping;
H_t – total height from the top of the piping to natural ground surface (cover);
γ_t – unit weight of backfill material;
C_1 – coefficient calculus with expression:

$$C_1 = \frac{L_t}{2k\mu_1 H_t}\left(1 - e^{\frac{-2k\mu' H_t}{L_t}}\right) \tag{2}$$

were μ is coefficient of internal friction of backfill material;
μ' – coefficient of sliding friction between the backfill material and the trench walls;
k – ratio of lateral pressure to vertical pressure for the backfill material (Rankine coefficient).

$$k = \left\{\tan\left(\frac{\pi}{4} - \frac{\varphi}{2}\right)\right\}^2 \tag{3}$$

were φ is angle of internal friction for the material used to fill the trench.

For a gas pipe of ∅2″ with external diameter D_0 = 60.3 mm and wall tickness s = 3.2 mm, piping height H_t = 0.9 m in a trench width L_t = 0.6 m (fig.1a), in a sandy clay with γ_t = 1800 daN/m^3, $\varphi = 14^0$ and $k\mu = k\mu'$ = 0.152. Depending of soil type and soil piping φ, k, μ and μ' are selected from EN 13480-6:2004.

Appling relations 1, 2 and 3 the load due to the backfill F_1 = 7,805 N/mm.

2.2. Determination of loads due to live loads

In the case of a concentrated live load F_7 in Newton, the load per unit length the piping is subjected to is given by equation [7]:

$$F_7 = C_7 \frac{F_c}{L} C_{\text{dyn}} \tag{4}$$

were F_c, is concentrated live load from soil surface;

L – piping length, loaded by F_c (equal to 1 if the actual length of the piping under consideration exceeds 1);

C_{dyn} – dynamic coefficient. For streets and roads the dynamic coefficient is given by relation [7]:

$$C_{\text{dyn}} = 1 + \frac{0{,}3}{H_t}, \tag{5}$$

C_7 – coefficient established with relation [7]:

$$C_7 = \frac{2}{\pi}\left(C_{71} + C_{72}\right) \tag{6}$$

were:

$$C_{71} = \arctan\left[\frac{B}{H_t} \cdot \frac{A \cdot (A^2 + B^2) - 2 \cdot A \cdot H_t \cdot (R_r - H_t)}{(A^2 + B^2) \cdot (R_r - H_t) - H_t \cdot (R_r - H_t)^2}\right] \tag{7}$$

$$C_{72} = \frac{B \cdot H_t}{B^2 + H_t^2} \cdot \frac{A \cdot (R_r^2 + H_t^2)}{(A^2 + H_t^2) \cdot R_r} \tag{8}$$

were:

$$R_r = \sqrt{A^2 + B^2 + H_t^2}\ ;\ A = \frac{L}{2};\ B = \frac{D_0}{2}. \tag{9}$$

For considered gas pipe of ∅ 2″ applying relation 4 we obtain $F_7 = 3.455 \cdot 10^{-5} F_c$ N/mm, were F_c is in Newton.

The stresses σ in the pipe wall may be derived from the values of the resultant torques using the following equation [7]:

$$\sigma(\alpha) = \frac{M(\alpha) \cdot \nu}{I} \tag{10}$$

were $M(\alpha)$ is the torque in pipe material ring section with unit width and is calculated with relation:

$$M(\alpha) = \left(\frac{1}{\pi} - \frac{\sin\alpha}{2}\right) \cdot Q \cdot \frac{D_m}{2} \tag{11}$$

were $Q = F_1 + F_7$ is total load per pipe unit length (see Fig.2.);

D_m – pipe mean diameter;

ν – Poisson coefficient;

$I = s^3/12$ – inertial torque of ring section with unit width.

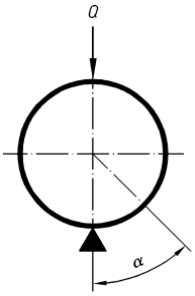


Fig.2. Unit ring with total load Q applied

If considered passing at soil surface a heavy equipment with total weight of 8 tf and this is divided 40% on front ax and 60% on back ax, in this case F_c = 8·0.6/2 = 2.4 tf = 24 kN.
As a result F_7 = 0.829 N/mm and Q = 8.634 N/mm. Maximum stresses is at $\alpha = 0$ and $\alpha = \pi$ and has the value σ_{max} = 9.905 MPa.

3.EXPERIMENTAL DETERMINATION OF BURIED PIPE STRESSES

3.1.Experimental determination of load due to backfill

To establish the stresses in buried pipes were realized 4 transducers presented in figure 3, [5].

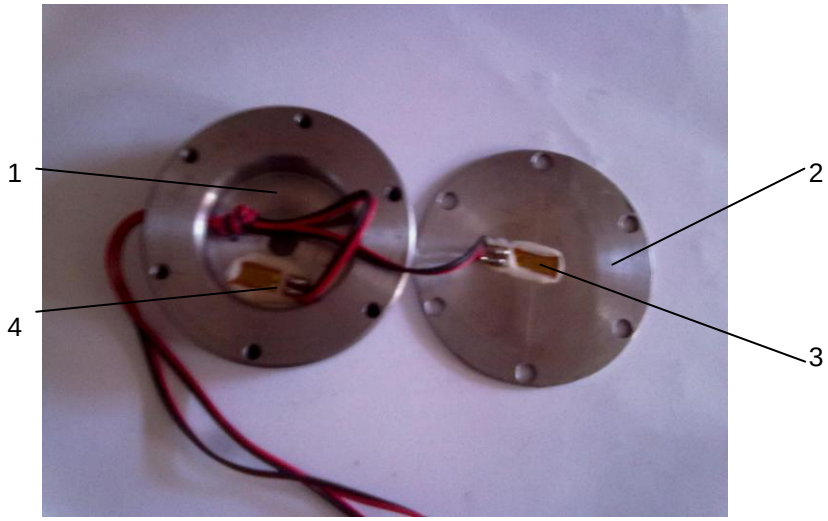


Fig. 3. Construction of transducers
1- transducer body; 2- active cover surface; 3-active strain gauge; 4- compensation strain gauge

For each transducers were established the characteristic dependence mV/V vs. load N, using a Spider 8 device and different loads. In figure 4 are presented these characteristics.

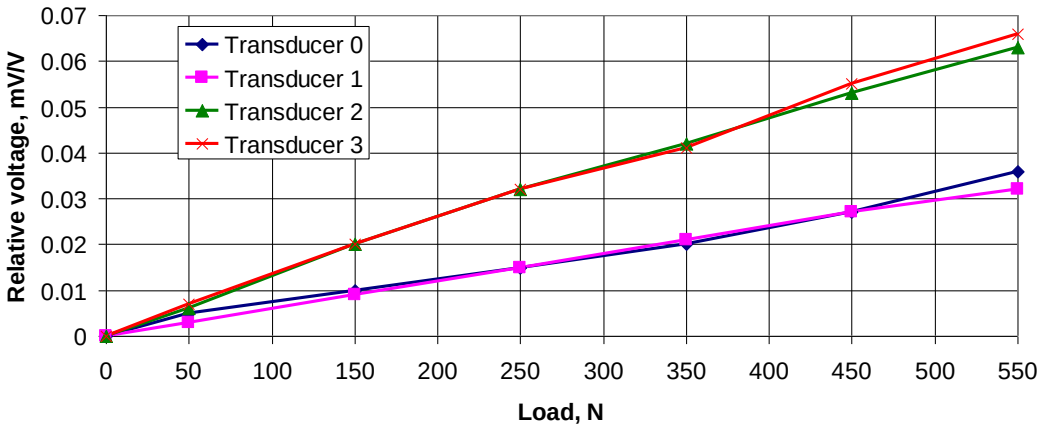


Fig. 4. Transducers load calibration

These transducers were fixed on a pipe at 1.33 m distances between transducers and at least 1 m from pipe end. In figure 5 is presented the pipe with transducers laying in the trench with piping height H_t = 0.9 m, trench width L_t = 0.6 m, [5].

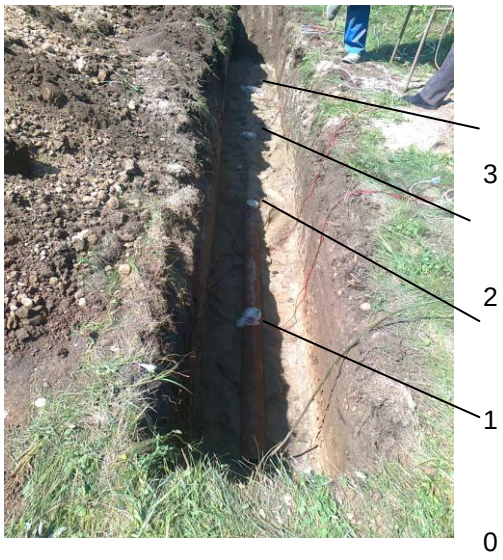


Fig. 5. Laying the pipe

Transducers connections with Spider 8 device were assured with insulated copper cables.

Backfill was sandy clay with γ_t = 1800 daN/m^3. The trench was filled in three stratums, after each with a beetle was performed the soil compaction. In figure 6 is presented the backfill compaction.



1 compaction **2 compaction** **3 compaction**

Fig. 6. Backfill compactions

The measured load with trench filled with sandy clay after compaction is presented in figure 7, [5].

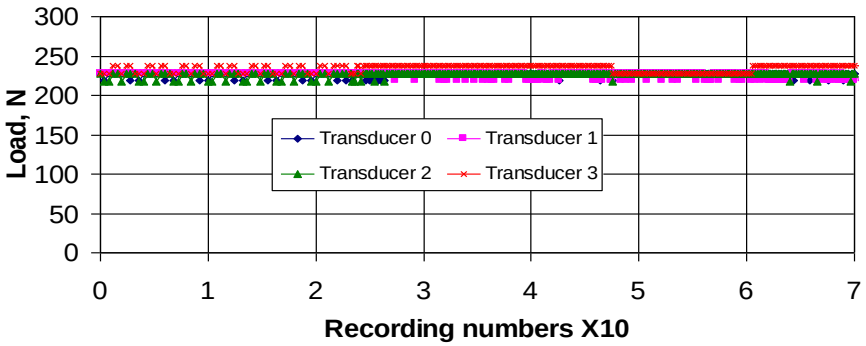


Fig. 7. Pipe covered with 0.9 m backfill compacted

From figure 7 could be observed that load due to backfill at all transducers are between 230-240 N. For ∅ 60 active surface of cover transducer the load per unit length due to backfill F_1 = 3.833 - 4N/mm.

3.2.Experimental determination of load due to live loads

At the soil surface of buried pipe an excavating machine of 8 tf pass along the pipe starting from 0 to 3 transducers. In figure 8 it is presented the total loads due to backfill and live loads, [5].

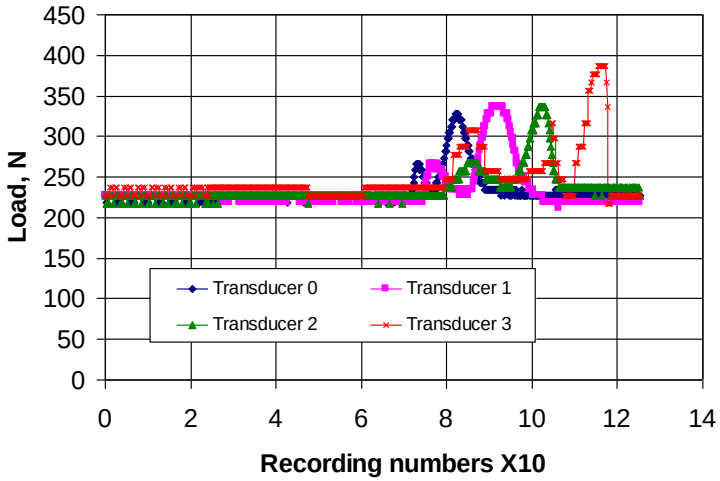


Fig. 8. Total loads due to backfill and excavator passing along the buried pipe

From figure 8 could be observed that the total loads due to backfill and excavator machine passing along the pipe is between 340 - 380 N, that means that total load per unit length Q = 5.666 – 6.333 N/mm and load per unit due to live loads F_7 = 1.833 - 2.333 N/mm.

4.CONCLUSION

Buried pipes under traffic roads diminish the pipes durability because [6]:
- in pipes are induced alternating stresses;
- induce in pipes aperiodic vibrations;
- elastic strain of pipes;
- passing yield strain of insulating materials.

Elastic strain of pipes due to live loads is important at gas distribution pipes because affect tee branch piece were the majority of failures appear. In the mean time this stresses affect the insulating materials by disbonding and reducing the thickness, so corrosion appear.

Comparing the theoretical values obtained using the EN 13480-6:2004 methodology with experimental values, we could observe that the standard give proper values for backfill material $F_{1standard}$ = 7.805 N/mm instead of $F_{1experimental}$ = 3.833 - 4 N/mm, due to backfill and live loads $Q_{standard}$= 8.634 N/mm instead of $Q_{experimental}$= 5.666 – 6.333 N/mm, but the loads due to live loads obtained respecting standard is significant smaller than experimental values $F_{7standard}$ = 0.829 N/mm instead of $F_{7experimental}$ = 1.833 – 2.333 N/mm. This difference is because the standard considers roads with pavements. Pavements failures induce greater loads in buried under roads pipes. In the mean time if at laying pipes we have different soil compaction or density, or rocks under pipe the loads will be greater.

ACKNOWLEDGMENTS

Authors are grateful to E.ON Gaz Distributie SA Targu Mures, for given support in accomplish experimental tests.

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DYNAMIC ANALYSIS OF A CAM MECHANISM WITH TRANSLATING FLAT FACE FOLLOWER

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Abstract: *This paper analyzes the dynamical behavior of a cam mechanism with translating follower. The designed cam mechanism is modeled with the finite elements method (FEM) in order to analyze its vibratory behavior. The FEM model is validated by comparing the theoretical values of the natural frequencies with the experimental ones of the prototype mechanism.*
Key Words: *cam mechanism, FEM, modal analysis*

1.INTRODUCTION

The cam mechanism is an important machine element used to control the motion of machine parts. In the design of a high speed cam mechanism, an important problem is to estimate the modal behavior of the structure of a cam-follower system in order to minimize the vibration of the follower system when subjected to cam-induced motion [1, 2].

Various methods have been proposed in the literature for the analysis and optimization of the cam mechanisms. In our previous research [3] the design parameters are determined by the minimization of the maximum compressive stress at the contact area of a cam-disk mechanism with translating roller follower, where the cam profile is described with the aid of cubic spline functions. Tsiafis et al. present in [4] a multi-objective procedure based on genetic algorithms to optimize the design parameters of a disk-cam mechanism with a roller follower, where as optimization criteria are considered the minimization of the cam size, of the input torque and of the contact stress. Kim et al [5] use a lumped mass-spring-damper to predict the dynamic behavior of cam-valve system. Teodorescu et al [6] present an analysis of a line of four-cylinder valve train system with camshaft flexibility to predict the vibration signature taking into account frictional and contact forces.

In the present paper the vibratory analysis of a designed and constructed cam mechanism is investigated. The natural frequencies and the mode shapes of the structure of cam-follower system are obtained from the model analysis of a FEM simulation. The experimental values of the natural frequencies of the constructed mechanism are compared with the theoretical ones to validate the FEM model.

2.DESIGNING AND MANUFACURING OF THE PROTOTYPE CAM MECHANISM

The investigated mechanism is a disk-cam mechanism with translating flat face follower (see Fig. 1). The center line of the follower passes through the center line of the cam shaft. The spring is chosen in order to keep the cam and follower in contact. An electrical motor provides the input torque to the camshaft through a belt transmission.

The CAD-CAM system developed in [7] is applied to design and manufacture the prototype cam mechanism. The maximum displacement of the follower is 5 mm and cycloidal displacement function is selected for the rise and return of the follower. The displacement, velocity and acceleration diagrams of the follower are illustrated in Figure 2. The theoretical cam profile is inserted in Fig. 3. The 3D solid model of the cam is given in Fig. 4, where the cam shape is determined to balance the camshaft. The cam is manufactured by a 3-axis CNC machine using spline interpolation.

The designed and constructed cam mechanism is presented in Fig. 5.

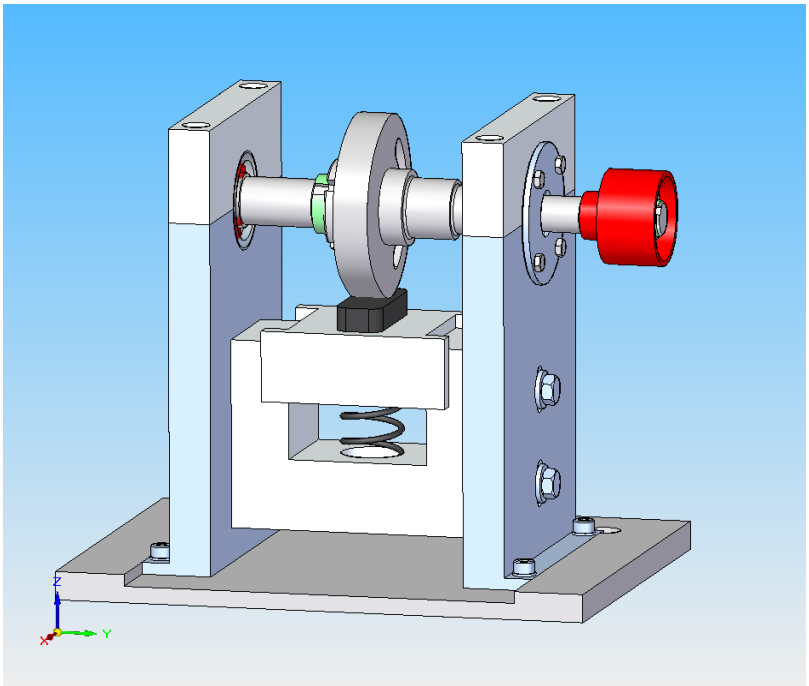


Fig. 1. 3D model of the cam mechanism

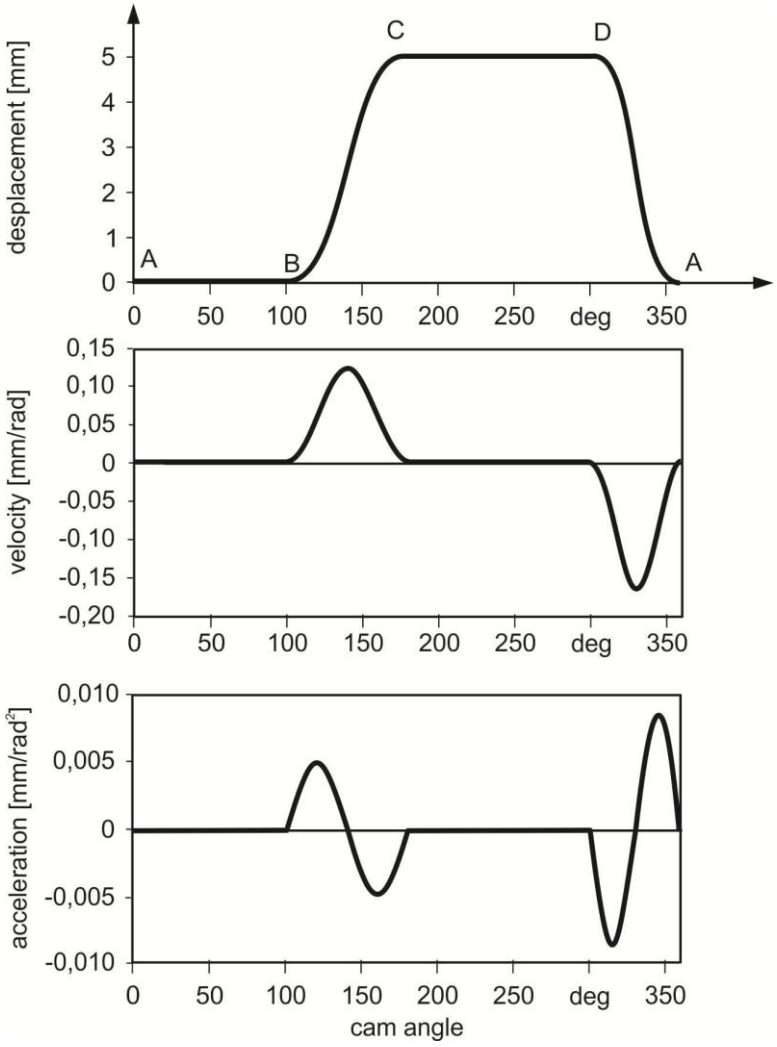


Fig. 2. Displacement, velocity and acceleration of follower

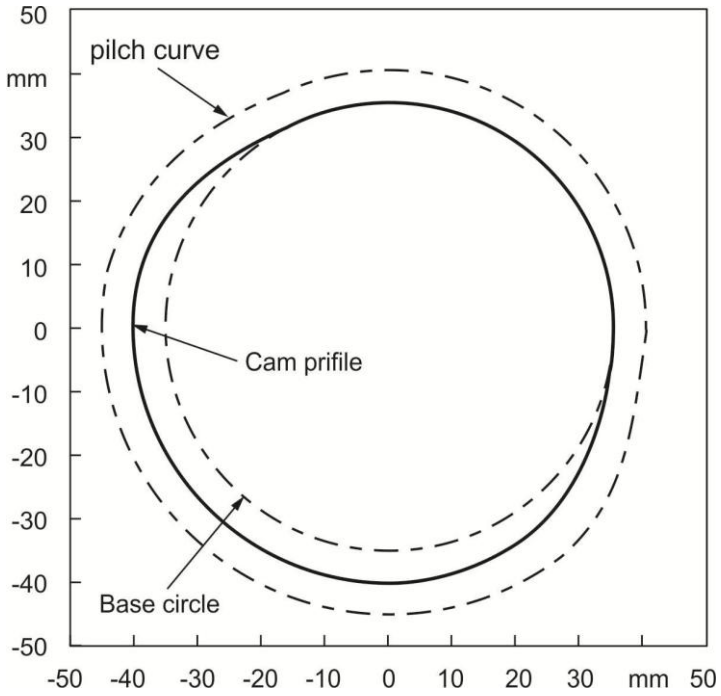


Fig. 3 . Theoretical cam profile

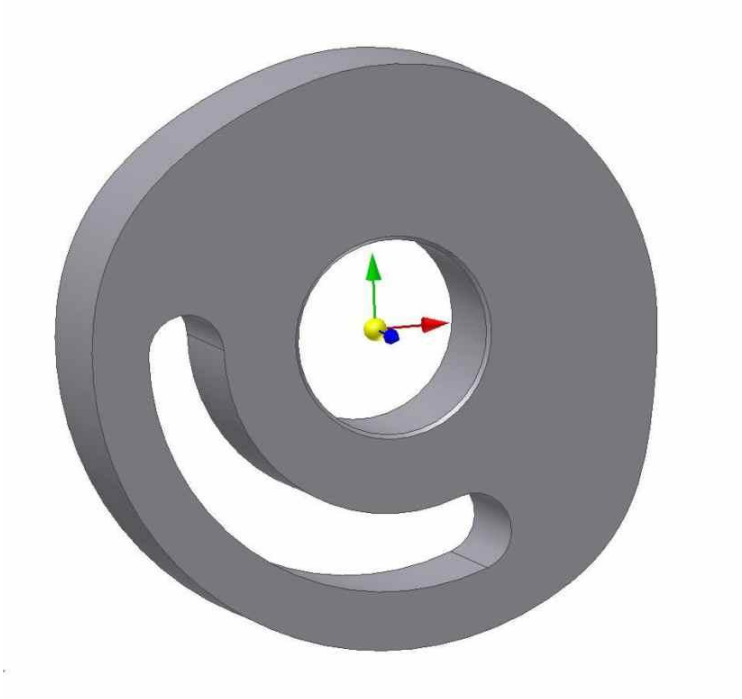


Fig. 4. Cam solid modeling

3.FEM SIMULATION OF THE CAM MECHANISM

The dynamic behavior of cam mechanism is performed with the finite element method (FEM). Using the CAD model of the cam mechanism implemented in the finite element software ANSYS, the FE model is obtained. The materials of the parts and the contacts of the model are defined properly. In the FE model of the mechanism the screws, bolts and ball bearings are replaced with the proper contact conditions. The meshing process is performed by the program automatically creating roughly 45011 nodes and 18866 elements. The meshed FE model and contact region of the mechanism is shown in Fig. 6.

A modal analysis is performed to determine the natural frequencies and the mode shapes of the cam-follower system by ANSYS software. The first six values of the natural frequencies and the corresponding mode shapes are inserted in the Table 1 left and Fig. 7 respectively.

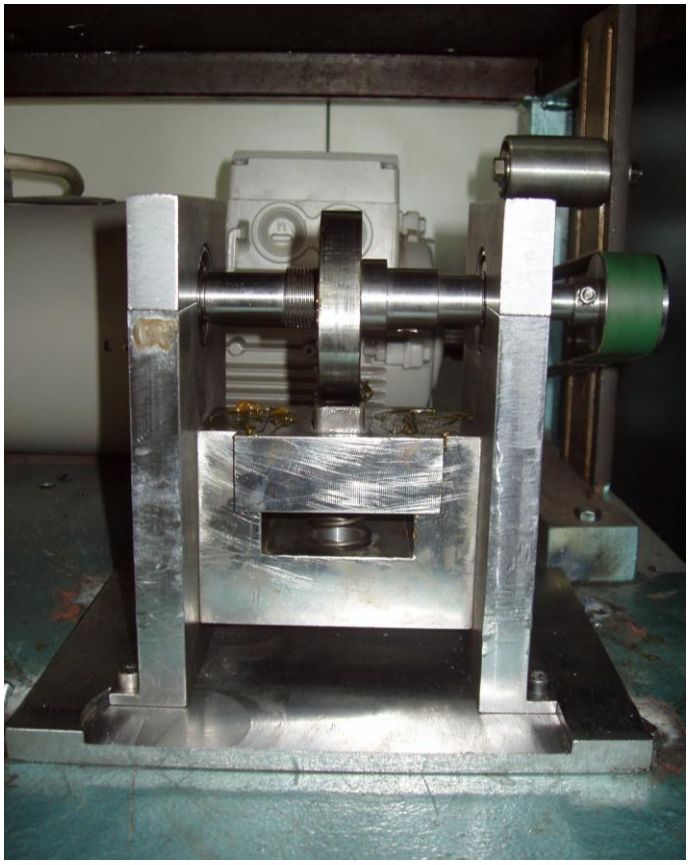


Fig. 5. Prototype cam mechanism

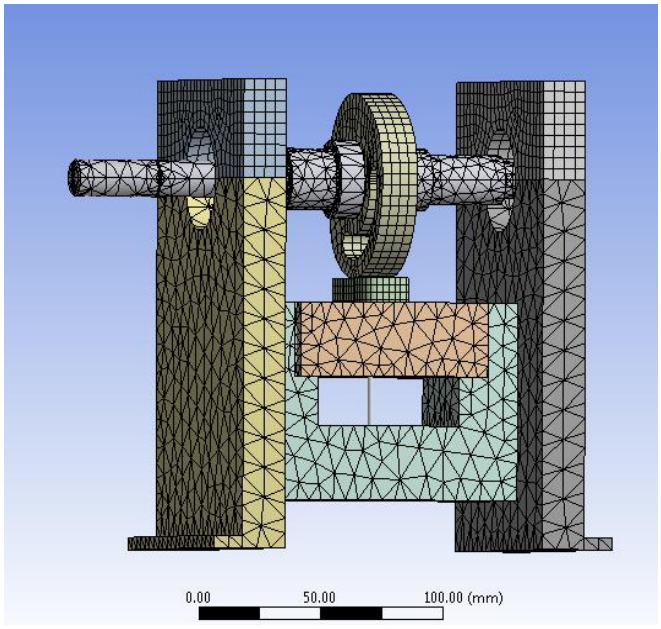
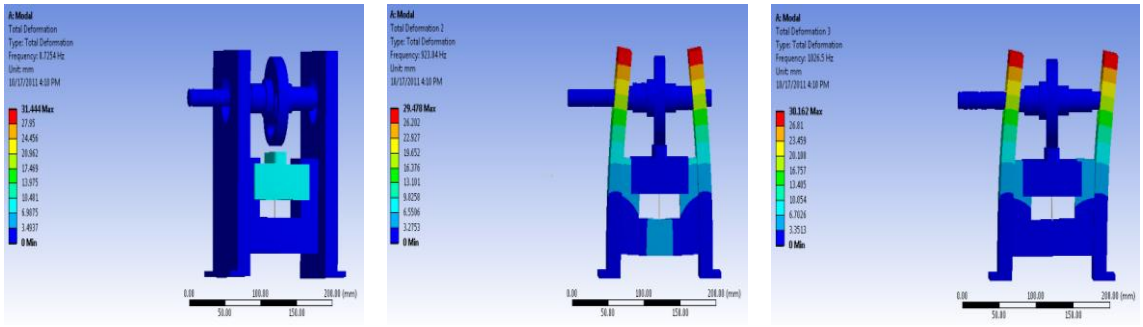


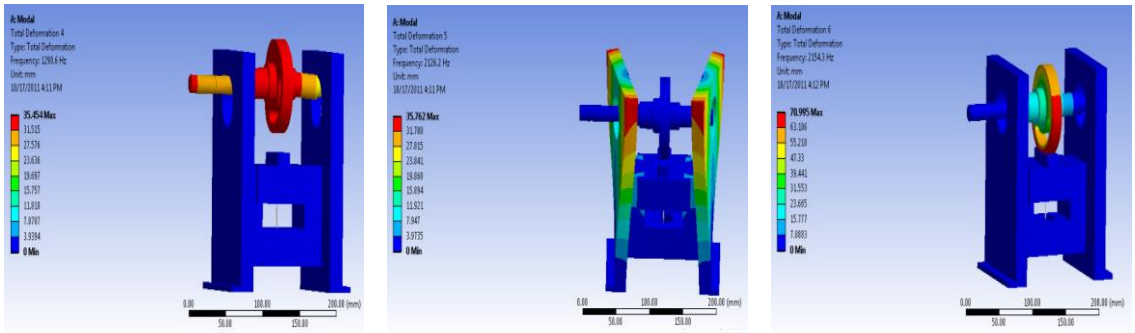
Fig. 6. 3D FE model of the cam mechanism

Tabel 1. FEM and experimental values of natural frequencies

Mode	Frequency (Hz)		Deviation (%)
	Finite Elements Method	FFT Analyzer	
1	8,725	8,667	0,67
2	923	914	0,99
3	1027	984	4,32
4	1291	1336	3,40
5	2126	2066	2,91
6	2154	2188	1,54



Mode 1 Mode 2 Mode 3



Mode 4 Mode 5 Mode 6

Fig. 7. Six mode shapes

The maximum total deformation value of each mode shape is shown in the Table 2.

Table 2. Maximum total deformation of each mode shape

Mode	1	2	3	4	5	6
Maximum deformation (mm)	31,444	29,478	30,162	35,454	35,762	70,995

The FE model of the mechanism is validated by an experimental procedure. The left bearing of the prototype mechanism camshaft is excited by an impulse force along the x, y, z directions successively. For each of these directions, the acceleration in the x, y, z directions is measured with the aid of an accelerometer attached on the camshaft right bearing in the corresponding direction. The measured signals of the acceleration and force are subjected to the FFT analysis and furthermore

the natural frequencies of the mechanism are evaluated. In the Table 1 right the experimental values of the natural frequencies are inserted. The comparison of the theoretical values with the experimental ones of the natural frequencies shows a good agreement.

It can be concluded that the FE model of the prototype mechanism is satisfactory and can be used for the dynamic analysis of the cam mechanism.

4.CONCLUSIONS

The dynamic behavior of a cam mechanism with flat face follower is investigated. This performance is evaluated with FEM simulation. Furthermore, the FEM model of the cam mechanism is validated experimentally. Moreover, the paper provides a basis for the optimal design of a cam mechanism for improving the mechanism efficiency.

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STIFFNESS INVESTIGATION OF AN ORTHOGLIDE PARALLEL MECHANISM INTEGRATED INTO A CNC MILLING MACHINE

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Abstract: *This paper analyzes the stiffness of a modified orthoglide parallel mechanism build for integration in a CNC milling machine. The parallel mechanism is driven and controlled by a vertical CNC milling machine. The designed mechanism is modeled with the finite elements method (FEM) in order to analyze the static behavior inside the workspace. The FEM model is validated by comparing the theoretical values of the natural frequencies with the experimental ones of the prototype mechanism.*

Key Words: *orthoglide mechanism, CNC milling machine, FEM, modal analysis*

1. INTRODUCTION

Parallel kinematic machines (PKM) are commonly used for machining processes because of their advantages such as high stiffness, low inertia, high accuracy and also the ability to have increased number of degrees of freedom compared to classic machine tools [1]. The construction of such a machine tool into a university laboratory for experimental and educational purposes requires high cost. In order to construct and demonstrate a PKM with low cost, the facilities (actuation, control, hardware, software) of a CNC milling machine existing into the laboratory can be used [2, 3]. For that purpose an orthoglide parallel mechanism with three degrees of freedom (dof) is used [4].

The stiffness of a parallel mechanism has direct impact on its position accuracy. Hence, it is desired to perform the stiffness modeling and evaluation of a parallel mechanism for the precise manipulation purpose. Various methods have been proposed in the literature for the analysis and optimization of the 3 dof parallel mechanisms. Gosselin et al. present in [5, 6] a new method to analyze the effect of the link flexibility on a parallel mechanism's stiffness named lumped kinetostatic modeling. Majou et al. present at [7] a parametric stiffness analysis of the orthoglide that allows a simple systematic analysis of the influence of the geometric design parameters and to quickly identify the critical link parameters. Pashkevich et al. present a new stiffness analysis method of over constrained parallel manipulators with flexible links and compliant actuating joints [8]. In our previous research [9], using a genetic algorithm, the optimal design of a symmetrical orthoglide mechanism was performed so as to maximize the workspace, the conditioning index and the stiffness of the mechanism, considering the limits imposed by the CNC milling machine geometry.

In the present paper the stiffness of the designed and constructed orthoglide mechanism is evaluated. Stiffness evaluation is obtained from results of a compliant analysis of the mechanism using a FEM simulation. Furthermore, the natural frequencies of the mechanism configuration corresponding to the center of the workspace are obtained from the model analysis of a FEM simulation. The experimental values of the natural frequencies of the same mechanism configuration are compared with the theoretical ones to validate the FEM model.

2. INTEGRATION OF AN ORTHOGLIDE MECHANISM INTO A CNC MILLING MACHINE

The parallel kinematic device integrated into a vertical CNC milling machine is a modified orthoglide parallel mechanism (see Fig. 1).

The mechanism consists from the base, a moving platform and three fixed-length links, connected to the base by prismatic joints. Each of the three links contains one parallelogram. The three parallelograms are connected to the moving platform and the sliders by revolute and universal joints

respectively. A serial 2-dof passive mechanism (arm in Figure 1) is attached for decoupling of the CNC machine x and y axes.

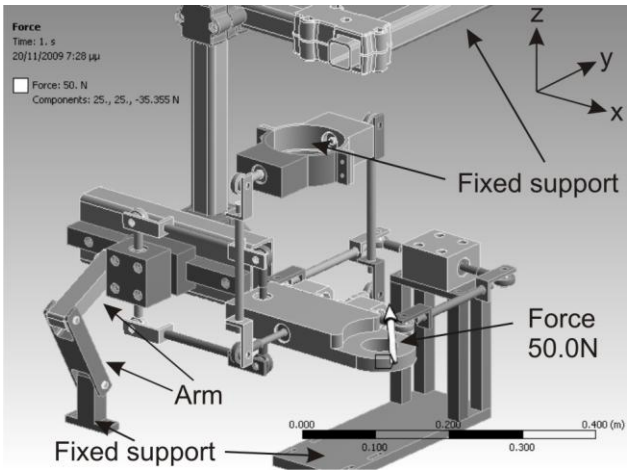


Fig. 1. 3D model of the modified orthoglide mechanism

The drive and the control of the prismatic joints in x, y and z directions are performed by CNC milling machine actuators. The moving platform of the mechanism has three translational degrees of freedom with respect to the base, so that it retains a constant orientation during the motion. Due to the geometry of the CNC milling machine, a semi symmetrical parallel machine is designed. The design parameters of the mechanism have been adjusted in order to gain volume for the workspace.

The designed and constructed orthoglide mechanism integrated into the CNC milling machine is presented in Fig. 2.

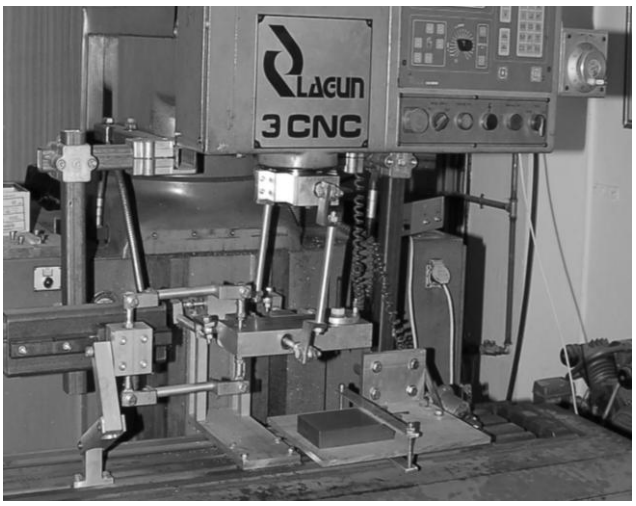


Fig. 2. Modified orthoglide mechanism integrated into a CNC milling machine

3. FEM SIMULATION OF THE ORTHOGLIDE MECHANISM

The stiffness of the orthoglide mechanism integrated into CNC milling machine is an important performance because higher stiffness allows higher machining speeds with higher accuracy of the end-effector.

The stiffness changes with the variation of the mechanism configurations within its workspace as well as the direction of the applied wrenches. Stiffness evaluation of the orthoglide mechanism can be obtained from results of a compliant analysis of the system. The main sources of compliance are considered the links, joints and the moving platform (end-effector) of the mechanism.

The evaluation of compliant displacements of the moving platform under given load exerted against it at different mechanism configurations is performed with the finite element method (FEM). Using a CAD model of the orthoglide mechanism implemented in the finite element software ANSYS, the FE model is obtained. As seen in Fig.1 the mechanism is fixed onto the CNC milling machine at four points. The materials of the parts and the contacts of the model are defined properly. In the FE

model of the mechanism the screws, bolts and ball bearings are replaced with the proper contact conditions. The meshing process is performed by the program automatically creating roughly 305812 nodes and 155193 tetrahedral elements. The meshed FE model of the mechanism is presented in Fig. 3 and can be seen that the size of the created elements depends on the geometry curvature and proximity of the parts.

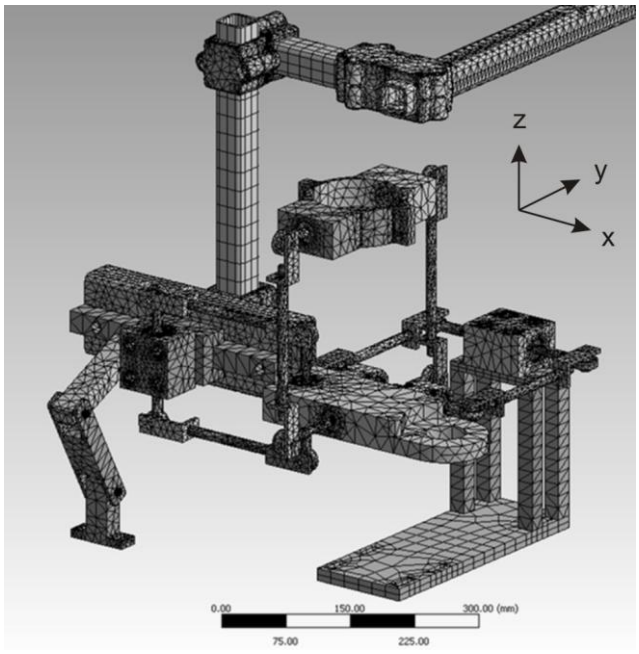


Fig. 3. 3D FE model of the modified orthoglide parallel mechanism

To simulate the moving platform compliant displacement under simulated cutting forces F_x=25 N, F_y= 25 N and F_z= 35.355 N applied in the tool within workspace of the mechanism, the compliance analysis is performed in four different xy levels of z axis. Sixteen points-positions are chosen in each xy level uniformly distributed inside workspace and so static analysis is performed for 4 x 16 = 64 different configurations of the mechanism. Thus, the global compliance behavior is taken into account.

The deformation of TCP of the moving platform is presented in Figs. 4 – 7. In each figure the deformation for 16 positions of the mechanism is presented for a specific z – axis level. It is observed that the deformation has a minimum value in an area near the center of the workspace and rises towards the edges.

The maximum and minimum values of moving platform deformation obtained from the static analysis into the whole workspace are presented in Table 1.

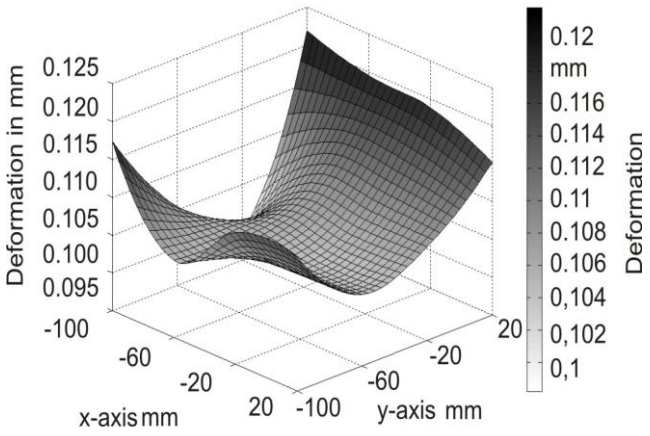


Fig. 4. TCP deformation of the mechanism with FEM simulation for z-axis level -120mm

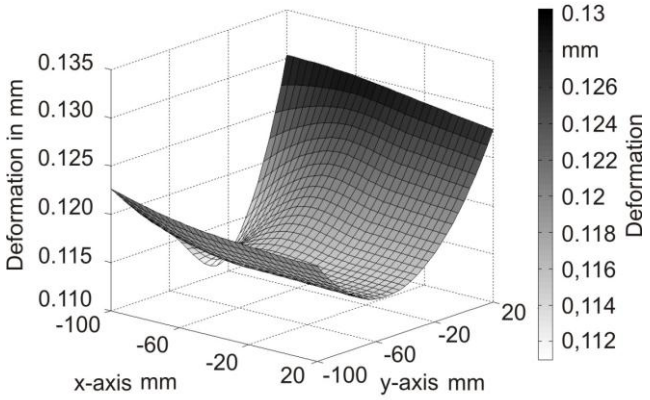


Fig. 5. TCP deformation of the mechanism with FEM simulation for z-axis level -80mm

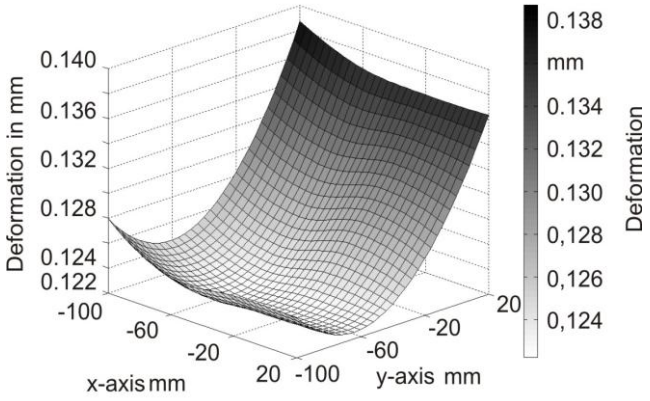


Fig. 6. TCP deformation of the mechanism with FEM simulation for z-axis level -40mm

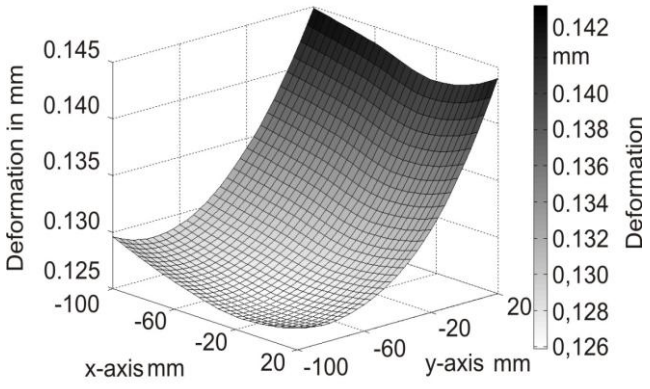


Fig. 7. TCP deformation of the mechanism with FEM simulation for z-axis level 0mm

Table 1. Maximum and minimum value of moving platform deformation

Deformation (mm)	
Maximum	Minimum
0.14484	0.098894

The FE model of the mechanism is validated by an experimental procedure. For the same configuration of the prototype mechanism the moving platform is excited by an impulse force along the x, y, z directions successively. For each of these directions, the acceleration in the x, y, z directions is measured with the aid of an accelerometer attached in the corresponding direction on the moving platform. The measured signals of the acceleration and force are subjected to the FFT analysis and furthermore the natural frequencies of the mechanism are evaluated. In Table 2 right the experimental values of the natural frequencies are inserted. The comparison of the theoretical values with the experimental ones of the natural frequencies shows a good agreement.

Table 2. Natural frequencies from FEM analysis and from actual mechanism with a FFT analyzer

Finite Elements Method		FFT Analyzer	
Mode	Frequency [Hz]	Mode	Frequency [Hz]
1		1	26
2		2	40
3	76	3	76
4	102, 113	4	107
5	121	5	125
6	164	6	144
7		7	181
8	225	8	208
9		9	242
10	298	10	274
11		11	328
12		12	350
13	384	13	372
14		14	382
15	401	15	422

It can be concluded that the FE model of the prototype mechanism is satisfactory and can be used for compliance analysis to different manufacturing tasks.

4. CONCLUSIONS

The stiffness of a low cost orthoglide mechanism integrated in a vertical CNC milling machine is investigated. The stiffness performance is evaluated by the compliance analysis of the mechanism with FEM simulation. The variation tendencies of stiffness within the workspace are illustrated and the stiffest working zone is determined. This area is near the center of the workspace of the orthoglide mechanism. Furthermore, the FEM model of the orthoglide mechanism is validated experimentally. Moreover, the paper provides a basis for the design of an orthoglide mechanism with stiffness properties taken into account.

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WEAR BEHAVIOUR OF HYBRID ZA27/SIC/GRAPHITE COMPOSITES UNDER DRY SLIDING CONDITIONS

Slobodan MITROVIĆ, Nenad MILORADOVIĆ, Miroslav BABIĆ, Ilija BOBIĆ, Blaža STOJANOVIĆ, Dragan DŽUNIĆ

Abstract: *The paper deals with tribological behaviour of hybrid composites based on ZA27 alloy reinforced with silicon-carbide (SiC) and graphite (Gr) particles. The tested sample contains 5% of SiC and 1% Gr particles. The experimental tests were performed on a "block-on-disc" tribometer. The main tribological parameter in the analysis was wear scar width, obtained by variation of normal loads and sliding speeds, under dry sliding conditions. Through observation of the changes in wear scar widths in dry sliding conditions, corresponding conclusions were made.*

Key Words: *ZA27 alloy, hybrid composites, tribological behaviour*

1.INTRODUCTION

Zinc–aluminium (ZA) alloys are important materials for tribological applications. They are especially suitable for high-load and low-speed applications. Their main advantages are good tribo-mechanical properties, low weight, excellent foundry castability and fluidity, good machining properties, low initial costs and environmental-friendly technology. Metal matrix composites (MMCs) have recently attracted considerable attention because of their potential advantages over monolithic alloys. Metal matrix composites based on ZA matrix are being increasingly applied as light-weight and wear resistant materials. Good characteristics of ZA alloys have inspired researchers to reinforce them with different dispersed reinforcement materials (SiC, Al_2O_3, glass fibres, graphite) in order to obtain better mechanical and tribological properties [1-3].

One of the major limitations of conventional ZA alloys is deterioration of their mechanical and wear resistance properties at higher temperatures (above 100°C) and their dimensional instability [4-6]. Recent investigations have focused attention to modification and improvement of the ZA27 alloy.

The mechanical properties of the ZA27 graphite reinforced composites are significantly changed by varying the amount of graphite [7-11]. Tribological tests show that addition of graphite particles to the ZA27 alloy matrix improves the wear resistance of the composite, despite of significant decrease in hardness. Graphite is a good choice for reinforcement of MMCs that need to have a good wear resistance, like: engine bearings, pistons, piston rings and cylinder liners.

The silicon-carbide reinforced composites exhibit reduced wear rate when compared to unreinforced ZA27 alloy specimens under the dry sliding conditions. The wear rate decreases with the increase of SiC content. The positive effects of SiC in improvement of the tribological behaviour of the ZA27 alloys are confirmed in [12-20].

The use of multiple reinforcements in zinc matrix hybrid composites provides better tribological properties than in composites with single reinforcement. Literature review shows that many researchers have considered partial influences of SiC and Gr reinforcements on the ZA27 alloys, while combined influence of SiC and Gr reinforcements is rarely investigated. This paper is an attempt to contribute to investigations of this combined influence on tribological behaviour of ZA27/SiC/Gr hybrid composites. The influence of sliding speed, loads and sliding distance on the tribological behaviour of ZA27/SiC/Gr hybrid composite is considered.

2.EXPERIMENTAL INVESTIGATIONS

The composite material with the ZA27 metal matrix reinforced by 5% SiC and 1% Gr particles (ZA27+5%SiC+1%Gr) was obtained by the compocasting procedure at the Laboratory for materials of Institute of Nuclear Sciences "Vinča".

The tests of the ZA-27/SiC/Gr composite's tribological characteristics were performed on the computer supported tribometer (Fig. 1) with "block-on-disc" contact geometry (Fig. 2) at the Centre for tribology at the Faculty of Engineering, University of Kragujevac. The main tribological parameter in the analysis was the wear scar width on the contact surface, obtained by variation of normal loads and sliding speeds. The tests were performed without lubrication, with variation of sliding speed levels (0.25 m/s, 0.5 m/s and 1 m/s) and contact load levels (10 N, 20 N and 30 N). The observed sliding distances during tests were: 30 m, 60 m, 90 m, 150 m and 300 m.



Fig. 1. The "block-on-disc" tribometer

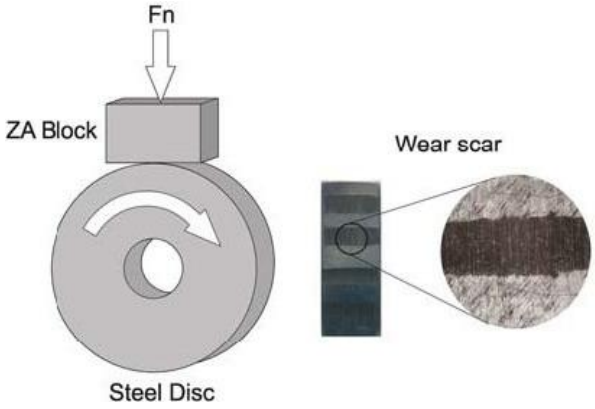


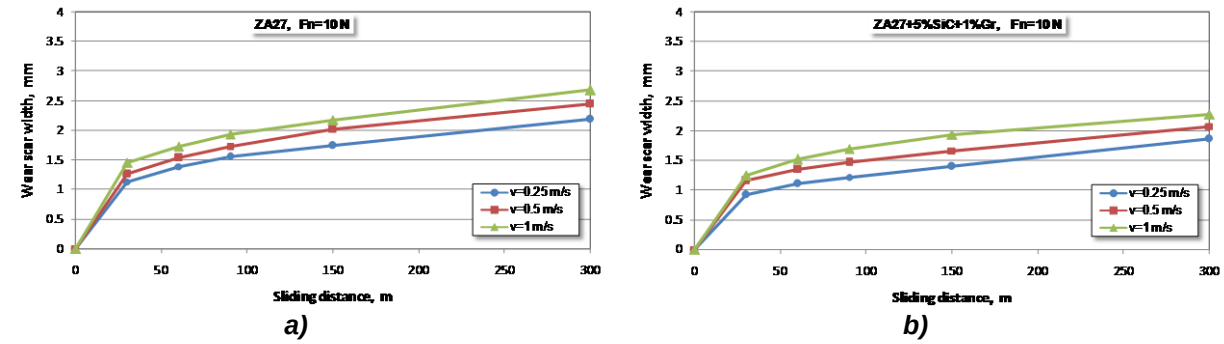
Fig. 2. The scheme of contact pair geometry

The test contact pair meets the requirements of the ASTM G77-05 standard. It consists of the rotational disc with diameter D_d=35 mm and width b_d=6.35 mm and of the stationary block of the width b_b=6.35 mm, length l_b=15.75 mm and height h_b=10.16 mm. The discs were made of steel 90MnV8 with hardness of 62 HRC and ground surfaces with roughness of R_a=0.42 mm, while the blocks were made of the tested ZA27+5%SiC+1%Gr composite.

3.THE RESULTS OF TRIBOLOGICAL INVESTIGATIONS

The curves of wear scar widths are presented in corresponding diagrams in the paper, depending on the sliding distance and for different values of sliding speeds and contact loads. Wear curves of ZA27 alloy and given hybrid composite are presented side-by-side in order to see the trends and values of respective wear scar widths.

Fig. 3 presents the wear scar width values depending on the sliding distance, for different selected values of the sliding speeds and for the applied load of F_n=10 N.



a) ***b)***

Fig. 3. Wear curves of: a) ZA27 alloy and b) ZA27+5%SIC+1%Gr composite for different sliding speeds and for the applied load of F_n=10 N

Generally, the wear behavior of the tested materials is characterized by very intensive wear during initial period, after which there is a period of stabilization. It could be noticed that wear of the composites was always significantly lower when compared to wear of the matrix ZA-27 alloy.

Fig. 4 shows the wear scar widths of the tested materials depending on the sliding distance, as functions of the applied load of F_n=20 N and different sliding speeds.

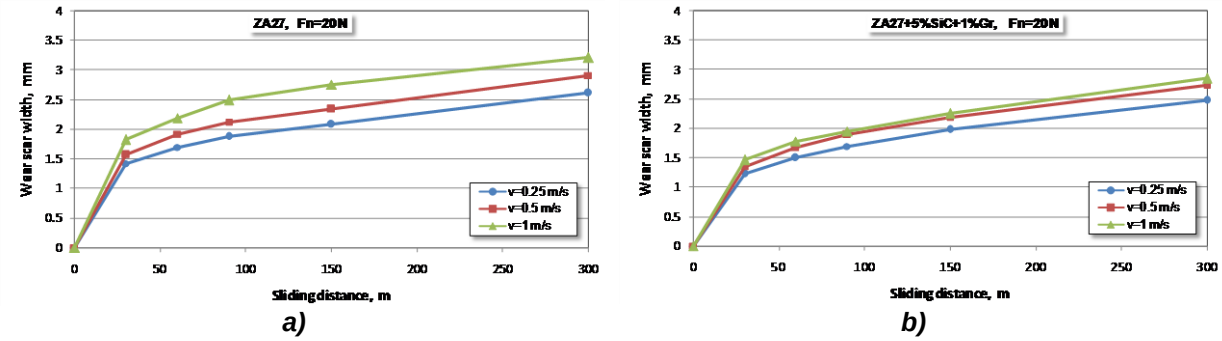


Fig. 4. Wear curves of: a) ZA27 alloy and b) ZA27+5%SIC+1%Gr composite for different sliding speeds and for the applied load of F_n=20 N

The curves of wear scar widths of the both tested materials for different sliding speeds and for the applied load of F_n=30 N are given in Fig. 5.

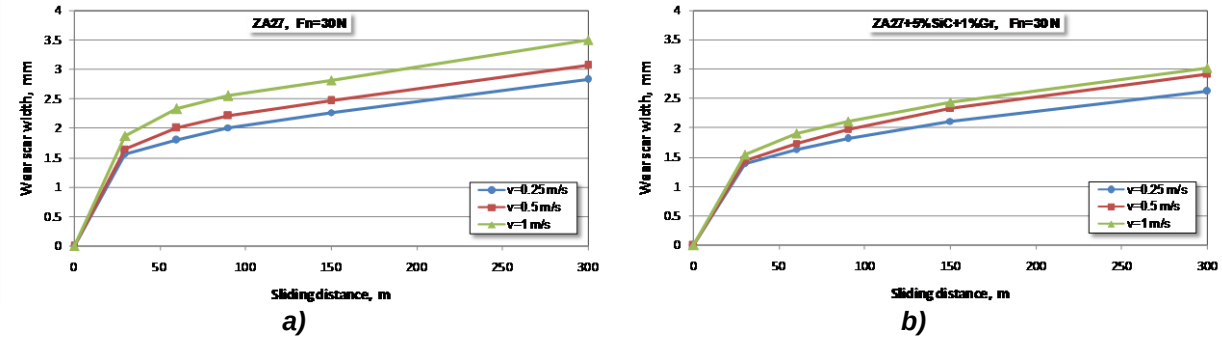


Fig. 5. Wear curves of: a) ZA27 alloy and b) ZA27+5%SIC+1%Gr composite for different sliding speeds and for the applied load of F_n=30 N

Obtained wear curves have the shapes that are consistent with theoretical models of the process of wear. From the presentations of the wear curves in Figs. 3 to 5, a zone of initial (intensive) wear is noticed that corresponds to a period of contact surfaces break-in and a zone of stationary (moderate) wear where uniform wear occurs. A rapid increase of wear scar width is characteristic for initial wear period for approximately 30 m of the sliding distance. After that, the increase of wear scar width is smaller and almost linear. For all given test conditions, wear curves have identical character. It may be noticed that the wear scar width in dry sliding conditions is the biggest for the highest sliding speed.

The shape and the outlook of the wear curves depend on achieved contact conditions, the intensity of the external load and the sliding speed, but also on the tribological characteristics of the tested materials. In order to comprehend the process of wear of the hybrid composite, as well as to be able to compare the wear scar widths of both tested materials, these values are presented together in Figs. 6 and 7. Solid lines on the diagrams refer to the wear scar width of the composite, while the wear scar width of the ZA27 alloy are denoted by dashed lines.

From the comparative presentations in Figs. 6 and 7, the nature of the normal load and sliding speed influences on the wear process in dry sliding conditions may be clearly noticed. With the increase of normal load and sliding speed, the wear scar width also increases, thus the largest values are noticed at highest sliding speeds and the largest contact loads.

Fig. 6 shows the influence of the sliding speed on both materials, for different values of normal loads.

Fig. 7 shows the effects of the normal load on wear scar widths of both given composite and alloy, for different values of sliding speeds and for sliding distance of 300 m.

By analysis of the obtained diagrams, it may be concluded that both tested materials have common nature of the wear process development for all contact conditions. Under the same test conditions, the observed composite material exhibits the better wear resistance.

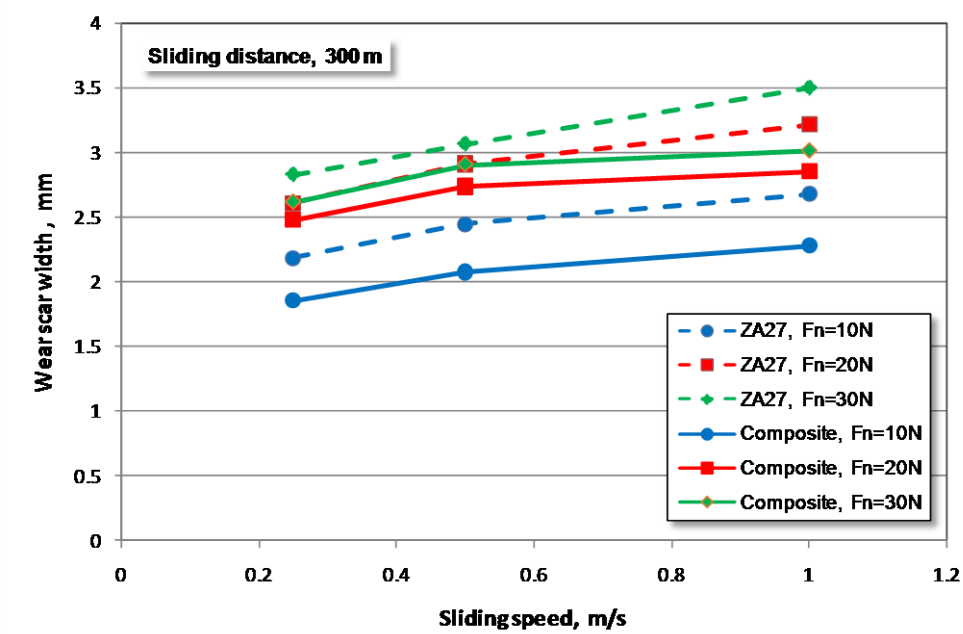


Fig. 6. Wear scar widths of ZA27+5%SIC+1%Gr composite and ZA27 alloy depending on sliding speeds, for different contact loads and for sliding distance of 300 m

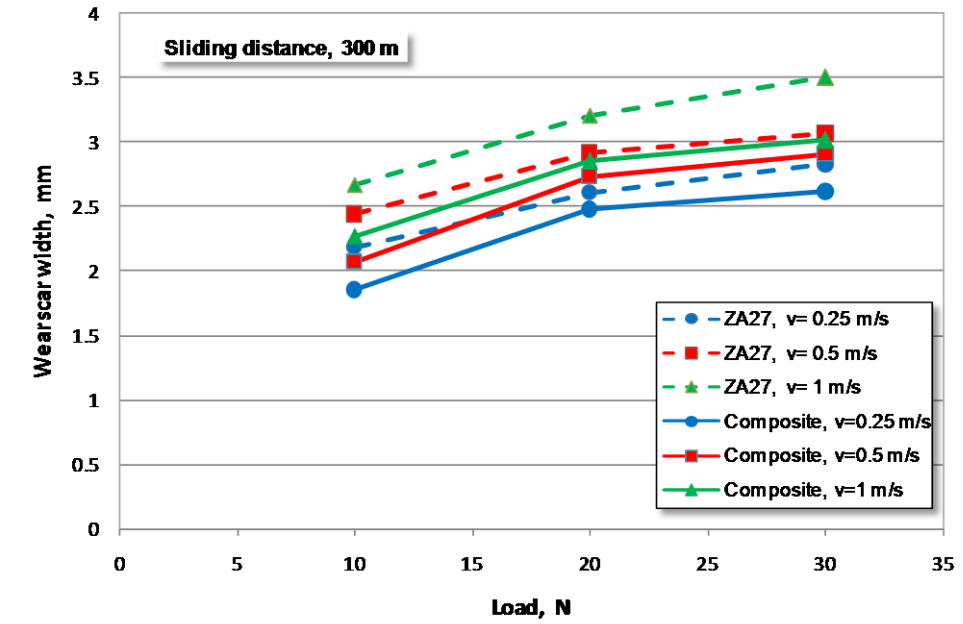


Fig. 7. Wear scar width of ZA27+5%SIC+1%Gr composite and ZA27 alloy depending on contact loads, for different sliding speeds and for sliding distance of 300 m

The comparative histogram representations of the wear scar widths were formed after 300 m of sliding distance, depending on the contact conditions (the sliding speed and the normal force) for the basic, ZA27, and composite ZA27+5%SiC+1%Gr materials (Fig. 8).

By analysis of histograms in Fig. 8, a trend is observed that the wear scar width increases with the increase of normal load. Also, the wear scar width increases with the increase of the sliding speed. This trend is valid for both observed materials. It is noticeable that the wear of the tested composites with addition of the SiC and graphite particles is always significantly lower compared to the wear of ZA27 alloy.`

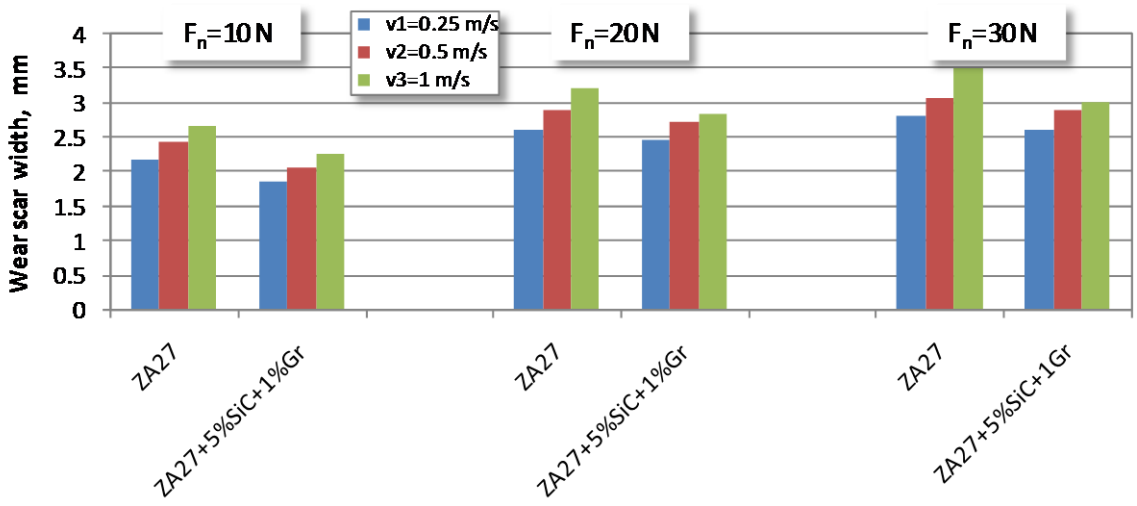


Fig. 8 Comparative histograms of wear scar widths of ZA27+5%SIC+1%Gr composite and ZA27 alloy

4.CONCLUSIONS

This paper presents an attempt to complete the tribological knowledge regarding developed composite materials with the ZA27 substrate alloy reinforced by the SiC and graphite particles. The goal is to further research the possibilities for broader application of the composites as the advanced tribo-materials in technical systems.

By monitoring the wear process through observation of wear scar widths in dry sliding conditions, the following conclusions can be made:

- Wear process evolution has the same character for both tested materials (basic ZA27 alloy and ZA27+5%SiC+1%Gr composite).
- Wear of the tested composite is smaller than wear of ZA27 alloy for all applied sliding speeds and normal loads.
- Values of the wear scar width of the observed composite increase with the increase of normal loads.
- Wear scar width also increases with the increase of the sliding speed.

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THE INFLUENCE OF LUBRICANT ON FRICTION COEFFICIENT OF HYBRID AL-SIC-GR COMPOSITES

Miroslav BABIĆ, Blaža STOJANOVIĆ, Slobodan MITROVIĆ, Ilija BOBIĆ, Nenad MILORADOVIĆ, Marko PANTIĆ

Abstract: *In the paper were shown the test results of tribological characteristics of hybrid composites with alloy base A356 reinforced by SiC and graphite. Hybrid composites are obtained by compo casting procedure. Tribological tests are realized on tribometer with block on disc compact pair in Tribological Center of Faculty of Engineering in Kragujevac. The tests were done for different normal load values, sliding speeds, sliding distance, with and without lubrication. Hybrid composite with 10% SiC and 1% graphite was used as a material. The main parameter analyzed in the paper is coefficient of friction obtained in the conditions with and without lubrication.*

Key Words: *Hybrid composites, coefficient of friction, tribometer, wear, friction.*

1.INTRODUCTION

Composite materials are made by unifying two or more different materials. Initial materials have mutually different properties, and their compound gives completely new material. It has unique, completely new and different features in comparison to components. The aim is to improve structural, tribological, thermal, chemical, and some other characteristics of individual material. Components do not mix with each other or dissolve so that two or more phases are clearly differed inside the composite [1,2].

Essentially, components are made of the base (matrix), whose content is significantly higher in comparison to other materials and reinforcement i.e. material by adding of which the desired features of composites are obtained.

When talking about composites with metal matrix, aluminum and its alloys are mostly used as a base. Aluminum and its alloys may accept various reinforcements and improvers. Aluminum composites have a number of positive features such as: small density, good thermal conductivity, and corrosion resistance. However, aluminum alloys have a certain disadvantages, as well, in form of higher coefficient of thermal expansion and inadequate tribological characteristic. The increase of stiffness, hardness, resistance to fatigue, as well as improvement of tribological characteristics is achieved by adding certain reinforcements and improvers and by forming aluminum composites. SiC, Al_2O_3, and graphiteare mostly used as reinforcements [3-11].

The influence of SiC, Al_2O_3, and graphite on tribological and mechanical characteristics is different. By increasing weight or volume percent of SiC and Al_2O_3, mechanical characteristics are improving, and by increasing weight or volume percent of graphite, thibological characteristics of composites are improving. Optimal values of tribological and mechanical characteristics of material are obtained by combining certain percent of these two materials [12-26].

2.PROCEDURE OF OBTAINING HYBRID COMPOSITES

Sub-eutectic Al-Si alloy EN AlSi7Mg0,3 (A356 alloy) of chemical composition (given in Table 1) is used as a base for obtaining composites.

Table 1. Chemical composition of (weight %) A356 alloy

Element	Si	Cu	Mg	Mn	Fe	Zn	Ni	Ti	Al
Percentage	7,20	0,02	0,29	0,01	0,18	0,01	0,02	0,11	residue

A356 alloy is aluminum alloy with silicon with addition of small amount of magnesium, intended for casting. It is widely applied in automotive and aviation industry. It is characterized as excellent castability and corrosion resistance. Its mechanical characteristics are significantly improved by heat treatment, especially by T6 regime of heat treatment.

Considering given task and chosen technological procedure of obtaining composites in Laboratory for materials of Institute of Nuclear Sciences “Vinča”, hybrid composites with aluminum matrix of A356 alloy and reinforcements SiC and graphite are developed.

The composites are obtained by compo-casting procedure (infiltration of reinforcement particles in semi-solidified cast of A356 alloy) and by applying laboratory equipment, consisting of processing part and part for measuring and regulating temperature. Ceramic pot is made of alumina with multiple layers [11,21,22].

3.TRIBOLOGICAL TESTS

Tribological characteristics tests of hybrid composites with aluminum base are of model type and are done on advanced and computer supported tribometer with block-on-disc contact geometry in Tribology Center of Faculty of Engineering in Kragujevac.

Tribometer provides variation of contact conditions in terms of shape, dimension and material of contact elements, normal contact load and sliding speed (Figure 1). The tests may be done in conditions with lubrication and without lubrication [1,2,4,5].

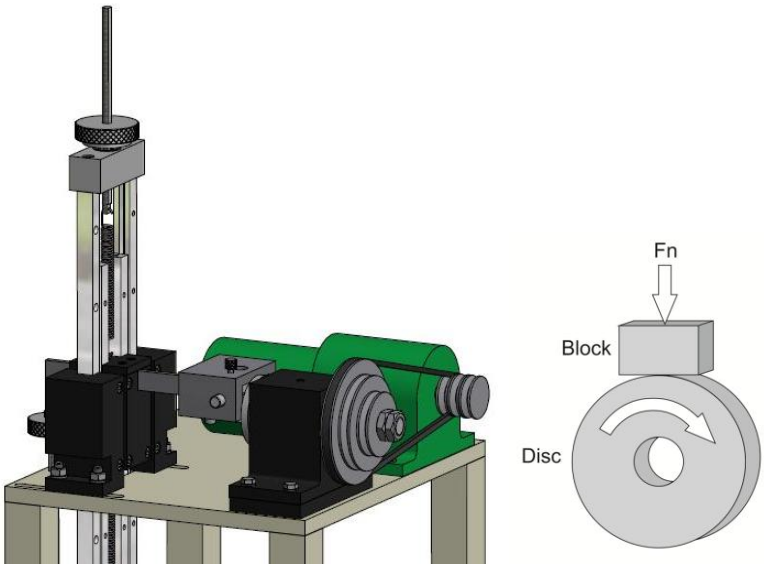


Fig. 1.Tribometer with block-on-disc contact pair

Tribological characteristics tests of hybrid composites is done on tribometer with block-on-disc contact pair for different normal loads, sliding speeds, sliding distance with and without lubrication. Namely, plan of tribological tests is based on variation of three different normal loads from 10 N, 20 N, and 30 N, three different speeds from 0.25 m/s, 0.5 m/s, and 1 m/s. Thereby, the measuring of coefficient of friction and broadness of wear track is being done for different sliding distances (30, 60, 90, 150, 300, 600, and 900m) without lubrication.

When it comes to lubrication, the tests are also done for three different loads (40 N, 80N, and 120N) and three sliding speeds (0.25 m/s, 0.5 m/s, and 1 m/s). Determining coefficient of friction and broadness of wear track is done for the crossed distance from 1200 m and 2400 m.

Hydraulic oil of HL type with advanced characteristics against wear, viscosity VG46 is used for lubrication. The lubrication of contact pair is realized by immersing the lower part of the disc up to the depth of 3 mm into the reservoir with oil of volume 30 ml, and at rotation it continually brings oil into the contact zone and it is doing the border lubrication of contact pair.

Tested contact pair meets demands of ASTM G 95 standard. Contact pair comprises rotating disc of diameter D_d=35 mm and broadness b_d=6.35 mm and stationary block of broadness b_b=6.35 mm, length l_b=15.75 mm, and height h_b=10.16 mm. The discs are made of steel 90MnCrV8 with hardness 62 – 64 HRC with grinded surfaces, roughness Ra=0.40 μm, and blocks of tested hybrid composite material A356-10SiC-1Gr.

4.RESULTS OF TRIBOLOGICAL TESTS

Tribological tests of hybrid composites with Al base is done for sample with 1% of graphite and 10% of SiC, as a comparative material is used A356 alloy.

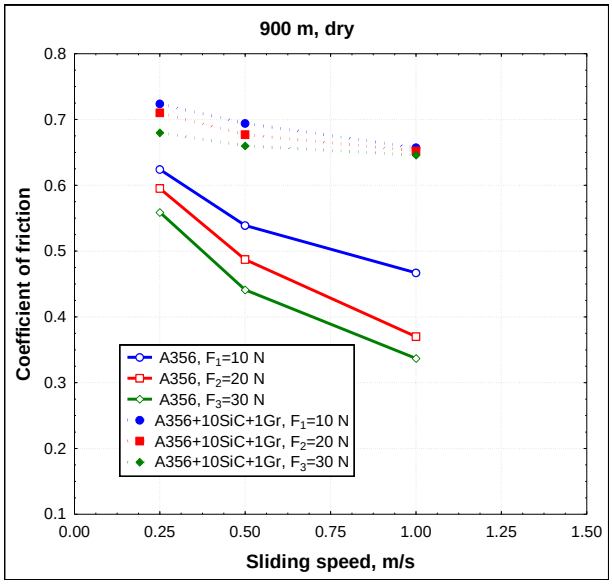


Fig. 2. Coefficient of friction dependence of sliding speed for different normal load valuess in conditions of dry friction

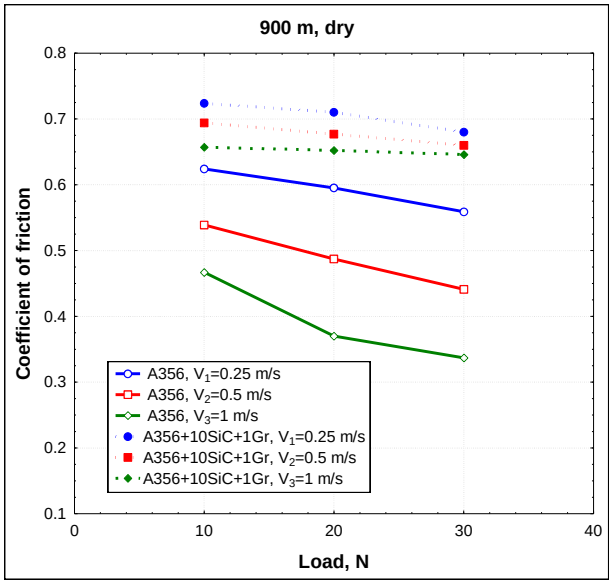


Fig. 3. Coefficient of friction dependence of load for different sliding speeds in conditions of dry friction

Figure 2 shows coefficient of friction dependence of sliding speed for all three loads. Figure 3 shows coefficient of friction dependence of load for all three sliding speeds (0.25 m/s, 0.5 m/s и 1 m/s). The results in Figs. 2 and 3 are obtained in condition of dry friction for sliding distance of 900 m.

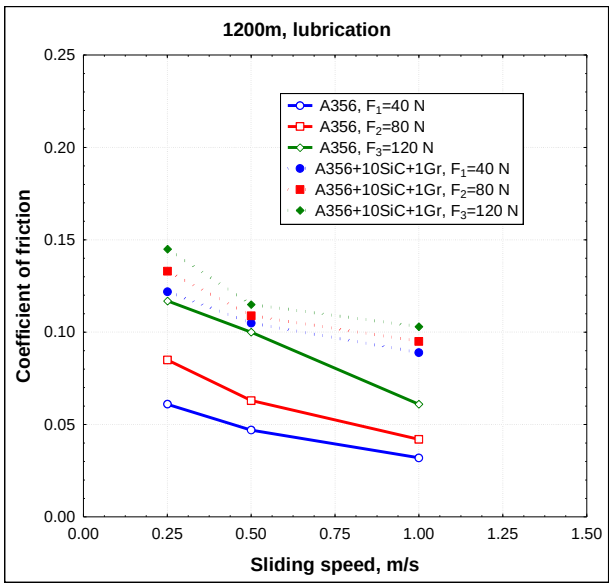


Fig. 4. Coefficient of friction dependence of sliding speed for different normal load values with lubrication

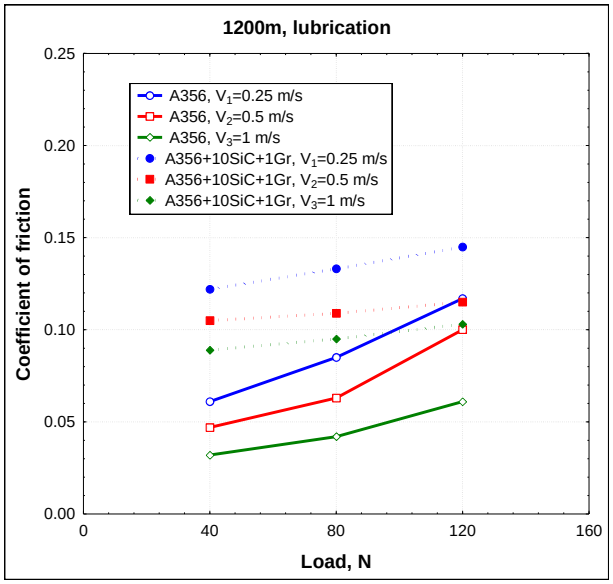


Fig. 5. Coefficient of friction dependence of load for different sliding speeds with lubrication

Figure 4 and 5 show coefficient of friction dependence of sliding speed and load. Loads vary from 40 N, 80 N and 120 N for three sliding speeds (0.25 m/s, 0.5 m/s и 1 m/s), sliding distance of 1200 m in conditions of lubrication.

5. ANALYSES OF OBTAINED RESULTS

Figure 6 and 7 at the same time show obtained values of coefficient of friction depending on sliding speed and load. Figure 6 shows the change of coefficient of friction in conditions without lubrication and Figure 7 in case with lubrication.

In case of dry friction (without lubrication) coefficient of friction decreases with increase of sliding speed. The highest values of coefficient of friction are at lowest loads of 10 N, while with increase of load, coefficient of friction decreases. The values of coefficient of friction for dry friction A356+10SiC+1Gr of hybrid composites are within the boundaries of 0.64÷0.72 (Fig. 6) [11,22,23,24], and the values are higher than the friction coefficient of base material A356 alloy.

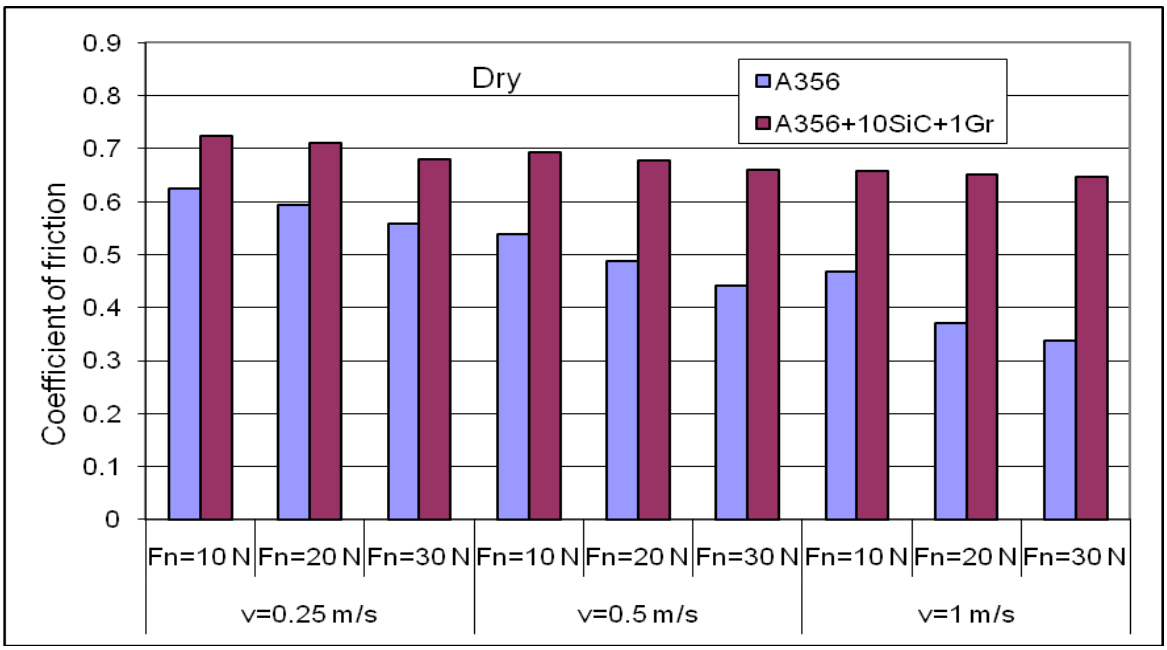


Fig. 6. Histogram representation of friction coefficient two tested materials (A356 and A356+10SiC+1Gr) for different normal load values (10N, 20N, 30N) with dry

Coefficient of friction decreases with increase of sliding speed in conditions with lubrication of contact pairs. At the same time with increase of load, coefficient of friction increases. Coefficient of friction of hybrid composites A356+10SiC+1Gr in condition with lubrication is 0.085÷0.145 (Fig. 7), and the values are higher than the friction coefficient of base material A356 alloy.

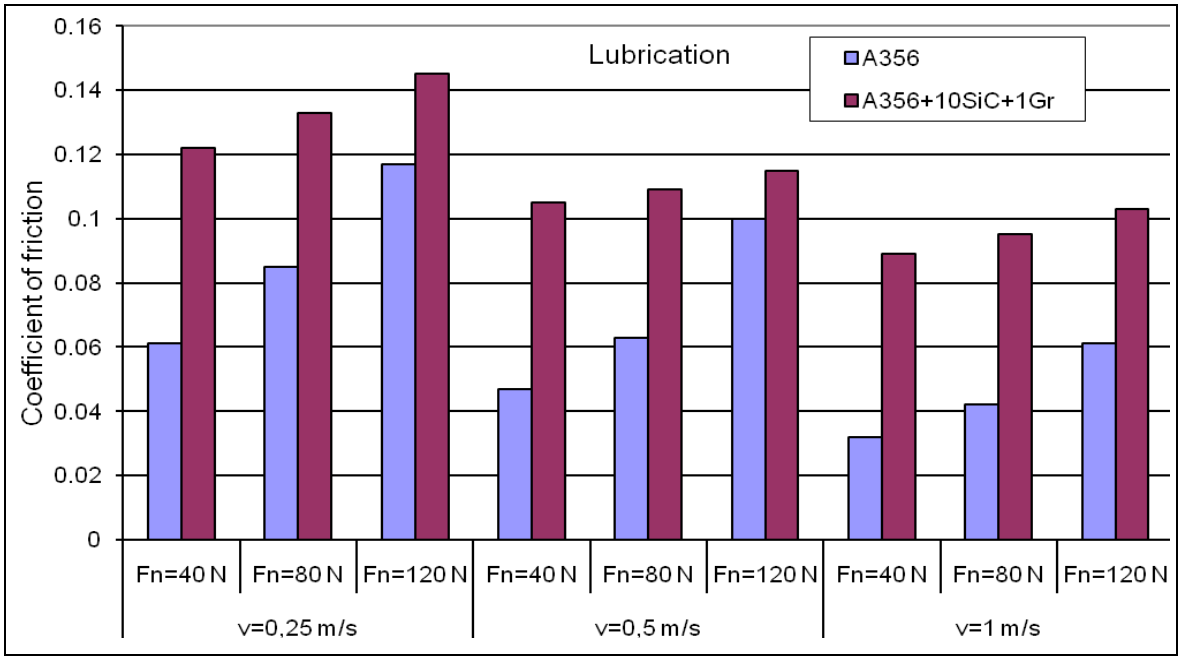


Fig. 7. Histogram representation of friction coefficient two tested materials (A356 and A356+10SiC+1Gr) for different normal load values (40N, 80N, 120N) with lubrication

Al-SiC-Gr hybrid composites are very much used in automotive industry. When composites are used for manufacture of braking discs, obtained values of coefficient of friction μ~0.7 are excellent, considering sliding distance and used materials.

However, if hybrid aluminum composites are used for manufacture of motor parts, pistons, cylinders or cardan shaft, then the use of lubrication is necessary.

6. CONCLUSION

Tests of friction characteristics of hybrid composites A356+10%SiC+1%Gr without lubrication show that:

- Hybrid aluminum composite in condition of dry friction has very high and pretty constant friction coefficient (μ~0.7).
- Due to presence of SiC, friction coefficient of hybrid aluminum composite is higher than the friction coefficient of base material.
- The changes of coefficient of friction are small with change of load and sliding speed.
- Coefficient of friction decreases with increase of load.
- Coefficient of friction decreases as well with increase of sliding speed.
- Decrease of coefficient of friction with increase of speed and load is conditioned by presence of graphite in contact.

Tribological characteristics of hybrid composite in conditions with lubrication show following:

- Coefficient of friction decreases with increase of sliding speed.
- The presence of SiC leading to an increase friction coefficient of hybrid composites as compared with the base material.
- Coefficient of friction increases with increase of load.
- The values of coefficient of friction are 5÷8 times lower values than in case of dry friction.
- Temperature in the contact is much lower.
- Intensity and size of wear are 3÷5 lower than without lubrication.
- Sliding distance increases with decrease of wear at the same time.

ACKNOWLEDGMENTS

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WEAR AND FRICTION PROPERTIES OF SHOT PEENED SURFACES OF 36CRNIMO4 AND 36NICRMO16 ALLOYED STEELS UNDER DRY AND LUBRICATED CONTACT CONDITIONS

Slobodan MITROVIĆ, Miroslav BABIĆ, Dragan ADAMOVIĆ, Fatima ŽIVIĆ, Dragan DŽUNIĆ, Marko PANTIĆ

Abstract: *Method of Shot peening is often used to increase static and dynamic strength of the work piece. This method can change the characteristics of the surface layer, and thus the tribological properties of such treated surfaces. The quality of the contact surfaces in tribological terms, refers to the roughness parameters and surface microgeometry. Conclusions, presented in this paper, are the result of numerous investigations of tribological behavior of shot peening surfaces in dry and lubricated contact conditions. As materials for tribological tests 36CrNiMo4 and 36NiCrMo16 alloy steels were used. The paper presents a comparative view of tribological behavior of materials under conditions with and without lubrication, as well as in terms of different values of normal load and sliding velocity. Tribological investigations showed that total effects of final machining by shot peening have positive influence on tribological behaviour of machined parts and that they can contribute to the improvement of tribological level of tribomechanical elements.*

Key Words: *shot peening, wear, friction, lubrication*

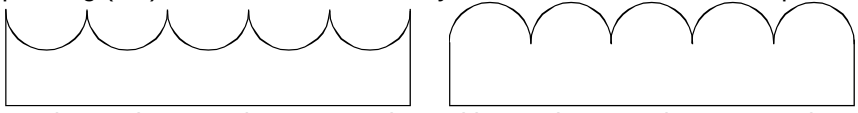
1. INTRODUCTION

Dynamic loads, present in the exploitation process of almost all technical systems, considerably affects reliability of contact elements which form a basic structure of technical systems. Resistance to fatigue of vital elements of technical systems mostly depends on contact layers characteristics. From that aspect, still in the projecting phase, we should pay certain attention to these layers. This is more significant if we know that failure can be gradual (mostly as the consequence of tribological processes development) or unexpected (fracture of elements).

Different methods are used to increase the resistance to fatigue that can occur also due to the wear. Improvement of characteristics is achieved, primarily, by thermal processing (induction and flame hardening), chemical-thermal processing (cementation and nitrating) and processing by surface plastic deforming (surface deforming by rollers, discs and balls, as well as by shot peening). Shot peening is the method of reinforcing contact surfaces, which is widespread in industry due to the very low price and easy integration in any production process. Mechanical characteristics of surface layers are improved by the shot peening.

Micro geometry of contact surfaces is a very important parameter for most of the tribological processes [1-6]. Topography of contact surfaces considerably changes by applying shot peening method, in the sense of worsening surface roughness parameters [7, 8]. The parameters of shot peening process affect, primarily, the schedule of residual stresses, i.e. on mechanical characteristics of material surface layer. Negative effects of surface defects could be eliminated or mitigated by proper choice of parameters of shot peening methods, primarily of ball size, its hardness and speed. The surface obtained after the process is anisotropic surface [9].

It is known that lower wear of surfaces corresponds to a higher fatigue hardness of material. It is not proper to compare surfaces obtained by different mechanical processing (grinding, scraping...), however by these procedures it is possible to achieve completely different distribution of material in surface layer, while the parameters of roughness are almost equal. Figure 1 shows the surface obtained by shot peening (1a.) and surface obtained by some other method of final processing (1b.).



a) Roughness A (Ra=1, Rz=1) b) Roughness B (Ra=1, Rz=1)

Fig. 1. Schematic view of the surface obtained by shot peening (A) and other methods of final process of surfaces (B) [9].

Topography of surfaces obtained by shot peening has characteristic peaks and valleys, shown in Fig 1a. This profile of surface roughness has positive influence on fatigue toughness in comparison to surfaces obtained by other final processing methods (Fig. 1b). Concentration of stress in bottom of the valley with roughness B is much higher than in the case of roughness A, which due to the presence of tangential force can lead to cracking and later, by its mutual joining, to separation of material from surface layers. The valleys obtained by shot peening, when in contact with lubrication, act like oil reservoirs (oil pockets). The presence of lubrication on these places contributes to generating of hydrodynamic pressure and therefore separation of contact elements [10].

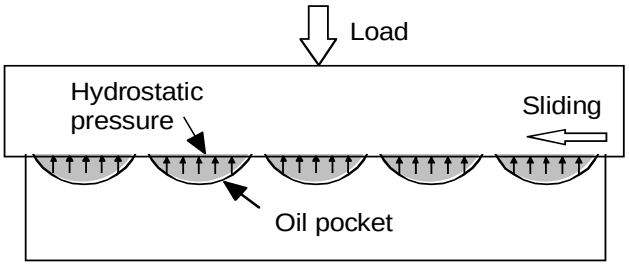


Fig. 2. Influence of contact surface topography obtained by shot peening on lubrication

With relative moving of two surfaces in contact, in the beginning the peaks of surface roughness are elastically deformed without sliding in contact points. The most important result of shot peening are residual stresses in surface layer of material [11, 12]. The increase of surface layer hardness is direct consequence of residual stresses presence. In accordance with that there is also increased elasticity of surface roughness. The risk of separating particles is decreasing with increased limit of elasticity [13].

The lack of shot peening method is that micro-cracks could be conceived due to highly concentrated loads, as well as ball impact of broken balls in the surface, and micro-cracks can spread and make large cracks. If the surface is exposed to variable loads over the period of time, large pitting damage can be produced. These negative consequences could be avoided by thermal process of material before shot peening process or by subsequent chemical process [14].

In recent years, a large number of numerical models and FE simulation with aim to optimize the process parameters of shot peening have been presented and also prediction of influence of certain parameters change on mechanical characteristics and fatigue material resistance [15-20].

With this paper, the authors wanted to show the test results of shot peening influence on tribological characteristics of alloyed steels 36CrNiMo4 and 36NiCrMo16 in conditions with and without lubrication at different values of sliding speed and normal load.

2. MATERIAL

Two alloyed steel, thermally processed (improved), 36CrNiMo4 and 36NiCrMo16 steels, are used for testing of the tribological characteristics of surfaces prepared by shot peening. The chemical composition of the observed materials is given in Table 1, while their mechanical characteristics are given in Table 2.

Tab. 1.
Chemical composition of tested materials

Steel	C%	Si%	Mn%	Cr%	Ni%	Mo%
36CrNiMo4	0.36	0.25	0.65	1.05	1.05	0.20
36NiCrMo16	0.36	0.30	0.60	1.80	3.85	0.33

Tab. 2.
Mechanical characteristics of tested materials

Steel	R_p, MPa	R_m, MPa	A_5, %	Z, %	$KU_{300/3}$, J
36CrNiMo4	900	1150	10	45	35
36NiCrMo16	1050	1340	9	40	30

Samples for tribological testing were made by cutting them from samples aimed for fatigue test. Cutting was realised by machine saw with intensive cooling in order to avoid changes of surface layers, due to high temperature.

Shot peening of samples by steel balls was realised at shot peening machine of ES-1580-1 model, PANGBORN.

Wanted effects of shot peening are obtained if selection of shot peening parameters is realised correctly, such as: ball diameter, Almen intensity, subjected area size coverage and shot duration of shot peening. Shot peening was realised using balls of d=0.8 mm (S330) diameter and 48 - 55 HRC hardness.

Based on literature recommendations, for 15mm thickness of the sample, Almen intensity of 16A was chosen. The largest effects of shot peening occur when the whole area is covered. Hence, coverage of P=1×98% was chosen. Duration of shot peening, necessary to achieve wanted Almen intensity (16A) was determined by Almen test strip, by creating saturation curve. Pressure of 4 bar and shot peening time of 5 min correspond to wanted shot peening intensity (16A).

Surface coverage on shot peened sample was observed by the magnifying glass with 10x magnification. It was determined that coverage was 98 % (complete coverage) with shot peening time of 5 min. Appearance of the surface before and after the shot peening for both tested materials are shown in Figure 3 and Figure 4.

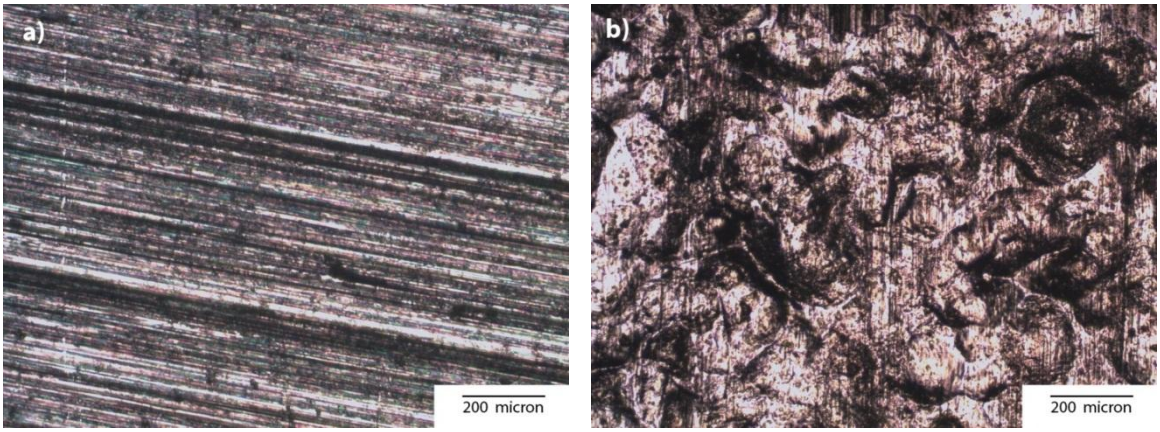


Fig 3. Appearance of the surface before (a) and after (b) shot peening for 36CrNiMo4 steel

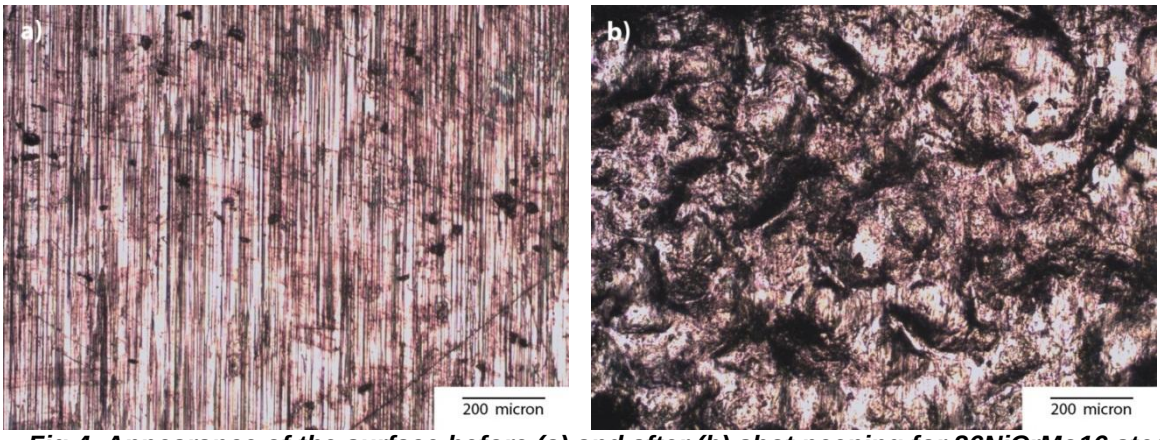


Fig 4. Appearance of the surface before (a) and after (b) shot peening for 36NiCrMo16 steel

3. EXPERIMENT

3.1. Surface topography (Surface roughness)

As a result of shot peening is completely changed topography in sense of height, shape, and statistics, by which shot peening process results and it is illustrated by 3D profile-gram in Figures 5 and 6 where comparative 3D display of ground surface and shot peened surface is shown for both tested materials.

It is obvious that shot peening produced distinguished increase of all altitudinal roughness parameters *(R_a, R_q, R_p, R_v, R_y, R_{tm}, R_{pm})*, in comparison to initial state obtained by grinding. Worsening of altitudinal roughness parameters is more distinguished with 36CrNiMo4 steel.

Besides the increase of parameters representing height of micro surface roughness, the shot peening process affects high increase of surface roughness parameters, as it is visible on corresponding profile.

Average value of arithmetic mean deviation (Ra) for 36CrNiMo4 steel in ground state is Ra = 0.28 μm and in peened state Ra = 1.81μm, while in case of 36NiCrMo16 steel Ra = 0.62μm is in ground state and Ra = 1.11μm in peened state.

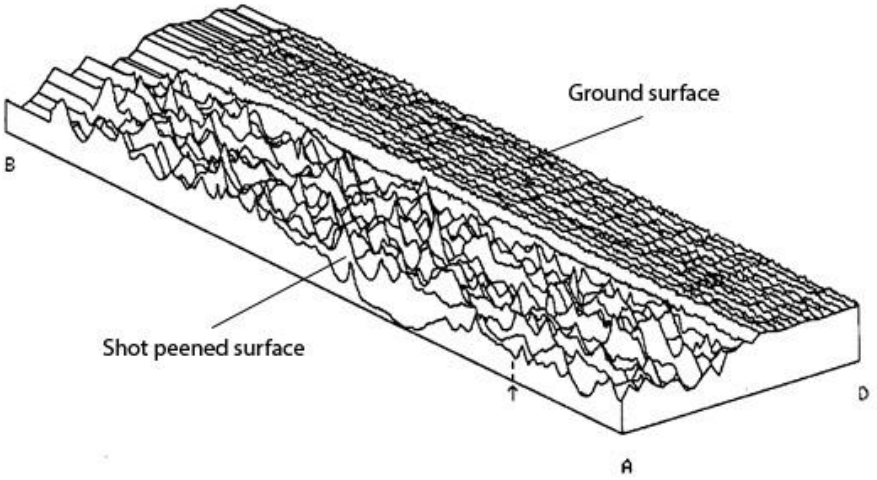


Fig. 5. Comparative 3D view of ground and shot peened surface for 36CrNiMo4

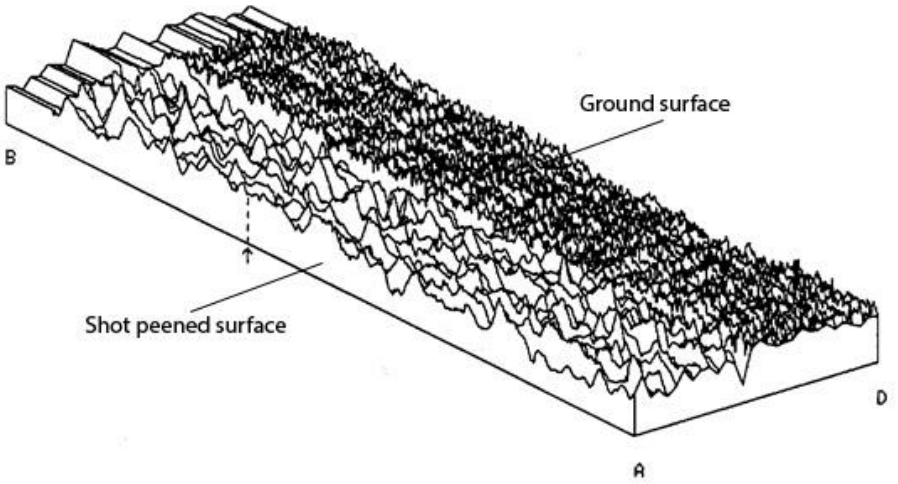


Fig. 6. Comparative 3D view of ground and shot peened surface for 36NiCrMo16

3.2. Micro-hardness

The values of measured hardness, as a function of the distance from the surface, are shown in Figure 7 (36CrNiMo4 steel) and Figure 8 (36NiCrMo16 steel).

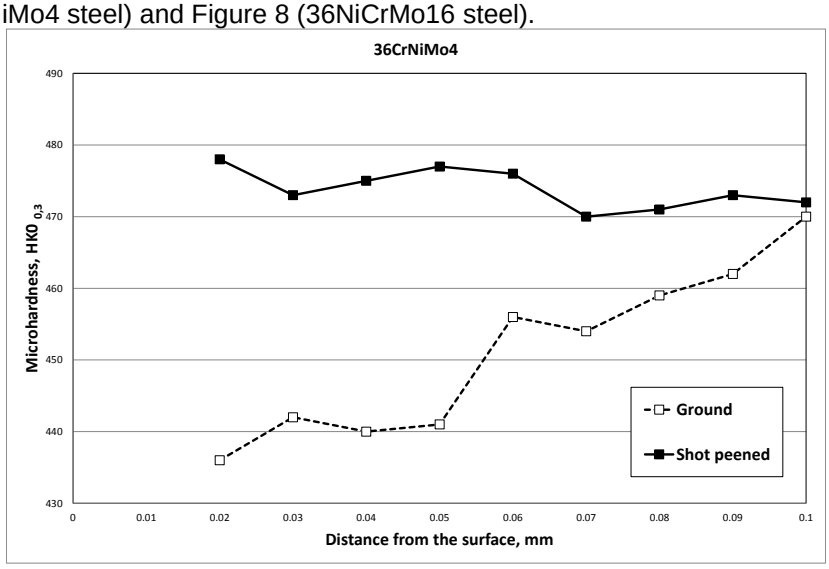


Fig. 7. Micro-hardness of alloyed steel 36CrNiMo4

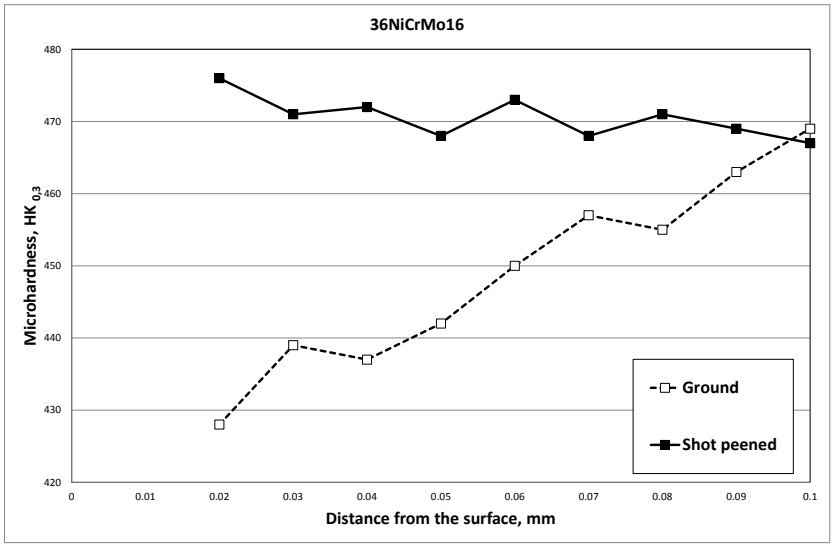


Fig. 8. Micro-hardness of alloyed steel 36NiCrMo16

Decrease of hardness in surface layer occurred in case of both steel samples. However, it is noticeable that peening increased hardness in surface layer up to depth of 0.1 mm. At that depth the hardness is even lower than in the core. For samples made from 36CrNiMo4 steel, the increase of hardness due to peening was 9.63 %, and for 36NiCrMo16 steel the increase is 11.22 %.

3.3 Tribological tests

Tribological tests were carried out in a computer aided block-on-disk sliding testing machine with the contact pair geometry in accordance with ASTM G 77–05. A schematic configuration of the test machine is shown in Figure 9. More detailed description of the tribometer is available elsewhere [21,22].

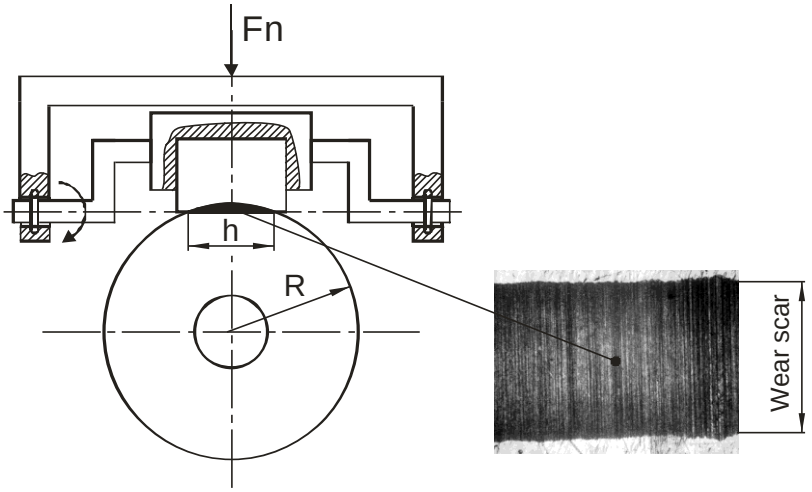


Fig. 9.The scheme of contact pair geometry

The test blocks (6.35x15.75x10.16 mm) were prepared from 36CrNiMo4 and 36NiCrMo16 steel with grounded and shot peened surfaces. The counter face (disc of 35 mm diameter and 6.35 mm thickness) was made of EN: HS 18-1-1-5 tool steel of 62HRC hardness. The roughness of the ground contact surfaces was R_a=0.45 µm. The tests were performed under dry and lubricated sliding conditions at different sliding speeds (0.25 m/s, 0.5 m/s, 1 m/s) and applied loads (10 N, 30 N, 50 N). The duration of sliding was 10 min for dry sliding and 30 min for lubricated sliding conditions. Each experiment was repeated five times.

The tests were performed at room temperature. The lubricant used was ISO grade VG 46 hydraulic oil, a multipurpose lubricant recommended for industrial use at plain and antifriction bearings, electric motor bearings, machine tools, chains, and gear boxes, as well as in high-pressure hydraulic systems. During the tests the discs were continuously immersed up to 3 mm of depth in 30 ml of lubricant.

The wear behaviour of the block was monitored in terms of the wear scar width (Figure 9). Using the wear scar width and geometry of the contact pair, the wear volume (expressed in mm^3) was calculated.

4. RESULTS and DISCUSSION

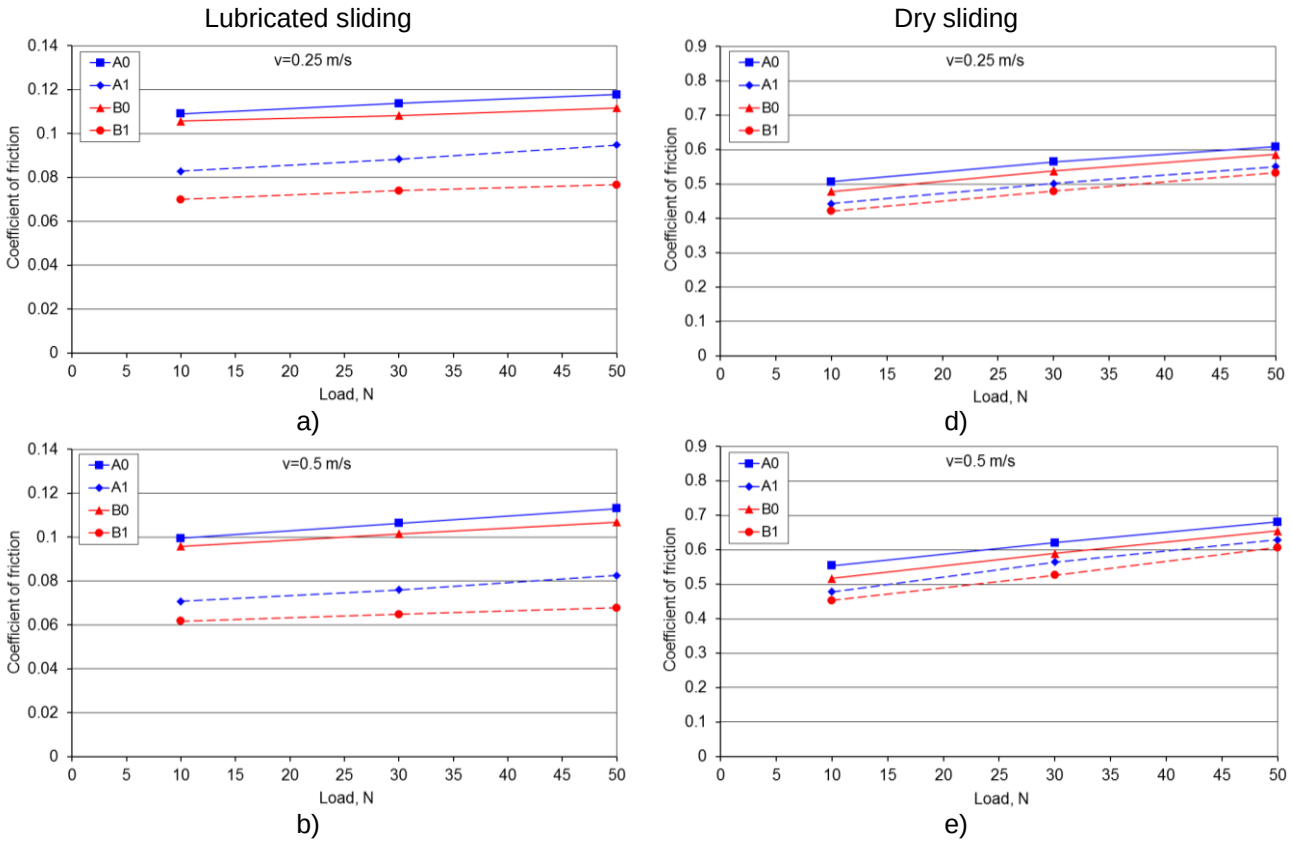
Further in the paper the material 36CrNiMo4 is marked as A, while the material 36NiCrMo16 is marked as B. Also, ground surfaces are marked as “0”, and surfaces made by shot peening as 1.

A0 – 36CrNiMo4, ground
A1 – 36CrNiMo4, shot peening
B0 – 36NiCrMo16, ground
B1 – 36NiCrMo16, shot peening

4.1 Friction

Friction force is very important tribological parameter which depends on numerous parameters, primarily materials of contact elements, contact geometry, quality of contact surfaces, conditions and parameters (sliding speed and normal load) under which contact is achieved.

Friction coefficient of tested samples depending on contact parameters, with and without lubrication, is shown in Figure 10. With increase of normal load, the value of friction coefficient increases and in same contact conditions the increase trend is almost identical for all tested samples. Increase trend of friction coefficient is more distinguished in condition without lubrication. Also, from the diagram it can be clearly seen that 36NiCrMo16 steel has better frictional characteristics in all contact conditions and for all values of contact parameters, in comparison to 36CrNiMo4 steel, as well as surfaces made by shot peening in comparison to ground surfaces. We should notice that the difference in friction coefficient between differently obtained surfaces of the same material is larger in conditions with lubrication, which is also the consequence of contact surfaces topography made by shot peening.



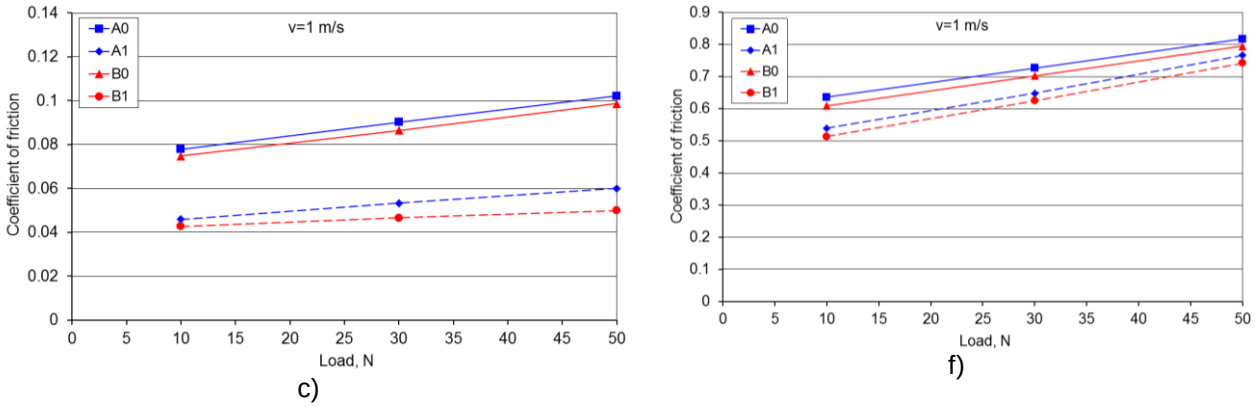
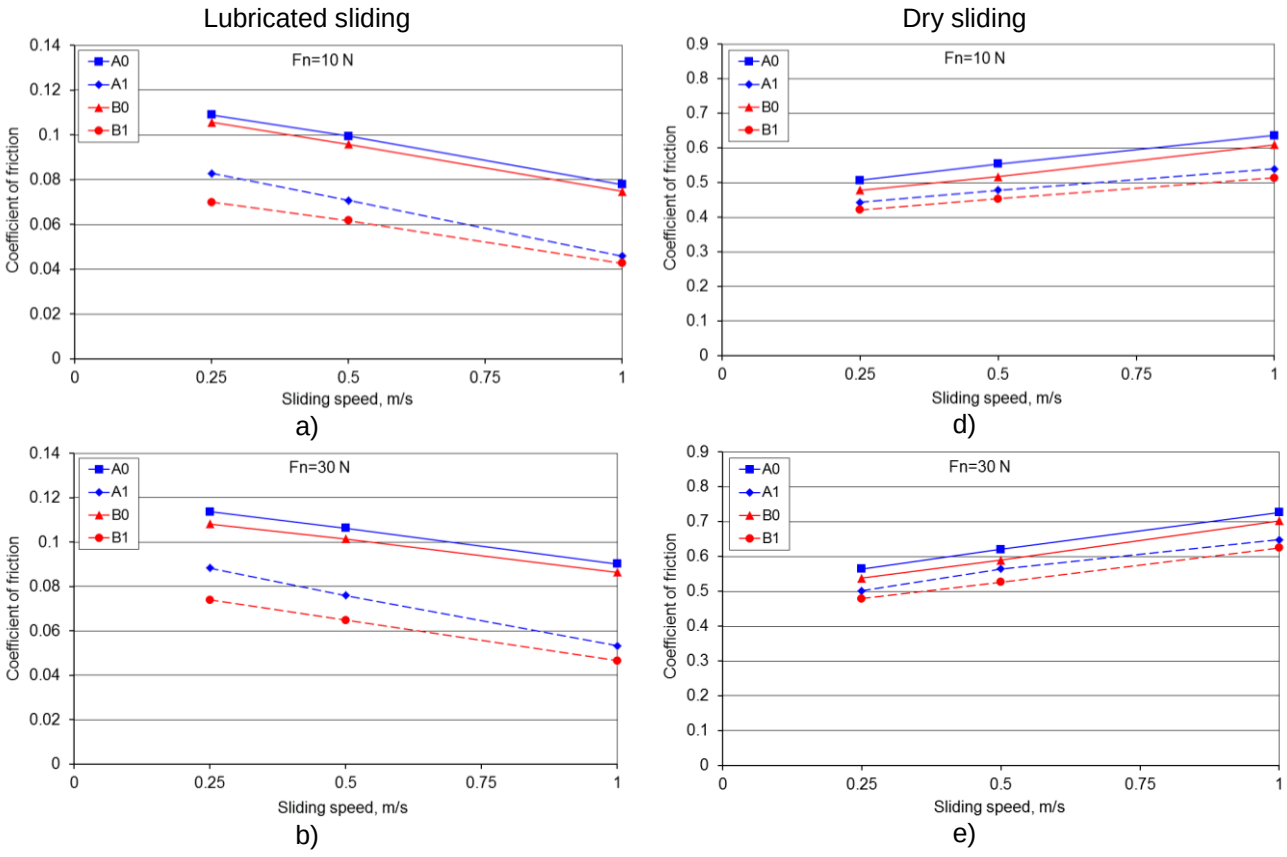
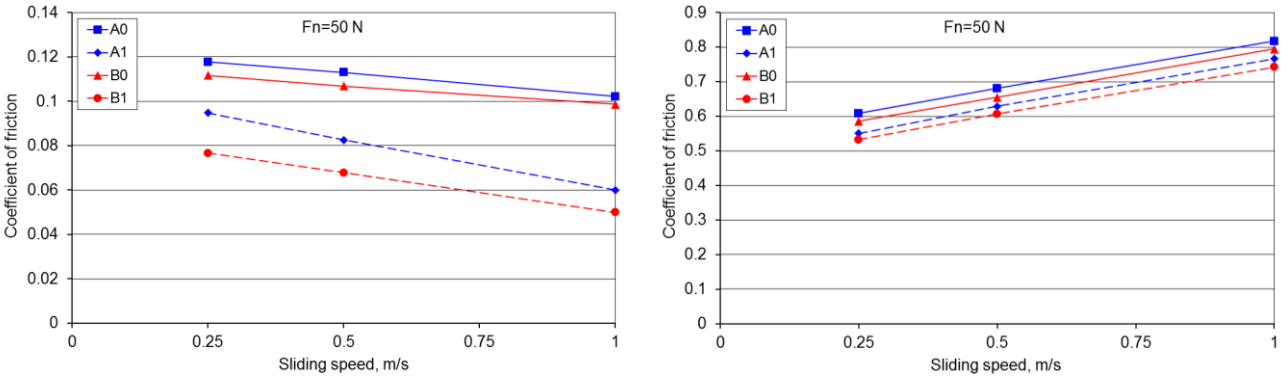


Fig. 10. Friction coefficient dependence of normal load and at constant values of sliding speeds (0,25, 0,5 and 1m/s), in conditions with and without lubrication

Friction coefficient dependence of sliding speed in conditions with and without lubrication is shown in Figure 11, where it can be clearly seen that friction coefficient in conditions without lubrication increases with increase of sliding speed, while in condition with lubrication the friction coefficient decreases with increase of sliding speed. Increase trend of friction coefficient in conditions without lubrication is almost identical for all tested samples, while the decrease is more distinguished for surfaces obtained by shot peening in conditions with lubrication.

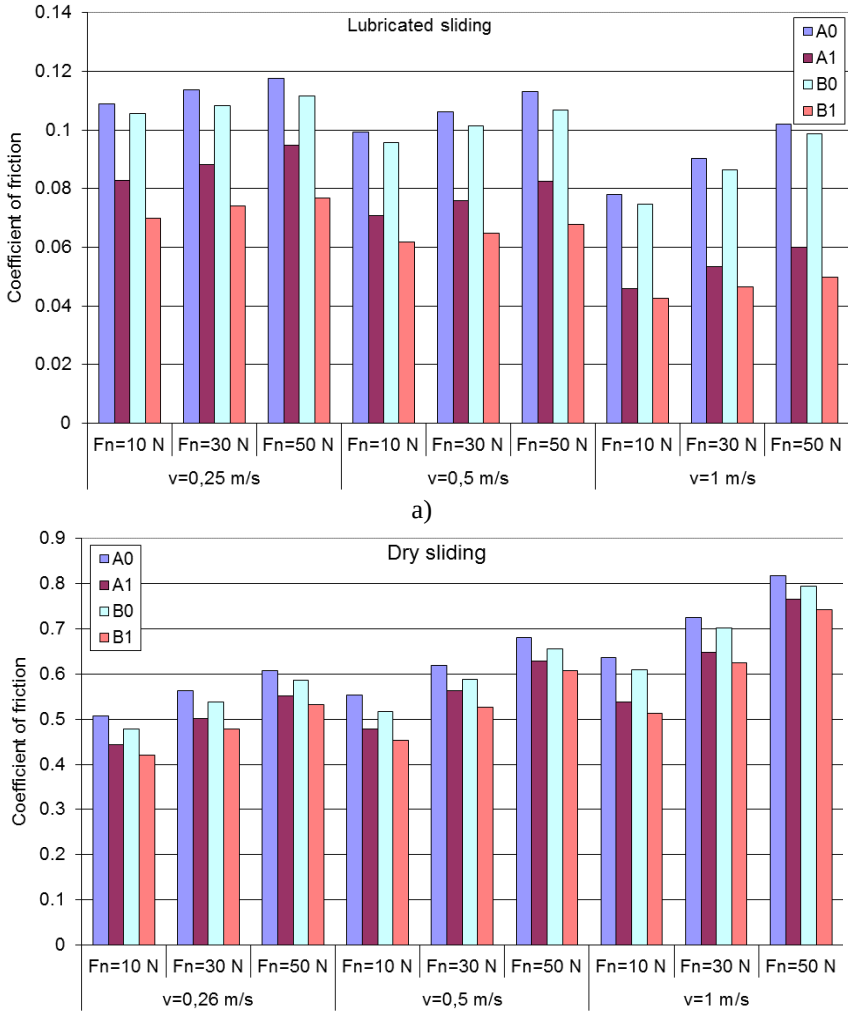




c) f)

Fig. 11. Friction coefficient dependence of sliding speed at constant values of normal load (10, 30 and 50N), in conditions with and without lubrication

Figure 12 shows histogram display of measured values of friction coefficient for all tested samples, in conditions with and without lubrication. In conditions without lubrication the value of friction coefficient of surfaces obtained by shot peening is for about 10% lower in comparison to ground surfaces of the same material, while the difference in condition with lubrication is within the limit of 20-40%. Bigger difference of friction coefficient values in conditions with lubrication at higher sliding speed has been noticed, which is the consequence of larger quantity of lubricant in the contact zone and specific topography of contact surfaces made as a consequence of shot peening. In those conditions the influence of hydrodynamic pressure is high and it is generated in valleys and considerably contributes to decrease of tribological phenomenon.



a)

b)

Fig. 12. Histogram display of friction coefficient dependence of contact parameters in conditions a) with lubrication and b) without lubrication

4.2 Wear

Wear is continuous unavoidable process that occurs as a consequence of direct contact of tribo-mechanical system elements. Figure 13 represents wear volume changes with change of contact parameters, in conditions with and without lubrications. From the diagram it can be clearly seen that wear volume increases with increase of load for all values of sliding speeds. Also, we notice that increase of wear volume with increase of load is almost identical for all tested samples, especially in conditions with lubrication. Significant increase of wear values with increase of normal load is noticed on ground surfaces in conditions without lubrication and at sliding speeds 0,5 and 1 m/s (Fig. 13e and 13f). The difference occurring at that occasion in comparison to shot peened surface is the result of considerably higher hardness of surface layer of these surfaces in comparison to ground surfaces. The surfaces prepared by shot peening have twice as less wear values in all contact conditions. From the diagrams shown in Figure 13 it can be noticed that 36NiCrMo16 steel has better wear resistance in comparison to steel 36CrNiMo4. This advantage is noticeable at all combinations of sliding speeds and normal load, in conditions with and without lubrication. Better wear resistance is the consequence of better mechanical characteristics of the material itself 36NiCrMo16.

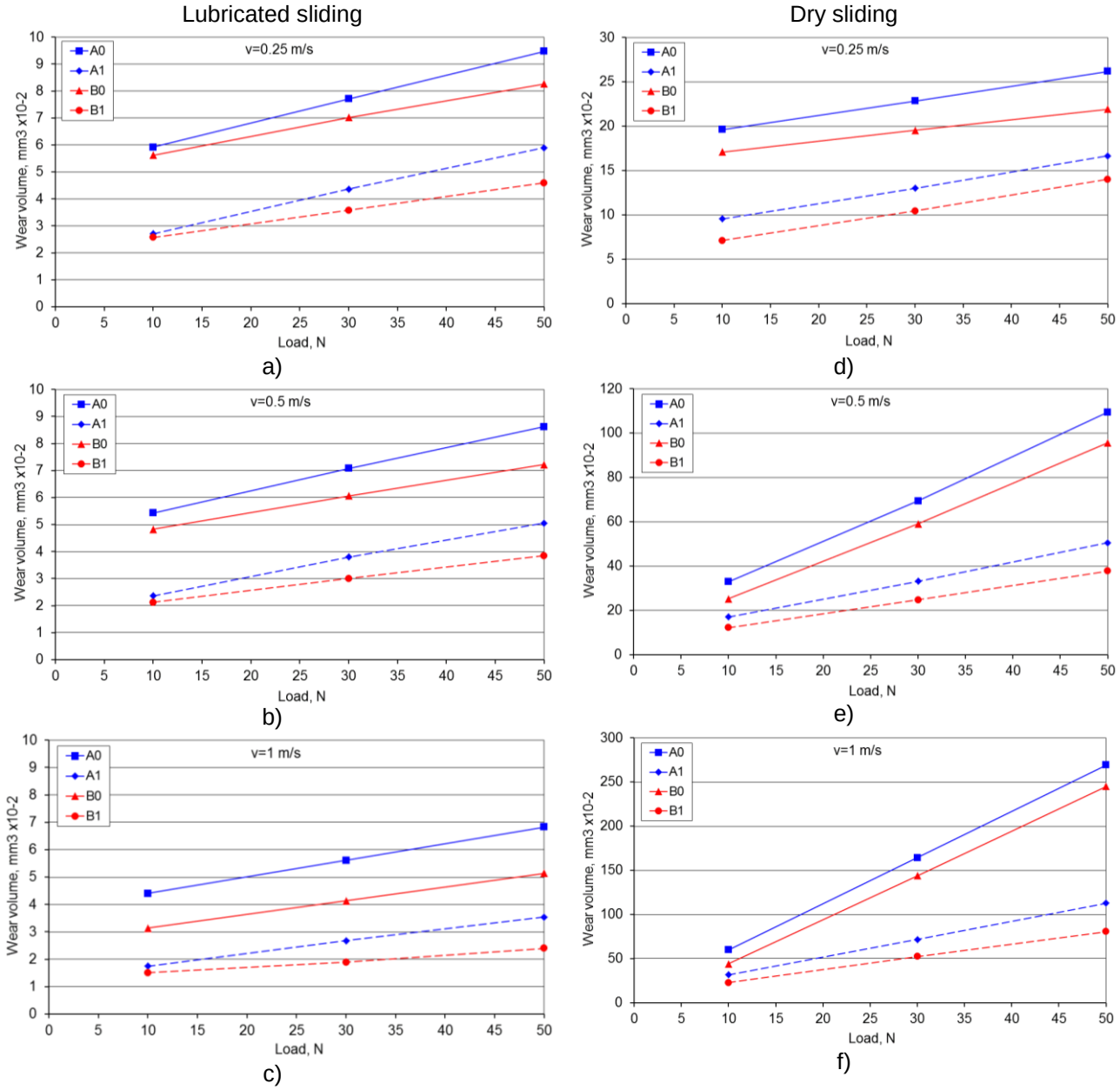


Fig. 13. Wear volume dependence of normal load at constant values of sliding speeds (0,25, 0,5 and 1m/s), in conditions with and without lubrication

Figure 14 represents change of wear volume with change of sliding speed in conditions with and without lubrication. In conditions without lubrication the wear volume increases with increase of sliding speed, while in conditions with lubrication the wear volume decreases with increase of speed, what is in direct dependence with lubricant quantity in contact zone. Namely, because of construction of tribometer itself, where disc at the bottom side is immersed in lubricant bath, we could say that with increase of speed the quantity of lubricant increases and that could be found between contact elements. This effect, to a large degree, depends on oil viscosity used at testing.

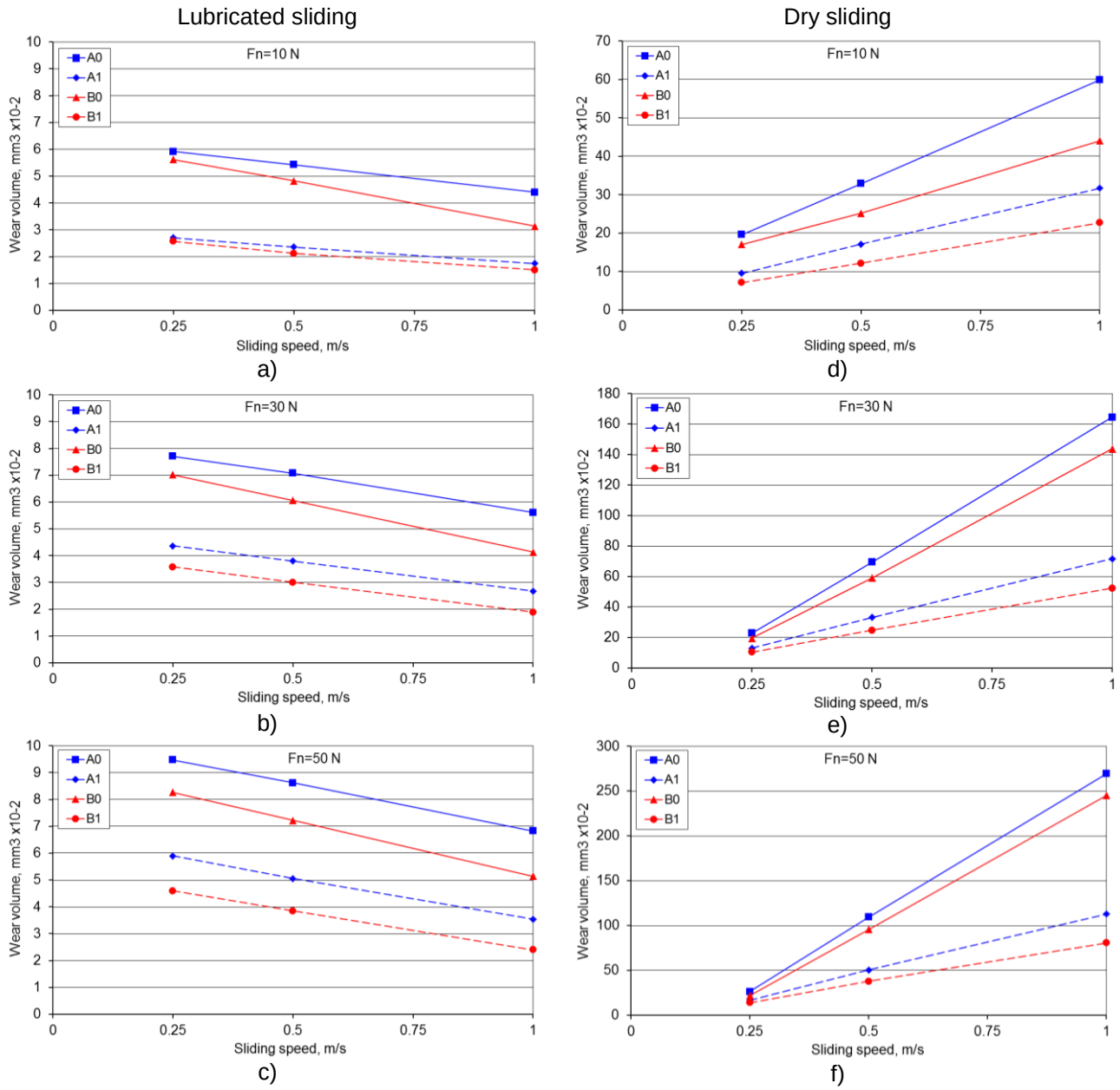
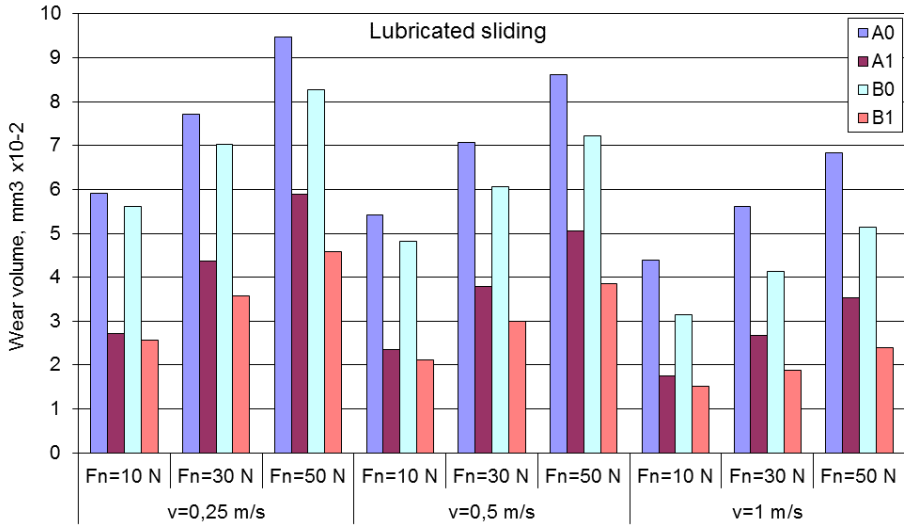
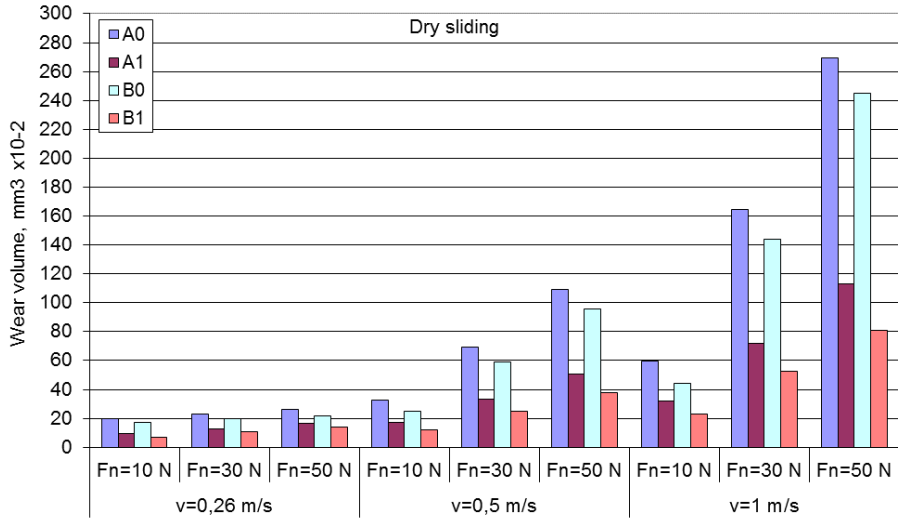


Fig. 14. Wear volume dependence of sliding speed at constant values of normal load (10, 30, and 50 N) in conditions with and without lubrication

Considerably lower wear values of surfaces obtained by shot peening, in conditions with lubrication, are consequence of contact surface topography. In conditions without lubrication the wear volume increases with increase of sliding speed, while in conditions with lubrication the wear volume decreases with increase of speed, what is in direct dependence with lubricant quantity in contact zone. Namely, because of construction of tribometer itself, where disc at the bottom side is immersed in lubricant bath, we could say that with increase of speed the quantity of lubricant increases and that could be found between contact elements. This effect, to a large degree, depends on oil viscosity used at testing.



a)



b)

Fig. 15. Histogram display of wear volume dependence of contact parameters (load, Fn [N]; sliding speed, v [m/s]): a) with lubrication and b) without lubrication

Comparative histograms of the wear volume dependence of load and sliding speed are given in Fig. 15. It is clearly noticed that wear resistance of surfaces obtained by shot peening in all combinations of contact parameters is 50% better in comparison to ground surfaces. This is the consequence of increased hardness and specific topography of surface layers in their valleys, besides lubricants, wear products are retained, and thus they are taken away from contact zone. Also, 36NiCrMo16 alloyed steel has 10-20% better wear properties in comparison to 36CrNiMo4alloyed steel, due to better mechanical characteristics.

Display of wear tracks of tested samples in conditions without lubrication is shown in Figure 16. By analysing wear tracks we could say that, for all tested samples, dominant wear mechanism is abrasive wear, what is verified by parallel scratches and abrasive grooves in direction of sliding and visible in wear tracks.

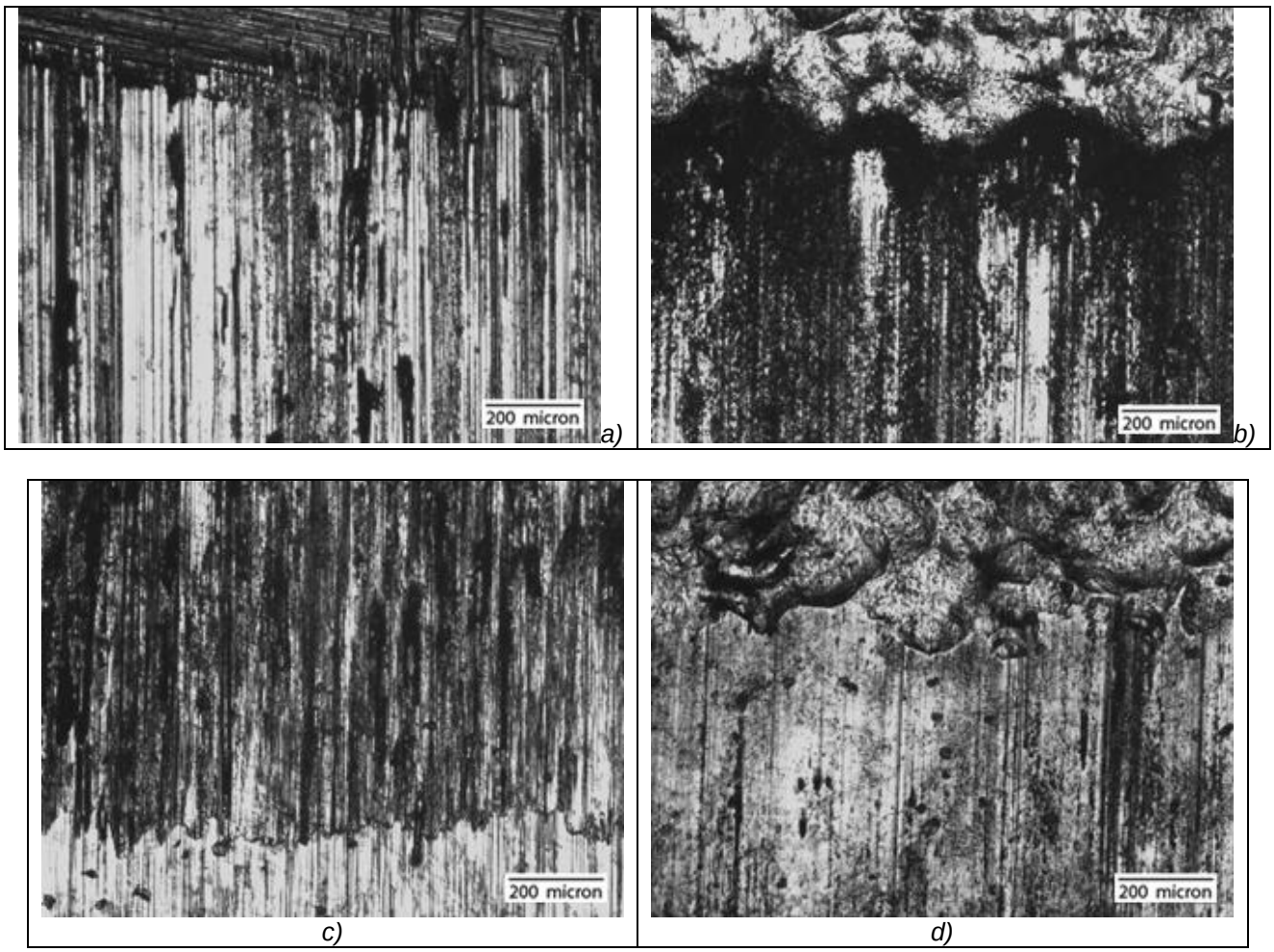
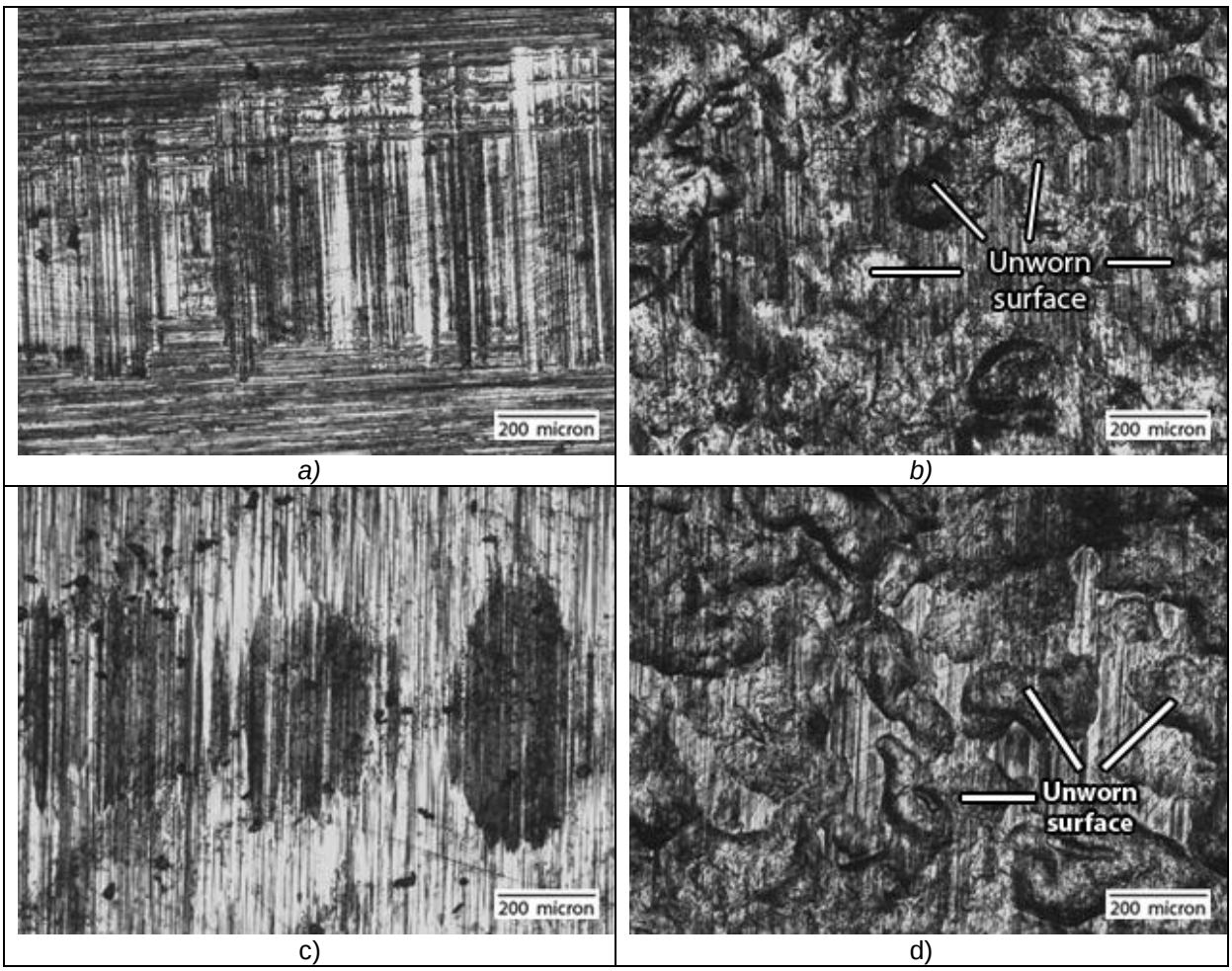


Fig. 16. Optical microscopy of wear tracks for dry contact (36CrNiMo4 steel): a) ground surface, b) shot peened surface and for 36NiCrMo16 steel: c) ground surface, d) shot peened surface

Figure 17 shows wear tracks after the sliding with lubrication. From figures 17b and 17d we can clearly see unworn parts of contact surfaces made by shot peening. Those places served as oil reservoirs and as places where wear products are to be collected during the contact. Based on the appearance of the wear track itself, we could also say that the dominant wear mechanism is abrasive wear. However, based on block-on-disc of contact geometry (contact per line, Herz's pressures) we could say that in initial moments of sliding the dominant wear mechanism is adhesive wear. This assumption especially makes sense at surfaces made by shot peening, primarily because of topography of surfaces, and because of increased elasticity of peeks of surface roughness.



a) b) c) d)

Fig. 17. Display of wear tracks under lubricated sliding conditions for steel 36CrNiMo4 a) ground surface, b) shot peened surface and for steel 36NiCrMo16 c) ground surface, d) shot peened surface

5. CONCLUSION

The results of tribological tests of surfaces made by shot peening, two alloyed steels 36CrNiMo4 and 36NiCrMo16 of very similar chemical compositions and mechanical characteristics, in conditions with and without lubrication, in variation of contact parameters (sliding speed and normal load) indicate following:

Primarily on good repeatability of represented method of testing, referring on small differences in values of friction and wear of these two steels, what is consequence of better mechanical characteristics of steel 36NiCrMo16 in comparison to steel 36CrNiMo4.

Surfaces made by shot peening show better wear resistance in comparison to ground surfaces of the same material. The difference in all contact conditions and at all values of contact parameters goes up to 50% , in favour of surfaces made by shot peening , what is the consequence of positive influence of shot peening process on mechanical characteristics and topography of contact surfaces. The value of friction coefficient in conditions without lubrication is about 10% lower at shot peened surfaces in comparison to ground surfaces, while that difference in conditions with lubrication is within the limit of 20-40%. At higher sliding speeds of contacts in conditions with lubrication, the difference in friction coefficient value is bigger, due to greater quantity of lubricants in the contact zone and possibility of making hydraulic pressure in valleys of surfaces obtained by shot peening.

The dominant wear mechanism was abrasive wear, both in conditions with and without lubrication. In conditions with lubrication, unworn parts of surfaces made by shot peening are clearly seen in wear tracks.

General conclusion is that the shot peening process has positive influence on tribological characteristics of materials in all conditions of making sliding contact.

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SOME REMARKS UPON EXPERIMENTAL FINDING OF COEFFICIENT OF RESTITUTION

Stelian ALACI, Constantin FILOTE, Florina Carmen CIORNEI, Ionut ROMANU, Valentin Dan AMARANDEI

Abstract: *the paper presents a method for calculus of coefficient of restitution for the case when between two bodies successive collisions happen. It is found that there is a variation of coefficient of restitution with impact velocity. Some applications, for straightforward results, use an average value of this coefficient. The present paper proposes a method for the calculus of average coefficient of restitution and suggests an explanation for the variation with velocity of coefficient of restitution.*

Key Words: *coefficient of restitution, free falling ball, Routh diagram, nanofocus scanning*

1.Theoretical consideration

The collision phenomenon is quite frequent in every day life. Generally, impact phenomena assume two approaches: the first method considers the colliding bodies as rigid ones. The variation of kinematic and dynamic parameters of the system is considered instantaneous. These variations are described by a series of coefficients expressing the ratio of the values for same parameter before and after collision, [1], [2]. The major disadvantage of this approach consists in an impossible estimation of the forces that expand during impact. A series of researches during the last decades attempted to consider a continuous variation of kinematic and dynamic parameters. The first to be mentioned are Dubowsky şi Freudenstein [3], and Hunt şi Crossley [4].

These last cited, started from describing the collision between a spherical surface and a body limited by a plane surface, using the Kelvin-Voigt model. A critical analysis of the model shows that it presents the advantages of hysteresis loop, but this loop is open in the origin and nor closed, as physical aspects require. To overcome this drawback, the two authors showed the means of modifying the characteristic equation of the model. Henceforth Lankarani şi Nikravesh [5], proposed an equation valid only for quasielastic collisions but recently, Flores, [6] enhanced the equation for the whole range of collisions. For the models where the parameters variation is supposed to be continuous, two phases are distinguished: the approach, starting from the moment when the first points come into contact, when the normal component of relative velocity becomes zero, and to the moment when the distance between these points becomes maximum, t_c, and the restitution following the approaching, and lasts till the moment t_f, when the complete detachment of the two bodies takes place. One must remark that the model imposes a continuous variation of dynamic parameters, and the coefficient of restitution COR appears in the characteristic equation. The equation proposed by Flores has the following form:

$$F_n = K\delta^n\left[1+\frac{8(1-c_r)}{5c_r}\frac{\dot{\delta}}{\dot{\delta}^{(-)}}\right] \tag{1}$$

Where K is a constant depending on the geometry and elastic characteristics of the contact regions, the normal force F_n the coefficient of restitution COR, c_r, the distance between points of contact δ, and the velocity at a certain instant, $\dot{\delta}^{(-)}$. One must mention that for applying the Flores model, the

friction coefficient is required. For the case of rigid body collision, but with Coulomb friction between bodies, Wang and Mason apply the Routh diagram, [7], in order to characterise the plane impact between two rigid bodies. They reach the conclusion that, besides the limit value for coefficient of friction, the coefficient of restitution plays an essential part in characterising the relative motion in the contact region, Fig. 2. The Routh diagram for the bidimensional collision is presented in Fig. 2. In this figure, the coordinates of a point are represented by the tangential and normal impacts, respectively.

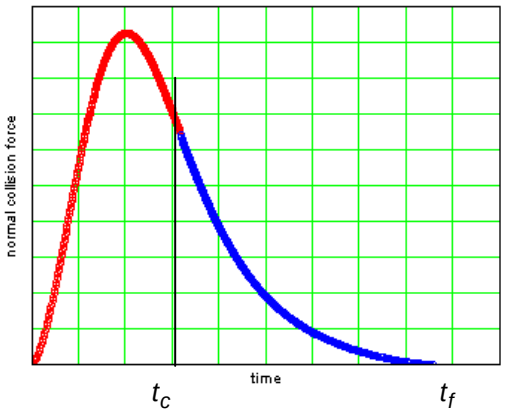


Fig.1 Impact variation, [8], for $e_N = 0.5$

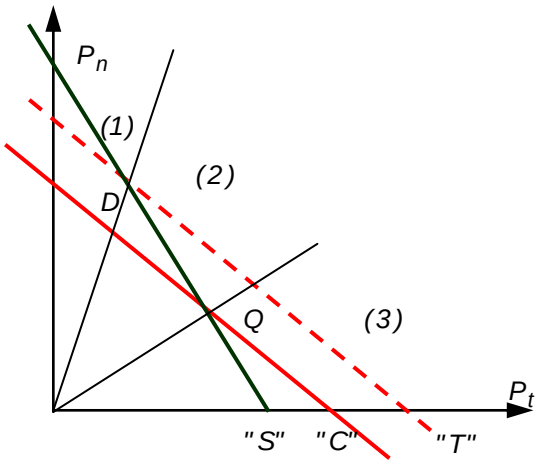


Fig.2 Percution plane

One can distinguish: the straight line “C” on which the normal approach is maximum (zero normal relative velocity), the straight line “T” on which the coefficient of restitution defined following Newton:

$$e_N = -\frac{v_n(t_f)}{v_n(t_0)} \tag{2}$$

takes an imposed value. The instants t_f, t_0 represent the final and initial moments, respectively and v_n the normal component of relative velocity. Another straight line is $"S"$, on which the sliding ends. The intersections between the first lines with the line $"S"$ are the points Q and D, and the positions of these points define in the impact plane there domains. The use of coefficient of friction defined by relation (2) in the regions (2) and (3) leads to a paradox noticed by Kane, [9], recognized by a final system energy greater than the initial one. This aspect is removed if the coefficient of restitution is defined using the Poisson’s relation, [10,11]:

$$e_P = \frac{\int_{t_c}^{t_f} F_n dt}{\int_{t_o}^{t_c} F_n dt} \tag{3}$$

Only inside region (1), both coefficients would have the same value. Concerning the kinematical definition of the coefficient of restitution, Hunt and Crossley, [4], quoting Goldsmith, show that it depends linearly on the impact velocity. From the above consideration, it is underlined the importance, for practical devices, of a correct estimation for this parameter and that for the situations when multiple impacts of bodies occur, a medium value is required for a simplified description of the system dynamic behaviour.

2. TEST RIG AND METHODOLOGY

The collision between a free falling bearing ball and the horizontal frontal surface of a steel disc, as shown in Fig. 3, was considered in the present paper. The ball, *1,* is set in free falling to impact the surface of the disc *2*, using a special designed launcher that allows an accurately controlled falling height. After launching, the ball and the disc surface suffer multiple successive collisions and due to subunitary value of coefficient of restitution, the height at which the ball rises is progressively diminishing. The shapes of the impacting bodies were chosen to ensure for the entire collision series

the same values of geometrical and elastic parameters of collision regions. The characteristic sound of an impact series is recorded and graphically plotted using specialized software. The image of such an acoustic signal is represented in Fig. 4.

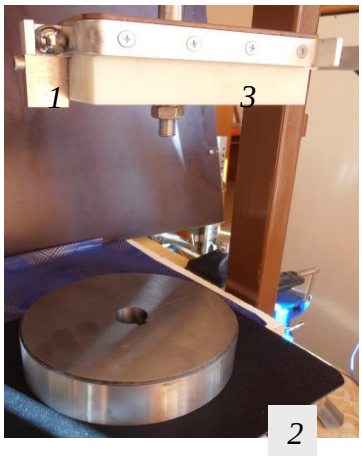


Fig.3 Testing device from lab

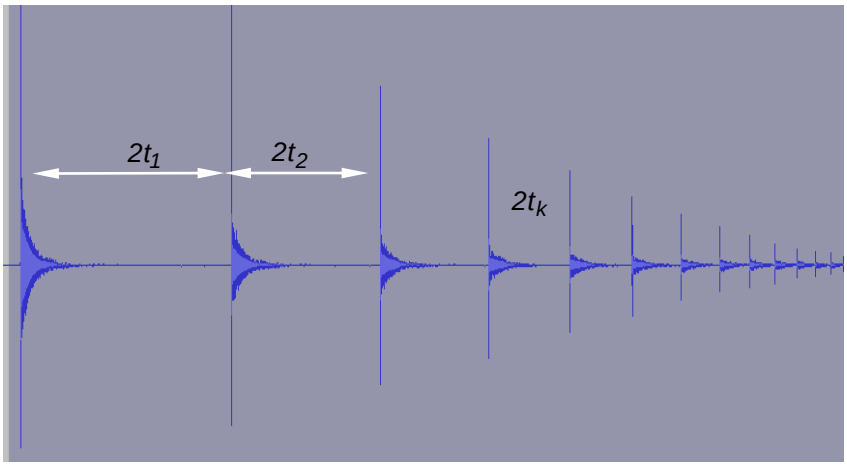


Fig.4 Image for acoustic signal occurring together with a series of collisions

From Fig. 4 it can be observed that the instant at which the collision happens can be precisely identified due to the shock wave accompanying the impact, [12]. Consequently, assuming the hypothesis that the collision time period is negligible compared to the time between two collisions, the coefficient of restitution correspondent to the "k" collision is:

$$e_k = \frac{v_{k+1}}{v_k} = \frac{g t_{k+1}/2}{g\, t_k/2} = \frac{t_{k+1}}{t_k} \tag{4}$$

For the first impact, the time t_0 is found by knowing the falling height h_0 for the ball from the launching device.

$$t_0 = \sqrt{2h_0/g} \tag{5}$$

3. EXPERIMENTAL RESULTS

Following the above presented methodology, experimental tests were made and the most significant results are presented in Fig. 5 and Fig.6, namely the variations of the time periods between two collisions and the coefficient of restitution corresponding to two collision series having the launching height $h_0^{(1)} = 0.220\,m$ and $h_0^{(2)} = 0.328m$.

It is necessary to adopt an average value of COR for a pear of materials with given geometries.

If we presume that the coefficient of restitution is constant, the equation:

$$e_n = \frac{t_{k+1}}{t_k} \tag{6}$$

shows that the time periods corresponding to a set of successive collisions must be in geometrical progression. So, we need to interpolate the experimental data with a function of form:

$$t = \exp(s_0 + s_1\xi) \tag{7}$$

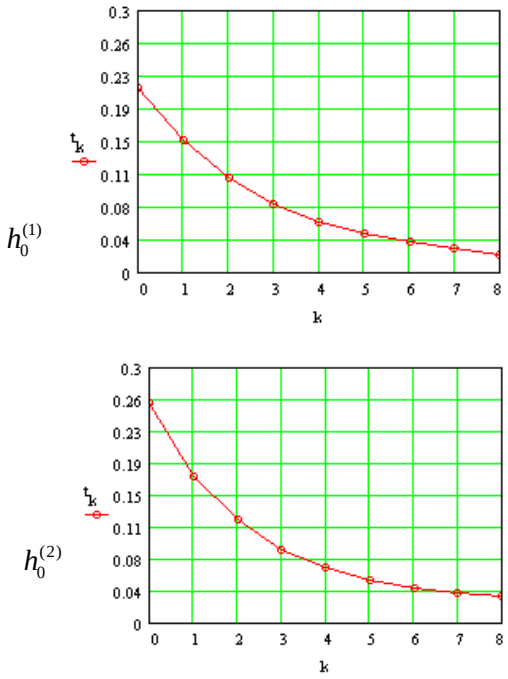


Fig.5 Variation of time period between two successive collisions for the two falling heights

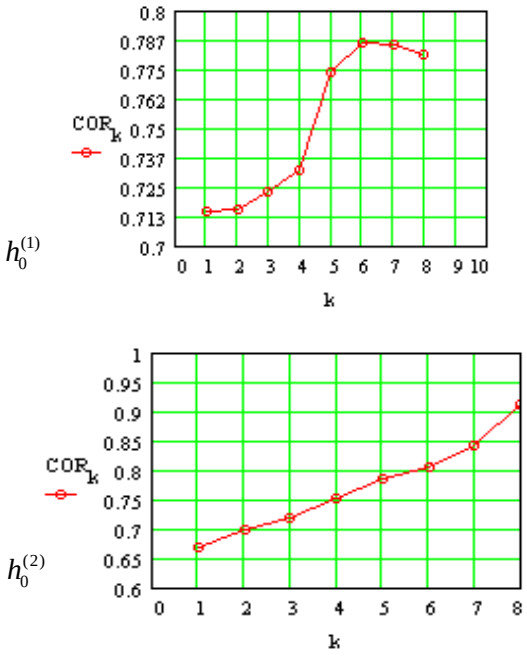
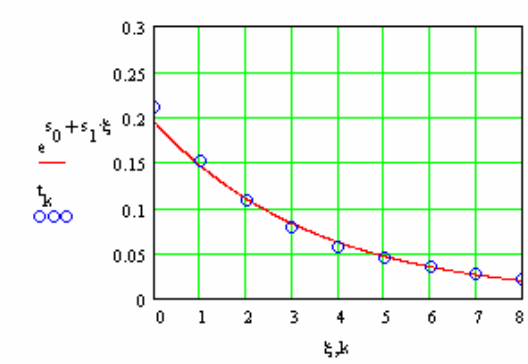


Fig.6 Variation of coefficient of restitution between two successive collision

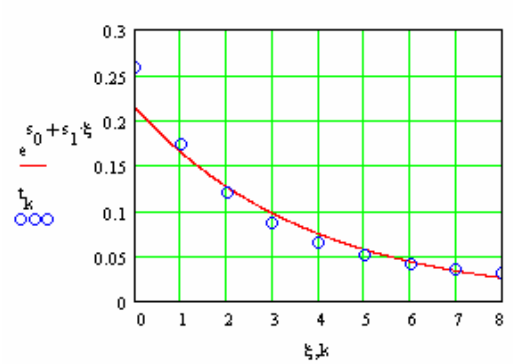
Finally, the average COR can be calculated as:

$$e_n^{(k)} = \frac{t_{k+1}}{t_k} = \frac{\exp[s_0 + (k+1)s_1]}{\exp[s_0 + ks_1]} = \exp(s_1) \tag{8}$$

In Fig. 7, there are presented the plots of experimental data and the curves obtained using the proposed interpolation relation together with the equation of the curves and the average value for theoretical COR.



$t = e^{-1.633-0.285\cdot\xi}$, $e_n = 0.752$ (COR)



$t = e^{-1.538-0.264\cdot\xi}$, $e_n = 0.768$ (COR)

Fig.7 Experimental points and the interpolation curve for the two cases

In order to explain the wide range of COR values, the disk was inclined with a very small angle. The traces of the successive collisions did not overlap, as seen in Fig. 8, and the collisions remain in zone 1 of Routh's diagram.

The collision traces were scanned using a laser profilometer, Fig. 9. From scanned traces, shown in Fig. 9, only the first two marks are spherical domes while the next ones are more difficult to characterize.

From the axial section of collision traces, Fig. 10, it is revealed that the first three marks are distinct and have sizeable different maximum depths and for the next traces, the shapes of the section

tend to overlap and more of that, the maximum depth is comparable to the roughness parameters. Under these circumstances, the theoretical model of contact between two smooth spheres is not appropriate.

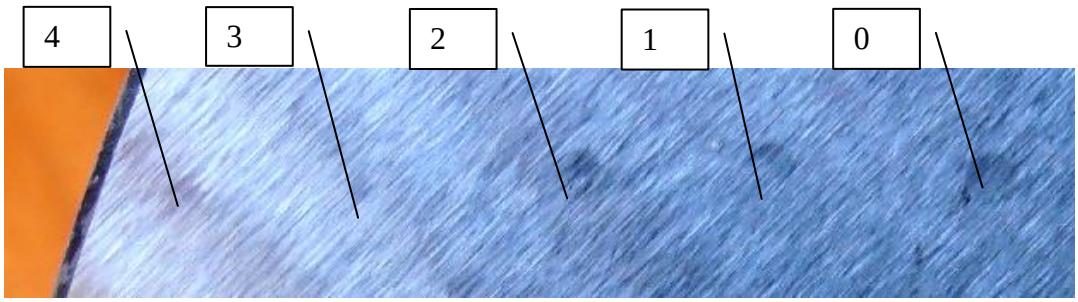


Fig. 8 Impact traces for a tilted surface

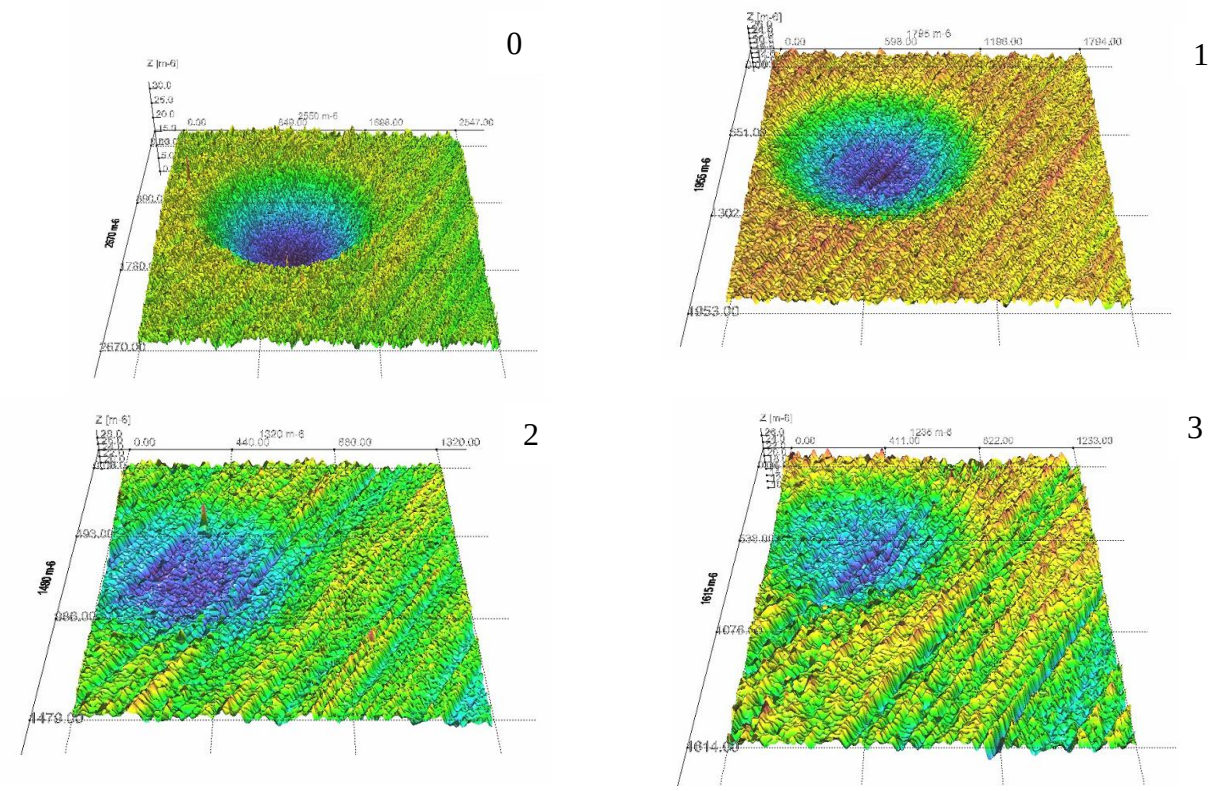


Fig.9. Images of successive collision marks (0…3) obtained by laser profilometry

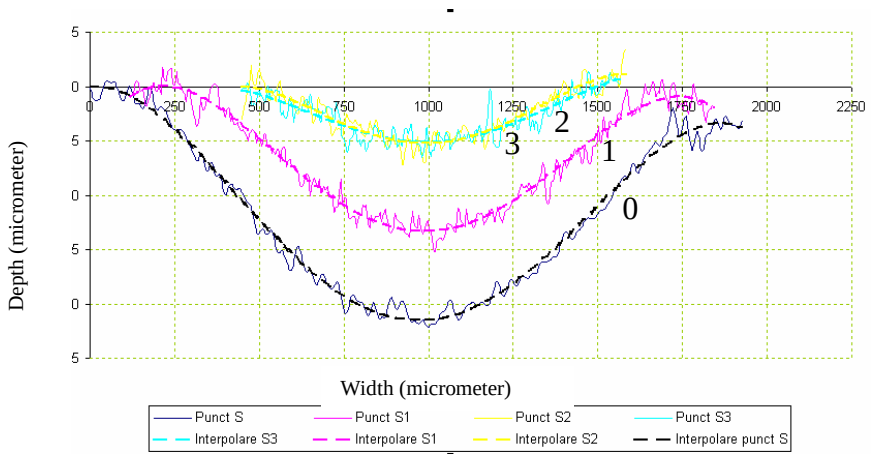


Fig. 10 For small values of impact velocities the maximum depth has the same order as the roughness parameters

4. CONCLUSIONS

The coefficient of restitution is, probably, the most important parameter which describes a collision phenomenon.

This parameter is necessary indifferent if the collision is considered as an instantaneous process between the rigid bodies or when the dynamical parameters are considered to have a continuously variation. There are two way to define COR: a kinematical one due to Newton and a dynamical one due to Poisson.

Although, in reality, COR depends by many factors in order to simplify the impact models we need to adopt a constant value to it.

If we consider the collisions between a free falling ball and a horizontal flat face of a cylinder, under the above presumption, the times, between the successive collision must be in a geometrical progression. The experimental data are approximated with an exponential curve and so, we can find an average value of the COR.

Using the scanned images of the impacts on the flat surface, it is shown in the paper, that when the roughness of one contacting bodies has the same dimension as maximum impact depth, the method must be applied with more carefully.

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EXPERIMENTAL MEASURING OF THE FRICTION FORCES IN THE PISTONS SEALS OF THE HYDRAULIC CYLINDERS

Catalin DUMITRESCU, Corneliu CRISTESCU,
Ioana ILIE, Liliana DUMITRESCU

Abstract: *The paper presents an experimental research in order to measure the friction forces which appear in the pistons seal of the hydraulic cylinders. There are presented the experimental device and the specific elements of the used experimental stand and, also, the experimental method used to determine the frictional forces within the pistons seals of hydraulic cylinders. Finally, there are presented, under the graphical shape, some experimental results obtained in experimental research.*
Key Words: *tribology, sealing, friction forces, hydraulic cylinders, experimental measurements*

1.INTRODUCTION

Hydraulic cylinders are basic components of hydraulic control and actuation systems, which convert hydrostatic energy into mechanical energy. Their dynamic behavior is strongly influenced by the forces which appear in the driving systems. One of these main forces is the friction forces.

Performing optimum mobile sealings represents a key factor for providing the reliability of the drive systems to which they belong, inclusively for reducing hard wears, caused by the modification of the kind of lubrication used. Some theoretical aspects were presented in tehnical journals [1,2,3]

This was the reason for which the hydraulics and pneumatics research institute from Bucharest has developed a serious activity of theoretical and experimental research, in order to know the quantitative and qualitative evolution of the friction forces during the working cycles [2].

The mobile/dynamic translation sealings are specific to the hydraulic cylinders (see Fig. 1) and there could be for sealing of the cylinders rod [3,4], or for sealing of the cylinders piston.

In Fig. 2 is presented a piston sealing, where they realize the sealing on the piston with diameter d, being in reciprocating translation motion on the stroke, in a fluid medium with the constant viscosity η and under the pressure p., S being the piston stroke, v and v_r being the velocities of the cylinder piston, in both directions.



Fig. 1. The hydraulic cylinder

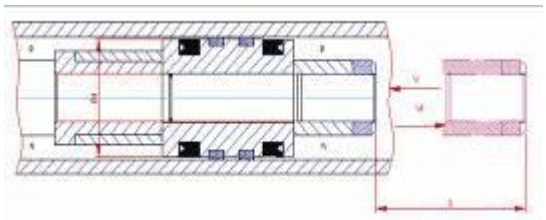


Fig. 2. The sealing of the cylinder piston

For experimental determination of frictional forces, occurring between the seals and cylinder body, was designed and developed an experimental device and a testing stand, equipped with modern “on-line” system for measuring the evolution of the parameters of interest [5].

2.SHORT PRESENTATION OF THE EXPERIMENTAL DEVICE

2.1. Experimental device principle

In order to evaluate the friction forces, from the piston sealing of the hydraulic cylinders, was projected and realized an original experimental device. For designing the experimental device, were taken into account o lot of basic requirements, the main of them are:

- Elimination, as much as possible, of the big masses in motion, for avoiding the occurrence of the inertial forces;
- Eliminating of the mechanical bindings which may occur in working;
- Providing fluid supply under various operational pressures;
- Measuring and recording of the evolution of the friction forces;
- Measuring and recording of the operational strokes and velocities;
- Measuring and recording of the operational pressure evolution;
- Measuring and maintaining under fluid pressure of piston sealings, during entire working stroke;
- Measuring continuously the temperature of the working fluid being between the gaskets.

2.2. The adopted technical solution and the principle of measurement

The adopted technical solution was the replacement of the piston cylinder head sealing, as in Fig. 2 with one new piston double sealed, as in Fig. 3, which consists in a new hollowed rod 1, two bushes 2 with their O-ring seals, a guidance bush 4, a washer 5 and a threaded nut 6, which close the piston system. The piston contains two spaces where are placed 2 U gasket shape type sealing, fixed with the wings facing one another, as in Fig. 3. The physical testing piston can be seen in Fig. 4. The cylinder liner 8 is used from an existing Rexroth hydraulic cylinder.

The operational fluid is injected, by a hand pump, between these two sealing elements, through the hollowed rod 1 and the guidance bush 4, which it strain, in an operational system, identical with that of a hydraulic cylinder running.

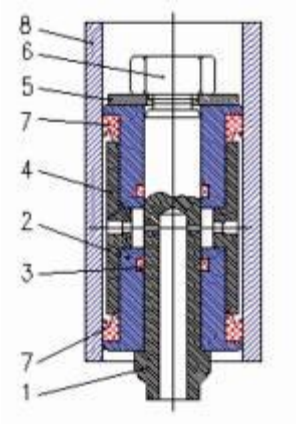


Fig. 3. The new piston solution



Fig. 4. Physical testing piston

2.3. The friction force Determination

The two friction forces from the two sealing, F_{f1}, and, respectively, F_{f2}, are, probably, not equal, for the same direction of motion of the piston, but, surely, can be comparable. That is why, it is assumed that the friction force represents, approximately, half of the force measured F_m, at the device, by the force transducer. If it is considered the fixed weight of the device G_f , and assuming that the two friction forces F_{f1}, and F_{f2} are, approximately, equally, it may be concluded that the friction force in one sealing ff, will be:

$$F_m = F_{f1} + F_{f2} \pm G_t \quad (1)$$

$$F_f = F_{f1} = F_{f2} = (F_m \pm G_f)/2 \quad (2)$$

Using these mathematical formulas, can be determine the friction force value from one sealing of the piston of the hydraulic cylinders.

2.4. Presentation of the experimental device

The experimental device (see Fig. 5) operates in vertical position and it needs the mounting of the rod of the experimental device on the mobile rod of the hydraulic cylinder from one existing stand.

From the Fig. 6, the experimental device consists of the following 5 main parts:

a. The lower spherical articulation ASI, through which rod (1) of the piston tested is attached / fixed by the RHC rod of hydraulic cylinder on the existing stand. Rod of the tested piston tp is made of pipe (1.1), drilled rod (1.3), on which is mounted piston and piece (1.2) for mounting the lower ball joint as1 consisting of spherical plastic/PTFE bushings (2) and (3), the spindle with spherical head (4) and cap for tightening bushes (5), as well as nut (6) and threaded piece (7), for fixing joint by the rod of the drive cylinder on the stand, providing reciprocating motion:
b. Dual seal test piston TP, containing the 2 seals U type, containing the 2 seals u type, which has been shown in Fig. 6. The rod of the piston has two holes, one for feeding, one for a pressure and temperature transducer;
c. Cylinder body (8)**,** which consists of a hydraulic cylinder "liner" (8), threaded flange (9), assembled on the fastening flange (10) with screws (11), attached, through the threaded piece (12), by the force transducer (13);
d. The force transducer (13), which can measure maximum value of force to 50 kN;
e. The upper spherical articulation AS2, which is fixed by the force transducer (13) with the threaded piece (14), which has a slot/bore where it is mounted, through the plastic/PTFE bushes 2 and 3, the spherical head of the threaded spindle (4), which is tightened by a nut (5), and fixing to the top beam/bridge of the stand, SBS, is done by the counter nut 6.



Fig. 5. The experimental device

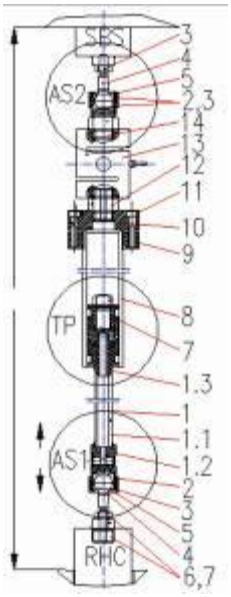


Fig. 6. Design of experimental device

3.PRESENTATION OF THE EXPERIMENTAL STAND

For experimental determination of frictional forces, occurring between the seals and piston of hydraulic cylinder, was designed and developed a testing stand (see Fig. 7 and Fig. 8) equipped with modern “on-line” system for measuring the evolution of the parameters of interest.



Fig. 7. Stand-view from left



Fig. 8. Stand-view from right

The operation principle of experimental device (1), (see Fig. 9), implies its mounting on a vertical existing stand/bench (2), (see Fig. 10), which have to assure the reciprocating movements.

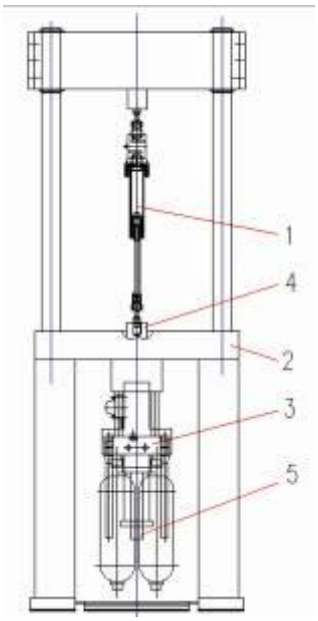


Fig. 9. Schematic representation of the bench equiped with experimental device



Fig. 10. The existing test bench equipped with experimental device

The existing bench/stand (2), available in the Tribology Laboratory of Hydraulics and Pneumatics Research Institute from Bucharest, by its own hydraulic plant (3), provides vertical movement in either direction, the movable rod (4) of the hydraulic cylinder of the existing stand assure the reciprocating movement to the hollowed rod and piston of the experimental device.

The measuring of the work stroke of the piston, in inside of the cylinder body, is made by the stroke transducer (5), presented in the Fig. 11. In Fig. 12, it can be seen the pressure and temperature transducer, which measures the pressure and temperature of the oil in inside of the hollowed rod of the piston, respectively, in the space between the two tested seals of the piston. The Fig. 13 presents the force transducer, used to measure the friction forces from the piston seals.



Fig. 11. The special stroke transducer of the existing stand



Fig. 12. The pressure and temperature transducer



Fig. 13. The force transducer

The experimental stand has others transducers as: a digital thermometer for the ambient temperature and, also, the flow transducer which can measure the oil flow from the main pump of the stand. Other pressure transducer measures the pressure at the hand pump, which assure the oil under pressure in the existing space between the tested seals.

By means of special electric cables, all signals provided by transducers reach the acquisition board installed on the computer, and this one, based on specialized software, allows the capture, storage and processing of the measured data.

4.SOME EXPERIMENTAL RESULTS

In order to measuring and recording of the variation of frictional forces, which appear within the piston seals of hydraulic cylinders, was developed a experimental research which lead to obtain a lot of graphical experimental results, some of them are presented bellow.

In this reason, was necessary the setting the parameters of interest and a testing methodology.

The experimental research started with the measuring of friction forces which appear in a piston seal with the diameter of 40 mm, for one single type of seal, named U sleeve, and one single kind of material, from which the gaskets were made, a rubber with hardness Shore 85.

In Fig. 14 and Fig. 15 are presented the complex graphical results for these 4 parameters, which include variation for 50 bar and 150 bar nominal pressure, for theoretical working speed of 0.100 m/s.

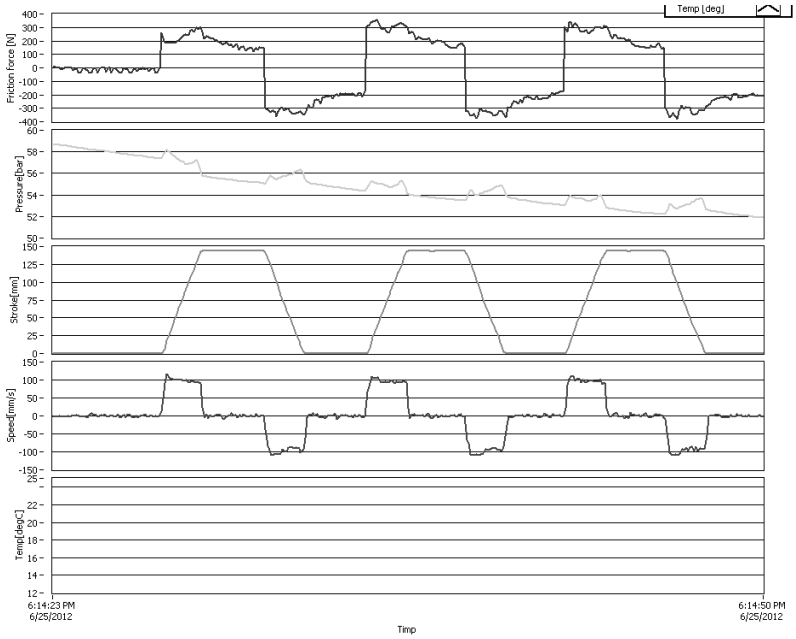


Fig. 14. The graphical variation for the main parameters at 50 bar

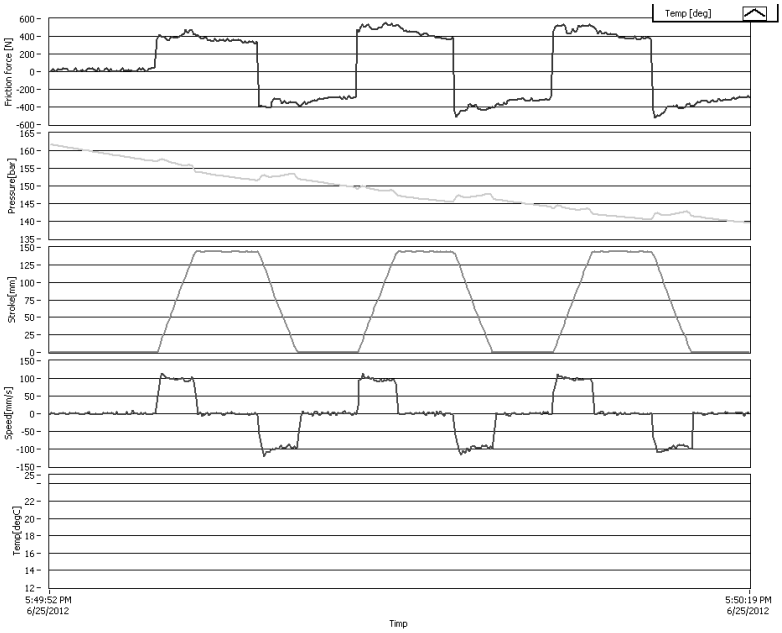


Fig. 15. The graphical variation for the main parameters at 150 bar

The measuring of friction forces was made for the working pressure between 0 and 250 bar, in pressure steps of 50 bar, for theoretical working velocities: 0.100 m/s. For each measurement, there were obtained the complex variation diagrams for the following parameters: the friction force; the working pressure; the working stroke and speed, and, also, the variation of the oil temperature.

The complex graphical variation creates a complete picture of the variation of frictional forces with increasing pressure between the two piston seals.

5.CONCLUSIONS

The paper presents the experimental device and the testing stand for measuring friction forces which appear in piston seals of hydraulic cylinders and there are shown graphic examples.

By the adopted technical solution, the experimental device is designed to precisely evaluate the friction force variation in the piston seals, versus time or operational stroke.

The valid measurements of frictional forces are obtained in downward stroke, due to the natural alignment of the piston rod with the force transducer that eliminates the occurrence of kneeing, locking and bending additional forces.

It is shown that the three graphs, for three consecutive cycles, which are almost identical, demonstrate *repeatability* of the process.

The measurement system, based on advanced transducers and electronic and computerized data processing, guarantees the accuracy of measurements performed on the stand.

There are a lot of experimental results, which will be compared with the theoretical results obtained by the mathematical modeling and numerical simulation [6, 7], the conclusion follow to be communicate.

The experimental decice and testing stand creates the possibility to develop a wide range of experiments and allows knowing the evolution of the friction forces.

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THIS SYSTEM IS "MULTIRED" WEAR AND MODULE POROCESA INVOLUTE TOOTHING

Miodrag Velimirović, Vlastimir Djokić

Abstract: *In engineering practice, there is a great variety of possible tasks in the design, manufacture and maintenance of gears. Therefore developed a number of software modules for the calculation of the vital elements of the power transmission. The developed software packages for designing gears are inflexible in relation to the user. For all the newly created concept transmissions require substantial upgrading program. One of the main uslkova for optimal design and manufacture gear drive is to have reliable quantitative data on the changes in the working areas zubčastog money. This is especially true where the manual transmission requires very low levels of noise and vibration.*

This paper analyzes the processes running on desktops, starting from the start point of coupling to the exit from Speg teeth. In order to solve the above problem, we undertook a series of partial integration programs and files in a software system. In this paper, the programming system "multired" and possible applications. Developed model is shown wearing the pair of teeth on the sides. We analyzed the processes of working surfaces of the teeth, from tooth surgery entrance to his exit from the loop. Research and developed a model based on the theory of thermo-elasto-hydrodynamic lubrication.

Keywords: *timing gears, involute gears, the process of wear*

1.INTRODUCTION

For the calculations of vital gear power transmitters' elements, a number of programming modules has been developed.. These programs can be used in calculating the parts independently of the transmitter structure, but for their compilation, linking and data entry it is necessary to develop separate programs for each transmitter concept. In order to solve the problem, the networking of the software modules and development of the software system for the gear power transmitter design have been introduced. The main system requirements are that it should enable:

- Designing of transmitters for general and special purposes.
- Simultaneous and automated transmitter design.
- Partial use of individual software modules
- Work with minimal input.
- Efficient selection and choice of materials, tools, oil, bearings and other standard transmitter elements.
- Insight into the calculation results and data access during the program execution process.
- Immediate utilization of output data.
- Partial program modification and a simple database update during system development

The above mentioned requirements are realized by linking software packages into a single system with a central database.

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2.DESCRIPTION OF THE PROGRAMME SYSTEM

For each transmitter concept a base of the formal system description has been formed, which defines the system elements and relations between the elements (the relative positions of the elements, kinematical links, etc.). Thus, the calculation results of a programming module can be used as an input of another module, independently of the selected transmitter concept and allow automated design of gear power transmitters. Programming system can be effectively used for the design of mechanical transmissions, check up of the already realized constructions, as well as the necessary calculations related to the repairing process of the mechanical elements and assemblies.

As a part of the complex software system, the appropriate software packages with the possibility of partial use were developed and validated in practice. This system is composed of the following program units:

PPR – Preprocessor has the task of data input and control, and connects the program modules in order to perform the required calculations. Preprocessor activates subroutines for the calculation of the parts that have been planned for the given transmitter variant. It also performs the selection of the manufacturing technology, materials and standard transmitter elements. Simple choice of calculating options has been enabled, and on basis, at, the minimum of required input data. Programming modules are interconnected, so that the results of a calculation module are used as an input of another module. Transmitter data are constantly being innovated and by corresponding iterative steps brought to a higher level. In Fig. 1 the form layout for the basic input data is given.

KONC - This module performs the primary selection of possible conceptual solutions in relation to the defined conceptual modes and transmitter exploitation conditions. From a set of alternative solutions stored in the database, a recommendation for the best concept choice is given. Based on the obtained transmitter data in the first phase of the design process in the communication with the database, the selection of one or more transmitter varieties is made. The final decision on the selection of the transmitter concept is brought by the user, on the basis of the relevant information in the dialogue with the computer. During this phase, generated transmitter data, with proper verification and amendment are stored in the database. However, if none of these pre-defined transmitter variants meets the requirements, then a design of a new solution is activated. Then, a part of a database with transmitter elements information is utilized. The program system, informed by defined requirements performs the composing of elements and proposes possible transmitter concepts. User intervention is, at this point, necessary, as is the input of additional data, in order for effective transfer of the devised concept to the base.

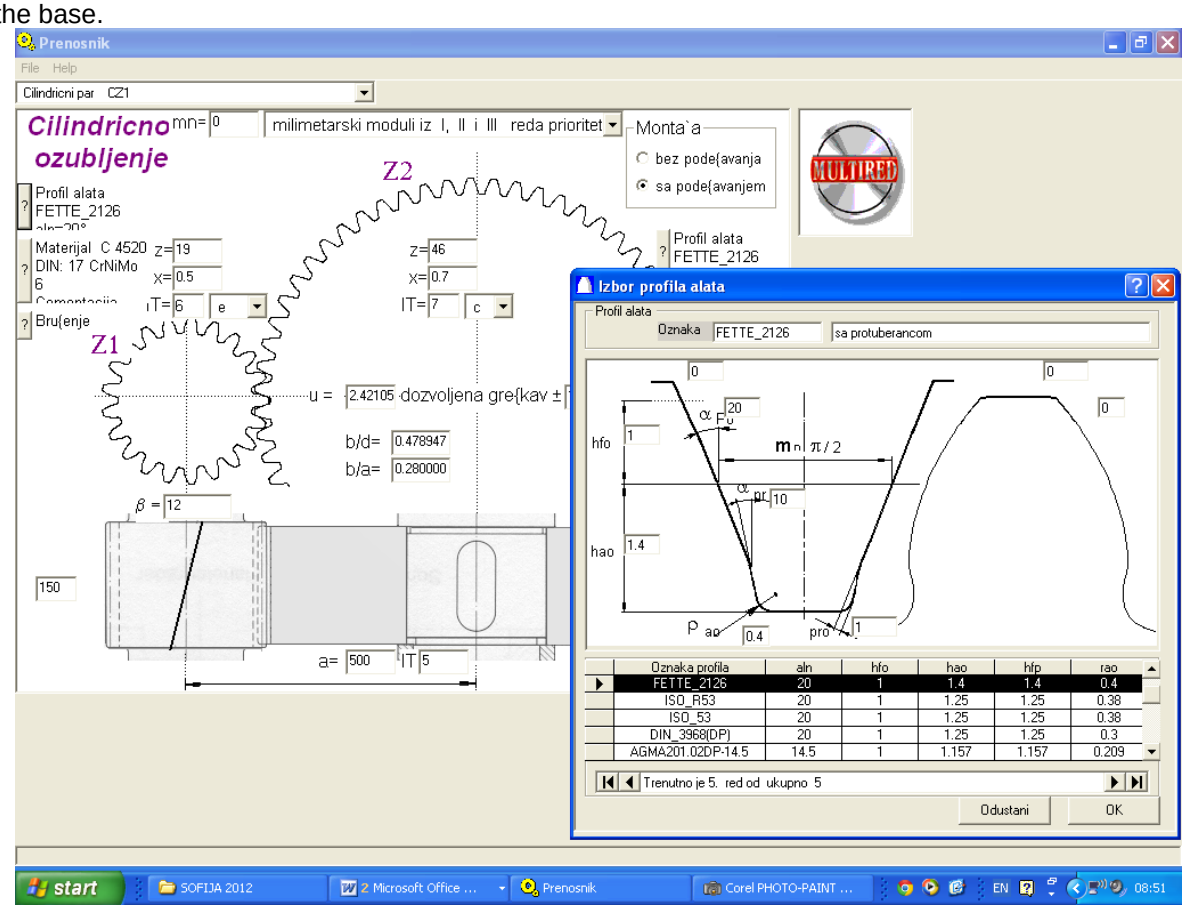


Fig.1 Form layout for basic data input

OPT program module for the analysis of the conducted calculations, selection of solutions and optimization. According to the customer request, a partial or complete optimization of transmitter elements is processed, for a given function objective and defined limitations. In doing so, through constant communication with the database after each calculating cycle, an innovation and update of existing transmitter data are performed.
PROR software package that contains the software modules for the calculation of the transmitter elements. Optimization is possible within these modules, but only of those parameters that have no impact on other gear power transmitter system elements. The program includes software modules for the calculation of transmitter elements and their activation is conditioned by the choice of calculation. Calling of software modules and execution of necessary calculations are accomplished by a preprocessor on the bases of the selected transmitter concept. Analogous to the aforementioned systems, specific programs for calculation have been developed, which are comprised within a block for PROR calculation. **PROR** program block includes the following programs:

- **DPP** program for the stress analysis and calculation of transmitter dynamic behavior;
- **PPS** program for the calculation of power transmission systems;
- **SPH**-program for the calculation of thermal stability and gear lubrication system;
- **DIJ**-program for designing a system for the diagnosis of correct functioning.

PPS- The program contains modules for the calculation of transmitter elements in the power transmission system. This part of the program system includes the following calculations:

- calculation of the gear tooth geometry ,
- determining the load of transmitter elements,
- load capacity calculation of transmitters according to different criteria,
- calculation of elastic deformation and shaft strength,
- calculation of bearings,
- calculation of the thermal stability of the transmitter and lubrication system

Program modules are interconnected, so that the calculation results of one module are used as an input date in another module. Transmitter data are constantly innovated, and through corresponding iterative steps are brought a higher level. Calculation and design process are carried out by appropriate control functions, and the user has constant access to data and the possibility of intervention through the appropriate dialog.

SPH-Calculation of transmitter thermal stability and of lubrication system is implemented by this program. This calculation determines the operating transmitter temperature, based on transmitter energy flows data, as well as cinematic and geometric parameters of the transmitter elements , constructional parameters relating to bearing layout and sealing, lubricants characteristics, and heat loss through the casing, foundation and transmitter elements. If the operating temperature exceeds the limit value, then the calculation of the cooling subsystem is applied.

DIJ- This program comprises designing of the diagnostic system for the correct functioning of the transmitter and appropriate safety devices.

3. BASIC SOFTWARE MODULES

As a part of the software system with the possibility of partial use, the following software packages have been developed and verified in practice:

- MOPT-calculates gear power transmitter elements load,
- MKCZP-cinematic calculation of the cylindrical outer and inner tooth,
- MKKG-cinematic calculation of conical and hypoid KLINGELNBERG ZYKLO-PALLOID-tooth,
- MKIOE-cinematic calculation of conical and hypoid OERLIKON SPIROMATIC tooth,
- MKIHR-cinematic calculation of conical HARBECK tooth,
- KIMGL-cinematic calculation GLEASON-CONIFLEX chamfers,
- MKIPZ-cinematic calculation of snail pairs,
- MCCZP-strength calculation, scuffing and wearing in cylindrical tooth,
- MCKZP-strength calculation, scuffing and wearing CONICAL tooth,
- CPMZP-strength calculation, wearing and thermal stability of snail pairs,
- MVR-load analysis, sizing and calculation of shafts, joints and connector elements
- MLE-choice and calculation of bearings,
- MMAT-selection of materials of gear tooth and snail pairs,
- MUL-choice of transmitter lubricants,
- MTO-energy loss calculations and calculations of transmitter thermal stability
- MTE- choice of machine for gear tooth production and calculations of technological parameters

• DIJC-diagnosing geometric parameters of worn or damaged CYLINDRICAL tooth transmitter elements

• DIJK-diagnosing geometric parameters of worn or damaged gear tooth transmitter elements
• DIJP-diagnosing geometric parameters of worn or damaged snail pairs.

4. SLIDING TOOTH FLANKS

The process of transfer of power is accompanied by rolling, sliding and high pressure in the contact zone. Between desktops pair of teeth in contact comes to friction, which leads to changes in temperature of oil and oil film thickness. When the oil film thickness is less than the roughness the result is the tearing of contact surfaces or the scuffing of the high-speed gear.

Identifications of relevant geometric-kinematics characteristics, of the characteristics of material and oil, characteristics of load and the conditions of exploitation have been considered. There has been established the relationship between hydrodynamic, elastic and thermal processes in the contact zone. The mathematical model has been developed in the form of parametric equations, and moves in the tangential speed, sliding speed, specific load, pressure, oil temperature, the temperature wave, viscosity, friction, oil film thickness and the tearing of tooth flanks.

At all points outside kinematics pole C (Fig. 2.), due to inequality of extensive velocity components in the direction of the tangent to the gear tooth flank a sliding occurs. For calculation of the slip velocity, and later other sizes influencing the tearing process there have been used as the basic parameters the attack angles on the tooth flank of driving gears α_{x1} and α_{x2}. The considerations have been limited to the evolute gear pairs, where the straights are on the flank points of contact, touches the base circle radius of inflected gears r_{b1} and r_{b2}, so that:

$$r_{b1}\cdot\tan\alpha_{x1}+r_{b2}\cdot\tan\alpha_{x2}=(r_{b1}+r_{b2})\cdot\tan\alpha_{w} \qquad /1/$$

Angle of attack of the equation 1 can be expressed as:

$$\tan\alpha_{x2}=\frac{1+u}{u}\cdot\tan\alpha_{w}-\frac{1}{u}\tan\alpha_{x1} \qquad /2/$$

where:

r_{x1}, r_{x2} - The current coordinates of the point of contact

r_{b1}, r_{b2} - Radius of basic circle

α_{x1}, α_{x2} - Angles of attack on the tooth flank

α_{w} - The angle of contact

Equation / 1 / and / 2 / are also valid for internal inflection, with the diameter and number of teeth of the gear wreath entered with a negative sign.

Tooth flanks are coupled along the active part of the point of contact A to E (Fig. 2.) and in this condition it is possible to determine the limiting values of attack angles α_{x1} and α_{x2}:

$$\alpha_{x1\min}=\alpha_{A1}=a\tan[(1+u)\cdot\tan\alpha_{w}-u\cdot\tan\alpha_{a2}] \qquad /3/$$

$$\alpha_{x1\max}=\alpha_{E1}=\alpha_{a1} \qquad /4/$$

where:

$u = Z_2 / Z_1 -$ transmission ratio

α_{a1}, α_{a2} - Angles of attack at the top of the wave

Limiting points of the single coupling (points B and D) are important for the study of the process of wear due to the jump in the load points. The rise of strain is more significant in gear with uncorrected gear profile. Angles of attack at points B and D can be expressed as:

$$\alpha_{B1}=a\tan(\tan\alpha_{a1}-\frac{2\cdot\pi}{z_1}) \qquad /5/$$

$$\alpha_{D1}=a\tan[(1+u)\cdot\tan\alpha_{w}-u\cdot\tan\alpha_{a2}+\frac{2\cdot\pi}{z_1}] \qquad /6/$$

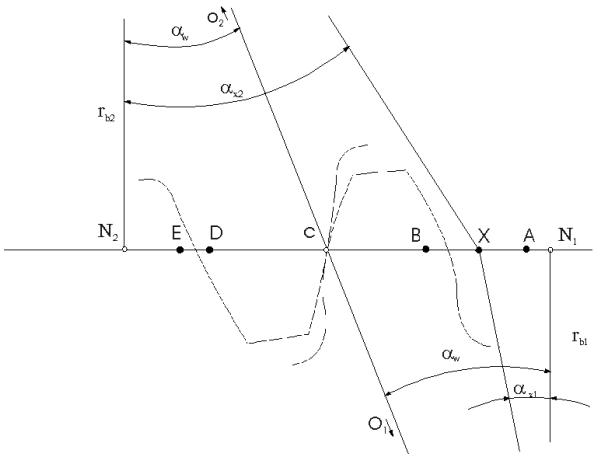


Fig.2. Coupling of spur gears

Peripheral velocities components in the direction tangent to the side of teeth can be defined as:

$$V_{tx1}=r_{b1}\cdot\omega_1\tan\alpha_{x1} \qquad /\ 7\ /$$

$$V_{tx2}=r_{b2}\cdot\omega_2\tan\alpha_{x2} \qquad /\ 8\ /$$

As $r_{b1}\cdot\omega_1=r_{b2}\cdot\omega_2$ the slip velocity at an arbitrary point of X can be determined as the difference of tangential velocity on the basis of the following expression:

$$V_{klx}=r_{b1}\cdot\omega_1(\tan\alpha_{x1}-\tan\alpha_{x2}) \qquad /\ 9\ /$$

The extreme values of the slip velocity at the beginning of inflection (point A) and the coupling end (point E), or parietal areas of high and low gears. Figure 3 shows the change of velocity in the direction tangent to the gear pair $z_1=18\ z_2=65$.

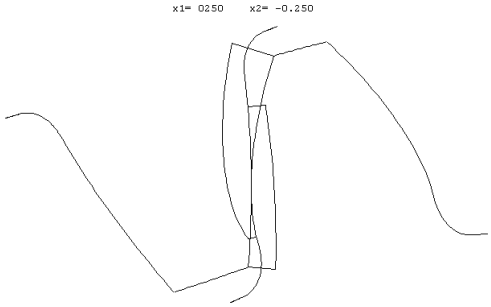


Fig.3. Velocity in the direction tangent to the side teeth

The relation between the sliding speed and the corresponding tangential sliding speed is the specific sliding:

$$\zeta_{1x}=\frac{V_{t1x}-V_{t2x}}{V_{t1x}}=1-\tan\alpha_{x2}/\tan\alpha_{x1} \qquad /\ 10\ /$$

$$\zeta_{2x}=\frac{V_{t2x}-V_{t1x}}{V_{t2x}}=1-\tan\alpha_{x1}/\tan\alpha_{x2} \qquad /\ 11\ /$$

In Fig. 4 changes of the specific sliding on the flanks of inflected gears.

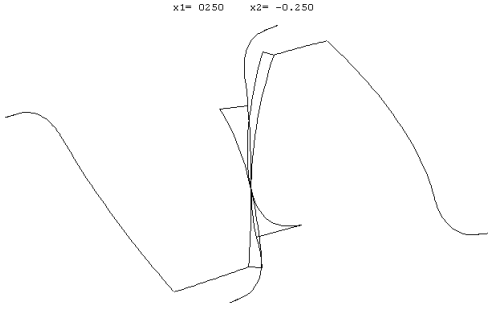


Fig.4. Specific sliding speed

5. THE STRAINS ON THE TOOTH FLANKS

During the inflection as a consequence of changes in the radius of curve of inflected profiles and the number of teeth simultaneously inflected occurs a change of surface pressure which are calculated on the basis of Hertz's theory of contact strains. The maximum contact pressure at the only once inflected gear pair can be defined as:

$$\sigma_H = \sqrt{\frac{F_n}{b_{ef} \cdot \rho_x} \cdot \frac{1}{\pi \cdot (\frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2})}} \qquad / 12 /$$

where:

$F_n \quad [N]-$ normal force on the tooth flank,

$E_1, \nu_1, E2_2, \nu_2-$ modulus and Poisson's ratio of strained materials,

$\rho_x = r_{b1} \frac{u \cdot \tan\alpha_{x1} \cdot \tan\alpha_{x2}}{(u+1) \cdot \tan\alpha_w} -$ reduced radius of curvature at arbitrary point of X.

In the current pole a reduced radius of curve C is:

$$\rho_C = r_{b1} \frac{u \cdot \tan\alpha_w}{(u+1)} \qquad / 13 /$$

The relationship of the reduced radius of the curve in an arbitrary point X and the reduced radius of curve in the current pole is defined as the factor of the radius of the curve, and it is:

$$\zeta_{\rho x} = \frac{\rho_x}{\rho_C} = \frac{[(u+1) \cdot \tan\alpha_w - \tan\alpha_{x1}]}{\tan^2 \alpha_w} \cdot \tan\alpha_{x1} \qquad / 14 /$$

Figure 5 shows the change in factors of the curve during the inflection of the gear pair.

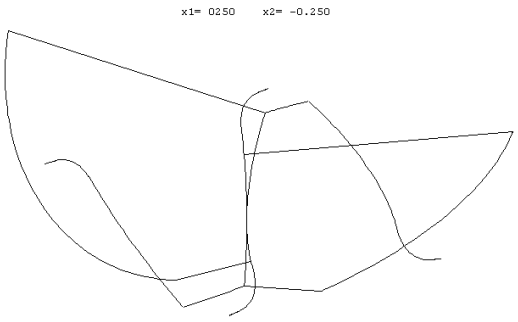


Fig.5. Change of factor of the curve radius during the during the inflection

As a result of changes in tooth position changes occur to the reduced curve as well in load changes. Because elastic disfigurements tooth elastic beam and the surface layer of the tooth, in case of multiple straining occurs an uneven load distribution. Load on one gear pair depends on the number of simultaneously inflected teeth and the position of tooth in this connection. In addition to this, the shape of tooth profile correction also affects the distribution of load (treated according to DIN 3990). Load distribution factor is given in function of the angle α_{x1} and conspicuously marked with $K(\alpha_{x1})$. The pressure in an arbitrary point X of the active part of contact can be expressed following equation

$$\sigma_{Hx} = K_{F.} \cdot \{K(\alpha_{x1}) \cdot [1 - \frac{\tan\alpha_{x1}}{(u+1) \cdot \tan\alpha_w}] \cdot \tan\alpha_{x1}\}^{-0.5} \qquad /15/$$

where is: $K_F -$ the load factor

The pressure in the current pole C in view of the equation / 12 / and / 13 / is possible to expressed in the form

$$\sigma_{HC} = K_{F.}[K(\alpha_w) \cdot \frac{u}{u+1} \cdot \tan\alpha_w]^{-0.5} \qquad / 16 /$$

Specific contact pressure as the pressure ratio at arbitrarily chosen point of contact of the active part of the X and the pressures on the current pole can be expressed on the basis of equations / 15 / and / 16 / in the following form:

$$\zeta_{\sigma H} = \{\frac{K(\alpha_{x1})}{K(\alpha_w)} \cdot \frac{u \cdot \tan^2 \alpha_w}{[(u+1) \cdot \tan_w - \tan\alpha_{x1}] \cdot \tan\alpha_{x1}}\}^{0.5} \qquad / 17 /$$

Change of specific contact pressure is shown in Figure 6, which shows the impact of the move from a double to a single interface.

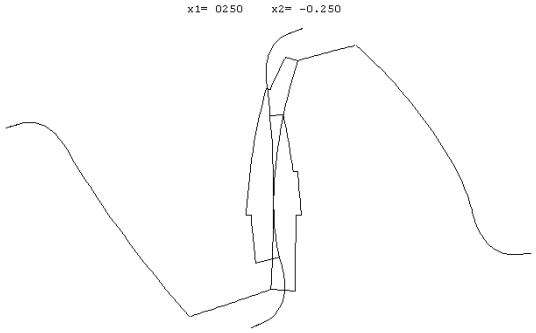


Fig.6. Change of specific pressure during the tooth inflection

6. WEAR OF FLANKS IN CYLINDRICAL GEARS

The wear contact surfaces is due to slippage that occurs between the loaded tooth flanks. Contact pressures of tooth flanks in practical application are within 500-2500. N/mm^2. The wear during development the preliminary use has positive effects on load distribution. Determination of tooth flank wear due to the sliding wear is relies as an idea on the work of Plew /2/. The wear of profile (lineal wear parameter) of teeth can be determined on the basis on the expression:

$$hw = k \cdot \zeta_x \cdot \rho_x \cdot \sigma^{1,4} \cdot N \qquad / 18 /$$

where:

k — wear factor which depends on the type of oil, materials and heat treatment of gears,

$\rho_x -$ reduced radius of curvature at arbitrary point of X,

$\zeta_x -$ specific sliding at an arbitrary point X,

$\sigma -$ operating voltage of the tooth flanks in an arbitrary point of X,

$N -$ number of cycles of the load of gears.

The wear of tooth flanks occurs when the oil film thickness is less than the amount of roughness. Research published by Grubin, Heiginsona and other authors, are based on elasto-hydrodynamic lubrication theory.

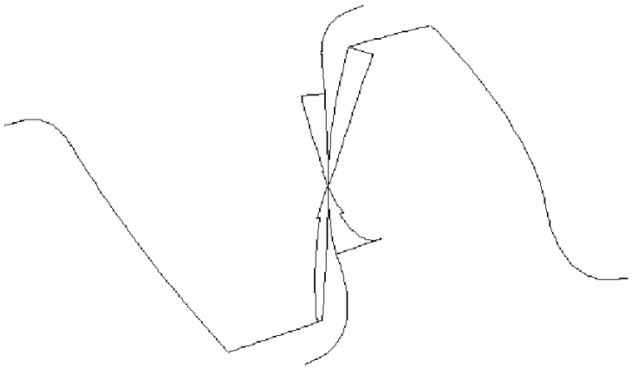


Fig.7. The form of wear for an inflected gear pair of shift $x_1 = 0.0$ and $x_2 = 0.0$

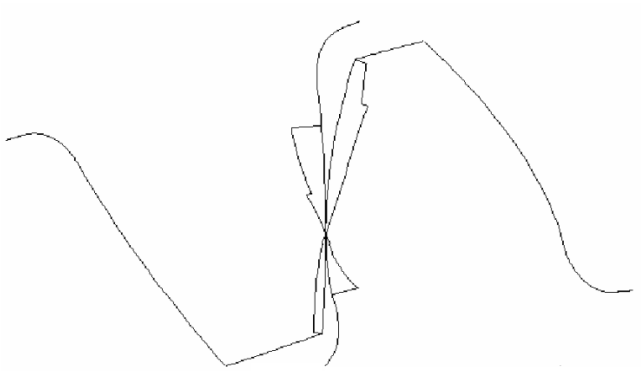


Fig.8. The form of wear for an inflected gear pair of shift x_1 = 0.25 and x_2 = - 0.25

Numerical solution of the oil film thickness are consistent, with a slight variation of a few percent can be reduced to:

$$h_{\min} = 2{,}65 \cdot U^{0,7} \cdot G^{0,54} \cdot \rho_x / W^{013} \qquad / 19 /$$

where:

$U = \eta_o \cdot V_{tsr} / E_r \cdot \rho_x -$ dimensionless speed parameter,

$G = \alpha \cdot E_r -$ dimensionless oil parameter,

$W = F_n / b_{ef} \cdot E \cdot \rho_x -$ dimensionless load parameter,

$E_r = \dfrac{2}{\dfrac{1-\nu_1^{\,2}}{E_1} + \dfrac{1-\nu_2^{\,2}}{E_2}} -$ reduced modulus of elasticity,

$V_{tsr} = (V_{tx1} + V_{tx2}) / 2 -$ mid-tangential velocity,

$\eta_o -$ viscosity of the lubricant,

$\alpha -$ piesocoefficient by Barus ($\eta = \eta_o^{\alpha \cdot p}$).

Figure 7 and 8 shows the wear of tooth flanks with different coefficients of the move of profiles. There has been noticed a significant effects of the move of profiles on the form of the worn coat and the intensity of wear. This can be explained by changes in speed and specific load.

7. CONCLUSION

The results of the completed research and application of the software systems to specific problems, indicate the validity of development of software module based systems, as it allows for the partial replacement of modules and a simple database update. The presented software system for the power transmitter design can be effectively used for:

- simultaneous and automated design of mechanical power transmitters;
- calculation of the vital transmission elements and verification of already implemented constructions, reparation needs of machine parts and assemblies, as well as the geometry definition of worn or damaged toothed gear or snail elements.
- calculating the durability and reliability of the vital system elements for power transmission
- calculations of technological parameters for machine adjustment for gear tooth production,
- comparative analysis of the validity of alternative choices in substitution of materials, oil and bearings.

Comparative analysis of numerical results, obtained by the mathematical model, and the large number of experimental data shows essential qualitative agreement (a form of worn profile) with a significant deviation from the wearing values.

Survey indicates a significant impact of profile shift on the shape of the worn out layer and wear intensity. Inadequate choice of profile shift leads to the intensification of the degradation processes and incidence of damage. This can be explained by changes in shifting speed and specific loads.

The performed analysis indicate that, in slow-motion gear toothed pairs, wearing calculations should be included as the basic criterion.

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TRIBOCHEMICAL CHARACTERIZATION OF Ti6AL4V ALLOY UNDER RECIPROCATING SLIDING CONDITIONS

Zinaida DONI, Mihaela BUCIUMEANU, Liviu PALAGHIAN

Abstract: *Tribochemical characterization of alumina and steel bearing balls sliding against Ti6Al4V alloy has been carried out using a ball-on-plate configuration. The corrosion behavior of Ti6Al4V was evaluated in an aqueous solution of 3.5% NaCl. The coefficient of friction is smaller under corrosive conditions then under dry conditions. It was observed a lower level evolution of the electrode potential and a more electronegative level in the case of ball steel/Ti6Al4V contact pair. It shows a higher degree of deterioration in the case of Al2O3/Ti6Al4V contact pair.*

Key Words: *electrochemical parameters, corrosion, reciprocating wear, light alloy*

1.INTRODUCTION

Tribocorossion is a synergetic effect between wear and corrosion. In order to study this phenomena is necessary first to see the wear behavior in the absence of corrosive environment and then to see the wear behavior under corrosive conditions.

Extensive reciprocating wear research has been carried out on a wide range of materials, including combinations of similar and dissimilar materials [1,2].

In this study were used dissimilar materials: for the specimen a titanium alloy Ti6Al4V and for the counterpart (ball) were used two different materials: bearing steel and ceramic (Al_2O_3).

The choice of different materials for ball and specimen was based on the fact that there are many applications where contact occurs between dissimilar materials, such as the contact between screw/washer and many other components [3]; as for example disk/blade attachments in the higher stages of compressor or turbine part of the aircraft jet engines [1].

Titanium alloys are widely used in aeronautical (e.g. disk/blade attachments in the higher stages of compressor or turbine part of the aircraft jet engines [1] and biomedical applications (e.g. total joint replacement [4,5]). The main characteristics of these alloys are high strength, low density, excellent corrosive resistance and excellent biological resistance. The main disadvantage of these alloys is their poor wear resistance [6,7].

I. Liu et. al. [1] showed that the wear of titanium alloy (Ti6Al4V) in air was controlled by a combination of abrasion, oxidation and delamination. Regarding the COF, H. Dong et. al. [5] showed that the COF for the pair alumina/Ti6Al4V was about three orders of magnitude higher than for the pair alumina/steel. Also, they observed that the wear rate of alumina increased with the applied load and the COF on the pair alumina/Ti6Al4V decreased with the applied load

The two contact pairs used in this study were also subjected to wear in aqueous solution of 3.5% NaCl.

The aim of this experimental study was to analyze the behavior of a titanium alloy under reciprocating sliding in contact with steel and ceramic balls (Al2O3) in dry and corrosive environment (an aqueous solution of 3.5% NaCl).

2.EXPERIMENTAL PROCEDURE

2.1.Materials

The wear test specimen material is a titanium alloy Ti6Al4V and for the counterpart (ball) were used two materials bearing steel and ceramic (Al_2O_3 - 99.6%).

The chemical composition for Ti6Al4V alloy is given in Table 1 and the mechanical properties of the are shown in Table 2.

Table 1. Chemical composition (weight %) of Ti6Al4V alloy

Elements	Al	V	Fe	Sn	Ni
Ti6Al4V	6.1	4.21	0,2	0,003	0,01

Table 2. Mechanical properties of Ti6Al4V alloy

Material	Mechanical properties			
	E (GPa)	$\sigma_{0.2}$ (MPa)	σ_r (MPa)	ε_r (%)
Ti6Al4V	115	989	1055	16,1

E – Young modulus; b – $\sigma_{0.2\%}$ Yield strength; σ_r - Tensile strength; ε_r - Rupture strain.

2.2.Experimental setups

Reciprocating wear tests were carried out on a tribometer type CETR PRO 5003D, equipped with a system for immersing the contact pairs in the electrolyte (fig. 1) [8,9]. The system was connected to a potentiometer type Volta Lab SP 50, which records the electrochemical parameters during the wear test. The experiments were carried out at three normal loads 100, 120 and 140 N.

The coefficient of friction (COF) and the electrode potential were recorded throughout the tests. The analysis of the degradation process due to tribocorrosion and mainly due to corrosion was based on linear polarization curves.

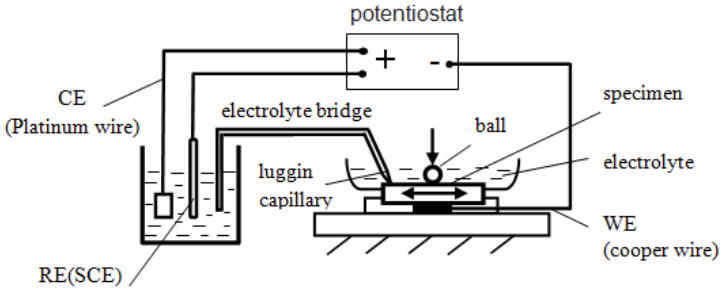


Fig. 1. Schematic of the corrosion wear method

Every 30 minutes was determined the electrode potential value (E_{corr}), as function of the current density, (i_{corr}).

3.RESULTS AND DISCUSSIONS

Figure 2 shows the evolution of coefficient of friction with the sliding distance in the case of preliminary dry reciprocating wear tests. The coefficient of friction showed an increasing tendency with the sliding distance for both contact pairs (Al2O3/Ti6Al4V and steel ball/Ti6Al4V).

It can be seen that the coefficient of friction for the pair Al2O3 ball/Ti6Al4V is smaller compared to the pair steel bearing ball/Ti6Al4V. It shout be highlighted that the COF for steel bearing ball/Ti6Al4V is more stable throughout the test.

Figure 3a shows the evolution of coefficient of friction with the sliding distance in the case of reciprocating wear tests in corrosive environment for Al2O3 ball/Ti6Al4V contact pair and for the three normal load values used in this study. It can be seen that the COF values are lower in the reciprocating wear tests in corrosive environment then in the dry reciprocating wear tests (from an average value 0,5 in dry conditions to 0,3-0,4 in corrosive environment).

Figure 3b shows the evolution of coefficient of friction with the sliding distance in the case of reciprocating wear tests in corrosive environment for steel bearing ball/Ti6Al4V contact pair and for the three normal load values used in this study. It can be seen that in this case the COF constantly increases with the sliding distance. Also, it can be observed that the COF decreases from about 0,15 - 0.2 for the pair steel bearing ball/Ti6Al4V to 0.3 - 0.4 for the pair Al2O3 ball /Ti6Al4V (the COF decreased by 50%).

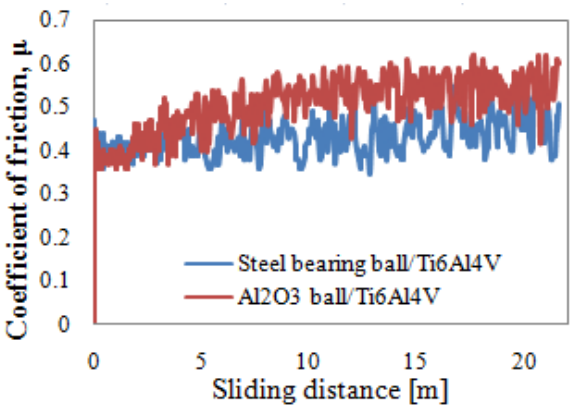
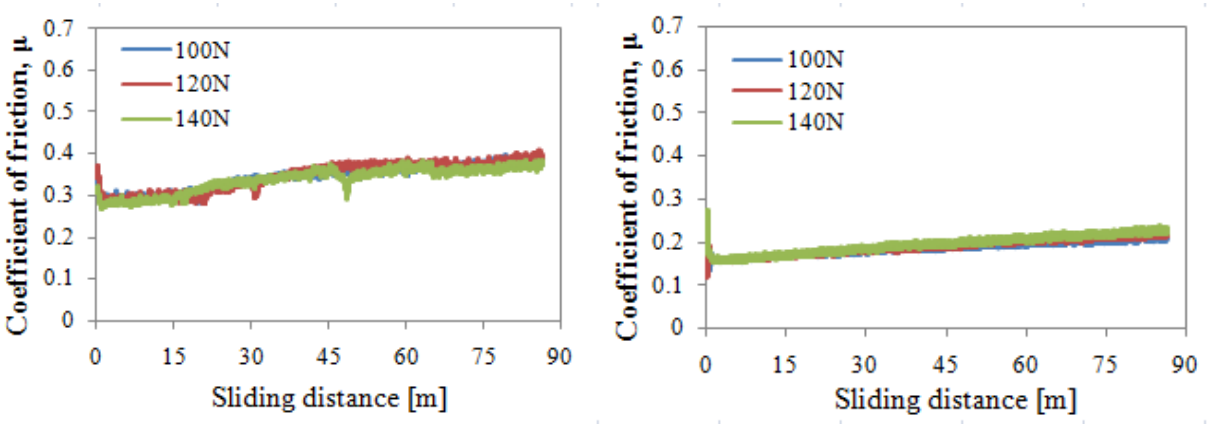


Fig. 2. Evolution of the coefficient of friction with the sliding distance for dry reciprocating wear tests



a b

Fig. 3. Evolution of the coefficient of friction with the sliding distance for reciprocating wear tests in corrosive environment: a. Al2O3 ball /Ti6Al4V and b. steel bearing ball/Ti6Al4V

Figure 4 presents the wear loss for both contact pairs. The values presented in this graph are average values of five measurements. In can be seen that under dry conditions the weight loss was smaller for the steel bearing ball/Ti6Al4V contact pair compared to the Al2O3 ball/Ti6Al4V contact pair.

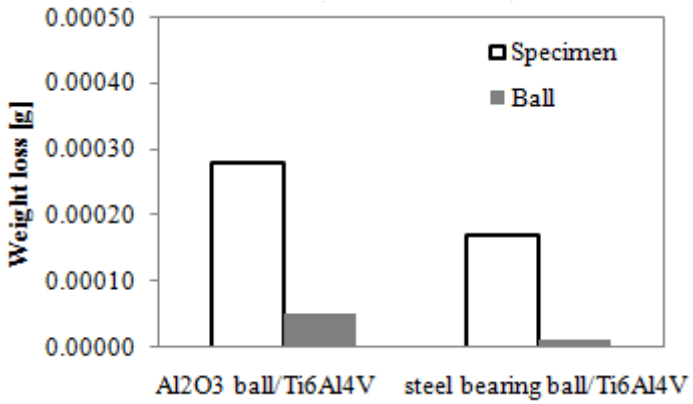


Fig. 4 Wear loss as a function of the contact pairs

The analysis of the degradation state of the surface layer manifested by the synergy between the micro and macroscopic changes and also by the stability of the process in corrosive environment can be reflected by the evolution of the electrode potential [10,11].

Thus, the evolution of the electrode potential during the wear process (figs 5,6) shows a similar behavior for both contact pairs studied. The peaks that can be seen on the plots represent the moment when there are some electrochemical changes due to the dynamics of the breaking and recovering processes of oxide layers on the studied material (Ti6Al4V). It can be remarked a higher stability of the oxide layers for the pair steel bearing ball/Ti6Al4V, that is in concordance with the

evolution of the weight loss (fig. 4). For this contact pair can be remarked an instability of the process for higher applied loads. An opposite behavior was obtained for the pair Al2O3 ball/Ti6Al4V where a higher stability of the process was observed at higher applied loads.

This behavior of the two contact pairs can be explained based on the level of surface quality of the balls. The steel bearing ball is highly polished and the ceramic balls have a roughness value of about Ra=0,2 due to material porosity.

Regarding the evolution of electrochemical parameters during the tribocorrosion process it should be highlighted that the potential of the metal is the way that the anodic and cathode reactions are maintained in equilibrium.

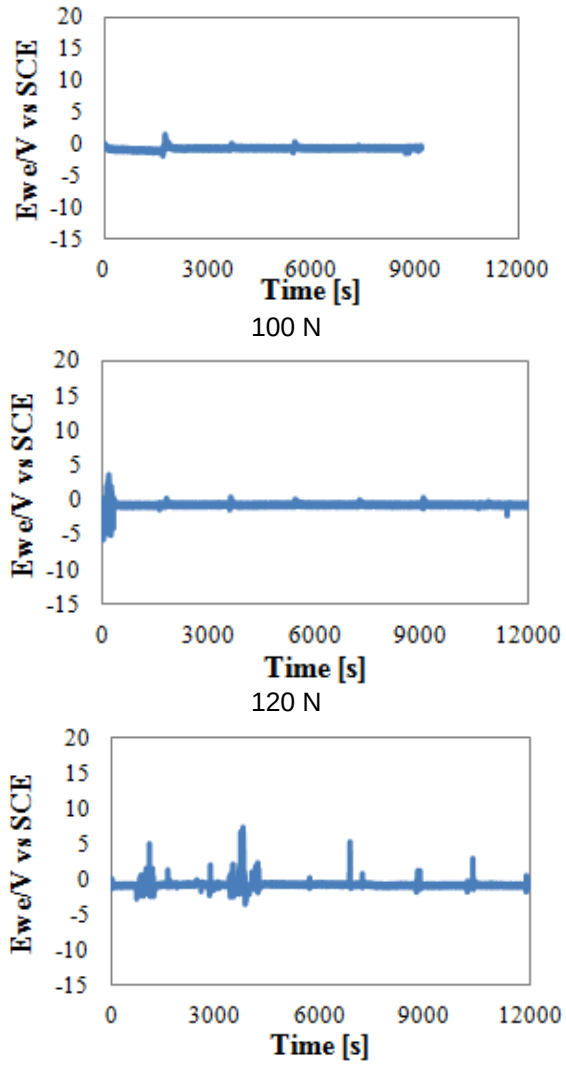


Fig. 5. Electrode potential vs. SCE (steel bearing ball/Ti6Al4V)

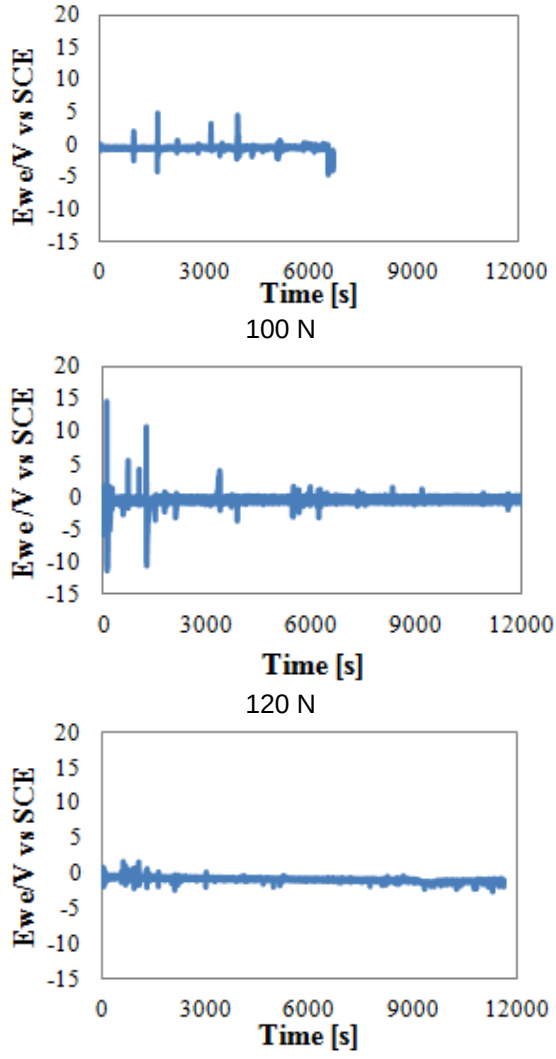


Fig. 6. Electrode potential vs. SCE (Al2O3 ball/Ti6Al4V)

The equilibrium potential accepted by metal without the electrical connection to metal is named OCP (Open Circuit Potential) or corrosive potential. The anodic or cathode current fixed at this potential is named corrosive current (i_{corr}) [12]. This current gives the possibility to determine the corrosion rate. The corrosive current (i_{corr}) cannot be measured directly, but can be estimated using electrochemical techniques. For any real system the corrosive current and the corrosion rate can be influenced by several variables, including the type of metal, electrolyte composition, the movement of the solution, etc.

In order to establish the dynamic of the degradation process by tribocorrosion was used the potentiostatic polarization method and Tafel analysis. Thus, every 30 minutes was determined the electrode potential value (E_{corr}), as function of the current density, (i_{corr}).

It can be seen in both cases (figs. 7 and 8) larger fluctuations of the parameter E_{corr} and it evolution towards more electronegative values with the increase of the applied load. On the other hand, by increasing the applied load there are less fluctuations. It can be observed that the fluctuations range is smaller for the pair steel bearing ball/Ti6Al4V compared to the pair Al2O3

ball/Ti6Al4V. It is confirmed that the intensity of wear process is higher in the case of the pair Al2O3 ball/Ti6Al4V compared to the pair steel bearing ball/Ti6Al4V. These aspects are also highlighted in figure 9 where it is shown the evolution of electrode potential, E_{cor} with time for both contact pairs (the values are in accordance with the values of the E_{cor} from figures 7 and. 8).

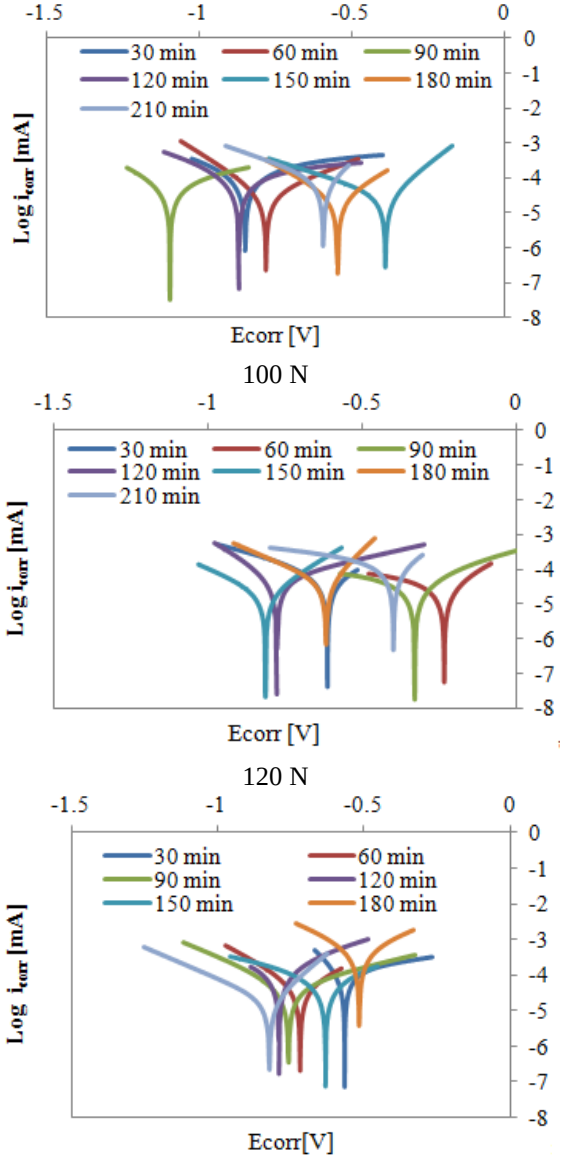


Fig. 7. Evolution of the Tafel curves (steel ball/Ti6Al4V)

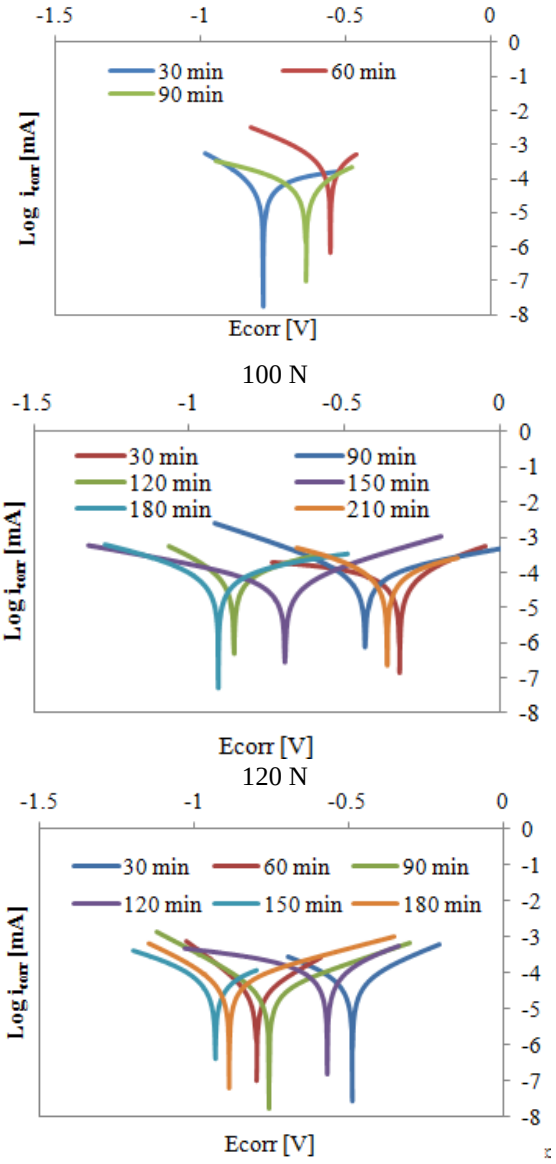


Fig. 8. Evolution of the Tafel curves (Al2O3/ Ti6Al4V)

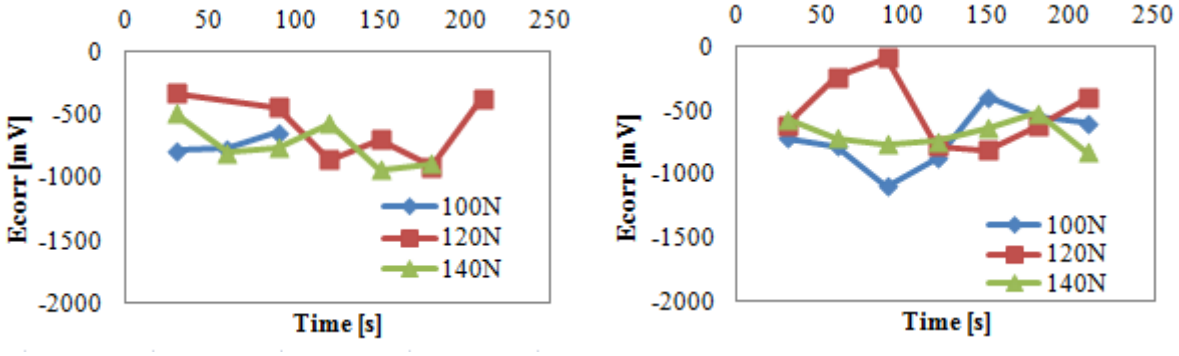


Fig. 9. Evolution of E_{corr} vs. Time: a. Al2O3 ball/Ti6Al4V and b. steel bearing ball/Ti6Al4V

4.CONCLUSION

The research describes the tribocorrosive behaviour in a comparative way for two contact pairs (Al2O3 ball/Ti6Al4V and steel bearing ball/Ti6Al4V).

The conclusions drawn from this work are as follows:

- higher coefficient of friction were observed for both contact pairs under dry conditions than under corrosive conditions*;*
- it is observed that the coefficient of friction for the pair Al2O3 ball/Ti6Al4V was 2 times higher than for the pair steel bearing ball/Ti6Al4V.
- the steel bearing ball/Ti6Al4V pair showed a better tribological behavior compared to Al2O3 ball/Ti6Al4V under dry test conditions and also in corrosive environment.
- The corrosive environment leads to an improvement of the tribological conditions.
- for the steel bearing ball/Ti6Al4V pair the chemical stability was higher.
- the different tribochemical behavior of the two contact pairs used in this study can be explained based on the surface quality.

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COPPER FRICTIONAL COATINGS UNDER CONDITIONS OF SELECTIVE TRANSFER

Gottlieb POLZER (Germany), Emilia ASSENOVA (Bulgaria) and Dr. TSERMAA (Mongolia)

Abstract: *The paper deals with the studies, knowledge and practices carried out in the Laboratories of the Department „Tribotechniques“ at the Higher Technical Schools in Chemnitz and Zwickau, Germany, under the guidance of the Head of the Department Prof. Dr. sc. Dr. Gottlieb Polzer. It focuses on the possibilities of the tribotechnologies in saving materials and energy by means of friction and wear reduction by frictional coatings and selective transfer of material*.
Key Words: *frictional coatings, selective transfer, no-wear effect, hydrogen wear*

1. INTRODUCTION

It is well known how small is the part of human knowledge, especially of the knowledge in tribology, which is used in practice. Extremely serious is the situation of application in practice of principally new knowledge, such are the cases with the effect of the selective transfer and the hydrogen wear mechanism in the frictional coatings. Wear reducing frictional coatings obtained under procedures of **selective transfer of material** between the contacting surfaces are of great importance for practical applications.

In 1966 D.N. Garkunov and I.V.Kragelskii have registered as a scientific discovery the selective transfer of material from one contacting specimen to the other under special conditions [1]. Of particular interest, both in theory and practice, were the studies of the No-wear friction and the hydrogen wear [2].

2. SELECTIVE TRANSFER OF MATERIAL

D. N. Garkunov and G. Polzer are of the first researchers in theory and practice of the selective transfer of material during friction of Cu-containing contact surface with special surface-active substances, the corresponding formation of the “servovite layer” (notion adopted as per analogy with the contact in animal/human articulation), and the resultant high reduction in friction and wear [1, 2, 3, 4]. Prof. Garkunov was awarded the 2005 Tribology Gold Medal for his “achievements in tribology, especially in the field of selective transfer”. Beside the mentioned references, the phenomenon of selective transfer is observed and commented in various tribological studies [5, 6, 7, 8, 9].

Characteristic for the process of selective transfer of material between the frictional surfaces is the formation of secondary layer with low shift resistance in the contact. This protective layer cannot accumulate dislocations and is highly antifrictional. The self-organization phenomena in this case depend on the interface energy and the material exchange. Generation of that layer requires special combination of materials of the contact surfaces, as well as special lubricant between them (e.g. glycerol). Synergy effect in the forming of new contact structures in the contact between surface materials and lubricant is desirable as optimization of the contact couple. Here, synergy is available, as two or more agents (contact surface material and lubricant), working together, produce a result not obtainable by any of the agents independently.

3. FRICTIONAL COATINGS UNDER CONDITIONS OF SELECTIVE TRANSFER

3.1. Overall consideration

The paper focuses in the procedures of obtaining brass and copper frictional coatings in the case of nonabrasive treatment of steel surfaces. Procedures of the study of copper or brass frictional coatings through selective transfer of materials are considered.

Tribologists have the task to keep the destruction as small as possible or to stop it, in order that the system comes to the equilibrium process between destruction and regeneration. Exactly this happens in the processes of selective transfer. This phenomenon is assisted by the rubbing of brass under the special conditions of selective transfer of material. A steel shaft to be coated is both subjected to rotation and to the pressure of the brass stick in the presence of a special lubricant. Some results of the basic studies and application in the area of copper frictional coatings are presented below. Based on equation of the theoretical physics, Prof. Polzer [3] had formerly derived equations of self-organization at friction. Always when destruction problems are available in nature, there are two possibilities for the whole system:

- There is simultaneous growth processes, which involve equilibrium between destruction and regeneration, or
- Most often destruction leads to exponential destroying of the whole system, in our case the tribological couple.

3.2. Experimental work

The phenomenon of direct coating deposition is assisted by the rubbing/deposition of brass under the special conditions of selective transfer of material. The principle scheme of the assembly is shown in Fig 1.

The steel shaft to be coated is both subjected to rotation and to the pressure of the brass stick in the presence of a lubricant. Different processes result with following peculiarities. In the contact zones emerges reactive coating deposition with special properties:

- Copper is rubbed on the steel friction surfaces with totally different electro-chemical potential.
- Not only the content but also the structure in the friction surfaces is being changed.

The press forces at the rotation of the brass stick involve great pressure in the contact zone between stick and basic material due to the relative small contact surface, hence a positive gradient of the shear strength in depth direction of the friction surface according to I. V. Kragelsky [10].

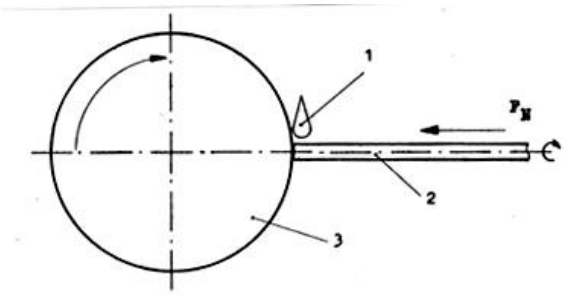


Fig. 1. Principle assembly for brass deposition on a shaft *(1 – surface active liquid; 2- brass rod; 3- shaft to be coated)*

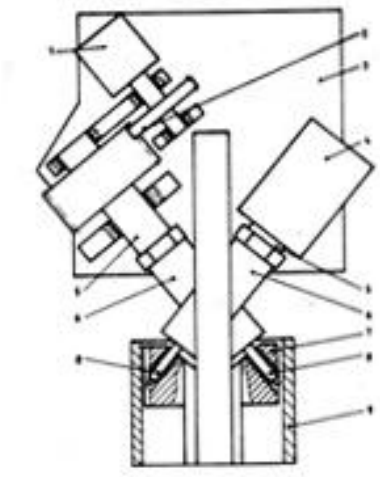


Fig. 2. MBZ 3A Brass-coating device for sliding bushes (application in lathes)

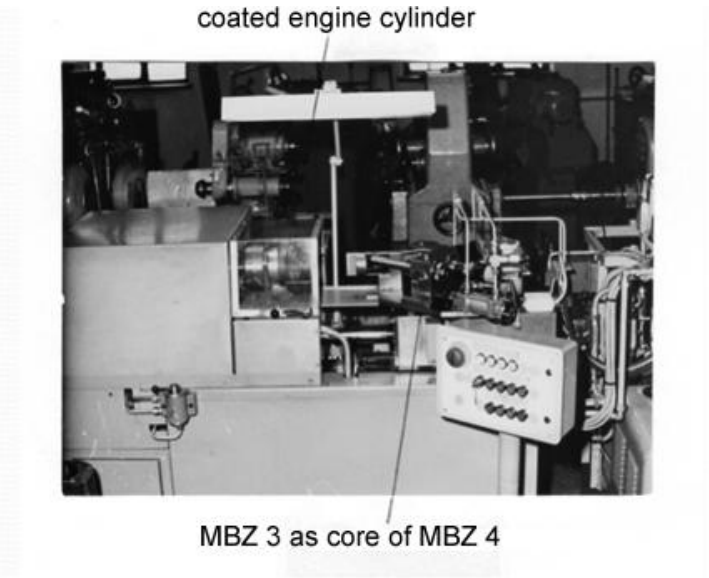
As a result, a tribological system appears which can bear higher loads at the influence of various processes. Different machines were designed and constructed at the Department Tribotechnik in Zwickau' Higher Technical School, corresponding to the principles of the frictional deposition and the ideas of the selective transfer. Many pieces of the devices „MBZ 1 B" for shaft coatings and „MBZ 3 A" (see Fig.2) for application in rotating machines were manufactured, e.g. the „MBZ 3 A" for engine cylinders was produced in 30 items. Unfortunately there is not sufficient use of the advantages of the deposition of copper frictional coatings in the overall practice.

Various applications of the brass-coating device are given in Figs. 2, 3, 4, 5.

The principle scheme of a device for deposition on cylinders of copper frictional coatings is given in Fig. 6.



Fig. 3. View of the brass-coating device MBZ 3A



4. The brass-coating device applied in automatic machine

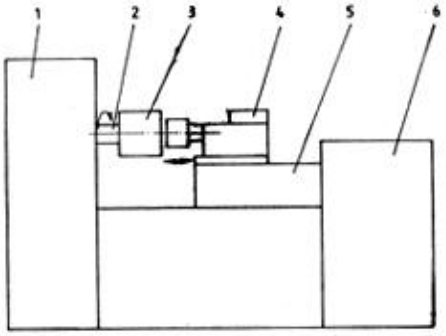


Fig. 5. MBZ 4A The brass-coating device with automated frictional coating process

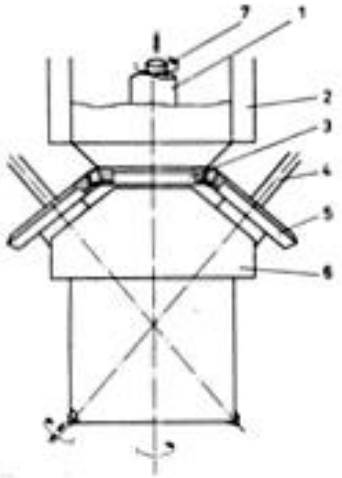


Fig. 6. Brass-coating device for cylinder-bushing by boring machine

Further, some diagrams referring to basic new results are presented. Fig. 7 shows the content of Cu and Zn in the brass in the shadowed zone for Cu Zn 37, as well as coated surfaces in depth.

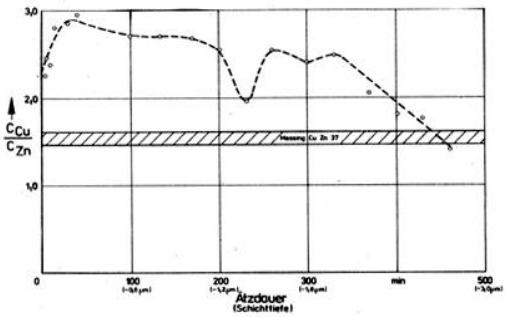


Fig. 7. Ratio of Cu and Zn in brass in the coating in different depth of the surface

In Figs. 8 and 9 is given the variation of hardness in depth; so we can obtain the strengthening also at different rotation speeds.

Figs. 10 and 11 show the percentage of the improvement (improvement of the wetting ability) in the usage of oil B for different lubricants and coated surfaces.

It is highly important for practical applications that the inclination for welding between the friction surfaces is significantly lowered under conditions of selective transfer.

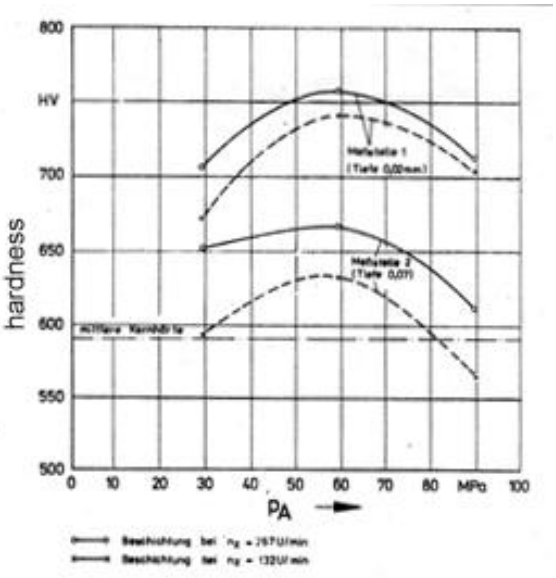


Fig.8. Hardness in different depth after frictional coating deposition on steel

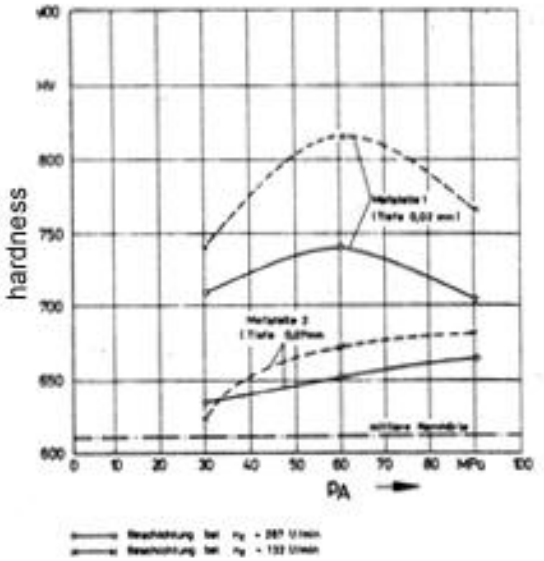


Fig.9. Hardness in different depth after frictional coating deposition on GGL25

Fig. 12 shows the reduction of hydrogen concentration of the friction surface in depth. By means of brass frictional coating, it can be obtained in different constructions of steel and cast iron not only the 10 - 20 % lowering of friction force, but also a changed wear distribution, which is to be seen, e.g., for the upper death point in engine cylinders of 2-cylinder-twotact-Ottomotors after various completed paths (see Fig. 13).This was the reason that the brass frictional coatings were successfully applied in the practice of the company Peißig in Zwickau especially in highly loaded race motors for more than 20 years.

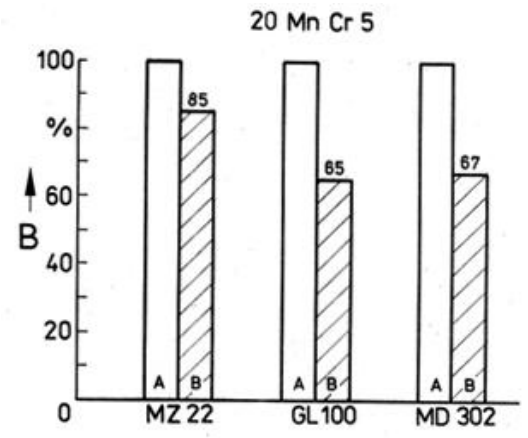


Fig. 10. Improvement of the oil-wetting for different oils by steel

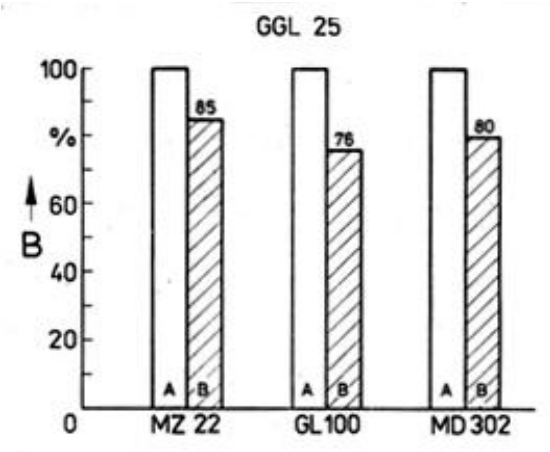


Fig. 11. Influence of the frictional coating on the wetting ability by cast iron

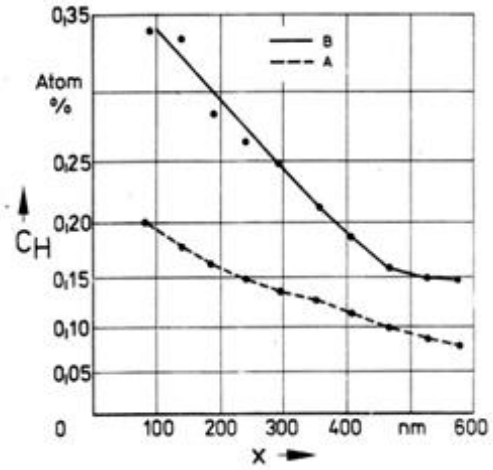


Fig. 12. Reduction of H_2 concentration at the frictional surface in depth

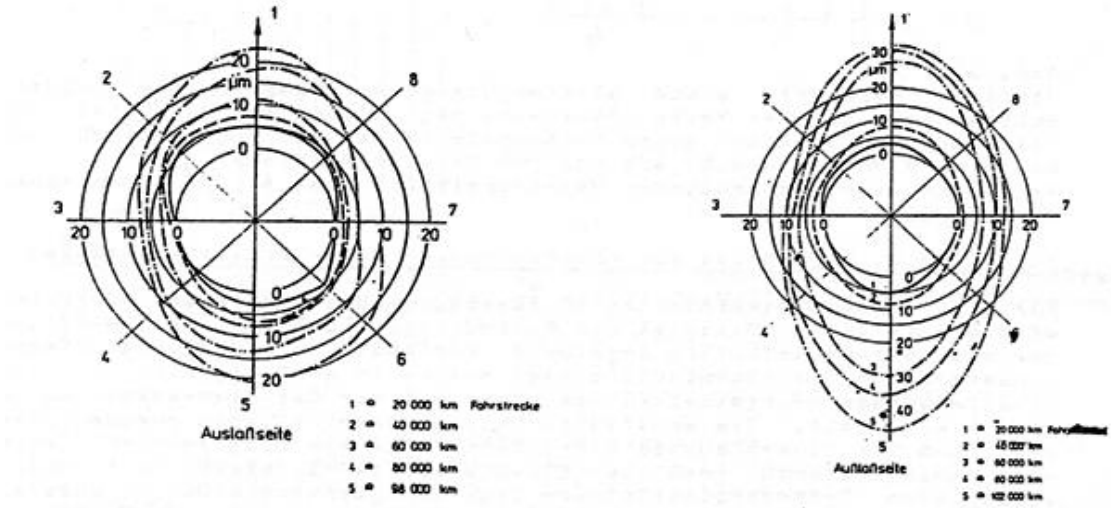


Fig. 13. Wear distribution in upper dead point of engine cylinder after different sliding paths: for cylinder with frictional brass coating (left) and without coating (right)

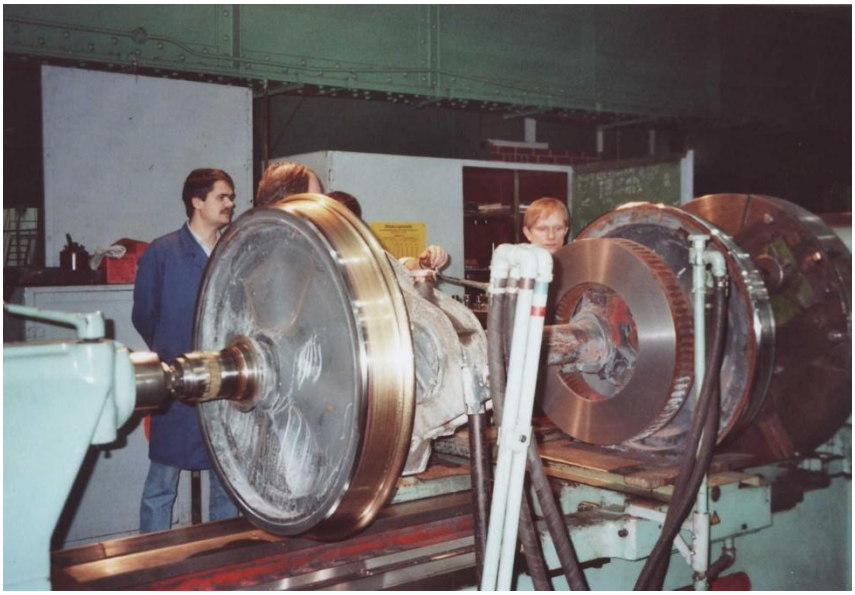


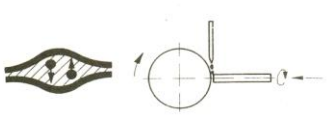
Fig. 14. Frictional coating of big wheels

4.CONCLUSION

In above tribological study, a self-organization in the system brass-glycerol-steel is observed and the obtained film – a designed or programmable coat with significant change of wear-resistance – is linked to the concept of a coating deliberately manipulated to influence its properties during friction. Major result is the low wear of components coated under condition of selective material transfer mode with wide practical application. Important is the reduction of the concentration of hydrogen at the frictional surface and, respectively, the lower hydrogen wear. It is highly important for practical applications that the inclination for welding between the friction surfaces is significantly lowered under conditions of selective transfer. A considerable practical result is the possibility for dismantling-free restoration of worn units/couples.

The practical implementation of brass-copper frictional coating is of extreme importance and was realized in Germany, Russia, Kazakhstan, etc.

The interdisciplinary character of the study and application of technologies for frictional coating formation, layer growth techniques, surface texturing, etc. involves intervention by specialists of different sciences. The work and collaboration between scientists of Russia, Germany, Poland, Bulgaria, Mongolia and Vietnam in this field was carried out by the International Council for Selective Transfer and Frictional coatings, established in 1990 in London.



INTERNATIONAL COUNCIL
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IMPACT OF MECHANOCHEMISTRY IN FERRITE CATALYST PREPARATION

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Abstract: *Spinel ferrite $Ni_{0.5}Fe_{2.5}O_4$ was successfully prepared by mechanochemical synthesis or thermal treatment. As precursor for synthesis of single phase nanosized ferrite materials was used co-precipitated nickel ferrite sample with additional intermediate phase of iron oxihydroxides (FeOOH). Moessbauer and X-ray diffraction measurements are made to establish magnetic structure and phase composition of synthesized spinel phase nickel ferrites. The investigations show that mechanochemically activated nanodimensional ferrite material has better textural characteristics than thermally treated sample. This is of great importance of their catalytic behavior.*

Key Words: *ferrite, co-precipitation, mechanochemical treatment, characterization*

РОЛЯ НА МЕХАНОХИМИЯТА ПРИ ПОЛУЧАВАНЕ НА ФЕРИТНИ КАТАЛИЗАТОРИ

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Резюме: *Шпинелен ферит $Ni_{0.5}Fe_{2.5}O_4$ е успешно получен чрез механохимичен синтез или термична обработка. Като прекурсор за синтеза на еднофазните наноразмерни феритни материали е използвана утаена никел съдържаща феритна проба,в която има примес от допълнителна междинна фаза - железен оксихидрооксид (FeOOH). Проведени са Мьосбауерови и рентгенодифракционни измервания за установяване на магнитната структура и фазовия състав на синтезираните шпинелни феритни материали. Изследванията показват, че механохимично активираният наноразмерен феритен материал има по-добри текстурни характеристики, в сравнение с термично обработената проба. Това е от голямо значение за тяхното каталитично поведение.*

Ключови думи: *ферити, съутаяване, механохимична обработка, охарактеризиране*

1. INTRODUCTION

It is well known that the physical and chemical properties of nanosize materials strongly depend on the preparation conditions. Consequently, different methods for preparation of nanosize powders were described in the literature. Especially important is the possibility to control particle size and particle size distribution during synthesis [1]. The use of biogenic materials as precursors for different ferrite synthesis is very promising and environmental friendly.

Mechanochemistry is the subject that deals with the chemical and physicochemical changes of substances induced by mechanical force [2]. In the last decade, mechanochemistry was frequently used to produce different nanosize compounds. Depending on the system and the applied conditions, solid state reactions could be done at room temperature or at reduced temperatures, because the mechanochemical treatment already induced structural changes [1]. Mechanochemical activation in a high energy ball mill is a popular technique for synthesizing metallic alloys and intermetallic

compounds that either have very complex compositions or have melting temperatures very high to prepare by conventional melting and alloying. The main advantage of the process is that it provides a situation of intense energy in localised parts of the load where solid state diffusion and dissolution are forced on, even though the resulting material may be thermodynamically unstable. Frequently, metastable structures, solid solutions and phases are formed [3]. High-energy milling is a very suitable solid state processing technique for the preparation of nanocrystalline ferrite powders exhibiting new and unusual properties. For example, high energy ball-milling leads to a change in the distribution of cations in both sites, which induces an increase of magnetic properties [4].

In our research paper we will demonstrate the advantage of mechanochemical synthesis to other methods for preparation of nanosized ferrite materials. The aim is to compare the physico-chemical properties of nanodimensional nickel contained ferrites ($Ni_{0.5}Fe_{2.5}O_4$) prepared by combination of co-precipitation and mechanochemical activation or low temperature treatment respectively.

2. EXPERIMENTAL

Nickel ferrite-type precursor sample was synthesized using co-precipitation procedure discussed in our research work [5]. The amount of 2.35 g co-precipitated $Ni_{0.5}Fe_{2.5}O_4$ spinel ferrite material was milled in container with volume 250 ml in nitrogen atmosphere for 3 hours and rotation speed 500 rpm. The weight ratio between balls and powder is 30:1. The milling activation process is carried out in high energy planetary ball mill type PM 100, Retsch, Germany. The low temperature treatment of the co-precipitated nickel contained ferrite sample ($Ni_{0.5}Fe_{2.5}O_4$) was performed in argon media for 3 hours at 300 ^oC in the furnace “Eurotherm”, England [6]. The structural properties of the produced nanodimensional ferrite materials were examined by various techniques - X-ray diffraction analysis and Moessbauer spectroscopy, BET method.

3. RESULTS AND DISCUSSION

Fig. 1 shows the X-ray diffraction (XRD) pattern of the initial nickel ferrite-type precursor material synthesized by co-precipitation procedure [5]. The sample contains both spinel phase ($Ni_{0.5}Fe_{2.5}O_4$) and intermediate phase FeOOH. Additional nickel-contained phases are not presented. Mechanochemical activation and thermal treatment at 300 ^oC and argon atmosphere of the initial material lead to formation of single non-stoichiometric spinel nanosized nickel ferrite material $Ni_{0.5}Fe_{2.5}O_4$ (PDF-75-0449; PDF-10-0325) which can be seen on the registered XRD patterns of samples (see Fig. 2 and Fig. 3). X-ray amorphous halo peaks are also obtained. Registered broad and low-intensity diffraction peaks confirm the high dispersion especially for mechanochemically prepared ferrite sample $Ni_{0.5}Fe_{2.5}O_4$.

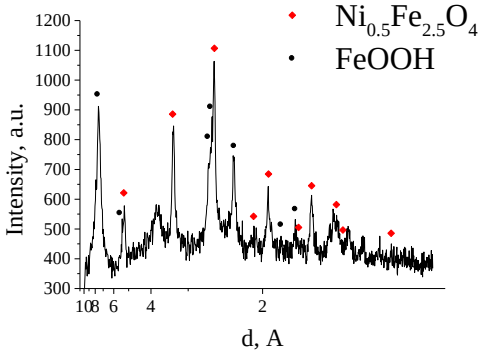


Fig. 1. XRD patern of initial material.

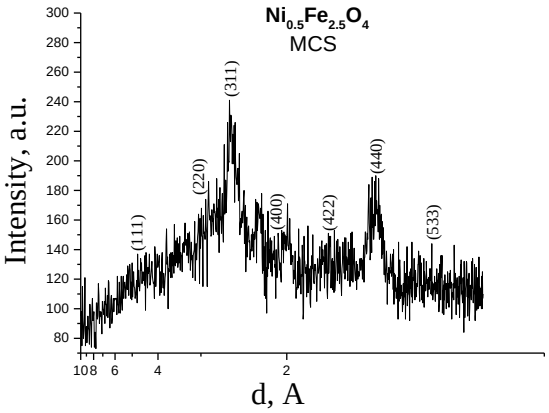


Fig. 2. XRD patern of $Ni_{0.5}Fe_{2.5}O_4$ after mechanochemical activation (MCS).

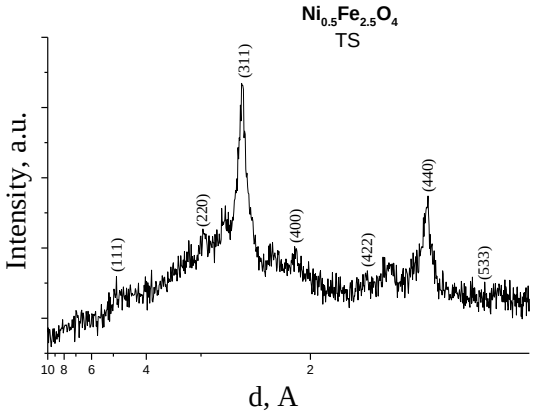


Fig. 3. XRD patern of $Ni_{0.5}Fe_{2.5}O_4$ after thermal treatment at 300 ^oC (TS).

The Moessbauer spectra of initial and treated samples at room temperature (RT) and low nitrogen temperature (LNT) are shown on Figures 4-7. The Moessbauer spectrum of precursor material at RT (not shown) registered the presence of doublet lines only. In order to investigate their origin LNT Moessbauer spectrum is obtained (Fig. 4). The evaluation of spectrum reveals the presence of spinel phase presented by sextet components. They correspond to tetrahedrally and octahedrally coordinated iron ions in nanosized ferrite material. The calculated values of hyperfine fields are smaller than the characteristic ones for the bulk material. Doublet components belong to iron oxihydroxide phase. Comparison of RT Moessbauer spectra of mechanochemically and thermally treated samples (see Fig. 5 and 6) reveals the different dispersity of the samples. It is well seen that the thermal treatment of precursor gives the synthesis of single phase spinel material having both doublet and sextet type components. In the case of mechanochemically prepared sample Moessbauer spectrum includes only superparamagnetic doublet components. The calculated hyperfine parameters according core-shell model show the presence of 3-5nm spinel material. This is confirmed by LNT spectrum of material (Fig. 7), as well as from calculated hyperfine parameters of spectra components.

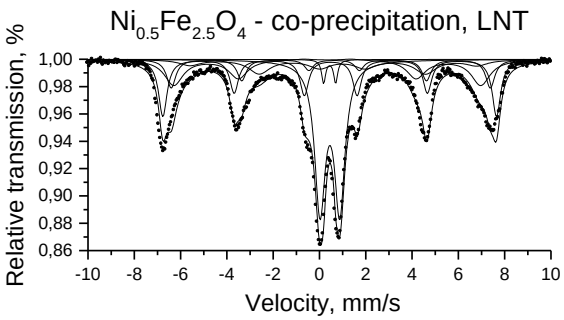


Fig. 4. Moessbauer spectrum of co-precipitated precursor material at LNT.

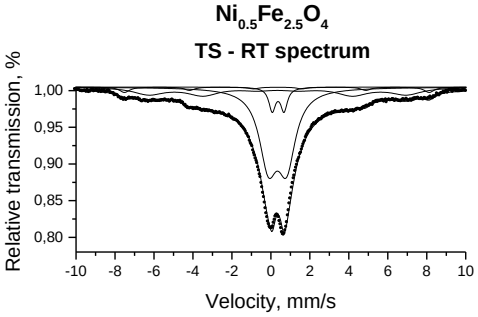


Fig. 5. Moessbauer spectrum of thermally (TS) synthesized nanosized ferrite material $Ni_{0.5}Fe_{2.5}O_4$ at RT.

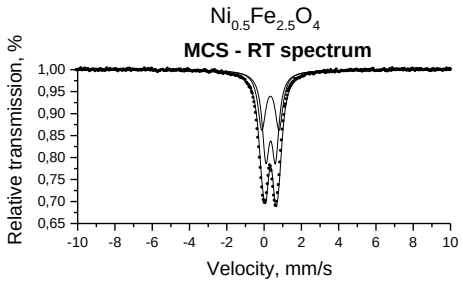


Fig. 6. Moessbauer spectrum of mechanochemically (MCS) synthesized nanosized ferrite material $Ni_{0.5}Fe_{2.5}O_4$ at RT.

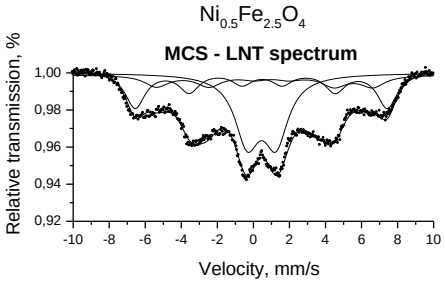


Fig. 7. Moessbauer spectrum of mechanochemically (MCS) synthesized nanosized ferrite material $Ni_{0.5}Fe_{2.5}O_4$ at LNT.

The performed experimental studies about textural characteristics of prepared ferrite samples present that differences in the specific surface area, maximum pore diameter, pore volume of mechanochemically synthesized $Ni_{0.5}Fe_{2.5}O_4$ (S_{BET} = 168 m^2/g; 3.5 nm; 0.129 cm^3/g) and thermally treated material (S_{BET} = 124 m^2/g; 8.6 nm; 0.339 cm^3/g) are affected by different routes for their production [7]. The use of mechanochemical activation for preparation of single spinel phase nanosized ferrite $Ni_{0.5}Fe_{2.5}O_4$ leads to product with higher specific area (S_{BET} = 168 m^2/g) than the material (124 m^2/g) obtained by low temperature treatment.

4. CONCLUSION

Series of nanosized ferrite materials $Ni_{0.5}Fe_{2.5}O_4$ are prepared by different synthesis routes such as co-precipitation and low temperature or mechanochemical treatment of co-precipitated ferrite samples. Study of magnetic properties of as-prepared materials shows superparamagnetic behavior of all ferrite-type materials at room temperature and at low nitrogen temperature. The mechanochemical activation and low thermal treatment lead to formation of single spinel phase. Mechanochemical synthesis provides the possibility to prepare nanosized materials with enhanced properties in comparison with thermally treated once. These samples show higher dispersity which is of great importance of their catalytic properties.

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PREPARATION OF ZnO-TiO_2 MIXED OXIDES SYSTEMS BY MECHANICAL ACTIVATION

Nina G. KOSTOVA, Martin FABIAN, Anna ZORKOVSKA, Boris KUNEV, Maya SHOPSKA, Peter BALAZ

Abstract: *Mixtures of ZnO and TiO_2 powders were mechanically activated using high-energy ball mill during different time intervals. The phase composition in the ZnO-TiO_2 system after milling was analyzed using the XRD method and Fourier-transforming infrared (FT-IR) spectroscopy. The influence of mechanical activation on mixed oxides synthesis along with changes within powders during mechanical treatment was observed. According to X-ray analysis, intensive milling of stoichiometric ZnO and TiO_2 powder mixture leads to decrease to crystalinity as a consequence of defect formation and the formation of a zinc titanate phase.*

Key Words: *mechanochemistry, mechanical activation, mixed oxides*

1.INTRODUCTION

The mixed oxides are among the most often investigated compounds, due to their wide range of applications. They are used as catalysts, semiconductors, sensors and magnetic materials [1, 2]. The mixed-oxides catalytic systems based on Zn-Ti have been applied as gas sensors for NO and CO, as pigments, adsorbents for the removal of hydrogen sulfide, liberated during the combustion of charcoal [3]. An important advantage of these catalysts is the fact that their regeneration occurs at moderate temperatures.

The mixed oxides can be prepared by different methods including the sol-gel process [4], spray pyrolysis [5], conventional solid-state interaction [6], mechanochemical synthesis [7] etc. The sol-gel method of preparation of mixed oxides possesses certain advantages in comparison to the rest of the listed methods such as high purity, homogeneity of the microstructure of the prepared powder materials and an appropriate control over the synthesis conditions. The mechanochemical synthesis is a powerful tool as well as an economically beneficial approach for the reparation of nanosized materials, including also the class of mixed oxides [8].

The titania-containing mixed oxides of the perovskite-like type are obtained mainly by the sol-gel method [9] or by the method of solid-state interaction [10]. The phase composition of the ZnO-TiO_2 system is quite complicated and it is determined to a great extent by the starting initial materials, applied in the synthesis as well as by the used additives and conditions of synthesis [11]. The system ZnO-TiO_2 can exist in the form of various compounds, including hexagonal $ZnTiO_3$, cubic Zn_2TiO_4 and another cubic $Zn_2Ti_3O_8$ phases [12-13]. Under the conditions of solid-state interaction, after calcination at 495^{o}C, the metastable $ZnTiO_3$ phase is being transformed into Zn_2TiO_4 and rutile phases.

The purpose of the present investigation was to synthesize ZnO-TiO_2 mixed oxide via mechanical activation of the stoichiometric mixture of TiO_2 (P25 Degussa) and zinc oxide. During the mechanochemical activation of mixtures of oxides the homogeinity of the initial materials is being improved, their reactivity is enhanced and therefore the reaction is occurring at lower temperatures [8].

2. EXPERIMENTAL

Mechanochemical synthesis of ZnO-TiO_2 mixed oxides were performed in a laboratory planetary mill Pulverisette 6 (Fritsch, Germany) by high-energy milling of stehiometric mixture of zinc oxide and commertial TiO_2 P25 (Degussa), containing 75 % anatase and 25 % rutile. The following experimental conditions were used for the mechanochemical synthesis. Loading of the mill : 50 balls af 10 mm in diameter; material of milling chamber, 250 ml; mass of sample 6 g; ball-to-powder ratio 73:1; room temperature, rotation speed of the mill planet carrier, 500 min^{-1}, milling time 20 or 30 min.

X-ray powder diffraction data were collected over an an gu lar range 15<2Theta<115° with steps 0.1 and fixed count ing time of 20s per step, using a D8 Advance diffractometer (Bruker, Germany),

work ing with Cu Ka radiation (40 kV/40 mA) and a scintillation point detector, arranged in Bragg-Brentano geometry. Fixed divergence slit of 0.3 mm width and receiving slit of 0.1 mm width were used and for back ground attenuation a secondary graphite monochromator was employed.

The infrared spectra of the samples were recorded by Nicolet 670 (Thermo Electron Co.). The method of dilution of the studied sample in KBr at concentration of 0.5 % was used.

3. RESULTS AND DISCUSSION

The structural changes, caused by the mechanical activation of a mixture of ZnO and TiO_2, processed in a high-energy mill, have been monitored by means of XRD. Figure 1 represents the XRD-patterns of the initial mixture of zinc oxide and titania as well as the pattern after mechanical activation in the course of 20 min.

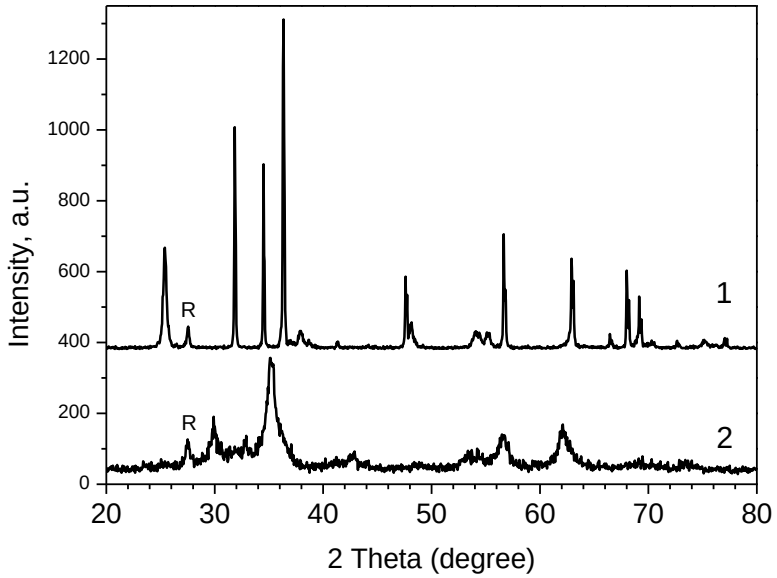
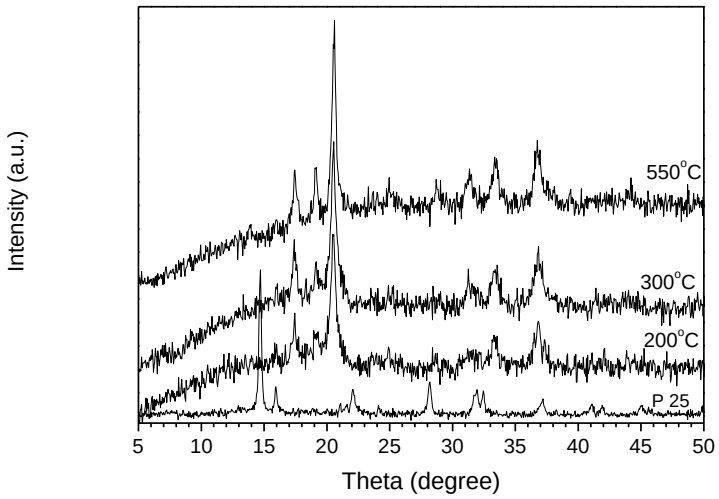


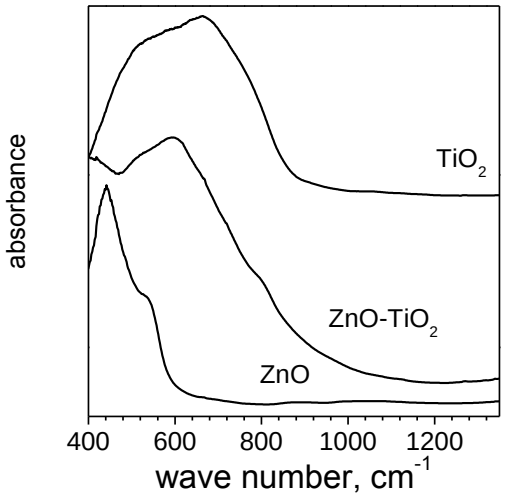
Fig. 1. XRD patterns of 1- initial mixture of ZnO and TiO_2, 2-mechanical activated mixture during 20 min.

The intensity of the diffraction lines of the mechanically activated samples after the processing has become considerably lower. The comparison of the represented XRD-patterns shows that an interaction is occurring between the initial oxides resulting in the formation of a new phase. Neither reflections of the initial zinc oxide are observed in the XRD pattern of the mechanically activated sample, nor those of anatase phase, however rutile phase is evidently present. Therefore, in spite of the short time interval of mechanical activation in a high-energy mill, a mechanochemical reaction has occurred, leading to the formation of zinc titanate. The precise analysis is difficult due to the overlapping of some of the diffraction lines, as for instance the (311) plane reflex of the orthotitanate phase Zn_2TiO_4 is being overlapped by the (110) plane reflection, belonging to the hexagonal metatitanate $ZnTiO_3$. The analysis proves simultaneously the formation of the phases of hexagonal $ZnTiO_3$ in addition to the reflections characteristic of the cubic Zn_2TiO_4 phase. It is important to note here that under the selected conditions of mechanochemical synthesis no formation of the third possible phase of cubic $Zn_2Ti_3O_8$ has been registered. The average size of the crystallites of the prepared powder samples, calculated by Scherrer's method, is about 50 nm. The rutile phase, which is about one quarter of the commercial TiO_2 Degussa P25 product, does not take part in the mechanochemical reaction under these specific conditions. No substantial differences have been observed in the XRD patterns of the samples, activated mechanically for 30 and for 40 minutes. This fact gives us the reason to suppose that under the chosen conditions of activation equilibrium of the mechanochemical reaction has been reached.



Фиг. 2. X-ray diffraction patterns of mechanochemically activated sample ZnO-TiO_2 at 30 min after calcination for 2 h at 200, 300 u 550°C.

Figure 2 represents the XRD patterns of a sample, activated mechanically for 30 min and thereafter calcined at 200, 300 and 550°C. A lowering in the intensity of the rutile diffraction line is being observed upon increasing the temperature of calcination up to 300°C. In parallel to this tendency there is an increase in the content of the hexagonal $ZnTiO_3$ phase. The higher calcination temperature leads to greater sharpness of the peaks, whereupon the intensity of the peaks, characteristic of $ZnTiO_3$, is growing up further after calcination of the sample at 300°C. The cubic $ZnTiO_3$ phase is unstable and after further calcination at higher temperature it is being transformed into the hexagonal phase. In our case of mechanochemically synthesized samples this process is occurring at a temperature, lower than that reported by Yamaguchi et al. [9], who have carried out a conventional solid-state reaction.



Фиг. 3. FTIR spectra of initial ZnO and TiO_2 P25 (Degussa) and mixed oxide ZnO-TiO_2 after mechanical activation during 30 minutes

Figure 3 illustrates the infrared spectra of the initial ZnO and TiO_2 oxides, as well as that of the mechanochemically synthesized ZnO-TiO_2 mixed oxide. An intensive band at 445 cm^{-1} is present in the infrared spectrum of the initial ZnO, owing to stretching v_s (Zn-O) bond vibrations. Absorption bands are observed in the 400-750 cm^{-1} region, which can be attributed to the Ti-O stretching vibrations of the [TiO_6] group. A band has been registered at 595 cm^{-1} with a shoulder at about 530 cm^{-1} in the spectrum of the mechanochemically synthesized sample due to vibrations of the metal-oxygen bonds, evidencing the presence of octahedral TO_6 groups in both forms $ZnTiO_3$ and Zn_2TiO_4. This result is in accordance with the data, reported by Shabalin [14]. The peaks at 595 cm^{-1} and 440

cm^{-1} could be assigned to the stretching vibrations of the Ti-O and Zn-O bonds [15, 16]. Although the registered bands are wide ones, they clearly show that during the mechanical activation of the ZnO-TiO_2 mixture a mechanochemical reaction is occurring resulting in the formation of zinc titanate.

4. CONCLUSION

The mechanochemical method for the preparation of mixed oxide ensures the simultaneous formation of hexagonal metatitanate $ZnTiO_3$ and cubic orthotitanate Zn_2TiO_4 . The latter phase is dominating in the samples. The multifunctional character of the mechanochemical activation involves accumulation of energy due to formation of new surfaces and structural disorder.

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MECHANOCHEMICAL SYNTHESIS AND CHARACTERIZATION OF $ZnFe_2O_4$

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Abstract: *Nanostructural Zinc ferrite ($ZnFe_2O_4$) materials have been subject of many studies because of their multifunctional properties. This work demonstrates the preparing of zinc ferrite nanopowders by high-energy ball milling of hydroxide carbonate precursor. The samples were characterized by X-ray diffraction and Mössbauer spectroscopy. The spinel phase of $ZnFe_2O_4$ with average crystalline size 10.45 nm and lattice parameter 8.38 Å was established after two hours mechanochemically treatment,.*

Key words: *mechanochemical synthesis, zinc ferrite, Mössbauer spectroscopy.*

1. Introduction

Spinel ferrites have the formula $M(Fe_2O_4)$, where M is usually a divalent cation such as manganese (Mn^{2+}), iron(Fe^{2+}), cobalt (Co^{2+}), nickel (Ni^{2+}), copper (Cu^{2+}), zinc (Zn^{2+}). The oxygen anions (O^{2-}) adopt a close-packed cubic crystal structure, and the metal cations occupy the interstices in the lattice arrangement. In each unit cell, containing 32 oxygen anions, 8 cations are coordinated by 4 oxygen anions (tetrahedral sites), and 16 cations are coordinated by 6 oxygen anions (octahedral sites). If the tetrahedral sites are occupied by M^{2+} cation and the octahedral sites are occupied by Fe^{3+} this structure is called the normal spinel structure. In the other case, that M^{2+} cations occupied a half of octahedral sites and Fe^{3+} ions are distributed in octahedral and tetrahedral sites, then it is called inverse spinel structure. It is also possible to have mixed structure spinel ferrites (partially inverse spinel structure) with formula $[M^{2+}_{1-\delta}Fe^{3+}_{\delta}][M^{2+}_{\delta}Fe^{3+}_{2-\delta}]O_4$ where δ is the degree of inversion.

Zinc ferrite ($ZnFe_2O_4$) has been a particular subject of study because of its contrasting magnetic properties compared to other spinel ferrites, e.g. low ordering temperature and antiferromagnetic ground state. This particular compound has a normal spinel structure, in which the iron atoms are located at B (octahedral) sites and Zn atoms occupy the tetrahedral A sites. Whereas most iron-rich ferrites are ferrimagnetically ordered at room temperature, the antiferromagnetic transition temperature (T_N) of stoichiometric, well-crystallized $ZnFe_2O_4$ is $T_N = 10\pm1$ K [1].

In literature have been reported different methods of synthesis of ferrite material, as co-precipitation [3, 4], ceramic [5], thermal [6], sol-gel [7], Spark plasma sintering [8]. Despite of well known approach to preparing zinc ferrite, mechanochemical activation is alternative synthesis route to nanostructure material with multifunctional properties and high vacancy densities [9, 10].

The purpose of present work is to demonstrate preparing of nanocrystalline zinc ferrite material by co-precipitation technology followed by high-energy mechanical milling. The dependence of duration of milling on crystal structure of observed material is object of discussion.

2. Experimental

2.1 Synthesis.

Zinc-iron oxide powders of $ZnFe_2O_4$ were prepared by two steps procedure of co-precipitation and mechanochemical treatment. The starting solution of $Fe(NO_3)_3.9H_2O$ and $Zn(NO_3)_2.6H_2O$ was precipitated with drop-wise addition of 1 M sodium carbonate up to pH= 9 at continuous stirring. The initially obtained precipitate was dried at room temperature (RT) to form precursor powder ($ZnFe_2O_4$-HC). At the second step of mechanochemical synthesis, the obtained precursor powder was milled using a Fritsch Planetary miller in a hardened steel vial together with fifteen grinding balls having different diameters (ranging from 3 to 10 mm). The balls-to-powder mass ratio was 10:1. The mechanochemical treated samples are denoted $ZnFe_2O_4$-MSx, where x= 0.5, 1, 2 is duration of treatment in hours.

2.2. Characterisation.

The powder XRD patterns were recorded by use of a TUR M62 diffractometer with Co Kα radiation. The observed patterns were cross-matched with those in the JCPDS database. The average crystallites size (D), the degree of microstrain (e) and the lattice parameters (a) were determined from the experimental XRD profiles by using the PowderCell-2.4 software [9]. The Mössbauer spectra were obtained at room temperature (RT) with a Wissel (Wissenschaftliche Elektronik GmbH, Germany) electromechanical spectrometer working in a constant acceleration mode. A ^{57}Co/Rh (activity ≅50 mCi) source and α-Fe standard were used. The experimentally obtained spectra were fitted to mathematical processing according to the least squares method. The parameters of hyperfine interaction such as isomer shift (IS), quadrupole splitting (QS), effective internal magnetic field (Heff), line widths (FWHM), and relative weight (G) of the partial components in the spectra were determined.

3. Results and Discussion

X-ray diffraction patterns of ball milled ferrite precursor powders are presented in Fig. 1. After 0.5 hour milling, there is not observed formation of zinc ferrite phase. There was no significant difference in sample treatment in one hour, where the mechanochemically activation is not still enough. The XRD spectra of samples treated for 0.5 and 1 hour still amorphous halo are seen. It is characterized with well expressed maxima at d about 2.54 and 1.5 that is clear sign for beginning of formation of ferrite phase with crystalline size under 5 nm. With increasing duration of the high-energy activation a well defined reflection of cubic spinel phase is appeared without the presence of any secondary phases. The results for average particle size, microstrain degree and lattice parameter are given in Table 1. The estimated average crystallite size for sample $ZnFe_2O_4$ MS2 is 10 nm, calculated by Williamson-Hall method.

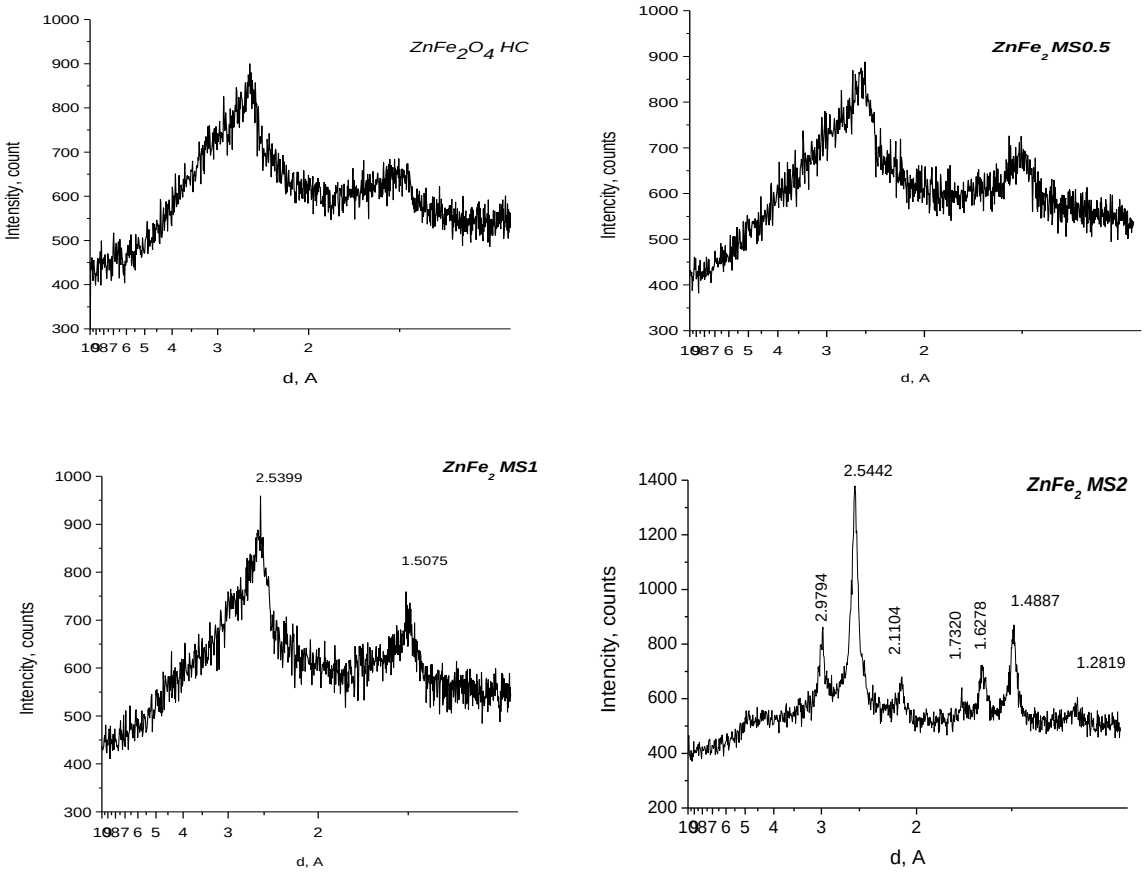


Figure 1. XRD spectroscopy of the mechanochemically synthesized sample

Table 1. Average crystallite size (D), degree of microstrain (e) and lattice parameters (a) determined from experimental XRD profiles

Sample	Phase	D, nm	e. 10^3 a.u.	a, Å
ZnFe2O4-MS2	Fd3m(227)-cubic	10.45	7.019	8.38

The Mössbauer spectra at room temperature of mechanochemically treated samples are presented in Fig. 2. Calculated parameters of hyperfine interactions are given in Table 2. Mössbauer spectra of all investigated samples are characterized by a paramagnetic doublet. Parameters of doublets correspond to Fe^{3+} in octahedral coordination. Values of quadrupole splitting of doublets are increased in comparison with these of well crystallized $ZnFe_2O_4$, which is expectable for nanosized and highly defective particles.

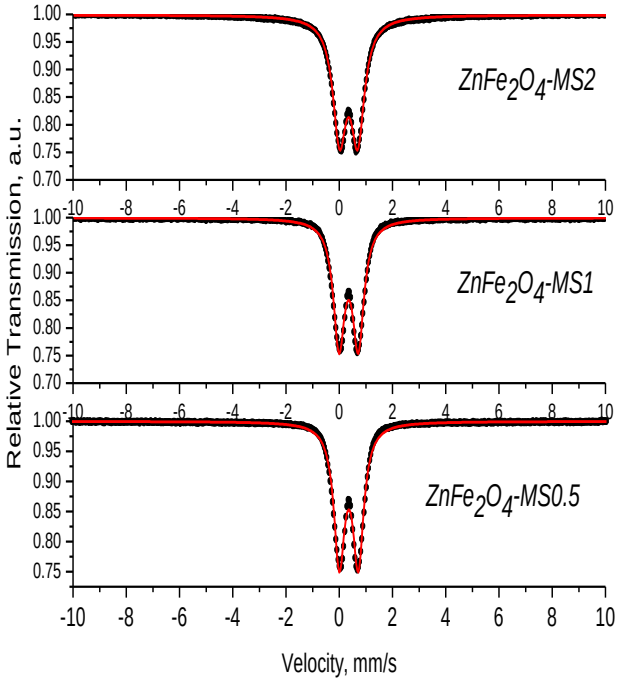


Figure 2. Mössbauer spectra of mechanochemically synthesized samples

Table 2. Parameters of Mössbauer spectra of the investigated samples

Sample	Components	IS, mm/s	QS, mm/s	H_{eff}, T	FWHM, mm/s	G, %
$ZnFe_2O_4$-MS0.5	Db	0.36	0.71	-	0.49	100
$ZnFe_2O_4$-MS1	Db	0.35	0.72	-	0.52	100
$ZnFe_2O_4$-MS2	Db	0.35	0.68	-	0.61	100

4. CONCLUSION

In this work it has been demonstrated that method of co-precipitation, follow by the high-energy ball milling results in the formation of nanocrystalline $ZnFe_2O_4$. It was established formation of cubic spinel structure with average particle size 10 nm and lattice parameter 8.38 Å after two hours mechanochemically treatment.

ACKNOWLEDGMENTS

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TRIBOLOGICAL PROPERTIES OF SPRAYED TiO_2 COATINGS DEPOSITED ON Al SUBSTRATE

Mara KANDEVA, Vladimir BLASKOV, Irina STAMBOLOVA, Nina G. KOSTOVA, Sasho VASILEV

Abstract: *In this study were examined TiO_2, thin films obtained by spray pyrolysis. After 300 abrasive cycles the anatase phase remains in the layers coated on the unpolished side of the substrate while the surface becomes smoother. The experimental results are presented for the dependence on mass export of road friction, the velocity dependence of mass wear of time, and change of wear resistance with time of contact interaction.*

Key Words: *tribology, solid lubricant, TiO_2, abrasive wear resistance,spray pyrolysis*

ТРИБОЛОГИЧНИ СВОЙСТВА НА СЛОЕВЕ ОТ TiO_2 НАНЕСЕНИ ВЪРХУ АЛУМИНИЕВА ПОДЛОЖКА

Мара КАНДЕВА, Владимир БЛЪСКОВ, Ирина СТАМБОЛОВА, Нина Г. КОСТОВА, Сашо ВАСИЛЕВ

Резюме: *В настоящата работа се изследват тънки филми от TiO_2, получени по метода на спрей пиролиза. Установено, е че след 300 абразивни цикъла се запазва анатазната фаза при слоеве нанесени върху неполираната страна на подложката, като повърхността им става по-гладка. Получени са експериментални резултати за: зависимостта на масовото износване от пътя на триене, зависимостта на скоростта на масовото износване от времето, изменението на износоустойчивостта във времето на контактно взаимодействие*

Ключови думи: *трибология, твърда смазка, абразивна износоустойчивост, спрей пиролиза*

1.ВЪВЕДЕНИЕ

Титановият диоксид е многофункционален материал с обещаващи сензорни, каталитични, биомедицински и др свойства. Покрития от TiO_2 с добри трибологични свойства са получени чрез физични методи [1, 2]. Данните обаче за получени чрез химични методи покрития за много оскъдни [3]. Спрей пиролизата наред със зол гел метода е един от основните химични методи за получаване на тънки слоеве [4]. Този метод е лесно достъпен, не изисква скъпа апаратура и разрешава смесване на прекурсорите на молекулно ниво.

Целта на работата е да се изследва износването и износоустойчивостта на образци от спрей пиролизирани слоеве от TiO_2 в условия на сухо триене с контратяло от абразивен материал, като се решават се следните конкретни задачи:

- изследване на зависимостта на масовото износване от времето;
- изследване на зависимостта на скоростта на масовото износване от пътя на триене.
- определяне на абсолютната интензивност на линейното износване.
- определяне на абсолютната износоустойчивост на линейно износване.

2.ЕКСПЕРИМЕНТАЛНА ЧАСТ

2.1. Получаване и охарактеризиране на слоевете

Титановият хлорид ($TiCl_4$) се разтваря в етанол (разтвор А). Полученият разтвор се смесва с изопропанол и бутил карбитол ($C_4H_9OC_2H_4OC_2H_4OH$) при интензивно разбъркване, след което се изпръсква върху нагрята алуминиева подложка. Една част от слоевете са отложени върху полираната страна на подложката, а другата – върху неполираната страна. Полученият образец се нагрява изотермично при температура 400^oC за 1 час. Фазовият състав на пробите е определен чрез рентгенов фазов анализ (XRD) при CuK_α лъчение. Сканиращ електронен микроскоп JSM-5510 of JEOL е използван за изследване на морфологията на филмите. Топографията на повърхността на слоевете е изследвана с помощта на атомно силов микроскоп NanoScopeV system (Veeco Instruments Inc.) работещ на въздух при стайна температура.

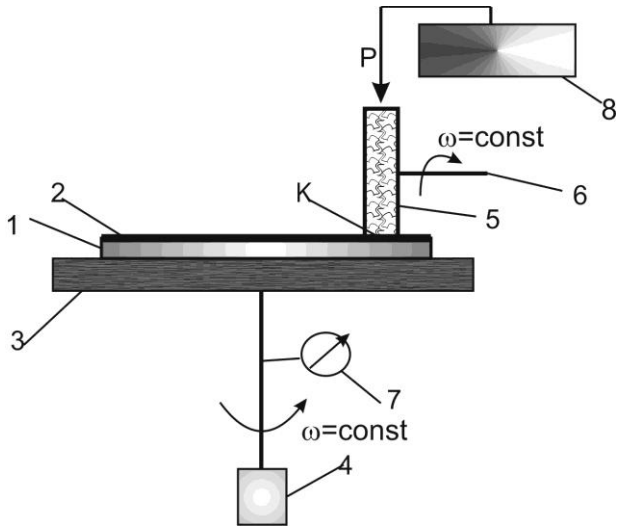
2.2. Методика и устройство за изследване на износването в условия на закрепени абразивни частици

Експерименталното изследване се осъществява по методика, разработена в научно-приложната лаборатория „Трибология" към катедра „МТМ" – МТФ-ТУ-София под ръководството на доц. д-р М. Кандева [5]. Методиката се реализира с устройство по кинематичната схема „диск-диск" на TABER ABRASER, който е модифициран към разработената методика. Методиката е съобразена с изискванията на действащия стандарт, хармонизиран с европейските стандарти [6].

Функционалната схема на устройството е представена на фиг. 1

Образецът 1 (тялото) с нанесено покритие 2 с форма на кръгла пластина е подходящо закрепен върху хоризонтален диск 3, който се задвижва от електродвигател 4 с постоянна ъглова скорост ω при брой на оборотите $n = 60\ tr/\min$.

Противотялото 5 представлява диск от специален абразивен материал *CS 10*, монтиран върху хоризонталната ос 6 в устройството 8, чрез което се задава желаното нормално натоварване P в центъра на контактната зона К. По този начин тялото 1 и противотялото 5 се намират на две кръстосани оси и при постоянната ъглова скорост на образеца 1 и постоянно номинално контактно налягане p_a триенето в контактната зона К поддържа постоянна скорост на ротация на противотялото 5.



Фиг. 1: ***Функционална схема на устройството за износване при триене с абразивно противотяло***

Методиката на изследване включва следната последователност:

1. Всички образци се подготвят с еднаква форма и размери преди и след нанасяне на покритието. Това е задължително условие, което гарантира достоверността резултатите от изследването.

2. Измерва се масата на всеки образец преди и след определен път L на триене (брой цикли N). Масата на образците се измерва с помощта на електронна везна тип WPS 180/C/2 с точност до 0,1 mg.

Преди всяко измерване с везната образците се почистват с разтвор, неутрализиращ статичното електричество.

3. Образецът 1 се закрепва върху носещия хоризонтален диск 3 и чрез лостова система в устройството 8 се задава желаното нормално натоварване P. Пътят на триене L се пресмята чрез броя цикли N, които се отчитат с оборотомера 8.

Основните параметри на изследването са:

- *абсолютно масово износване* m, $[mg]$ - представлява разрушената маса от покритието в процеса на износване, която се определя като разлика между масите на образеца преди и след определен път на триене.
- *скорост на масовото износване* dm/dt $\left[mg/\min\right]$ - представлява разрушената маса от покритието за определено време, в случая за време една минута.
- *интензивност на линейното износване* i - представлява разрушената дебелина на покритието за единица път на триене. Това е бездименсионно число, което се изразява чрез разрушената измерена маса по формулата:

$$i = \frac{m}{\rho.A_a.L} \tag{1}$$

където:

ρ е плътността на покритието. В случая $\rho(TiO_2) = 3{,}89 g/cm^3$; $\rho(Al) = 2{,}7 g/cm^3$

A_a е номиналната контактна площ на взаимодействие.

L е пътят на триене, който се пресмята чрез броя цикли N по формулата:

$$L = 2\pi.R.N \tag{2}$$

Параметърът R представлява разстоянието между оста на въртене на носещия диск и масовия център на контактната площадка между образеца 1 и контратялото 5.

- *абсолютна линейна износоустойчивост* I - представлява бездименсионно число и се пресмята като реципрочна стойност на интензивността на износване, т.е.

$$I = \frac{1}{i} = \frac{\rho.A_a.L}{m} \tag{3}$$

- *номинално контактно налягане* p_a, $[N/cm^2]$ - представлява нормалното натоварване, което се разпределя на единица номинална контактна площ на взаимодействие A_a, т.е.

$$p_a = \frac{P}{A_a} \tag{4}$$

- *средна скорост на плъзгане* V, $[cm/s]$ - линейната скорост на центъра на тежестта на контактната площадка, която се определя по формулата:

$$V = \omega.R = \frac{\pi.n}{30} R \tag{5}$$

В таблици 1 са представени данни за образците.

Таблица 1: ***Описание на образците***

№ на обр.	Описание на образеца
1	Неполирана с покритие от TiO_2 при $p_a = 9{,}43 N/cm^2$
2	Полирана без покритие при $p_a = 17 N/cm^2$
3	Неполирана без покритие при $p_a = 17 N/cm^2$
4	Полирана с покритие с TiO_2 при $p_a = 17 N/cm^2$
5	Неполирана с покритие с TiO_2 при $p_a = 17 N/cm^2$

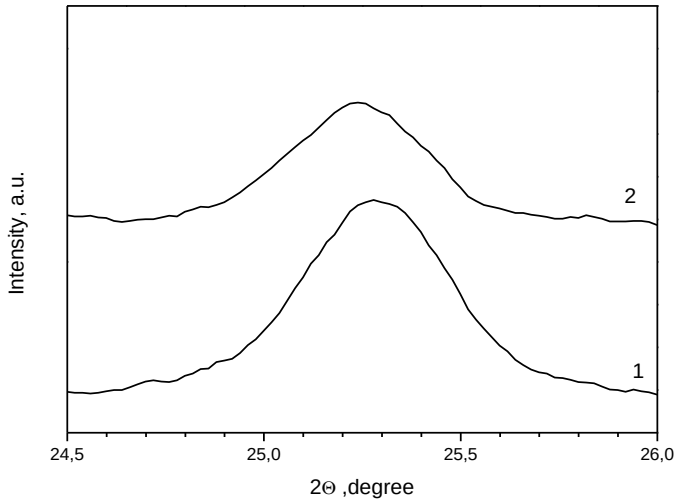
В таблица 2 са представени параметрите на контактното взаимодействие, при които е проведено експерименталното изследване.

Таблица 2: ***Параметри на експеримента:***

Номинална контактна площ, A_a	$26.10^{-6}\,[m^2]$
Средна скорост на плъзгане, V	$17{,}90\ [cm/s]$

3.ЕКСПЕРИМЕНТАЛНИ РЕЗУЛТАТИ

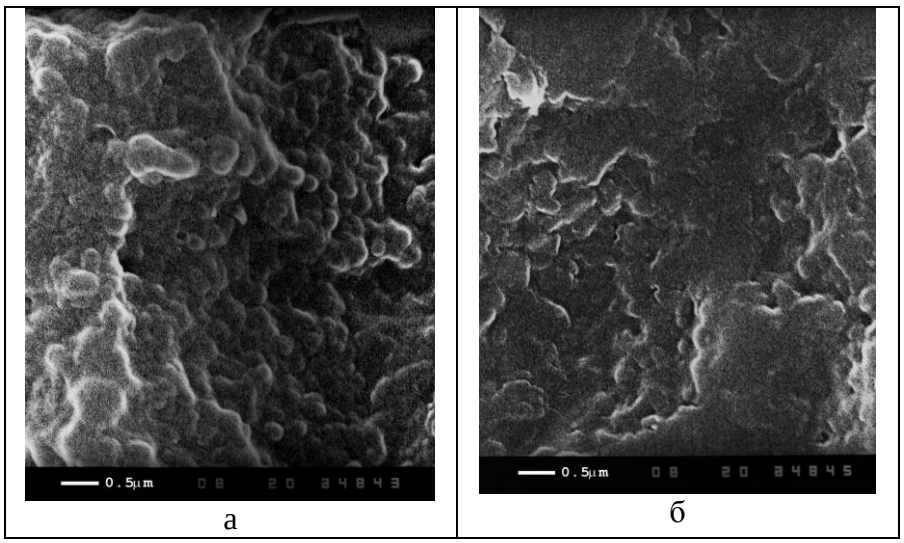
На фигура 2 са представени рентгеновите дифрактограми на слой от титанов диоксид преди и след 300 абразивни цикли.



Фиг 2: Рентгенови дифрактограми на слой от TiO_2 преди (1) и след 300 абразивни цикли (2)

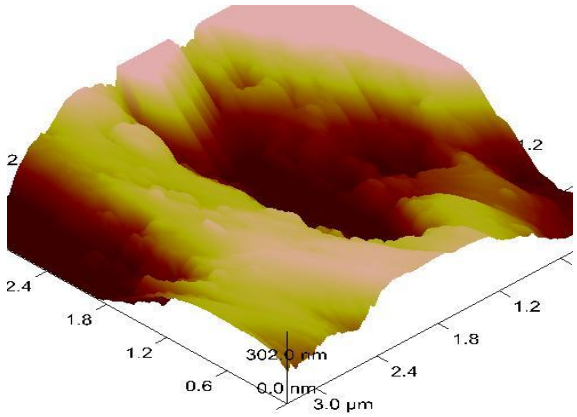
От рентгеновите дифрактограми на слоеве преди и след абразивно износване се установи, че анатазната фаза се запазва и след 300 абразивни цикъла (Фиг.2).

Снимки на електронно сканиращ микроскоп (SEM) и атомно силова микроскоп (AFM) са показани съответно на фиг.3. и фиг. 4. Повърхността на образците с нанесен слой от TiO_2 преди износване е неравна (фиг. 3-a). След 300 цикъла на абразивно триене повърхността вече е значително по-гладка (фиг. 3-b и фиг. 4), което е указание за протичането на пластична деформация. Тази информация заедно с представените по-долу данни за износоустойчивостта на анатазните слоеве показва, че слоят от TiO_2, когато е нанесен върху неполирана страна на алуминиевата подложка има по-висока адхезионна якост и по-голяма пластичност. Подобно поведение за слоеве от TiO_2 , нанесени върху стъклена подложка, е наблюдавано от W. Zhang и съавтори [3].



а б

Фиг. 3: SEM фотографии на слой от TiO_2 нанесен на неполираната страна на подложката преди (а) и след 300 абразивни цикли (б)



Фиг. 4: Топография на повърхността на слой от TiO_2 нанесен на неполираната страна на подложката след 300 абразивни цикли получена от атомно силова микроскопия.

Експерименталните резултати за износването на всеки образец са представени в таблици. В таблици 3, 4 и 5 са представени резултати за износването на образци от неполирана подложка, съответно без покритие и с покритие при две стойности на контактното налягане. В таблици 6, 7 и 8 са представени резултати за износването на полирана подложка, съответно без покритие и с покритие при една стойност на контактното налягане. Интензивността на износване и износоустойчивостта са изчислени съответно по формули (1) и (3).

Таблица 3: ***Експериментални резултати за масовото износване, скоростта на износване, интензивността на износване и износоустойчивостта на образец №3 (Неполирана основа без покритие-Еталон);*** $\left(p_a = 17N/cm^2\right)$

Път на триене $L\ [m]$	18	36	54
Брой цикли N	100	200	300
Време t [min]	1,67	3,34	5
Износване $m\ [mg]$	1,4	2	2,3
Скорост на износванет $[mg/\min]$	0,84	0,6	0,46
Интензивност на износване i	$1.1.10^{-6}$	$0,79.10^{-6}$	$0,6.10^{-6}$
Износоустойчивост I	$0,91.10^{6}$	$1,26.10^{6}$	$1,67.10^{6}$

Таблица 4: ***Експериментални резултати за масовото износване, скоростта на износване, интензивността на износване и износоустойчивостта на образец №5 (Неполирана основа +покритие*** TiO_2***);*** $\left(p_a = 17N/cm^2\right)$

Път на триене L $[m]$	18	36	54
Брой цикли N	100	200	300
Време t [min]	1,67	3,34	5
Износване m $[mg]$	0,4	0,6	0,9
Скорост на износването $[mg/\min]$	0,24	0,18	0,18
Интензивност на износване i	$0{,}22.10^{-6}$	$0{,}17.10^{-6}$	$0{,}17.10^{-6}$
Износоустойчивост *I*	$4{,}54.10^{6}$	$5{,}88.10^{6}$	$5{,}88.10^{6}$

Таблица 5: ***Експериментални резултати за масовото износване, скоростта на износване, интензивността на износване и износоустойчивостта на образец №1 (Неполирана основа +покритие*** TiO_2***);*** $\left(p_a = 9{,}43N/cm^2\right)$

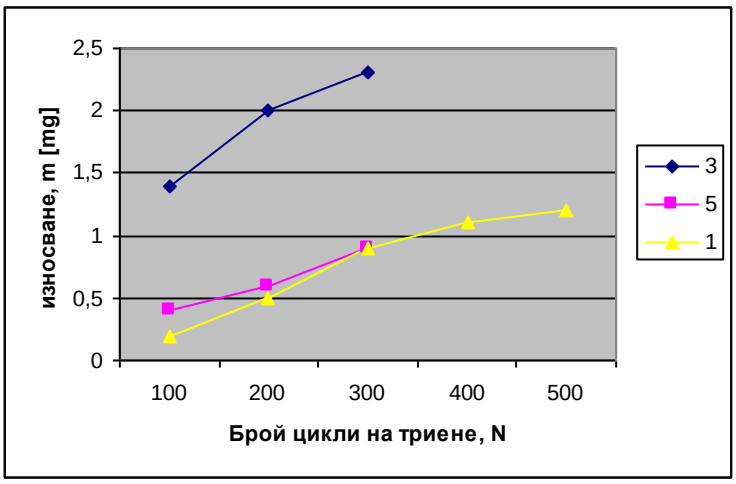
Път на триене L $[m]$	18	36	54	72	90
Брой цикли N	100	200	300	400	500
Време t [min]	1,67	3,34	5	6,67	8,34
Износване m $[mg]$	0,2	0,6	0,9	1,1	1,2
Скорост на износването $[mg/\min]$	0,12	0,18	0,18	0,16	0,14
Интензивност на износване i	$0{,}11.10^{-6}$	$0{,}16.10^{-6}$	$0{,}16.10^{-6}$	$0{,}15.10^{-6}$	$0{,}13.10^{-6}$
Износоустойчивост *I*	9.10^{6}	$6{,}25.10^{6}$	$6{,}25.10^{6}$	$6{,}7.10^{6}$	$7{,}7.10^{6}$

Таблица 6: ***Експериментални резултати за масовото износване, скоростта на износване, интензивността на износване и износоустойчивостта на образец №2 (Полирана основа без покритие);*** $\left(p_a = 17N/cm^2\right)$

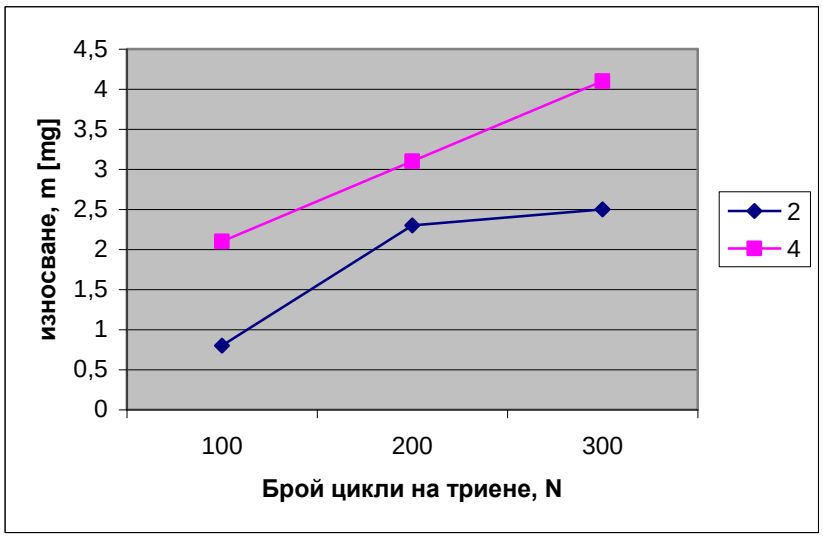
Път на триене L $[m]$	18	36	54
Брой цикли N	100	200	300
Време t [min]	1,67	3,34	5
Износване m $[mg]$	0,8	2,3	2,5
Скорост на износването $[mg/\min]$	0,48	0,69	0,5
Интензивност на износване i	$0{,}63.10^{-6}$	$0{,}9.10^{-6}$	$0{,}66.10^{-6}$
Износоустойчивост *I*	$1{,}58.10^{6}$	$1{,}1.10^{6}$	$1{,}5.10^{6}$

Таблица 7: ***Експериментални резултати за масовото износване, скоростта на износване, интензивността на износване и износоустойчивостта на образец №4 (Полирана основа +покритие*** TiO_2***);*** $\left(p_a = 17N/cm^2\right)$

Път на триене L $[m]$	18	36	54
Брой цикли N	100	200	300
Време t [min]	1,67	3,34	5
Износване m $[mg]$	2,1	3,1	4,1
Скорост на износването $[mg/\min]$	1,26	0,93	0,82
Интензивност на износване i	$1{,}16.10^{-6}$	$0{,}85.10^{-6}$	$0{,}75.10^{-6}$
Износоустойчивост *I*	$0{,}86.10^{6}$	$1{,}18.10^{6}$	$1{,}3.10^{6}$



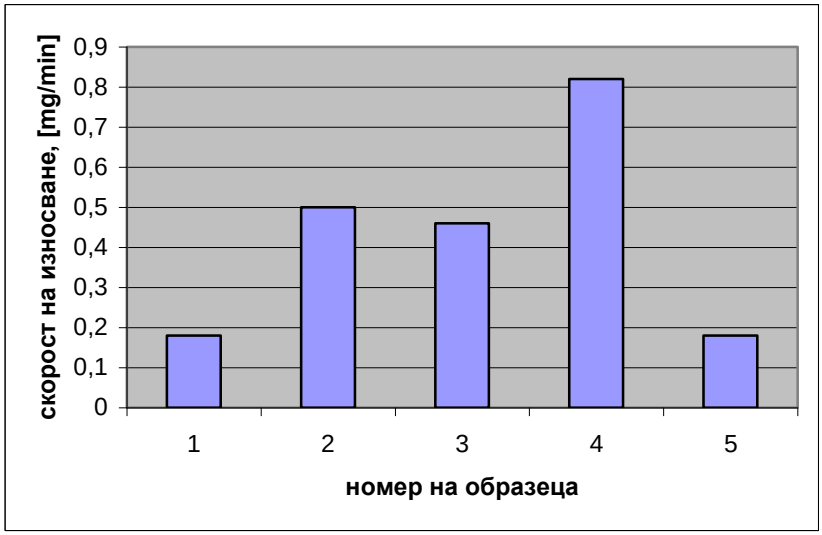
Фиг. 5: ***Зависимост на износването от броя цикли на неполирана основа: 3 – без покритие, при*** $p_a = 17N/cm^2$***; 5 – с покритие*** TiO_2 ***при*** $p_a = 17N/cm^2$***; 1- с покритие*** TiO_2 ***при*** $p_a = 9{,}43N/cm^2$



Фиг. 6: ***Зависимост на износването от броя цикли на неполирана основа: 2 – без покритие, при*** $p_a = 17N/cm^2$***; 4 – с покритие*** TiO_2 ***при*** $p_a = 17N/cm^2$

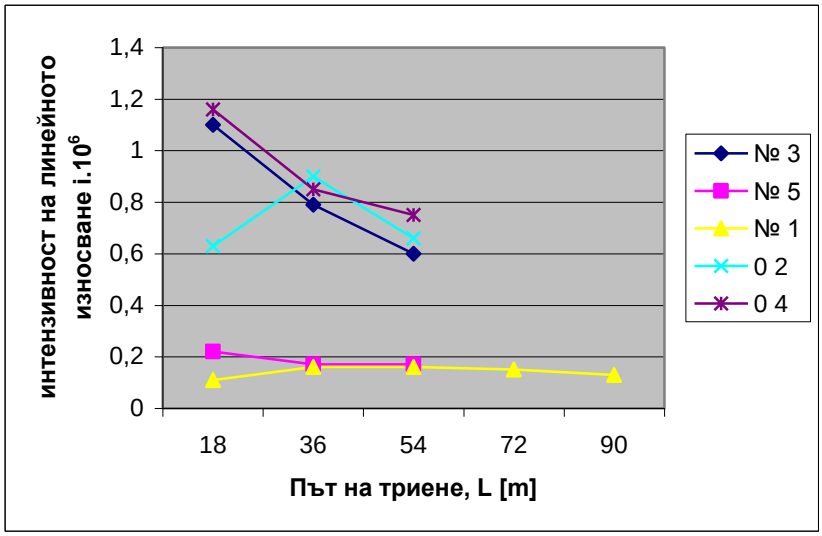
На фигури 5 и 6 е представена графично зависимостта на масовото износване от броя цикли на триене съответно за покрития, нанесени върху полирана и неполирана подложка.

На фиг. 7 е представена скоростта на масовото износване на всеки образец за един и същ брой цикли на триене - $N = 300$.



Фиг. 7: Скорост на износване на образците при $N = 300$ ***цикъла***

Интензивността на линейното износване не е постоянна в процеса на триене. На фиг. 8 е представена зависимостта на интензивността на абразивното износване от пътя на триене за всички образци.



Фиг. 8: Зависимост на интензивността на линейното износване от пътя на триене.

Предвид на нестационарния характер на скоростта на масовото износване и на интензивността на линейното износване в процеса на взаимодействие износоустойчивостта е определена за един и същи път на триене $L = 54\ m$, т.е. $N = 300$, след изтичане на периода на приработване на различните образци. Резултатите се представени на фиг. 9.



Фиг.9: Износоустойчивост на образците при път на триене $L = 54\ m$

(1)

4.ЗАКЛЮЧЕНИЕ

Основните резултати в настоящата работа се свеждат до:

- Получени са спрей пиролизирани слоеве от TiO_2 върху полирана и неполирана алуминиева подложка.

- Получени са експериментални резултати за износването на слоевете в условия на сухо триене с абразивен диск, по-конкретно - изменението на масовото износване и скоростта на масовото износване от броя цикли на триене; изменението на интензивността на линейното износване от пътя на триене; износоустойчивостта за серията образци при един и същ път на триене.

- Установено е, че изменението на масовото износване от времето (брой цикли) има нелинеен характер като тенденцията е достигане на по-малка и постоянна скорост на износване. Периодите на приработване на различните слоеве имат различна продължителност. Изключение се наблюдава при слой, нанесен на неполирана основа при контактно налягане $p_a = 17 N/cm^2$ (фиг. 6, образец № 4), при който зависимостта има линеен характер.

- Показано е експериментално, че интензивността на износването има нестационарен характер в процеса на контактното взаимодействие и различен за различните повърхнини (фиг. 8).

- При направеното изследване най-висока износоустойчивост се наблюдава при слоеве от TiO_2,нанесени върху неполирана алуминиева подложка (образец № 1) - $I = 6{,}25.10^6$ при контактно налягане $p_a = 9{,}43\ N/cm^2$. При по-високо контактно налягане $p_a = 17\ N/cm^2$ износоустойчивостта на слоеве от TiO_2 е също по-висока - $I = 5{,}88.10^6$ от тази на слоевете, нанесени върху полирана подложка $I = 1{,}18.10^6$, т.е. около 500%. Последният резултата се предполага, че се дължи на по-високата адхезионна якост между слоевете и подложката.

- От рентгеновите дифрактограми на слоеве преди и след абразивно износване се установи, че анатазната фаза при слоеве, нанесени върху неполираната страна на подложката, се запазва и след 300 абразивни цикъла. След 300 абразивни цикъла повърхността на слоевете става по-гладка от изходната, което говори за протичане на пластична деформация по повърхностния слой в процеса на триене.

БЛАГОДАРНОСТИ

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КОРЕСПОНДЕНЦИЯ

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TRIBOLOGICAL MEASUREMENTS OF POLYPROPYLENE NANOCOMPOSITES BY SCRATCH AND FRICTION TESTS

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Abstract: *MWCNTs are used as extremely strong nano-reinforcements for nanocomposites due to their superior electrical, thermal, and mechanical properties to produce a new generation of reinforced plastics with better application properties. In this experimental study the tribological properties of iPP/MWCNT polymer nanocomposites with nanofiller concentrations in the range of 0.05-1%wt MWCNT with maleic anhydride amount respectively from 0 up to 7.5wt % are investigated by using three types of test methods.*

Key Words: *tribology, polypropylene nanocomposites, MWCNT*

1.INTRODUCTION

Tribology is a science and technology of surfaces that are in contact and relative motion and it involves friction, wear of materials, scratching and rubbing [1]. While attention of academia and industry on materials properties is largely focused on mechanics, wear causes losses in industry at least not smaller than fracture caused by mechanical deformation [1].

Tribological parameters include surface roughness, mechanisms of adhesion, friction and wear [1-10]. Friction is the resistance to motion that occurs whenever one solid body is in contact with another solid body. A friction coefficient is defined as a ratio of the force that resists sliding to the normal force [2-8]. Wear is most often defined as the unwanted loss of solid material from the solid surface caused by mechanical interactions and can lead to debris generation, binding, slop, and limited life. The purpose of the research in tribology is to minimize and remove losses that occur due to friction and wear at all levels, where rubbing, grinding, polishing, and cleaning of surfaces take place. While tribological performance does not have a single unique definition, broadly speaking, materials with low wear rates and low friction coefficients are desired [2]. The main wear mechanism is adhesion, which is an important component of friction [1].

Tribology of ceramics and metals present in many industrial processes is described more frequently in the literature than tribology of polymeric materials [1]. Increasing applications of polymeric materials require knowledge of their tribological properties – very different from these of other materials. Traditional tribology developed originally for metals cannot be applied to polymer-based materials (PBMs) for many reasons. PBMs are viscoelastic and brittle and their properties depend on time – in contrast to metals and ceramics [1]. The next is that a part of the motion energy turns into heat and the test temperature has a direct impact on the wear of polymers. During the tests some polymers anneal above their glass transition temperature Tg, while others remain below Tg. On the point of contact surface, elastic, plastic and/or viscoelastic deformation take place during the friction. Deformation is accompanied by the dissipation of mechanical energy that depends on the type of strain, conditions of sliding, mechanical properties, environmental and other factors. Therefore, a comparison between mass of products produced during the wear testing has limited value and currently there is no generally accepted test method for determining wear of polymers. Traditional experimental methods of wear determination, based on the amount of debris formed, are not well usable for PBMs since often there is no debris – while there is significant material displacement (top ridge formation, densification). Also polymers often have complex multiphase structures – what makes evaluation of their tribological behavior relatively difficult.

Polymers, generally with low stiffness and low strength, exhibit low friction due to weaker interactions, but high wear in comparison with ceramics and metals. In general, neat polymers do not

have the tribological performance required for most applications, but concerning polymer nanocomposites there are many examples for a good balance between good mechanical strength, low friction and low wear. One of the key challenges regarding the manufacture of such nanocomposites for tribological applications is that only well distributed and dispersed nanoparticles lead to uniformly enhanced polymer properties [2]. Agglomerates of filler particles with a size of several tens of microns in diameter can act as localized stress concentration sites [3]. Tribology is inherently complex and state of the art in polymeric nanocomposites. It includes many qualitative descriptors of important system parameters, such as particle dispersion, bulk mechanical properties, debris morphology, and transfer film adhesion, morphology, composition, and chemistry [2]. Despite instances of remarkable wear reductions at unprecedented loadings, there is a lack of general agreement within the literature on the mechanisms of wear resistance in these nanocomposites. In addition, results appear to vary widely from study to study with only subtle changes of the filler material, blending technique or experimental conditions [2]. In many cases, improved wear resistance after nanoparticle inclusion is attributed to improved mechanical properties such as strength, hardness, and toughness without any quantitative measurement of these properties [2].

Factors that influence the tribological properties of polymers are structure and position of macromolecules on the surface, degree of crystallinity, type of polymer (homopolymer, block copolymers, etc.), composition of polymer blends, chain orientation obtained during the processing (extrusion, etc.), molecular structure (linear, branched or cross-linked), molecular weight distribution and thermal history [1]. Particle shape may play an important role on the entanglement of the polymer at the surface and has influence on the strength of the interface. The addition of filler or fibers to a polymer matrix reinforces the material when there is good adhesion between the filler and the matrix.

Although its resistance to crack initiation is very high, in crack propagation the resistance of the iPP matrix is very low; therefore, when a crack or mechanical failure exists, the matrix can break very easily especially at low temperatures. Therefore, a great deal of effort has been made to modify its mechanical properties such as blending iPP with inorganic fillers in the form of nanoparticles to improve the frictional behavior of a wear resistant polymer [2]. Carbon-nanotubes (CNTs) have been used as a reinforcing material in polymers from the date of their inception and CNTs could effectively enhance the friction-reduction and antiwear capacity of the nanocomposite because it increased their load capacity and mechanical strength [4-8]. However, chemical functionalization can introduce defects in nanotubes, thereby degrading their mechanical properties. Thus, some researchers have used maleic anhydride grafted PP (PP-g-MA) as the compatibilizer to improve dispersion of the purified CNTs without further chemical modification in PP matrix [9].

In this experimental study the tribological properties of iPP/MWCNT polymer nanocomposites with nanofiller concentrations in the range of 0.05-1%wt MWCNT with maleic anhydride amount respectively from 0 to 7.5wt % are investigated. The obtained results help to improve the knowledge on the effect of both iPP maleinization and nanotube contents on the tribological properties, particularly COF, thus to find the best optimal material formulation.

2.MATERIALS AND METHODS

A masterbatch of 20 wt% MWCNTs in polypropylene was obtained in pellet form from Hyperion Catalysis International, USA, wherein the MWCNTs are commercially manufactured from high purity, low molecular weight hydrocarbons in a continuous, gas phase, catalyzed reaction. Typical outside diameter range of the tubes is from 10 to 15 nm, the lengths are between 1 and 10 microns, and their density is approximately 1.75 g/cm^3. The delivered masterbatch is produced by initially dispersing intertwined agglomerates of nanotubes into the polymer.

Isotactic polypropylene (iPP) homopolymer “Buplen” 6231 with density ρ = 0.901 g/cm^3 and melt flow index MFI (230/2.16) of 12.2 g/10 min, supplied by Lukoil Neftochim Co., Bulgaria, was used as the matrix polymer. Maleic anhydride grafted polypropylene (PP-g-MA) Licomont AR 504, product of Clariant GmbH, Germany, was used as a chemical compatibilizer.

Nanocomposites were produced by direct melt compounding in a Brabender DSE 35/17D twin screw extruder according to a two-step process. The masterbatch was diluted to different carbon nanotube concentrations in the range of 0.05 to 1 wt% with neat iPP at melting temperature of 200°C and a screw speed of 30 rpm. The extruded composites were cooled and pelletized. In order to improve the carbon nanotube dispersion, these compositions were extruded in 2 runs and further calendered as sheets with thickness of about of 1.5 mm at melting temperature of 230°C and the same screw speed. PP-g-MA was added into the nanocomposites in the concentration range from 2.5 to 7.5 wt% at the second run. The rheological and structural characterizations did not provide indications for degradation of the processed materials, as tested after each extrusion run. The labeling of test samples with and without maleic anhydride (PP-g-MA) and different MWCNT concentration is given in Table 1.

Friction behavior of the polypropylene nanocomposites was studied with module system UMT-2M (CETR, USA). Fig. 1 shows the scheme of the friction module of the UMT-2M. The tribological properties of two types of sliding wear - the rotational motion (ball/pin-on-disc) and reciprocating motion (ball/pin-on-flat) can be achieved on this system using rotary motor drive and linear motor drive, correspondingly. The force applied can be in the range of 5 mN to 1kN, and precision spindle of rotary drive can rotate the lower specimen at speeds ranging from 10 rpm up to 1000 rpm [10].

The experiments were performed for distance of 10 mm by sliding test using three configurations at following testing conditions: 1) scratch on plate - constant force of 2N with test rate of 0.083 mm/s for 2 min; 2) pin on plate - constant force of 2N, test rate - 2 mm/s for 5 min; 3) ball on plate - increasing force from 0.5 up to 4N, test rate - 2 mm/s for 5 min. For the scratch test-micro-cutting blade, composite diamond, tip radius 0.8 mm was used, for pin on plate test 416 stainless steel pin, 6.35 mm x 25.4 mm (dia. x length) was used and for ball on plate - 440-C stainless steel balls, dia. 6.35 mm correspondingly (Fig. 2). Thus the coefficient of friction (COF) was determined in the bulk volume and on the surfaces, respectively. At least two measurements were made for each composition.

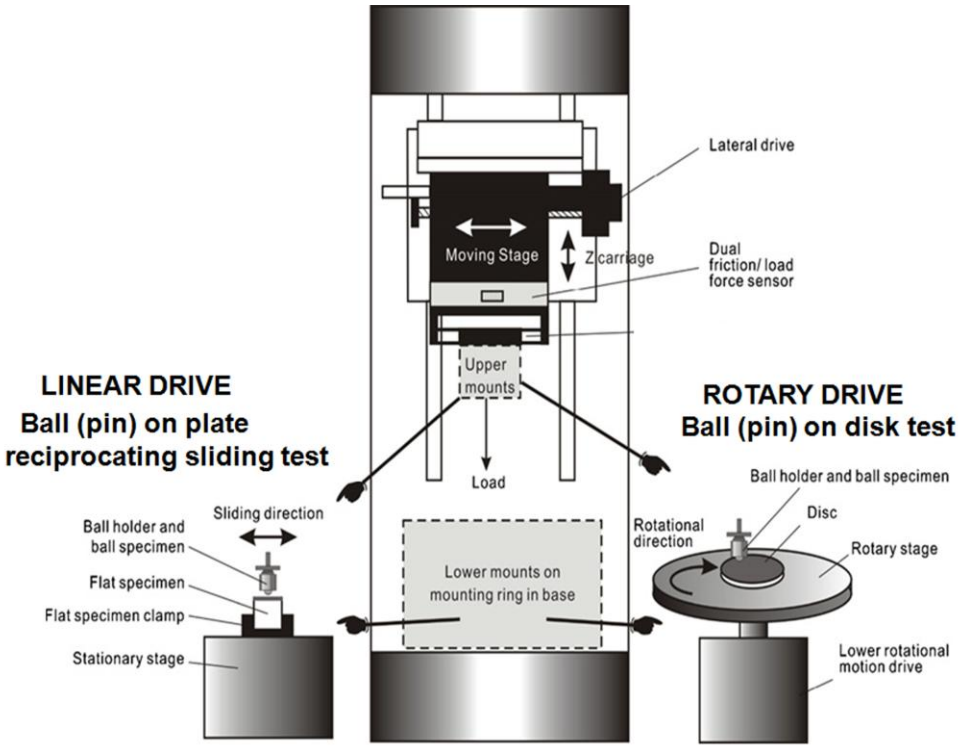


Fig. 1. Schematic of UMT-2M friction test

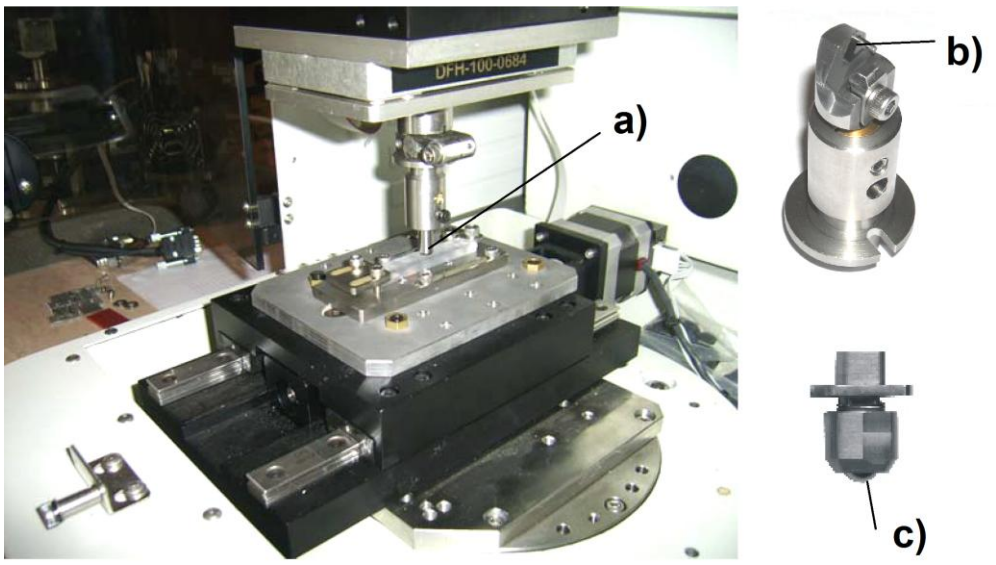


Fig. 2. Pictures of: a) pin-on-plate UMT test set-up; b) ball holder c) scratch holder

Table 1. Sample designation and obtained COF at scratch, COF at pin on plate and COF at ball on plate.

	Sample	Sample index	COF Scratch	COF Pin on flat	COF Ball on flat
1	iPP	PP	2.527	0.202	0.067
2	iPP+5 wt% PP-g-MA	PP5M	2.113	0.208	0.05
3	iPP+0.05wt%MWCNT	PP0.05NT	2.681	0.282	0.076
4	iPP+ 5%PP-g-MA +0.05wt%MWCNT	PP5M0.05NT	1.979	0.235	0.077
5	iPP+0.1wt%MWCNT	PP0.1NT	2.613	0.274	0.077
6	iPP +5wt% PP-g-MA +0.1wt%MWCNT	PP5M0.1NT	2.003	0.244	0.083
7	iPP+0.5wt%MWCNT	PP0.5NT	2.262	0.231	0.136
8	iPP+2.5wt% PP-g-MA +0.5wt%MWCNT	PP2.5M0.5NT	1.955	0.267	0.064
9	iPP+5wt% PP-g-MA +0.5wt%MWCNT	PP5M0.5NT	2.226	0.274	0.086
10	iPP+7.5wt% PP-g-MA +0.5wt%MWCNT	PP7.5M0.5NT	2.032	0.384	0.087
11	iPP+1wt%MWCNT	PP1NT	2.442	0.355	0.081
12	iPP+5wt% PP-g-MA +1wt%MWCNT	PP5M1NT	2.087	0.305	0.095

3.RESULTS AND DISCUSSION

The values of the coefficient of friction (COF) strongly depend on the type of sliding test configurations used, i.e. scratch, pin or ball on flat (table 1). Some variations at the values are due to the imperfect distribution and dispersion of the carbon nanotubes. Figures 3 and 4 show the change in friction coefficient versus time at pin on plate test for PP7.5M0.5NT nanocomposite and at ball on plate test for PP5M1NT nanocomposite. Both are sliding tribology test with reciprocating motion. At ball on plate test the COF curves are not as horizontal as at pin on plate test. This is due to the fact that pin on plate test was made at constant force and ball on plate was made at increasing force. Obviously, when the tribology test is performed with increasing force, enough time should be foreseen for stabilization of the coefficient of friction value. The second noticeable difference is that the variations of the middle values from the COF values for pin on plate test are bigger, which is due to bigger contact area of pin tip with the sample surface than in the case of ball tip.

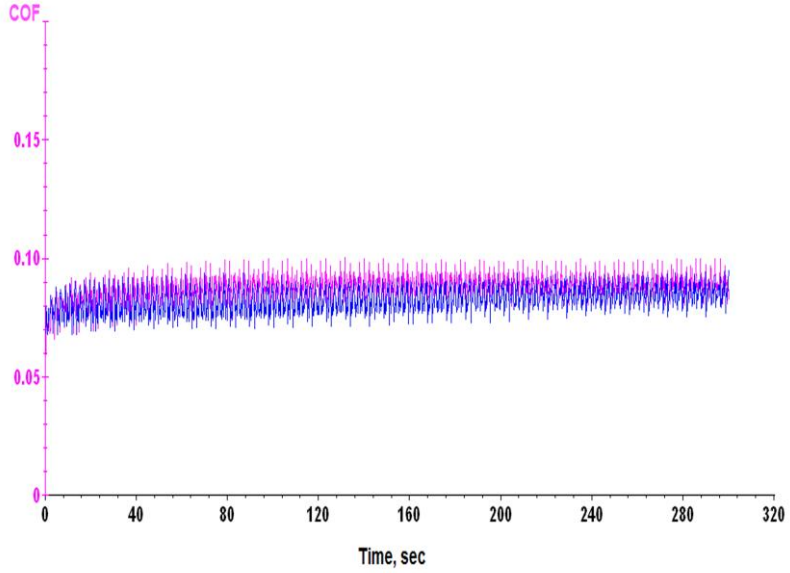


Fig. 3: COF at ball on plate test of PP7.5M0.5NT nanocomposite

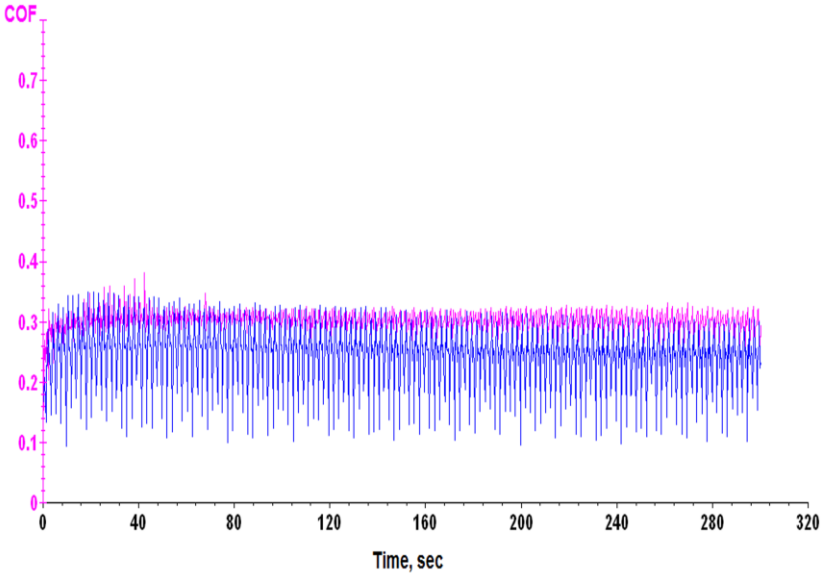


Fig. 4: COF at pin on plate test of PP5M1NT nanocomposite

Effect of MWCNT concentration on tribological properties of PP

Figure 5 presents graphically the variations and differences in COF for different non-maleinated nanocomposites obtained by the three performed tests. In scratch on flat experiment, the tendency for the COF is to decrease with increasing the concentration of MWCNT, although the addition of small quantity of MWCNT of 0.05 and 0.1 wt% leads to increase of COF compared to neat PP. This means that the bulk friction behavior of the PP/MWCNT nanocomposites is improved at bigger quantity of MWCNTs. In pin on flat and ball on flat experiments a slight increase of COF is observed by increasing the MWCNT contents, compared to neat PP, which presents mostly the surface properties of the nanocomposites**.** As a whole the variation of the COF values are smaller in reciprocating motion test than in scratch test. This means that the properties in the bulk are more different at different zones than on the surface of the samples.

However, the improvement in the mechanical properties at bigger quantity of MWCNTs at scratch test arises from several factors. Firstly, PP-g-MWCNTs promote the crystallization of PP and the crystallites strengthen the composites. Secondly, PP-g-MWCNTs are well dispersed in the matrix, allowing a more uniform load distribution. Thirdly, the PP chains grafted onto MWCNTs enable a more efficient load transfer from the matrix to the nanotubes [9].

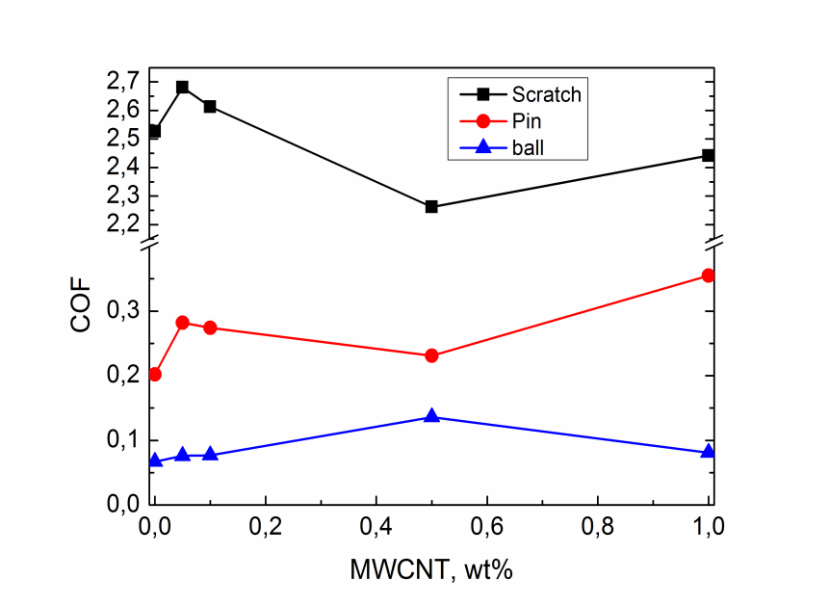


Fig. 5: COF of non-maleinated PP/MWCNT nanocomposites vs. MWCNTs contents

Effect of MWCNT concentration on tribological properties of 5 wt% maleinated PP

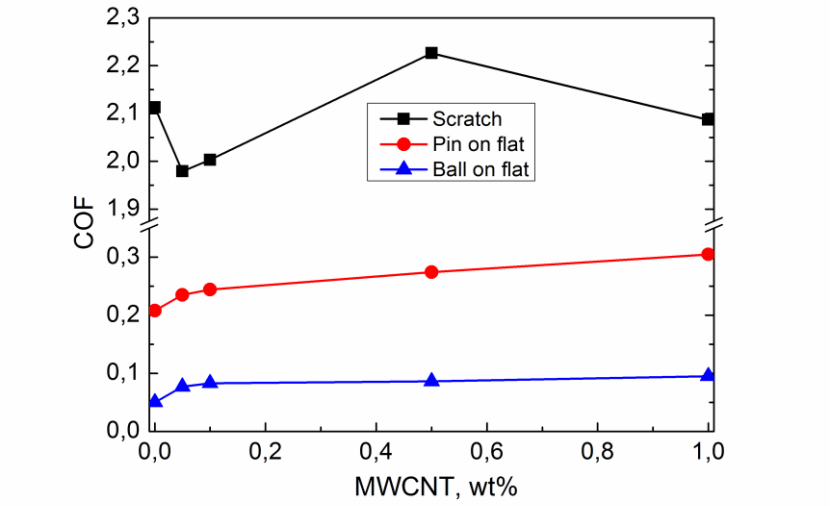


Fig. 6: COF of maleinated with 5% PP-g-MA PP/MWCNT nanocomposites vs. MWCNTS contents

In scratch on flat experiment (Fig.6) with increasing the concentration of MWCNT, the COF of the bulk decreases (except at the point PP5M0.5NT). Pin on flat and ball on flat experiments show that with increasing the concentration of MWCNT, a slight enhancement in COF on the surface is observed compared to the 5 wt % maleinated PP. Tendency is clear for both reciprocation tests - ball and pin, and in the scratch test the variations are bigger.

Enhancement of the properties observed at scratch test is due to the better dispersion and adhesion of CNTs with PP matrix because of PP-g-MA in the volume of the samples.

Effect of maleic anhydride additive on tribological properties of 0.5 wt% PP/MWCNT

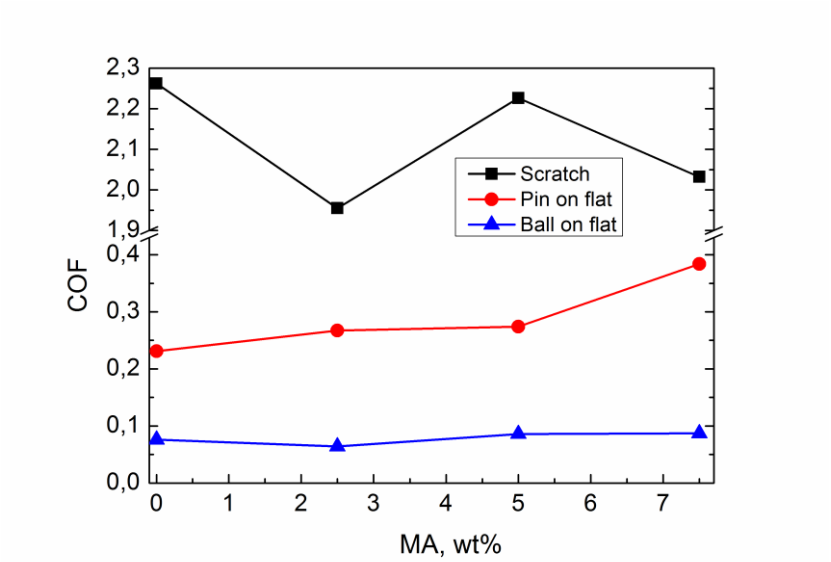


Fig. 7: COF of PP/MWCNT nanocomposite with 0.5% CNT vs. PP-g-MA contents

In scratch experiment (Fig.7) with increasing concentration of maleic anhydride, the COF decreases, however the results are not smooth. The zigzag like curve speaks for non-homogeneity of the bulk volume. The results from pin on flat and ball on flat experiments demonstrate a slight increase of COF with increasing concentration of MA, compared to non-maleinated 0.5 WT % PP/MWCNT composite. Observed again is the big difference of the friction properties at the surface compared with those in the bulk of the samples.

Scratch on flat (Z-displacement)

Fig. 8 confirms that the addition of maleic anhydride improves the friction behavior of 0.5% PP/MWCNT nanocomposite, which could be related to a better dispersion of nanotubes in the maleinated IPP.

However, the increase of the MWCNT contents results in a slight increase of the COF, if compared to the 5wt % maleinated PP (Fig.7).

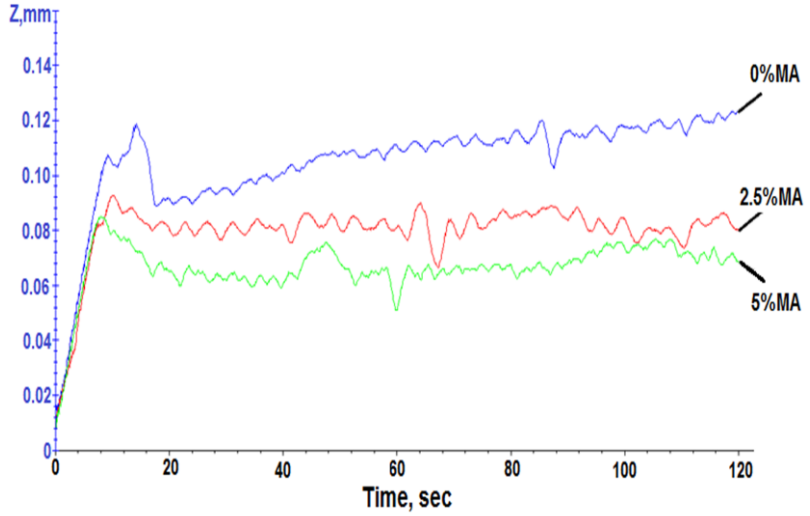


Fig. 8: Displacement of PP/MWCNT nanocomposite with 0.5% CNT vs. PP-g-MA contents

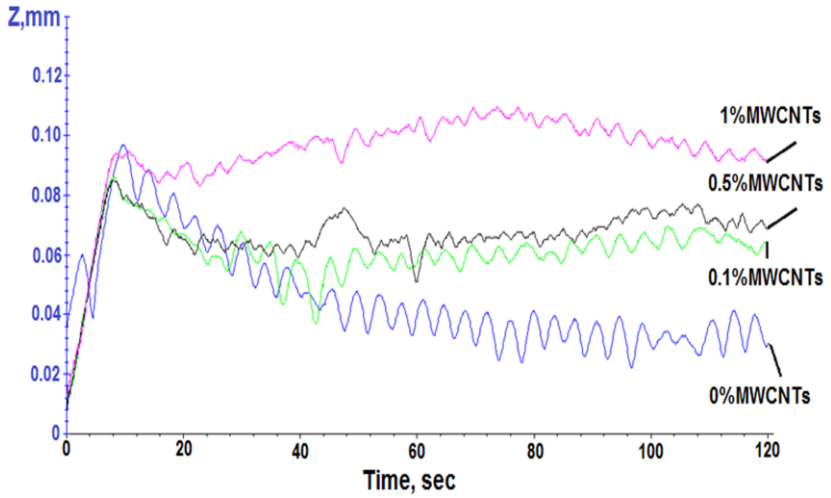


Fig. 9: Displacement of maleinated with 5% PP-g-MA PP/MWCNT nanocomposites vs. MWCNTS contents

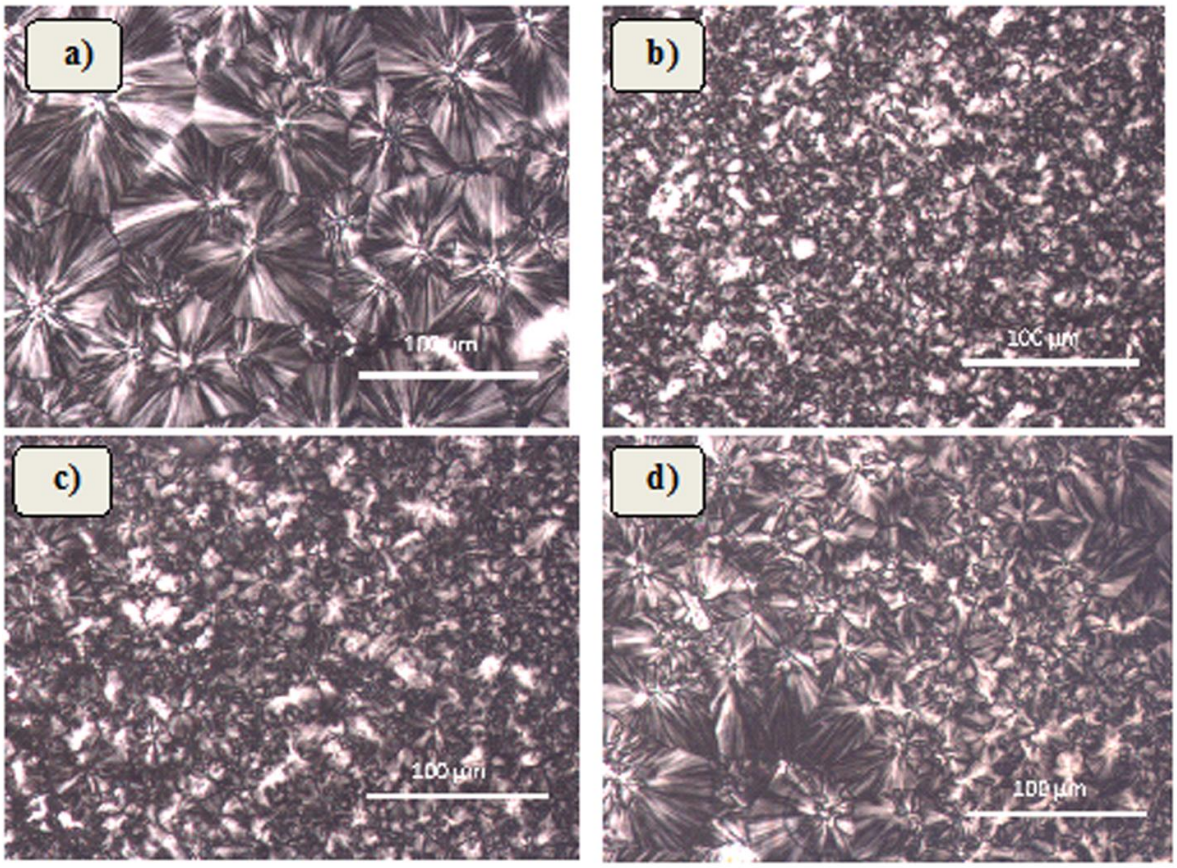


Fig. 10. Optical micrographs: a)PP; b)PP0.05CN; c)PP0.05CN5M; d)PP5M.

Optical micrographs

Optical microscopy is used for visualization of the morphology of nanocomposites, as well as for confirming the structure-property relationships. Therefore, morphological characterization is very important for the evaluation of the dispersion state of carbon nanotubes in the polymer matrix. The efficiency of nanofillers in reinforcing the polymer matrix is primarily determined by the degree of its dispersion in the matrix as the number of nucleated crystals supposed to be proportional to the surface area of the filler [11, 12].

The presence of a crystalline phase in the PP matrix creates a structure similar to the case of a two phase polymer blend with one phase being the crystals and the other phase the amorphous

domain. In Fig.10a) typical spherolite structure could be seen with big crystal lamellas as rays of pure PP, when there are no additives in the PP to influence the crystallization process.

Figure 10b), representing microstructure of PP0.05CN nanocomposite, shows that the spherolites size is not just smaller in the presence of MWCNT. It is very difficult to see well defined spherolites. The presence of nanotubes provides a tremendous amount of heterogeneous nucleation sites at crystallization process and they act as effective nucleating agents. From a thermodynamic point of view, fillers and other kinds of impurities can never exist in a crystal. Therefore, nanotubes are expected to be found only in the amorphous phase [13]. The crystalline phase rejects the nanotubes to the edges of the lamellae during the crystallization growth stage and therefore the nanotubes are located in the amorphous phase between the lamellae and form a continuous path in this blend-like structure. Obviously, the agglomeration of nanotubes in clusters or single nanotubes in the nanocomposite cannot be seen clearly in this magnification on an optical microscopy micrograph. At low MWCNTs contents the formed agglomerates are in lower magnitude and a better dispersion can be seen. This is due to the tendency of nanotubes to interact with each other due to surface forces. During their formation CNTs have surface carboxyl groups and eventually some hydroxyl groups. These interact through hydrogen bonding or due to weak Van der Wall's forces creating clusters and agglomerates.

Comparing the microstructures of PP0.05CN nanocomposite (Fig10b)) with PP0.05CN5M (Fig 10c)) different filler dispersion efficiency could be seen, achieved in both composite systems. This gives the ability to distinguish individual spherolites and to obtain better structure. Fig 10c) shows that the presence of PP-g-MA can lead to strong hydrogen bonding between carboxyl/ hydroxyl groups of the CNTs and maleic anhydride groups of PP-g-MA and can stabilize the morphology and enhance the interfacial interaction between PP/CNTs and finally promotes homogeneous dispersion of CNTs [9] [14,15]. Optical observation have proved that MA promotes the dispersion of individual carbon nanotubes and limits the presence of nanotube aggregates by wrapping the nanotubes due to hydrogen bonding and increasing their diameter [16].

In Fig. 10d) formation of different spherolites by sizes could be observed by the addition of PP-g-MA to PP. Obviously the maleic anhydride obstructed the crystallization process of PP, but not to so large extent, because it does not have so direct nucleating effect to spherolites.

4.CONCLUSION

In the present paper the tribological properties of maleinated and non-maleinated iPP/MWCNT polymer nanocomposites on the surface and in the bulk were studied based on three types of test methods.

The scratch configuration results show clear tendency of improvement of the friction behaviour of the bulk PP/MWCNT nanocomposites by increasing both carbon nanotube and maleic anhydride contents. The not so smooth results are explained with a non-homogeneous dispersion of the MWCNTs in the PP.

While the COF results obtained by pin on flat and ball on flat experiments differ from those obtained by scratch experiment, this confirms that the friction properties at the surface differ from those of the bulk. This will be subjected to further research.

From the optical micrograph observations, it could be concluded that the added PP-g-MA promotes the dispersion of individual carbon nanotubes and limits the presence of nanotube aggregates.

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FRICTION IN MECHANICAL SYSTEMS WITH RECTILINEAR MOTION

GEORGY MICHEV

Abstract: *The present paper considers brief overview of the theories of friction in mechanical systems with rectilinear motion. Based on the critical analysis of these theories, a theoretical model of friction is proposed and is verified experimentally. A regression relationship between friction force and contact deformations is being proved.*

Using the dimension analysis and Buhingem's theorem, a dimensionless value X is found. The physical interpretation of the latter reveals new concept about friction nature in mechanical systems with rectilinear motion.

By means of the research plan of the Greaco-Latin squares, a generalized formula for calculation of tangential contact deformations, correspondingly the friction force, in dependence of basic design and technological parameters of the system is found.

Key Words: *Up to 5 keywords in 10pt Arial, Italic, Justified*

ТРИЕНЕ В ПРАВОЛИНЕЙНО ДВИЖЕЩИ СЕ МЕХАНИЧНИ СИСТЕМИ

ГЕОРГИ МИШЕВ

Резюме: *В настоящата работа се прави кратък преглед на теориите на триене в праволинейно движещите се механични системи. На базата на критичен анализ на тези теории е създаден теоритечен модел на триенето, който е доказан експериментално. Доказана е регресионата връзка на силата на триене от контактните деформации.*

С помощта на анализа на размерностите и теоремата на Бухингем е намерано бездименсионно число X. Физическото тълкуване на това бездименсионно число дава съвършенно нова предсава за същността на триенето в праволинейно движещите се системи.

С помощта на изследователски план на гръко-латински квадрат е намерена обобщена формула за изчисляване на тангенциалните контактни деформации, респ. На силата на триене от основните конструктивни и технологични параметри на системата.

Ключови думи: *ред до 5 ключови думи - 10 pt Arial, Italic, Justified.*

I. ВЪВЕДЕНИЕ

Триенето като процес е извесно още на първобитните хора. Благодарение на триенето на две твърди тела, без да разбират същността на процеса, те са получавали огън за приготвяне на своята храна.

1. За първи път класическите идеи на триенето са формулирани от Леонардо да Винчи (1452 – 1519) в своите знаменателни очерци, които се състоят в следното:

- силата на триене е правопропорционална на натоварването;
- коефициента на триене не зависи от приведената площ на контакта;
- статичния коефициент на триене е по голям от кинетичния;
- коефициента на триене не зависи от скоростта на плъзгане.

На базата на тези класически идеи по късно френския учен Амонтон е провел редица експерименти.

През 1778 година Шарл-Огюст Кулон предлага двучленна формула за триенето, съгласно която:

(I.1) $$F_R = A + B.N; \qquad \mu = \frac{A}{N} + B$$

където *A* е характеристиката на сцеплението на двете тела. Тази формула съдържа две съставляващи на силата на триене, едната от която не зависи от външното натоварване. Според Кулон коефициента на триене за всяка конкретна триеща двойка не остава постоянен и се променя в зависимост от приложеното натоварване.

Класическият закон на Амонтон-Кулон без значителни изменения съществува и до днес. Този закон дава удивително пълна представа за механизма на триене и количествено се изразява с формулата:

(I.2) $$F_R = \mu.N$$

където F_R – сила на триене;

μ - коефициент на триене;

N - нормална сила.

2. Теория на механичното сцепление, предложена от Амотон де ла Гир (1699) и Паран (1703), обяснява триенето на металите описвайки механизма на взаимодействие между отделните грапавини на допирателните повърхнини. Според тази теория триенето при покой и триенето при движение представлява силата, необходима за повдигане на грапавините на горната повърхност над тези на долната повърхност. Тангенсът от ъгъла на наклона на тези неравности (грапавини) е равен на коефициента на триене.

3. Теорията на електростатичните сили обяснява явлението на скокообразно движение (Stick-Slip-effekt) при триене на метални повърхнини с възбуждането на поток електрони, създаващи нагрупвания на заряди с противоположна полярност на разделителните повърхнини.Създадените електростатични сили задържат повърхнините и ги принуждават да се движат скокообразно.

4.Теорията на молекулното притегляне, предложена от английския физик И.Дезагюле (1704), а по- късно и от Томплинсън (1928) и Харди (1936), дава ново тълкуване на процеса на триене. Тя обяснява силата на триене като дисипация (разсейване) на енергия при “изкубване” на атоми от едното тяло от зоната на атомно привличане на повърхността на второто тяло. Според тази теория се отдава първостепенна роля на механизма на атомно-молекулното взаимодействие между триещите се материали [1].

5.Теория на заваряването, срязването и следата, предложена от Боуден и Тейбор през 1950 година, днес е широко приета за изясняване на механизма на триене на металите [2,3,4]. Високото налягане, възникващо в определени площадки на допиране, поражда местно заваряване. При относително плъзгане на повърхнините образуваното съединението се срязва. Това срязване образува адхезионната съставляваща на силата на триене.

Ако горния елемент е изработен от по-твърд материал отколкото долния, то при плъзгането грапавините му ще образуват драскотини или ще прорежат каналчета по долната повърхнина. Този ефект на образуване на следи води до появата на деформационната съставляваща на силата на триене. Следователно, два са основните фактори, които определят триенето, възникващо между несмазани повърхнини при тяхното относително движение. Първият и обикновенно най-голям фактор се явява адхезията в областта на реалния контакт [2], а втория - деформацията на контактните повърхнини. При отсъствие на взаимодействие на тези фактори общата сила на триене се определя с формула:

(I.3) $$F_R = F_A + F_D$$

където F_R е общата сила на триене;

F_A – адхезионна компонента на силата на триене ;

F_D - деформационна компонента на силата на триене .

Според Мур [5] при сухо триене коефициентът на адхезионно триене е два пъти по-голям от коефициента , породен от действието на деформационната съставляваща на силата на триене.

6.Молекулно-механичната теория, предложена от Крагелски И.В. [6,7,8,9], по същество се доближава до тази на Боуден и Тейбор, като отчита основните фактори на влияние върху триенето – адхезионната и деформационната съставляваща. Съгласно тази теория силата на триене се определя от адхезията в зоната на контакта и деформирането на тънкия повърхностен слой, обославящо появяването на тангенциални напрежения в триещите повърхнини.

За обяснение на основните особености на сухо триене, Крагелски въвежда понятието “трето тяло”, което се формира между триещите се повърхнини. Показана е реологичната

природа на фрикционния контакт, разгледано е явлението на предварително преместване, както и основните моменти, характеризиращи триенето [8].

Според тази теория основните моменти, характеризиращи триенето са:

- Взаимодействието на телата при триене се съсредоточава в определен обем на материала, имащи еластично-пластични свойства. Този обем може да се разглежда като "трето тяло";

- Върху свойствата на "третото тяло" оказват влияние състоянието на повърхнините, налягането между телата, времето на престой на контакта, скоростта на приложеното натоварване;

- При взаимното преместване на телата се появяват едновременно разрушаване и формиране на "третото тяло";

- Налягането оказва значително влияние на големината на коефициента на триене;
- Силата на триене зависи от времето на престои на неподвижният контакт;
- При незначителни скорости на движение, същото има скокообразен характер;
- Силата на триене зависи от скоростта на взаимното преместване.

Молекулно-механичната теория, допълнена по-късно от много изследователи [10,11,12,13 и др.] характеризират триенето като съвкупност от физико-химични процеси при които:

- Увеличаването на силата на триене с нарастване на нормалното налягане при постоянна контактна площ се обуславя от наличието на молекулна грапавост;
- Силата на молекулното привличане увеличава външното нормално натоварване по големина, равна на равнодействащото молекулно притегляне;
- Пълната енергия, изразходвана при триене, се натрупва от загуби за образуване на нови повърхнини, деформиране на триещата двойка, отделяне на топлина и т.н.

Във всички досегашни изследвания на триенето на твърди тела и полимери се отбелязва зависимостта на силата и коефициента на триене от нормалното натоварване, скоростта на плъзгане и от времето на неподвижен контакт. Досегашните изследвания на природата на повърхностното триене показват, че в най-общ случай този процес се обуславя от адхезионното и деформационното взаимодействие на границата на контакта.

Много от първоначалните закони и теории на триенето по своята същност са чисто геометрични или само механични явления. Това е особено характерно за теорията на механичното сцепление и първоначалната теория на молекулното притегляне.

1. Теорията на механичното сцепление представлява чисто геометрична теория на триенето и може да бъде отхвърлена, тъй като относителното повдигане и пропадане на неравностите (грапавините) на повърхнините на горния детайл спрямо неравностите на долния в процеса на плъзгане, не довежда до дисипация на енергията, а механизмът на триенето определено се явява дисипативен;

2. Теорията на електростатичните сили има съществени слабости:

- вследствие на изтичане (утечки) на електрони от разделителната повърхнина за продължителен период от време, коефициентът на триене би трябвало да се намали, но такова явление не се наблюдава;
- електростатичното електричество се получава само при взаимно триене между диалектрични материали;
- при триене на метал върху метал не може да се създаде електростатично електричество. Ако се приеме, че такова се създава между два метала, то това е възможно само при изолация на двата метала от земята тогава това електростатично електричество между триещите се повърхнини се запазва. Ако обаче няма изолация, то съгласно класическите закони на електритехниката, потенциал не може да се създаде, тъй като има изтичане на електрони. Това означава, че при заземени машини не може да има формиране на електростатична сила, т.е. на сила на триене, още повече автоколебания при праволинейно движение. Това се опровергава от практиката, тъй като могат да се създадат автоколебания при много добре заземени машини, с което се доказва несъстоятелността на електростатичната теория;

3. В атомно-молекулните теории на триене на твърдите тела, голяма част от явленията, свързани с обясняването на този процес (промени в структурата на кристалната решетка, адхезионни и кохизионни явления) се разглеждат на основата на атомно-молекулното взаимодействие. Именно от тази гледна точка работите на Б.Дерягин имат голям приоритет при разработване на биноминалния закон на триене. От тази позиция обаче, възникват редица проблеми, свързани с действието на металната връзка между атомите в кристала. Тя може да бъде изучена точно с помощта на общата квантова механика , което при тях не се разглежда.

4. Теорията на заваряването, срязването и следата, която се явява доразвитие на теорията на молекулното привличане, дава удовлетворително физическо обяснение на триенето на металите на макроскопично ниво. Тази теория обаче не може да обясни редица явления в практиката, освен това тя няма експериментално доказателство. Отдаването на предпочитание на адхезионната компонента пред деформационната [4,5] в процеса на триене има редица дискусионни моменти:

∗ За да се извърши студено заваряване на контактите са необходими следните условия [21]:

- чисти повърхнини без окиси;
- сходство на кристалните решетки на металите;
- достатъчно високо налягане, което да превишава напрежението на смачкване.

Тези условия не могат да бъдат изпълнени едновременно за контактуващите метали, вследствие на което не може да се твърди (докаже), че адхезионната компонента на силата на триене е по-голяма от деформационната. Освен това силата на взаимодействие между две еднакви повърхнини зависи от четвъртата степен на разстоянието между повърхнините и обемната плътност на електроните в твърдите тела [14].

Твърдите тела обикновенно се покриват с твърди корици (окисни, газови покрития и др.), които са с дебелина от порядъка на 30÷50 $\overset{o}{A}$ [15]. Тези корици предпазват лежащите под тях микрограпавини от адхезионното взаимодействие [16]. Якостта на образуващите се в този случай адхезионни връзки зависи от свойствата на контактуващите корици.

Според някои изследователи [17,18] за да се осъществи заваряване на твърдите тела е необходимо да се отделят от контактните повърхнини различните окисни корици, например при значителни пластични деформации, при което кориците се разкъсват и се открива чист метал. Освен това в реалните механични системи между триещите се повърхнини се появява трето тяло - мажеща течност.

Изследването на адхезионното взаимодействие на твърдите тела, тяхното свързване и заваряване до този момент не са увенчани с успех, тъй като нито практиката, нито теорията разполагат с ясни зависимости, характеризиращи това явление [16,19]. Основната причина се заключава в това, че досега не се отдало достатъчно детайлно да се проанализира комплекса от протичащи в този случай процеси, всеки от които се подчинява на свои закономерности.

∗ Според тази теория при относителното придвижване на две повърхнини, грапавините на по-твърдия метал издълбават каналчета или правят драскотини върху по-мекия метал, вследствие на което се формира деформационната компонента на силата на триене, т.е. грапавините на единия метал се явяват микроскопични режещи ръбчета. След продължителна работа на двете части би трябвало да се получи идеално гладка повърхнина на по-мекия метал, вследствие на режещите качества на грапавините, в резултат на което деформационната компонента, а от там и силата на триене след време да намалява. Но такова намаляване на силата на триене не се забелязва. Освен това при еднакво твърди тела, деформационната компонента на силата на триене би трябвало да отпадне.

∗ Теорията на Боуден и Тейбор не може да обясни падащата характеристика на силата на триене от скоростта (за малките и средни скорости). Според теорията при много високи скорости на плъзгане, металните повърхнини са подложени на интензивно фрикционно нагряване, което води до съществено изменение на състоянието на контактния метален слой, в резултат на което силата на триене намалява. Измененията на контактуващите повърхнини, свързани с тези процеси на триенето, се менят от обширно пластично течение при високи скорости, до разтопяване на грапавините при свръхвисоки скорости [5]. Скоростта, при която може да възникне стопяване на микрограпавините, достига около 1000 m/s, т.е. няколко пъти превъзхожда скоростта на звука при нормална температура [5]. Такива високи скорости не се срещат в обикновената практика но падащата характеристика на силата на триене от скоростта е ясно изразена при по-малките и средни скорости на плъзгане. Освен това провеждането на експериментите за снемане на тези характеристики е от порядъка на секунди (10÷20 s), което време е недостатъчно за фрикционно нагряване на повърхнините температури, необходими за изменение на сътоянието на контактните повърхнини.

Трябва да се отбележи още, че нагряването на повърхнините води до по-интензивно заваряване на контактните грапавини (относителната заварена площ ще се увеличи), което води до увеличаване на адхезионната компонента, т.е. до увеличаване на силата на триене. В действителност има обратно явление – намаляване на силата на триене с увеличаване на скоростта на плъзгане.

Класическият закон на триенето в най-добра степен се покрива с действителността. Това се дължи на използвания коефициент на триене, който варира в голям диапазон. Но този закон не

може да опише механизма на триенето. Освен това не може да се използва в инженерната практика на етапа на конструирането на машините. В потвърждение на това да решим един пример, като приемем нормалната сила *N=500 daN*. Коефициентът на триене е:

$\mu = 0{,}1 \div 0{,}35$ за чугун-чугун [19];

$\mu = 0{,}5 \div 0{,}8$ за стомана-стомана [19];

$\mu = 0{,}1 \div 0{,}5$ за стомана-чугун [19].

Тогава силата на триене за чугунени направляващи ще бъде:

$$F = (0{,}1 \div 0{,}35).500 = (50 \div 150)\ daN$$

Изчисляването на силата на триене по закона на Амонтон-Кулон показва един съществен недостатък: използване на коефициента на триене, който варира в големи граници. Това води до вариране на силата на триене също в големи граници, което се явява едно неудобство в процеса на проектиране и конструиране на металорежещите машини, т.е. инженерът-конструктор не може предварително, в процеса на конструиране, да определи големината на появяващата се в плъзгащите се повърхнини (направляващи, лагери и др.) сила на триене, вследствие на което не може да се търси конструктивно и технологично решение за намаляване на силата на триене, за да се получи плавно (без трептения) движение.

II. ТЕОРЕТИЧЕН МОДЕЛ НА ТРИЕНЕТО

Резултатите от измерванията на преместването на носещото тяло на праволинейно движещ се плъзгач (супорт) спрямо носещото тяло на неподвижно противотяло (тялото на машината) се разглеждат в две направления: нормално към номиналната повърхнина на плъзгане и тангенциално по направление на плъзгането (тангенциално направление). Тези премествания се разглеждат като съставени от контактни деформации и микропреплъзгвания.

Собствените тела на плъзгача и противотялото се разглеждат като идеално твърди, а грапавините - като деформируеми. В съответствие на горната хипотеза нормалното и тангенциалното преместване са съответно:

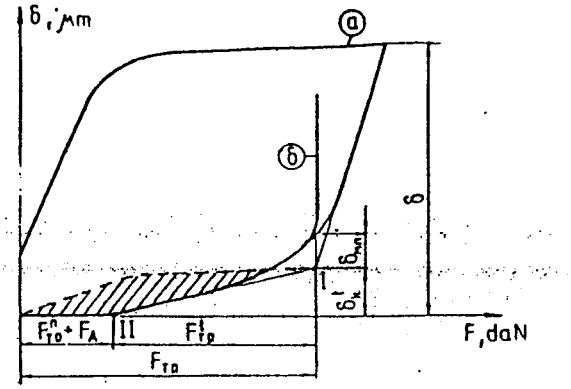
(II.1)
$$\Delta_n = \delta_k^n + \gamma_n$$
$$\Delta_t = \delta_k^t + \gamma_t$$

където Δ_n и Δ_t са съответно нормалното и тангенциалното преместване;

δ_k^n и δ_k^t - нормалните и тангенциалните контактни деформации;

γ_n и γ_t - нормалните и тангенциалните микропреплъзгвания.

Определянето на тангенциалните контактни деформации и тангенциалните микропреплъзгвания става с помощта на натоварващо-деформационната диаграма ($F - \delta -$ диаграма, фиг. II.1) .



Фиг. II.1 Натоварващо-деформационна диаграма

От тази диаграма могат да се определят: силата на триене F_{mp}, тангенциалните контактни деформации δ_k^t и деформациите на подавателния превод δ. Тангенциалните контактни

деформации се появяват до момента на преодоляване на силата на триене F_{mp} (т. I – фиг. II.1). След точка I започват деформациите на превода δ.

Изхождайки от деформационно-натоварващата диаграма и от уравнен ия (II.1) се определя:

$$\delta_k^t = \Delta_t - \gamma_t$$

В това уравнение има две неизвестни: δ_k^t и γ_t. За да се определят тези неизвестни се използува допълнително условие:

(II.2) $$\delta_k^t = k.\left(F - F_o\right)$$

където k е коефициент на пропорционалност, който може да се вземе от диаграмата в началния квазилинеен участък;

F_o - стойността на силата, от която започва линейния участък.

За определяне на γ_t се използува нова работна хипотеза, съгласно която формула (II.2) важи и извън линейния участък на диаграмата. От тази хипотеза следва, че нелинейността се дължи на появата на микропреплъзгвания, които се определят по формулата:

(II.3) $$\gamma_t = \Delta_t - k.\left(F - F_o\right)$$

II.1 Анализ на силите в допирния контакт

За изясняване на контактните премествания и пораждащите се явления от това се направи анализ на силите в допирния контакт под действието на външни активни сили. На фиг. II.2 е разгледан модел на осреднена грапавина на допирната повърхнина на една триеща двойка. Общата допирателна в дискретната контактна област (т. А) на двете повърхнини сключва ъгъл α с геометричната равнина на допиране. При натоварването на супорта се срещат следните случаи:

I. случай: Натоварване на супорта само с нормална сила $\overrightarrow{N}$ (фиг. II.2,а).

Нормалната сила $\vec{N}$ се формира от силата на теглото на супорта $\vec{G}$ и външната активна натоварваща сила $\overrightarrow{N_0}$ т.е.

$$\vec{N} = \vec{G} + \overrightarrow{N_0}$$

Нормалната сила може да се разложи на две компоненти:

- $\overrightarrow{N_1}$ е нормална към общата допирателна на двете грапавини;
- $\overrightarrow{N_2}$ - тангенциална към общата допирателна на двете грапавини.

Силата N_1 поражда нормални локални контактни деформации $\delta_{k_i}^n$, а силата N_2 поражда нормални микропреплъзгвания γ_{n_i}. В дискретните контакти, където напрежението на смачкване е по-голямо от допустимото, се появяват молекулярни взаимодействия (адхезионно връзки) δ_A. В резултат на това възникват две компоненти на силата на триене в *i*-тия контакт:

- $F_{R_{N_i}}^n$ е компонентата на силата на триене в локалния контакт, възникваща в резултат на нормалните локални контактни деформации;
- $F_{R_{A_i}}^n$ е адхезионната компонента на силата на триене в локалния контакт, възникваща в резултат на разкъсване на молекулярните връзки (микрозаварки), вследствие на наличието на нормални микропреплъзвания.

Тогава

(II.4) $$F^n_{R_N} = \sum F^n_{R_{N_i}}$$

е компонентата на силата на триене, възникваща в резултат на наличието на нормалните локални контактни деформации по цялата допирна площ, и

(II.5) $$F^n_{R_A} = \sum F^n_{R_{A_i}}$$

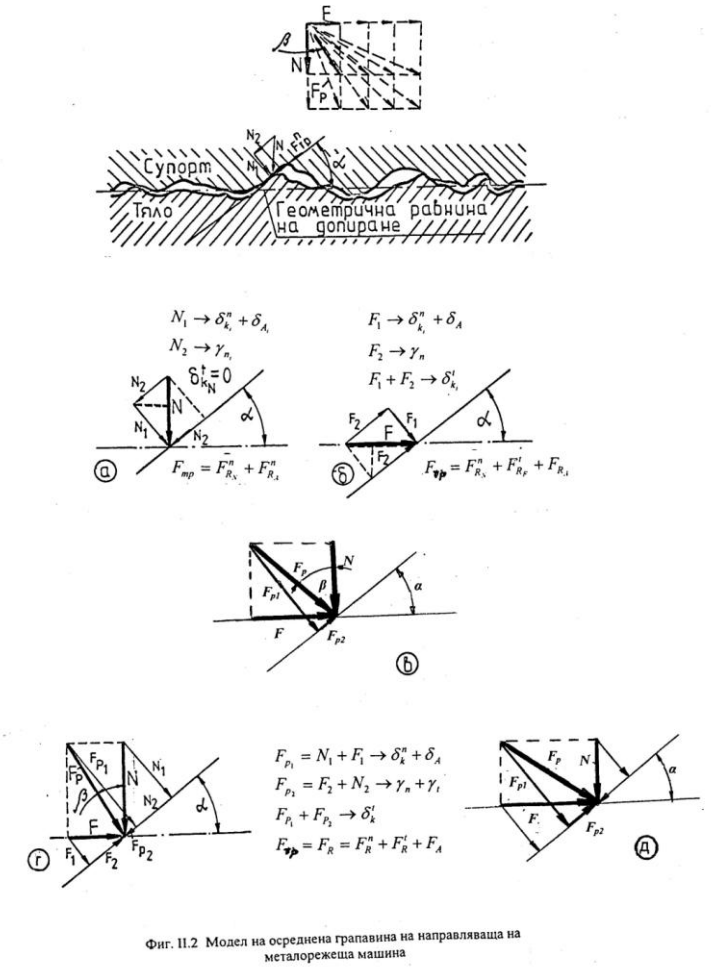
е адхезионната компонента на силата на триене, възникваща в резултат на разкъсване на молекулярните връзки (микрозаварки), вследствие на появилите се микропреплъзгвания в контакта по цялата допирна площ.

II. Случай: Натоварване на супорта само с тангенциална сила *F* (фиг. II.2,б).
Този случай би бил възможен, само ако супорта се апроксимира в точка. В реалните условия това е невъзможно, затова този случай не се разглежда.

III. Случай: Натоварване на супорта едновременно с нормална $\vec{N}$ и тангенциална $\vec{F}$ сили (фиг. II.2,в).

Равнодействуващата им сила $\overrightarrow{F_p}$ може да се разложи на две компоненти:

- $\overrightarrow{F_{p_1}}$ е нормалната компонента към общата допирателна;
- $\overrightarrow{F_{p_2}}$ - тангенциална компонента към общата допирателна.



Фиг. II.2 Модел на осреднена грапавина на направляваща на металорежеща машина

Фиг.II.2 Модел на осреднена грапавина на допирните повърхнини

Под действието на нормалната компонента $\overrightarrow{F_{p_1}}$ възникват нормални контактни деформации δ_k^n, а под действието на тангенциалната компонента $\overrightarrow{F_{p_2}}$ - тангенциални контактни деформации δ_k^t. Под действието на двете компоненти възникват и микропреплъзвания в нормално γ_n и тангенциално γ_t направление.

В зависимост от съотношението на големините на силите *N* и *F* се срещат два частни случая:

а) $\frac{F}{N} \le tg\alpha$ (фиг. II.2,г). Този случай е налице, когато $\overrightarrow{N_2} > \overrightarrow{F_2}$. Тогава тангенциалната компонента $\overrightarrow{F_{p_2}}$

на равнодействуващата сила създава микропреплъзвания по посока на взаимното сближаване на собствените тела на супорта и тялото;

б) При $\frac{F}{N} \ge tg\alpha$ (фиг.II.2,д). Този случай е налице когато $\overrightarrow{N_2} < \overrightarrow{F_2}$. Тогава тангенциалната компонента $\overrightarrow{F_{p_2}}$ на равнодействуващата сила създава микропреплъзвания по посока на взаимното отдалечаване на собствените тела на супорта и тялото.

И в двата частни случая възникват следните компоненти на силата на триене:

F_R^n - деформационна компонента, възникваща в резултат на нормалните локални контактни деформации δ_k^n;

F_R^t - деформационна компонента, възникваща в резултат на тангенциалните контактни деформации δ_k^t;

F_A - адхезионна компонента, възникваща в резултат на разкъсването на молекулярните връзки (микрозаварки), вследствие на микропреплъзванията в двете направления γ_t и γ_n.

Следователно общата сила на триене се състои от три компоненти:

(II.6) $$F_R = F_R^n + F_R^t + F_A$$

При това $F_R^d = F_R^n + F_R^t$ представлява деформационната компонента на силата на триене, а $F_A = F_{R_A}^n + F_{R_A}^t$ представлява адхезионната компонента на силата на триене.

II.2 Експериментално доказателство на теоретичния модел

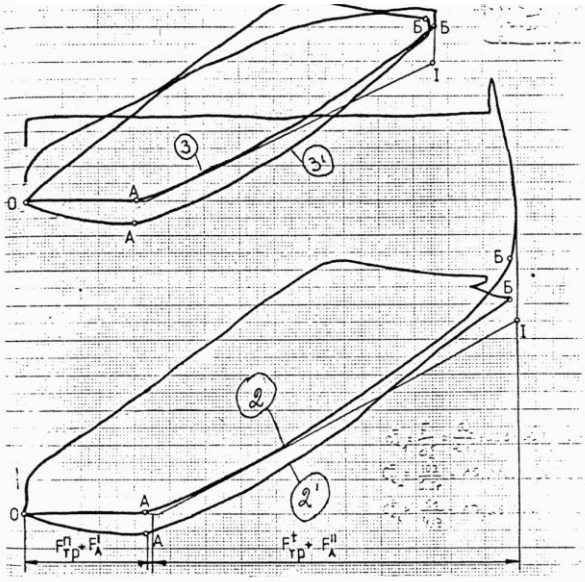
Експерименталните изследвания за доказване на теоретичния модел на триенето се проведоха по методика описана в [20]. На фиг. II.3 е показан експерименталния запис на натоварващо-деформационните диаграми ($F-\Delta_t$-диаграма и $F-\Delta_n$-диаграма) в двете взаимно перпендикулярни координати (Y_1 и Y_2).

Както се вижда от записите, до точка II от $F-\Delta_t$-диаграмата (фиг. II.3 - запис 1,2), супорта се премества надолу ($F-\Delta_n$-диаграма, фиг. II.3 - записи 1' , 2') , т.е. има сближение на собствените тела на плъзгача и противотялото едно спрямо друго, в резултат на което възникват нормални контактни локални деформации δ_k^n и нормални микропреплъзгв ания γ_n. В резултат на това възникват две компоненти на силата на триене:

- F_R^n - възниква в резултат на преодоляване на локалните нормални контактни деформации;
- F_A^n -възниква в резултат на разкъсване на молекулярните връзки (микрозаварки) вследствие на нормалните микропреплъзгвания.

След точка II до преодоляване на силата на триене - точка А - възникват тангенциални контактни деформации δ_k^t и тангенциални микропреплъзгвания γ_t ($F-\Delta_t$-диаграма), като в същото време супорта се премества нагоре ($F-\Delta_n$-диаграма) до достигане на линията на плъзгане, т.е. има взаимно отдалечаване на двете собствени тела. В резултат на това възникват две компоненти на силата на триене:

* F_R^t - деформационна компонента, възникваща в резултат на преодоляване на тангенциалните контактни деформации δ_k^t;



Фиг. II.6 Експериментални записи на натоварващо-деформационни диаграми в две взаимно перпендикулярни координати

както и формирането на силите в дискретния контакт. Доколкото присъствието на контактните деформации като компонента на преместването се отбелязва за първи път, възниква въпросът за ролята на тези деформации при формирането на силата на триене и влиянието им на автоколебателния процес.

* F_A^t- адхезионна компонента, възникваща в резултат на разкъсване на предварително образувалите се молекулярни връзки (микрозаварки) вследствие на микропреплъзгванията в тангенциално γ_t и нормално γ_n направления.

Следователно:

(II.7) $$\overline{F_R}=\overline{F_R^n}+\overline{F_R^t}+\overline{F_A^n}+\overline{F_A^t}$$

Като се положи

(II.8) $$\overline{F_A}=\overline{F_A^n}+\overline{F_A^t}$$

се получава формула (II.6).

Следователно, силата на триене се явява съпротивителна сила за преодоляване на контактните деформации и сила, необходима за разкъсване на образувалите се молекулярни връзки (микрозаварки).

Както се вижда от фиг. II.3 експериментът потвърждава състоятелността на хипотеза (II.1) за съществуването на две компоненти на контактни премествания: на нормални и на тангенциални премествания, както и формирането на силите в дискретния контакт. Доколкото присъствието на контактните деформации като компонента на преместването се отбелязва за първи път, възниква въпросът за ролята на тези деформации при формирането на силата на триене и влиянието им на автоколебателния процес.

От проведените експериментални изследвания се установи, че силата на триене основно се формира от тангенциалните контактни деформации. Анализът на проведените многобройни изследвания доведе до намиране на емпиричната връзка между тангенциалните контактни деформации и силата на триене, изразена със зависимостта:

(II.9) $$F_R = A.\delta_k^t + B$$

където *A* и *B* са коефициенти, зависещи от материала на триещата двойка, от качеството на триещите повърхнини и от тяхното състояние.

III. НОВ МЕТОД ЗА ПРЕСМЯТАНЕ НА СИЛАТА НА ТРИЕНЕ В ПРАВОЛИНЕЙНО ДВИЖЕЩИ СЕ СИСТЕМИ

С помощта на анализа на размерностите, теоремата на Бухингем и метода на Релей е намерено бездименсионното число:

(III.1) $$X = \frac{p.R_a^3}{V^2.m}$$

където p е нормалното налягане в допирните повърхнини;

R_a - грапавост на допирните повърхнини;

V - скорост на праволинейно движещото се тяло на грибодвойката;

m - маса на движещото се тяло.

Описаното бездименсионно съотношение (III.1) от четирите фундаментални променливи *p, V, R_a, m* може да бъде представено във вида:

(III.2) $$X = \frac{p.R_a^3}{m.V^2} = \frac{X_1}{X_2}$$

където $X_1 = p.R_a^3$ е натрупаната потенциална енергия в контакта;

$X_2 = m.V^2$ - кинетичната енергия на движещата се шейна.

Това показва, че *X* се явява съотношение на кинетичната енергия на контакта в резултат на микропреплъзгванията и натрупаната потенциална енергия на преддеформацията на контакта. Това физическо тълкуване дава съвършенно нова представа за същността на триенето при праволинейно движещите се части.

За намиране на обобщена формула за изчисляване на тангенциалните контактни деформации се проведоха множество експериментални изследвания. Проведените изследвания бяха изпълнени при изследователски план на гръко-латински квадрат. След статистическа обработка и допълнителни преобразования се получи следната обобщена формула за определяне на тангенциалните конткатни деформации в допирните повърхнини на една трибосистема:

(III.3) $$\delta_k^t = 0{,}0392.\frac{p^{1{,}1}.R_a.m^{0{,}17}}{V^{1{,}33}}$$

От уравнение (III.3) се вижда, че най-голямо влияние върху големината на тангенциалните контактни деформации оказва скоростта на праволинейно движещото се тяло *V*, а най-малко е влиянието на масата *m* на движещото се тяло.

Заместващи уравнение (III.3) в уравнение (II.9) и се използват установените коефициенти за стоманени триещи двойки, то се получава следната обобщена формула за силата на триене от основните технологични и конструктивни параметри на една праволинейно движеща се механична система:

(III.4) $$F_R = 2{,}784.\frac{p^{1{,}1}.R_a.m^{0{,}17}}{V^{1{,}33}}$$

Тази формула е удобна за ползване от конструкторите на производствена техника още във фазата на проектирането им.

IV. ЗАКЛЮЧЕНИЕ

1. Направеният критичен анализ на теориите на триене позволи да се пристъпи към изясняване и изграждане на модел на триенето в праволинейно движещите се механични системи;
2. Изграден е модел на триенето в контактните повърхнини, съгласно който общата сила на триене се състои от три компоненти:
   - деформационна компонента, възникваща в резултат на появилите се нормални локални контактни деформации;
   - деформационна компонента, възникваща в резултат на появилите се тангенциални контактни деформации;
   - адхезионна компонента, възникваща в резултат на разкъсване на изградените молекулярни връзки (микрозаварки), вследствие на микропреплъзгванията в двете направления (нормално и тангенциално);
3. Експериментално е доказан теоретичния модел на триене, при което за първи път се разграничават контактните деформации от контактните микропреплъзгвания;
4. Намерена е количествена зависимост между силата на триене и тангенциалните контактни деформации;
5. Намерено е бездименсионното число $X = \frac{p.R_a^3}{V^2.m}$, включващо основните фактори, влияещи върху тангенциалните контактни деформации, което се явява база за по нататъшни теоретични и експериментални изследвания на триенето в праволинейно движещи се механични системи;
6. Намерени са енергетични съотношения, които се явяват критерии за формирането на силата на триене в праволинейно движещи се механични системи;
7. Дадено е ново физическо тълкуване на процеса триене: триенето се явява съотношение на кинетичната енергия на контакта в резултат на микропреплъзгванията и натрупаната потенциална енергия в резултат на преддеформацията на контакта;
8. Намерена е обобщена формула за изчисляване на тангенциалните контактни деформации, респ. на силата на триене в праволинейно движещи се механични системи, отчитайки влиянието на основните конструктивни и технологични параметри на изпълнителния орган на системата (супорт, шейна и т.н.);

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HD LUBRICATION OF JOURNAL BEARINGS BY PSEUDO-PLASTIC LUBRICANTS

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Abstract: *A numerical study of the performance of a steady state loaded finite journal bearing lubricated with pseudo-plastic fluid is presented. The analysis is extended to a bearing with thin elastic layer on the shaft and its radial distortions are taken into consideration.The modified Reynolds equation introducing a "nonlinear factor" by Wada and Hayashi is worked out.The numerical solution demonstrates effects of non-Newtonian properties of pseudo-plastic fluid on the journal bearing performance.*

Key Words: *pseudo-plastic lubricants, elastohydrodynamic (EHD) lubrication*

1. INTRODUCTION

In recent years HD lubricated bearings have been used under ever more severe conditions of high speed and heavy loads. Under light load and high speed the air is used as a lubricant because if the small viscous resistance. On the other hand, under heavy load and high speed, oils containing additives are used.

The viscosity of lubricating oils decreases with an increase of temperature. Present day lubricating oils contain a large quantity of high molecular-weight polymers as the viscosity index improver in order to prevent viscosity variation with temperature change. It is known that such polymer-thickened oils have the same behavior as pseudo-plastic fluids. Though favorable results of investigation on hydrodynamic lubrication for non-Newtonian fluids of this type are important, virtually no progress has been made due to difficulties involved in analytical and experimental treatments.

There are some papers which refer to performance characteristics of bearings lubricated by pseudo-plastic fluids [1-5, 8, 10, etc]. Mainly the goal of these works is to derive the modified Reynolds equation for such kind of lubricants and to receive analytical solution of it. Only few numbers of published papers are in the field of behaviour of finite length journal bearings.

Along with that it is important to consider in the analysis and additional major factors affecting the HD journal bearing performance like elastic deformation of contact surfaces, which cause a reduction in pressure, generated in the oil film [6, 7, 9, etc.] With regard to all mentioned, the purpose of the present work is to study the effect of interaction of the non-Newtonian properties of pseudo-plastic lubricant and shaft's liner elastic deformation on the performance (film forces, Sommerfeld number, attitude angle and frictional force) of HD journal bearings.

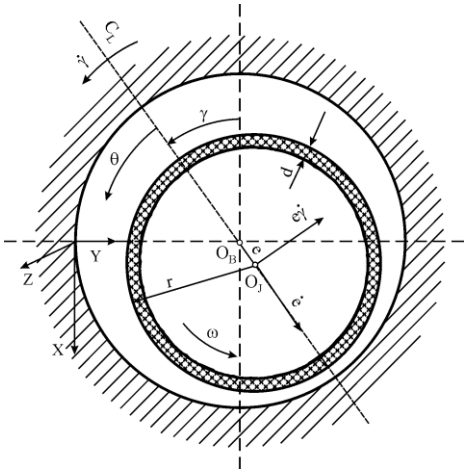


Fig.1 Journal bearing with a soft layer on the shaft

In the current study the problem is investigated for a non-Newtonian lubricant under isothermal and isoviscous conditions. The bearings' shaft is covered with a thin resilient layer, whose radial displacements are of the same order of magnitude as the film thickness (Fig. 1). The effect of pseudo-plastic kind of the lubricant is taken into account by modified Reynolds equation governing the film pressure.

2. ELASTOHYDRODYNAMIC MODEL OF LUBRICATION

2.1. Flow characteristics and modified Reynolds equation

It is well known that lubricating oils, with viscosity index improver added, exhibit the same characteristics as pseudo-plastic fluids. In that case the relationship between the shear stress and shear rate may be approximated by the following equation:

$$\tau + k\tau^3 = \eta \frac{d\gamma}{dt} \tag{1}$$

If the values of η do not vary, the nonlinearity of the flow curve increases with the value of the coefficient of pseudo-plasticity *k*. In pseudo-plastic non-Newtonian fluids, $k > 0$, while in Newtonian fluids $k = 0$.

The Reynolds equation, which governs the pressure distribution, is obtained from the integral form of continuity equation. For steady loaded finite journal bearing under laminar conditions the modified Reynolds equation for pseudo-plastic fluids can be written as [3]:

$$\frac{\partial}{\partial x}\left\{\frac{1}{\eta}\left[\frac{h^3}{12}\frac{\partial p}{\partial x} + \psi\frac{h^5}{80}\left(\frac{\partial p}{\partial x}\right)^3\right]\right\} + \frac{\partial}{\partial z}\left\{\frac{1}{\eta}\left[\frac{h^3}{12}\frac{\partial p}{\partial z} + \psi\frac{h^5}{80}\left(\frac{\partial p}{\partial z}\right)^3\right]\right\} = \frac{\omega r}{2}\frac{\partial h}{\partial x} \tag{2}$$

where ψ is “nonlinear factor”, which is given as

$$\psi = k\left(\frac{\eta u}{C}\right)^2 = \bar{k}\left(\frac{\bar{\eta}\omega r}{C}\right)^2. \tag{3}$$

It is known, that for Newtonian fluids $k = 0$ and from Eqn (2) can be obtaining the classical Reynolds equation. The above equation is more general, as it includes the case of Newtonian fluids.

Each term of the right-hand side of Eqn (2) indicates, respectively, the action of wedge, stretch or squeeze. In hydrodynamically lubricated bearings using pseudo-plastic fluids, the film pressure is developed by the same three terms as are used for Newtonian fluids.

By applying the above mentioned modified Reynolds equation to journal bearings, the bearing performance can be obtained. In consideration of the dimensionless expressions mentioned above the modified Reynolds equation for a steady load takes the following nondimensional form:

$$\frac{\partial}{\partial\theta}\left[\frac{H^3}{12}\frac{\partial\Pi}{\partial\theta} + \psi\frac{H^5}{80}\left(\frac{\partial\Pi}{\partial\theta}\right)^3\right] + \alpha^2\frac{\partial}{\partial z_1}\left[\frac{H^3}{12}\frac{\partial\Pi}{\partial z_1} + \alpha^2\psi\frac{H^5}{80}\left(\frac{\partial\Pi}{\partial z_1}\right)^3\right] = \frac{1}{2}\frac{\partial H}{\partial\theta} \tag{4}$$

Nomenclature

c	Radial clearance , [m]	x, y, z	Orthogonal Cartesian coordinates
C_{ij}	Oil film damping coefficients	u, v, w	Velocity components, [m.s^{-1}]
d	Shaft liner thickness, [m]	W	Load-carrying capacity, [N]
E	Young's modulus, [Pa]	$\bar{W}$	Dimensionless load-carrying capacity
e	Eccentricity, [m]		$= W(c/r)^2/6\eta\omega rL$
h	Film thickness, [m]	$\alpha = 2r/L$	Diameter to length ratio
H	Dimensionless film thickness $= h/c$	$\beta = c/r$	Clearance ratio
k	Coefficient of pseudo-plasticity	γ	Attitude angle, [rad]
L	Bearing axial length, [m]	$\varepsilon = e/c$	Eccentricity ratio
m	Mass of rotor per bearing, [kg]	$\theta = x/r$	Circumferential coordinate
p	Hydrodynamic pressure, [Pa]	δ	Liner surface points radial displacement, [m]
r	Shaft liner outer radius, [m]	υ	Kinematical viscosity of the lubricant, [m^2/s]
Re	Global Reynolds number $= \omega r c/\upsilon$	η	Dynamic viscosity of the lubricant, [Pa.s]
S	Sommerfeld number	μ	Poisson's ratio
τ	Shear stress	Π	Dimensionless pressure $= p.(c/r)^2/6\eta\omega$
ψ	Nonlinear factor	ω	Shaft angular velocity, [s^{-1}]

2.2. Oil-film thickness equation

The film shape in the journal bearing can be evaluated from the following equation, which describes the film geometry:

$$h(x,z) = c + e\cos\theta + \delta \,. \tag{5}$$

In current analysis is used an approach that aims to superimpose the deformation of the layer on the shaft, caused by hydrodynamic pressure generated onto the oil film thickness. By this way the film thickness is modified to take into account the respective elastic deformations, which are represented by the last term of above equation.

For numerical solution the above equation is modified to:

$$H = 1 + \varepsilon\cos\theta + \bar{\delta} \,. \tag{6}$$

Determination of the liner's surface point's radial displacements is carried out in accordance with the Vlassov three-dimensional model of elastic foundation for the case of thin layer [6]:

$$\bar{\delta} = \frac{6\,\eta\omega r^2}{c^3}\,\frac{(1-2\mu)(1-\mu^2)d}{E(1-\mu)^2}\,\Pi \tag{7}$$

2.3. Load-carrying capacity and attitude angle

Integration of the dimensionless pressure over the bearing area gives the non-dimensional load-carrying capacity, calculated by:

$$\bar{W} = \sqrt{\bar{W}_1^2 + \bar{W}_2^2} = \frac{\beta^2}{6\eta\omega r L} W \,. \tag{8}$$

where $\bar{W}_1$ and $\bar{W}_2$ are the components along and perpendicular to the line of centers and they represent respectively as:

$$\bar{W}_1 = -\int_{-1}^{1}\int_{0}^{2\pi} \Pi\cos\theta\, d\theta dz_1 \,; \qquad \bar{W}_2 = \int_{-1}^{1}\int_{0}^{2\pi} \Pi\sin\theta\, d\theta dz_1 \,, \tag{9}$$

Consequently, the attitude angle γ is calculated by

$$\gamma = tan^{-1}\left(\bar{W}_2/\bar{W}_1\right) \tag{10}$$

and the Sommerfeld number may be defined as [13]

$$S = \frac{W\beta^2}{\eta\omega r L} = 6\bar{W} \tag{11}$$

Integrating the shear stress τ_{xy} around the journal surface, the dimensionless friction force acting on the journal can be derived; subsequently the friction coefficient can be calculated and written as

$$\bar{F} = \int_{0}^{1}\int_{0}^{2\pi} \left.\frac{\partial\bar{u}}{\partial y_1}\right|_{y_1=H} d\theta dz \,; \qquad C_F = \frac{\bar{F}}{\bar{W}} \,. \tag{12}$$

3. NUMERICAL SOLUTION AND RESULTS

3.1. Numerical solution

EHD problem presupposes simultaneous solution of the modified Reynolds equation for pseudo-plastic fluids (4), film thickness equation (6) and elasticity equation (7).

The dimensionless modified Reynolds equation is solved numerically using the finite difference method with application of an over-relaxation procedure in order to improve the convergence rate.

For pressure distribution the Reynolds boundary conditions were used and because of which the negative pressure values are immediately put to zero. The film domain is divided by the grid spacing. Various mesh sizes have been tried and a mesh with 118 intervals in the circumferential direction and 30 intervals across the bearing width is used. This size gives a rapid rate of convergence and agreeable computer working time. It was observed that increasing of the number of grid points almost does not affect the results. The convergence criterion adopted for pressure is $\left|\left(1-\sum \Pi_{new}/\sum \Pi_{old}\right)\right| \le 1.10^{-7}$.

3.2. Results and discussion

The present analysis showed that the effect of non-Newtonian properties of pseudo-plastic lubricant can be presented by nonlinear factor ψ while from another side the effect of deformability of the shafts layer - by parameters μ and E. Then, considering the mathematical model, the governing parameters are eccentricity ratio ε, diameter to length ratio α, ψ and elastic layer parameters μ, E.

In the computations are used the following main operating conditions, which represent the investigated effects: for Newtonian fluid – $\psi = 0$; for pseudo-plastic fluid - $\psi = 0,1$, $\psi = 1$ while the elasticity parameters are: $E = 2.10^{11}$ [Pa], $\mu = 0,25$ (rigid case); $E = 7,33.10^{7}$ [Pa], $\mu = 0,4$ (soft case). The results were obtained for diameter to length ratio α equal to 1,0 whereas the eccentricity ratio ε was varied from 0,1 to 0,9.

The effect of non-Newtonian lubricant's properties and respectively deformability of the shafts liner on the pressure profile by the bearing's line of centers is presented on Figures 2.

It has been observed that the maximum pressure values reduce with the values of the nonlinear factor ψ and larger deformability values. It is clear from the figure that the pressure in pseudo-plastic fluids is smaller as compared with Newtonian fluids. When the nonlinear factor approaches zero, the pressure distribution represents the pure EHD lubrication case and if deformations are ignored the lubrication is pure hydrodynamically.

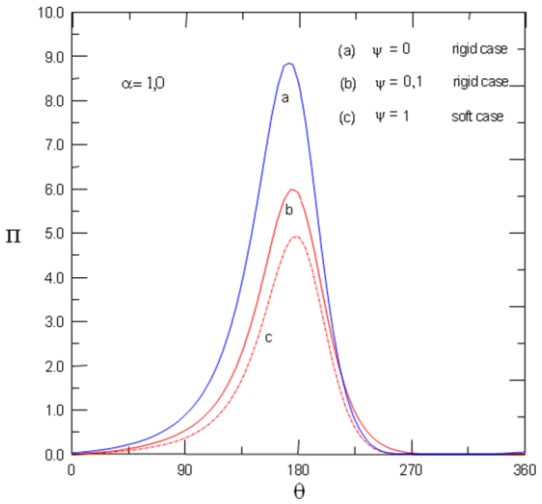


Fig. 2 Distribution of pressure Π

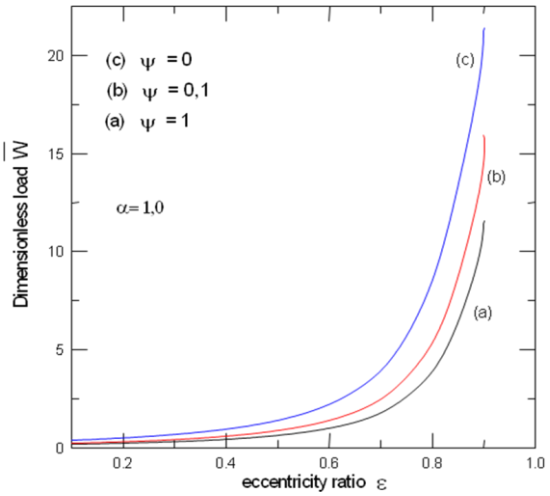


Fig. 3 Load carrying capacity

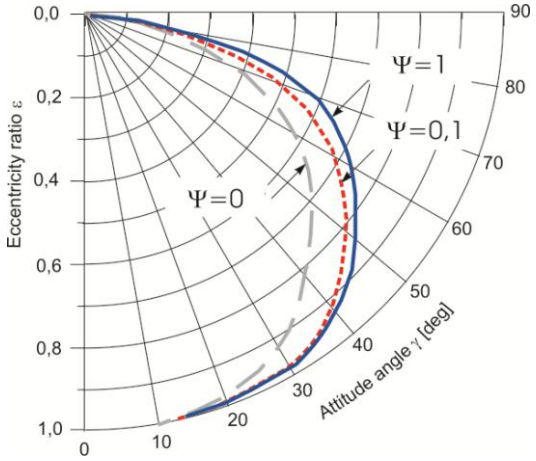


Fig. 4 Attitude angle vs eccentricity ratio

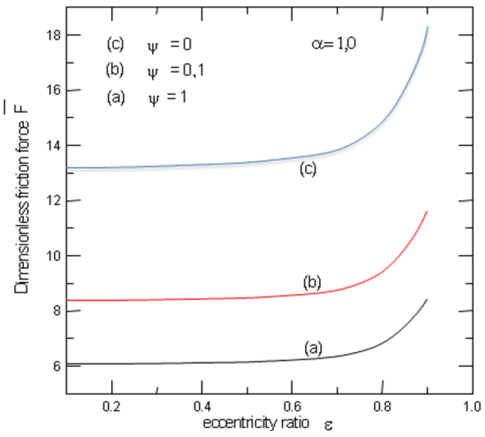


Fig. 5 Dimensionless frictional force

Analogical as the influence on HD pressure, the dimensionless load-carrying capacity becomes smaller at pseudo-plastic fluids than at Newtonian oils (for the same eccentricity ratio), as it is shown on Figure 3, where the presented results refer to the soft case. Obviously, similar tendencies must be waiting and for Sommerfeld number values.

Figure 4 shows the effect of turbulence on attitude angles. The attidude angle at pseudo-plastic oils is larger than that Newtonian lubricants. Furtermore, this tendency can be recognized more clear at the middle and biggger eccentricity ratios; especially at eccentricities between 0.3 and 0.9.

The influence of non-linear factorn of pseudo-plastic fluid on the dimensionless frictional force is presented on Figure 5. For all of the eccentricity ratios the frictional force is remarkably smaller than that for Newtonian fluid. The same effect can be expected and on the friction coefficient.

4. CONCLUSION

In the present paper was studied the effect of interaction of the non-Newtonian properties of pseudo-plastic lubricants and shaft's liner elastic deformation on the dynamic performance of HD journal bearings.

On the base of modified Reynolds equation of pseudo-plastic fluids are calculated pressure distribution, film thickness and elastic distortions of the surface points. By this way performance characteristics of the journal bearing are founded and the main conclusions can be written as follows: The maximum values of hydrodynamic pressure apparent decreases below that of Newtonian fluids. The load carrying capacity, Sommerfeld number and frictional force also reduced as the effect on them is more evident at high eccentricities. These tendencies become more pronounced at higher values of nonlinear factor.

ACKNOWLEDGMENTS

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RESEARCH OF THE TRIBOLOGICAL CHARACTERISTICS OF THE COATINGS OVER 100Cr6 STEEL

Stefan DISHLIEV

Abstract: *In the current work tribological characteristics are investigated of coatings on steel 100Cr6, applied method PVD. TiN, ncAlTiN/αSi_3N_4 and ncAlCrN/αSi_3N_4 were coated. To determine the adhesion, the method by dynamically loading a diamond cone (Rockwell-C impact test) and the method of scratching (Scratch test) were used. The coatings hardness was determined by Vickers method using hardness tester FISCHERSCOPE ® H100, and the coatings thickness was determined using Calotest. Based on the experimental results were identified and evaluated tribological properties of the coatings (coating adhesion, hardness and thickness) created by PVD method on steel 100Cr6.*

Keywords: *Tribological characteristics; Hard coatings; PVD-method; Coating adhesion; Coating hardness; Coating thickness*

ИЗСЛЕДВАНЕ НА ТРИБОЛОГИЧНИТЕ ХАРАКТЕРИСТИКИ НА ПОКРИТИЯ ВЪРХУ СТОМАНА 100Cr6

Стефан ДИШЛИЕВ

Резюме: *В настоящата работа се изследват трибологичните характеристики на покрития, нанесени по метода PVD, върху стомана 100Cr6. Бяха нанесени покритие от TiN и нанокомпозити от вида ncAlTiN/αSi_3N_4 и ncAlCrN/αSi_3N_4. Използвана бе методика за определяне на адхезията на покритията по метода чрез динамично натоварване с диамантен конус (Rockwell-C impact test) и метода на надраскването (Scratch test). Твърдостта на покритията бе определена по метода Викерс, измервайки се автоматично с нанотвърдомер FISCHERSCOPE® H100, а дебелината на покритията бе определена по метода чрез местно изтриване с въртяща се стоманена сфера. На базата на проведените изследвания бяха определени и оценени трибологичните характеристики на съответните покрития (адхезия на покритието, твърдост и дебелина), нанесени по PVD метода върху стомана 100Cr6.*

Ключови думи: *Трибологични характеристики; Твърди покрития; PVD-метод; Адхезия на покритието; Твърдост на покритието; Дебелина на покритието*

1. ВЪВЕДЕНИЕ

Покритията се използват твърде широко в съвременната техника и бита. Свойствата на покритието и изборът на метода за нансянето му зависят от свойствата на конструкционния материал, върху който то се нанася, наричан най-често подложка. Едно и също покритие, нанесено върху различни конструкционни материали или изделия, може да има съществено различни свойства и предназначение. Следователно функционалните свойства на покритията и методите за тяхното нанасяне зависят от изискванията, които се предявяват в съвременните условия за производство и експлоатация към конструкционните материали. В машиностроенето се прилагат главно два вида покрития: корозоустойчиви и повишаващи трибологичните свойства на детайлите. Корозоустойчивите покрития имат за цел да предпазят външните повърхнини на детайлите от атмосферни влияния, да предадат необходимия търговски вид на изделието и др. Вторият вид покрития имат основна цел да подобрят трибологичните свойства на работните повърхнини на детайлите и възлите. Основно тези покрития са метални, но в последно време развитие получиха и т.н. комбинирани покрития [1].

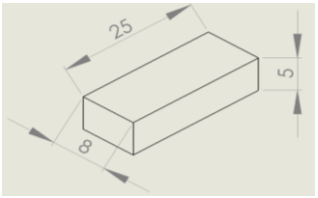
2. ЦЕЛ НА РАБОТАТА

Настоящата работа има за цел да изследва трибологичните характеристики адхезия, твърдост и дебелина на покритията *TiN*, *ncAlTiN/αSi$_3$N$_4$* и *ncAlCrN/αSi$_3$N$_4$*, нанесени по метода *PVD*, върху подложка от стомана *100Cr6*. За постигането на тази цел е необходимо да се решат следните задачи:

1. Изготвяне на образци от стомана *100Cr6* и покриването им с покрития *TiN*, *ncAlTiN/αSi$_3$N$_4$* и *ncAlCrN/αSi$_3$N$_4$* по метода *PVD*;
2. Провеждане на експериментални изследвания;
3. Анализ на резултатите и изводи.

3. ТВЪРДИ ПОКРИТИЯ

За провеждане на експерименталните изследвания бяха изработени опитни образци под формата на правоъгълен паралелепипед, с размери показани на фиг.1 от стомана *100Cr6* (химичен състав: *C*-0,963%; *Si*-0,26%; *Mn*-0,61%; *P*-0,013%; *S*-0,003%; *Cr*-1,81%; *Mo*-0,22; *Cu*-0,05; *Al*-0,011), използвана за танкети на търкалящи направляващи на металорежещи машини.



Фиг. 1. Форма и размери на опитните образци

След изработването им образците бяха подложени на термична обработка в последователността: отгряване (200 – 250 *HB*), закаляване (61 – 62 *HRC*) и отвръщане (59 – 60 *HRC*). След термообработката им образците бяха шлифовани и полирани.

След изготвянето им образците бяха покрити с три вида покрития по метода *PVD* в Централна лаборатория по приложна физика – Пловдив – БАН:

- *ncAlTiN/αSi$_3$N$_4$*, градиентен нанокомпозит;
- *ncAlCrN/αSi$_3$N$_4$*, градиентен нанокомпозит;
- *TiN*.

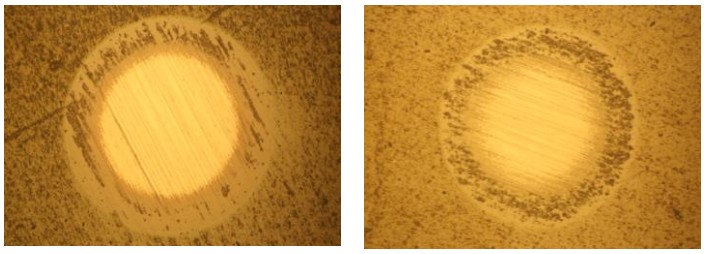
4. ЕКСПЕРИМЕНТАЛНИ ИЗСЛЕДВАНИЯ И РЕЗУЛТАТИ

4.1. Определяне на дебелината на покритията

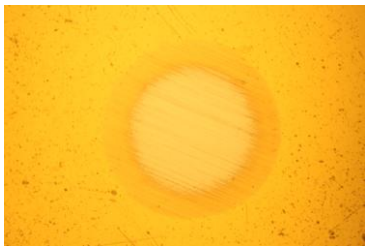
За целта бе използвана методика за определяне на дебелината на покритията чрез местно изтриване с въртяща се стоманена сфера [3]. От проведените изследвания, количествените стойности за дебелините на покритията, нанесени върху стомана *100Cr6* са дадени в табл.1. На фиг.2 са покзани снимки на отпечатъците за определяне на дебелините на покритията *ncAlTiN/αSi$_3$N$_4$* и *ncAlCrN/αSi$_3$N$_4$*. На фиг.3 е покзана снимка на отпечатъка за определяне на дебелината на покритието *TiN*.

Таблица 1. Стойности на дебелините на покритията върху стомана 100Cr6

Покритие	***ncAlTiN/αSi$_3$N$_4$***	***ncAlCrN/αSi$_3$N$_4$***	***TiN***
$H_{пок}$, μm	2	3	2



Фиг. 2. Снимки на отпечатъците за определяне дебелините на покритията ncAlTiN/αSi$_3$N$_4$ и ncAlCrN/αSi$_3$N$_4$ върху стоман 100Cr6



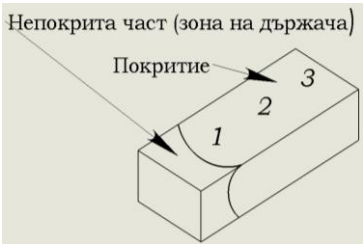
Фиг. 3. Снимка на отпечатъка за определяне дебелината на покритието TiN върху стомана 100Cr6

4.2. Експериментални изследвания за оценка на адхезията на покритията

Методите, използвани за оценка на адхезията са: метод чрез динамично натоварване с диамантен конус (Rockwell-C impact test) [4] и метод на надраскването (Scratch test) [2].

4.2.1. Оценка на адхезията на покритията по метода чрез динамично натоварване с диамантен конус (Rockwell-C impact test)

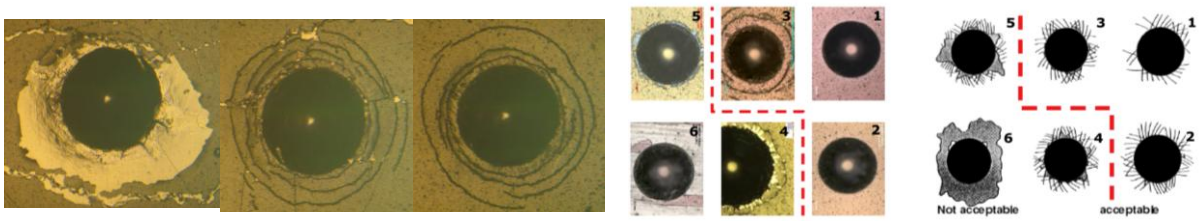
Бе използван стандартен Роквел твърдомер с индентор диамантен конус при натоварване на индентора 1500*N* и времезадържане 10*сек*. За всяко покритие бяха реализирани три отпечатъка съответно в области 1, 2 и 3 от фиг.4 и визуализирани с микроскоп МИМ-10 при увеличение 100 пъти.



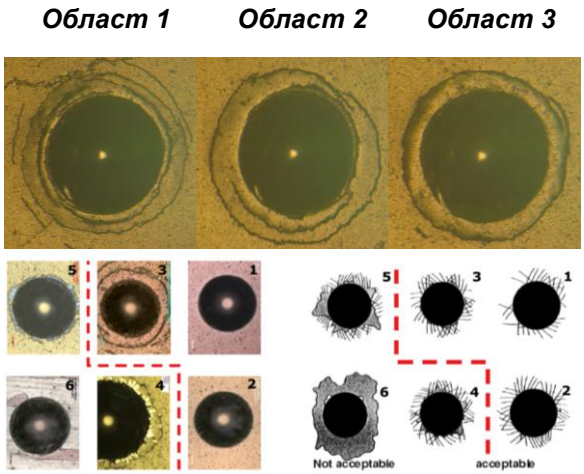
Фиг. 4. Схема на покрит образец от стомана 100Cr6 с обозначени областите в които са направени отпечатъци

Отпечатъците, получени за покритите образци със съответните покрития в съответните области и графичната илюстрация на критериите за оценка са дадени на фиг.5, фиг.6, фиг.7.

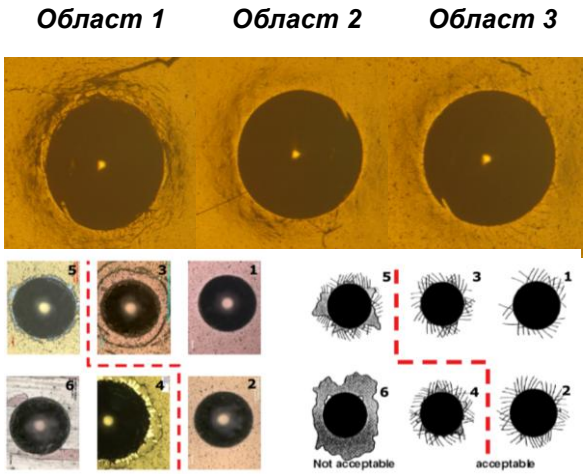
Област 1 ***Област 2*** ***Област 3***



Фиг. 5. Експериментални отпечатъци, получени за покритието nc-AlTiN/αSi$_3$N$_4$, сравнени с критериите за оценка на адхезията



Фиг. 6. Експериментални отпечатъци, получени за покритието nc-AlCrN/αSi$_3$N$_4$, сравнени с критериите за оценка на адхезията



Фиг. 7. Експериментални отпечатъци, получени за покритието TiN, сравнени с критериите за оценка на адхезията

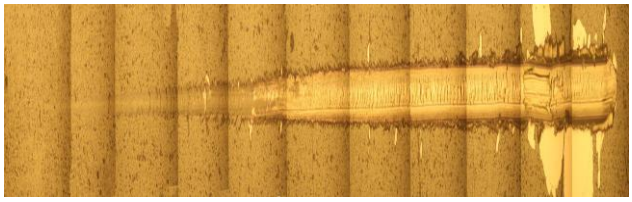
4.2.2. Определяне на адхезията на покритията по метода на надраскването (Scratch test)

От направените експерименталните изследвания, резултатите, които представляват количествените показатели за критичните натоварвания F_{C1} - на появата на първите частични откъртвания по повърхността на покритието и F_{C2} - на разрушаване на покритието (при 75% напълно отделено от подложката покритие), са дадени в табл.2.

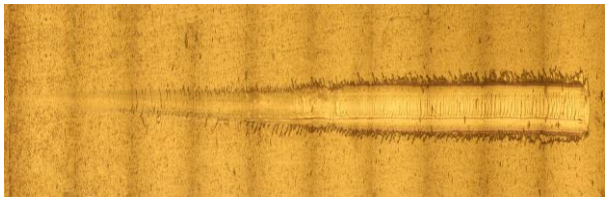
Таблица 2. Количествени стойности на експерименталните резултати

Покритие / Сила, *N*	*ncAlTiN/αSi$_3$N$_4$*	*ncAlCrN/αSi$_3$N$_4$*	*TiN*
F_{C1}	24	25	37
F_{C2}	38	52	65

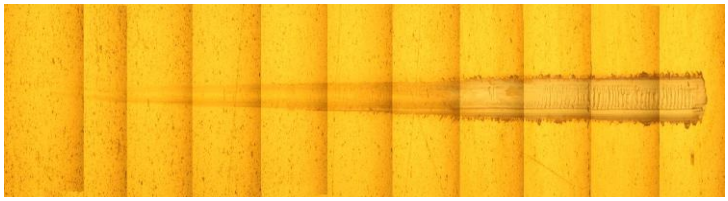
На фиг.8, фиг.9 и фиг.10 са показани снимки на следите от *Scratch test* за покритията *ncAlTiN/αSi$_3$N$_4$*, *ncAlCrN/αSi$_3$N$_4$* и *TiN*.



Фиг. 8. Снимка на следата от Scratch test за покритие ncAlTiN/αSi$_3$N$_4$ върху стомана 100Cr6



Фиг. 9. Снимка на следата от Scratch test за покритие ncAlCrN/αSi$_3$N$_4$ върху стомана 100Cr6



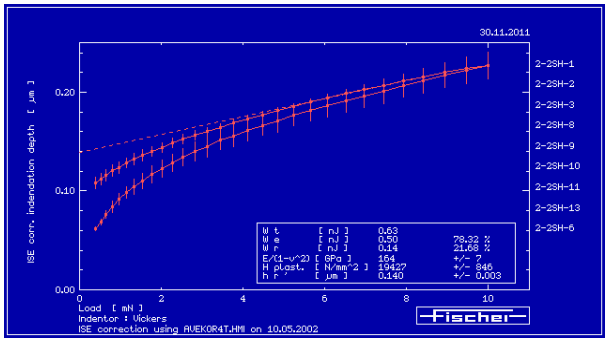
Фиг. 10. Снимка на следата от Scratch test за покритие TiN върху стомана 100Cr6

4.3. Определяне на твърдостта на покритията

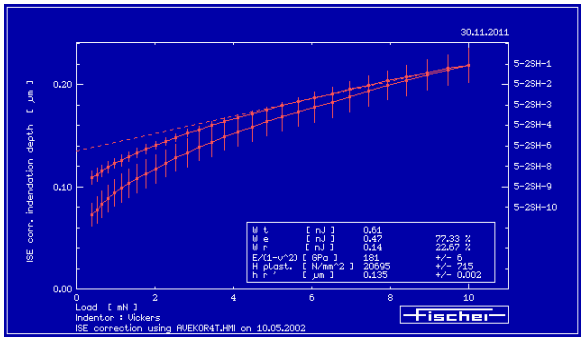
Твърдостта на покритията бе определена по метода Викерс, измервайки се автоматично с нанотвърдомер FISCHERSCOPE® H100 [5]. Получените количествени стойности за измерените параметри са дадени в табл.3. На фиг.11, фиг.12 и фиг.13 са дадени индикаторни диаграми за сила – деформация от потъване на индентора в покритието в процеса на измерване на твърдостта.

Таблица 3. Твърдост на покритията, нанесени върху стомана 100Cr6

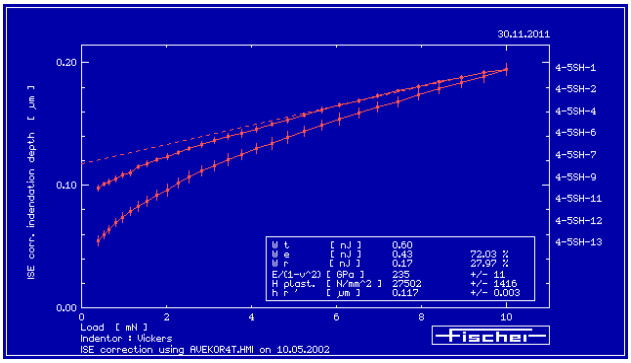
Образец с покритие	***F, mN***	***HU, MPa***	***$H_{plast.}$, MPa***	***E*, GPa***	***W_{tot}, nJ***	***W_r, %***
***ncAlTiN/αSi$_3$N$_4$* градиентен нанокомп.**	10	15912	19427	164	0,63	21,68
***ncAlTiN/αSi$_3$N$_4$* многослойна струк.**	10	14643	17217	153	0,71	29,13
ncAlCrN/αSi$_3$N$_4$	10	17676	20695	181	0,61	22,67
TiN	10	23302	27502	235	0,60	27,97



Фиг. 11. Натоварващо-разтоварваща диаграма от процеса за измерване на твърдостта на покритие ncAlTiN/αSi$_3$N$_4$



Фиг. 12. Натоварващо-разтоварваща диаграма от процеса за измерване на твърдостта на покритие ncAlCrN/αSi$_3$N$_4$



Фиг. 13. Натоварващо-разтоварваща диаграма от процеса за измерване на твърдостта на покритие TiN

5. АНАЛИЗ НА РЕЗУЛТАТИТЕ И ИЗВОДИ

1. От резултатите, получени след проведените експериментални изследвания за оценка адхезията на покритията *ncAlTiN/αSi$_3$N$_4$*, *ncAlCrN/αSi$_3$N$_4$* и *TiN*, нанесени върху подложка от стомана *100Cr6,* по метода чрез динамично натоварване с диамантен конус (Rockwell-C impact test), може да се обобщи следното:

- отпечатъците върху покритие *ncAlTiN/αSi$_3$N$_4$* показват наличие на концентрични пукнатини по границата му и петна от разслояване. Отпечатъците по вид, отнесени към критериите за оценка може да се причислят към критерии №4 и №5 (Зона на отпечатъка с пукнатини и петна от

разслояване; Петна от разслояване по цялата окръжност на отпечатъка), спрямо които адхезията на покритието може да се счита за не добра (неприемлива);

- отпечатъците върху покритие *ncAlCrN/αSi$_3$N$_4$* показват наличие на единични концентрични пукнатини по границата им без петна от разслояване. Отпечатъците по вид, отнесени към критериите за оценка може да се причислят към критерий №2 (Зона на отпечатъка с единични пукнатини и без разслояване), спрямо който адхезията на покритието може да се счита за добра (приемлива);

- отпечатъците върху покритие *TiN* показват наличие на пукнатини по границата им, без наличие на разслояване. Отпечатъците по вид, отнесени към критериите за оценка може да се причислят към критерий №2 (Зона на отпечатъка с единични пукнатини и без разслояване), спрямо който адхезията на покритието може да се счита за добра (приемлива);

2. От резултатите, получени след проведените експериментални изследвания за оценка адхезията на покритията *ncAlTiN/αSi$_3$N$_4$*, *ncAlCrN/αSi$_3$N$_4$* и *TiN*, нанесени върху подложка от стомана *100Cr6,* по метода на надраскването (Scratch test), може да се обобщи следното:

- следите от надраскване върху покритията *ncAlCrN/αSi$_3$N$_4$* и *TiN* показват едно добро тяхно поведение по отношение на адхезията им. При нито една от следите от надраскване върху двете покрития не се наблюдава наличие на разслояване и количествените стойности на силата F_{C2} настъпват след обезпечаване на 40% от дължината на следата;

- отново най – високи стойности за силите F_{C1} и F_{C2} показа покритието *TiN*, като едно от най - утвърдените, универсални и масово използвани покрития;

- добри показатели по отношение на стойностите на силите F_{C1} и F_{C2} показа и покритието *ncAlCrN/αSi$_3$N$_4$*;

- стойностите на силите F_{C1} и F_{C2} за покритието *ncAlTiN/αSi$_3$N$_4$* са най-ниски. Силата F_{C2} настъпва преди обезпечаване на 40% от дължината на следата. Наблюдават се и петна от разслояване, най-видимо изразени в края на следата. Това показва, че адхезията на съответното покритие към съответната подложка е лоша.

3. Изследваните покрития притежават висока твърдост, като отчитайки и добрите им показатели по отношение на адхезията спрямо подложката, те могат да бъдат предложени за експлоатация в натоварени трибодвойки.

БЛАГОДАРНОСТИ

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THERMOGRAPHY APPLICATION IN RESEARCH OF TRIBOLOGICAL PROCESSES

Anna ANDONOVA

Abstract: *There are many sources of errors when using infrared thermography in temperature measurements for tribology's purposes. To obtain reliable quantitative estimates it is important to be known how those sources of error affect the measurement uncertainty. Some of them are known and famous in performing typical thermographic measurements. However, the use of thermography in Tribology presents many new challenges for measurements due to factors such as the requirement for high magnification, high-speed of the surface, polarization effects, micro black body, emissivity variation and others. The results of study and characterization of some specific sources of error and the resulting uncertainties in the specificity study of tribological processes are given in the paper.*
Key Words: *tribology, infrared thermography, measurements, uncertainty*

ПРИЛОЖЕНИЕ НА ТЕРМОГРАФИЯТА ПРИ ИЗСЛЕДВАНЕ НА ТРИБОЛОГИЧНИ ПРОЦЕСИ

Анна АНДОНОВА

Резюме: *При използване на инфрачервената термография за измерване на разпределението на температурата за целите на трибологията има много източници на грешки. За получаването на достоверни количествени оценки е важно да се знае как тези източници на грешки влияят върху неопределеността на измерването. Някои от тях са познати и известни при извършването на типични термографски измервания. Въпреки това използването на термографията в трибологията представя нови предизвикателства при обследването, дължащи се на фактори като изискване за висока степен на увеличение, висока скорост на повърхността, ефекти на поляризация, ефекти на микро черно тяло, изменение на коефициента на излъчване и др. В статията се дават резултати от изследване в тази област и се характеризират специфични източници на грешки и резултантните неопределености, предвид спецификата на измерванията с приложения в областта на трибологията*
Ключови думи: *трибология, инфрачервена термография, измервания, неопределеност*

1.ВЪВЕДЕНИЕ

Трибологията е интердисциплинарна наука, изучаваща процесите на триене и взаимодействието на телата в зоните на контакта. Надеждността и времето на живот на много електромеханични детайли са обусловени от явлението триене и износване. Износването води до нарушаване на херметичността, изменение на точността и др.. Триенето води до загуба на енергия, прегряване, повишаване на енергийните разходи. Явленията на триене и износване са взаимно обусловени: триенето води до износване, а износването на повърхностите води до изменение на триенето. За ликвидиране последствията от износване се провеждат текущи и капитални ремонти за замяна или възстановяване на износените детайли. В процеса на експлоатация борбата срещу износването се провежда с извършване на планови технически обслужвания.

Значимо средство в борбата за намаляване загубите от износване и триене е измерването и оценяването на фактическата повърхност на контакта. Използват се различни експериментални методи за характеризиране на тази повърхност. Всички те могат да се разделят на две групи: методи за изучаване отпечатъка на повърхността (контакта се нарушава) и методи на пряко или косвено изследване на площта в условията на контактуване

[1, 2]. Термографските изследвания може да се отнесат към първата и към втората група методи, в зависимост от това дали се прилага пасивна или активна форма на термография. По долу са анализирани най-често срещанете източници на грешки при извършване на обследване на трибологични процеси

2.ПРЕДПОСТАВКИ ЗА ПРИЛОЖЕНИЕ НА ТЕРМОГРАФИЯТА ЗА ИЗСЛЕДВАНЕ НА ТРИБОЛОГИЧНИ ПРОЦЕСИ

Наличието на трибодеформации, в резултат на което се повишава няколкократно температурата, а не рядко в някои области и точки дори взривообразно, е основна предпоставка за изследване възможностите за приложението на инфрачервената термография в трибологията. Важна особеност е, че действието на температурата се ограничава в пространството на трибозоната и бързо спада извън нея. Многобройни експерименти [3-5] показват наличие на корелация между температурата и редица физически параметри като физико-механични свойства на триещите се тела, тегло, скорост, съпротивление, степен на неравност на повърхнината на триене, химичен състав на контактуващите тела и много други.

3.ВЛИЧНИЕ НА ИЗТОЧНИЦИТЕ НА НЕОПРЕДЕЛЕНОСТ ПРИ ТЕРМОГРАФСКИ ИЗМЕРВАНИЯ В ТРИБОЛОГИЯТА

Източниците на неопределеност при термографските измервания могат да се обединят в различни групи: калибровка на камерата, преобразуване на възприеманата в истинска температура, оптика на камерата, електронни ефекти, други.

Първата група източници на неопределеност са свързани с чувствителността на използваната камера – офсета и наклона на линейната калибровъчна линия. Те пряко влияят върху неопределеността на амплитудата на измерваната температура.

Когато се използва черно тяло за калибриране на термокамерата обикновено се приема, че коефициентът на емисия на черното тяло е 1. Обаче при извършен експеримент с две черни тела, всяко установено на 600°C с инфрачервена камера, чувствителна в областта 7,5 -12 μm, разлика от 0,04 в коефициентите на емисия (първото тяло е с коефициент 0,99, а второто с 0,95) води до разлика в излъчваната температура от 11°C. Тази разлика във възприеманата температура се дължи единствено на разликата в емисиите. Следователно, ако не се взема предвид коефициента на емисия може да се получи значителна грешка, дори когато този коефициент е близък до 1.

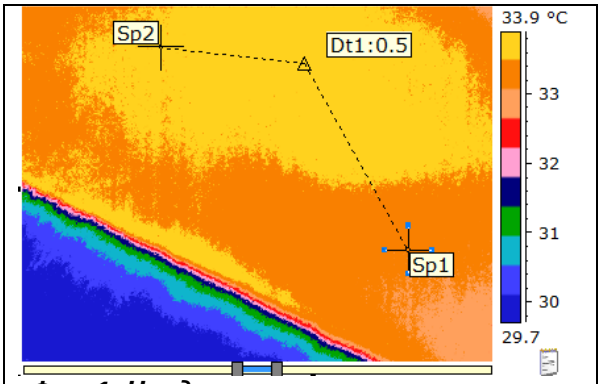
Друг източник на неопределеност е зависимостта на чувствителността на камерата към поляризацията на измереното топлинно излъчване. За да бъде поляризацията значим източник на неопределеност, трябва измереното топлинно излъчване да бъде поне частично поляризирано и чувствителността на камерата трябва да варира като функция на ъгъла на поляризация. При оценка на неопределеността е разглеждана само линейна поляризация. Чувствителността на камерата към поляризацията е оценена с наблюдаване на черно тяло и използване на линеен поляризатор, при завъртане на различни ъгли. Отклонението в интензивността е не повече от 10%.Така например грешката във възприеманата температура от 600 °C, произтичаща от ±5 % вариране на интензитета е +10,9 °C, когато цялата светлина е линейно поляризирана успоредно и -11,1 °C, когато светлината е линейно поляризирана перпендикулярно на посоката на снимане. Съществуват различни причини да подозираме, че наблюдаваната светлина по време на работа може да бъде поляризирана [6]. Може например да се използва поляризатор за редуциране на ефекта от отражение в термокамерата [7].

Друга важна особеност при термографските измервания е свързана с непълното разбиране за разрешаваща способност и повтаряемост. Накратко казано, резолюцията е най-малката възможна разлика между двете стойности на измерваната температура, които могат да бъдат измерени, а повторяемостта е обхватът от стойност, постигнат чрез многократни измервания при същите условия. Дори ако отклика на една камера е линейна функция на интензитета, той не е линейна функция на температурата и така разделителната способност на измерената температура зависи от температурата, която се измерва. Т. е. трябва внимателно да се отчита по време на експериментите дадена стойност на разделителната способност от спецификацията на термокамерата за какъв температурен обхат се отнася. Също трябва да се има предвид, че в рамките на една и съща термограма, по-топлите части имат по-фина температурна разделителна способност от по-студените части.

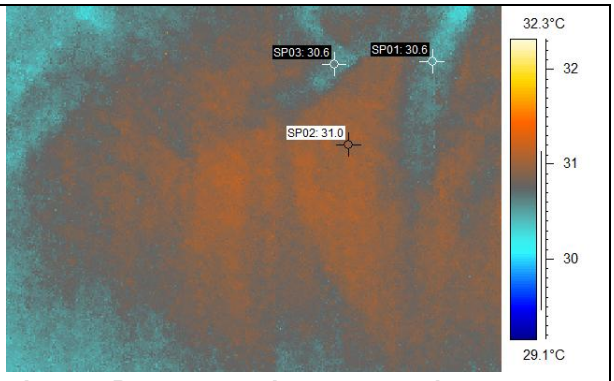
След като термограмата е получена и се преобразува във възприемана температура, следващата стъпка е да се преобразува тази температурата. Излъчваната температура е температурата предсказвана от уравнението на Планк [8] без да се вземат предвид отраженията. От друга страна възприеманата температура включва и излъчваната и отразената температури от измервания образец. Преобразуването на възприеманата

температура в истинска е източник на неопределеност от втората група при измерванията на температури чрез термографски подход. Тази група има пряко влияние върху амплитудата на неопределеността на измерване на температурата. Докато неопределеността в коефициента на излъчване обикновено доминира и други източници на неопределеност могат да бъдат също толкова важни. Един такъв възможен източник може да бъде неединната текстура на изследвания обект (фиг.1). Неединните повърхностни текстури заснети по време на работа се характеризират с различни коефициенти на емисия. Това може да бъде причина да се отчете разлика между температурата измерена допълнително от термодвойки и възприеманата температура от инфрачервената камера. Например, поради възникваща деформация или износване повърхността на обекта става по- различна, което води до промяна на коефициента на излъчване.

Наличието на кухини по повърхността на обекта или излизане от фокус поради ограничената дълбочина на фокусното поле на камерата може да доведе до вариране на коефициента на емисия и достигане на разлики до 0,4, което обикновено е необичайно за повърхността на обекта. С такива големи вариации на коефициента на емисия е трудно да се избегне голямата неопределеност на температурата. Кухините могат да се проявят като микро черно тяло, повишаващо ефективния коефициент на излъчване. Обикновено кухината е по-топла от лицевата част на обекта, но точно каква е температурата трудно може да се прогнозира, ако неравномерният коефициент на емисия не се отчита коректно. За да се избегне нееднаквия коефициент на емисия може да се прилага дълго време на интегриране за формиране на изображението.



Фиг. 1. Неединна структура, при която се получава разлика от 0,5^{0}C,поради изменчивост на коефициента на емисия



Фиг. 2. В кухините(Sp01 и Sp03)се отчита нереално по-висока температура от лицевата част (Sp02)

Движението на обекта по време на работа води до това, че всеки пиксел на резултантното изображение дава осредна стойност на повърхностната температура за по-голяма област. Това означава, че пикселът няма да представя средна (аритметична) температура. Това е така, защото уравнението, преобразуващо интенсивността в температура е силно нелинейно. За да се преобразува правилно възприеманата в истинската температура, трябва да се има предвид, че чувствителността на инфрачервената камера е функция на дължината на вълната. В Таблица 1 е даден пример за значителната разлика, която се получава при такова преобразуване за отделни дължини на вълната или за обхват от дължини.

Таблица 1. Различни стойности на T_{tr} при различни допускания за λ при T_{ap} = 600 °C, T_{en}= 20 °C, ε = 0.5, и w_λ = 1 за всички λ

Допускане за λ	λ_1 (μm)	λ_2 (μm)	Изчислена T_{tr} (°C)
Горен и долен номинал на камерата	7.5	13.00	877
Измерена реакция на цялата система	8	12	886

В литературата съществуват множество модификации на уравнението на Планк. При някои се вземат предвид такива ефекти, като отражение, пропускливост, атмосферно поглъщане, многократно отражение, изменение на коефициента на излъчване от температурата, използване на една дължина на вълната или интегриране в даден обхват от дължини на вълните. В този случай може да се използва формулата [4]:

$$S = \left| \left(\int_{\lambda_1}^{\lambda_2} \frac{w_\lambda / \lambda_5}{e^{\frac{c_2}{\lambda Tap}} - 1} d\lambda \right) - \left(\varepsilon \int_{\lambda_1}^{\lambda_2} \frac{w_\lambda / \lambda^5}{e^{\frac{c_2}{\lambda Ttr}} - 1} d\lambda \right) - \left((1-\varepsilon) \int_{\lambda_1}^{\lambda_2} \frac{w_\lambda / \lambda^5}{e^{\frac{c_2}{\lambda Ten}} - 1} d\lambda \right) \right| \quad (1)$$

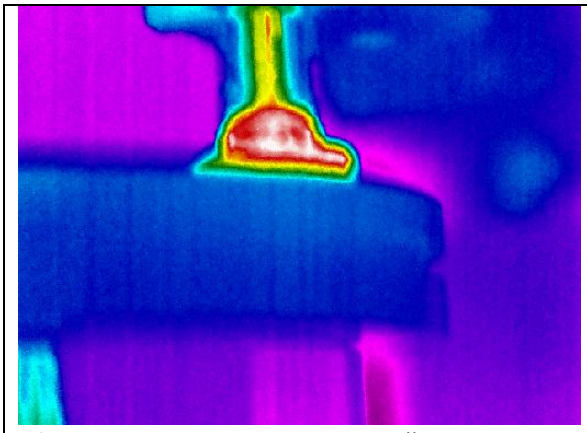
където λ е дължина на вълната, λ_1 и λ_2 са най-малката и най-голямата дължини на обхвата на камерата, w_λ е относителната чувствителност на камерата при λ, ε е коефициентът на емисия на обекта, c_2 е втора радиационна константа (14387 μmK), T_{ap} е възприеманата температура на изследваната повърхност, измерена с камерата, T_{tr} е действителната температура и T_{en} е температурата на околната среда. Ако някоя от стойностите на T_{tr}, T_{ap} или ε не са известни, може да се напасва неизвестната стойност, докато се минимизира S. Ако се подходи по същия начин и за T_{en} може да се получи голяма неопределеност.

Един специфичен проблем в трибологичните приложения е факта, че често изследваните повърхности оксидират. Оксидацията е реакция, която отнема време и понякога е екзотермична, ендотермична или температурно неутрална. Оксидацията променя цвета и следователно и коефициента на емисия на повърхността. Едно от последствията на влиянието на окисните слоеве е, че след изпитването трябва да се оцени коефициента на емисия на слоя по време на изпитването.

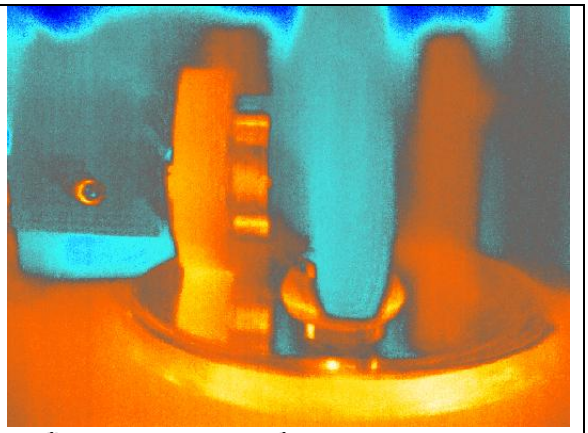
Няма оптична система, която да дава перфектни термограми при всякакви условия. Оптичната система влияе директно както върху амплитудата, така и на пространствената неопределеност на температурните измервания. Това са друга група неопределености, които включват оптичното преплитане на пикселите. Особено, когато е налице високо съотношение между най-светлите и най-тъмните области, нежеланото разсейване и отражение води до влияние на интензивността на едни пиксели върху интензивността на други пиксели.

Различни източници на неопределеност са свързани с електрониката на камерата и те спадат към друга група източници на неопределеност. Те влияят директно върху амплитудата и времевата неопределеност на температурните измервания. Доколкото тези източници са свързани с параметрите и характеристиките на съответната камера, те не се обсъждат тук.

На фиг.2 са показани термограми от изследвания на износването на твърди покрития, при които бе проведено и изследването на факторите, оказващи влияние върху неопределеността на температурните измервания. Извършвани са експерименти за термографска оценка на износоустойчивостта при сухо триене (фиг.3,а) и при абразивно износване(фиг.3,б).



а) тестване на износоустойчивост при сухо триене



б) тестване на абразивно износване

Фиг. 3. Термографски изображения от тестови постановки

На тези „сурови” образи може да се забележи наличието на основните източници на непределеност в температурните измервания, като.отражение, различен коефициент на емисия, преплитане на пиксели, оксидация, движение на обекта, релефна повурхност и др.

4.ЗАКЛЮЧЕНИЕ

Инфрачервената термография е техника, която може да се използва в трибологията. Обаче трябва правилно да се разбира влиянието различните източници на неопределеност, за правилно обследване и интерпретиране на данните. Основните източници на неопределеност са обединени в няколко групи със специфични особености. За да се определи дали един

източник на неопределеностоказва влияние при всяко измерване, трябва да се има предвид, че термографските измервания описват температурата на определено място за определен времеви интервал. Затова, всяко температурно измерване съдържа няколко неопределености, свързани с времето, амплитудата и пространството. Всяка неопределеност може да влияе върху крайната неопределеност на измерването.

БЛАГОДАРНОСТИ

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КОРЕСПОНДЕНЦИЯ

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EROSION WEAR OF NICKEL COATINGS WITH NANO-SIZE PARTICLES OF SILICON CARBIDE

Mara KANDEVA, Dimitar KARASTOYANOV, Aleksandar VENCL

Abstract: *The paper proposes procedure and device for the study of erosion wear of materials and coatings under the action of air jet bearing hard abrasive particles. Experimental results about the coatings mass wear, erosion rate and erosion wear-resistance have been obtained. Chemical Ni coatings were studied containing nano-size particles of silicon carbide. Comparative study was carried out of erosion without and with nano-size particles in both cases with and without heat treatment. The nano-particles were of average size 35 nm by chemical solution between 5 and 7 vol. %. The investigation is related to the completion of the program of the Science Investigations Fund Contract № Д02-13/2009 directed by Assoc. Prof. Dr. Eng. D. Karastoyanov, and CEEPUS Project CIII-BG-0703-01-1213 "Modern Trends in Education and Research on Mechanical Systems - Bridging Reliability,Quality and Tribology".*

Key Words: *tribology, coatings, wear, erosion, nano-particles*

ЕРОЗИЙНО ИЗНОСВАНЕ НА НИКЕЛОВИ ПОКРИТИЯ С НАНОРАЗМЕРНИ ЧАСТИЦИ ОТ СИЛИЦИЕВ КАРБИД

Мара КАНДЕВА, Димитър КАРАСТОЯНОВ, Александар ВЕНЦЛ

Резюме: *В работата е разработена методика и устройство за изследване на ерозийното износване на материали и покрития под въздействието на въздушна струя, носеща твърди абразивни частици. Получени са експериментални резултати за масовото износване, скоростта на ерозията и ерозийната износоустойчивост на покрития от химически никел, съдържащи наноразмерни частици от силициев карбид. Проведено е сравнително изследване на ерозията на покрития без и с наноразмерни частици, нетермообработени и термообработени. Наночастиците имат среден размер от 35 nm с концентрация в химическия разтвор от 5 до 7 обемни процента. Изследването е свързано с изпълнение на задачи по дог. № Д02-13/2009 към Фонд „НИ"с ръководител проф. д-р инж. Д. Карастоянов и Проект CEEPUS CIII-BG-0703-01-1213 "Modern Trends in Education and Research on Mechanical Systems - Bridging Reliability,Quality and Tribology".*

Ключови думи: *трибология, покрития, износване, ерозия, наночастици*

1.ВЪВЕДЕНИЕ

Каландрирането е технологичен процес, който се състои в пропускане на материал между валове (каландри) при определени режими до получаване на листов материал – хартия, картон, кожа, фолио и т.н. Каландровите валове в различните производства работят при различни температурно-динамични условия и в резултат на сложните контактни взаимодействия при триене те интензивно се износват.

Увеличаването на ресурса на каландровите валове в световната практика е чрез нанасяне на тънки износоустойчиви покрития от твърд хром. В България колектив от Института по информационни технологии при БАН и Технически университет-София разработва проект за замяна на неекологичния индустриален хром с покрития от никел, съдържащи частици с нано- и микроразмери от различно естество. Проведени са системни изследвания на параметрите на износването и износоустойчивостта на химически никелови покрития с различни наноразмерни частици в условия на сухо триене по повърхнина със закрепени абразивни частици.

При абразията механизмите на износване се свързват с надраскването и в някои случай с изравянето на повърхностния слой от острите ръбовете на абразивните частици.

Ерозията се интерпретира като процес на разрушаване на повърхностния слой вследствие дискретното ударното въздействие на частици, носещи се от флуиден поток [1,2,4].

В настоящата работа се представя изследване на химически никелови покрития в условия на ерозийно износване под въздействието на въздушна струя, носеща абразивни частици.

2.ОПИСАНИЕ НА ИЗСЛЕДВАНИТЕ ПОКРИТИЯ

Наноструктурираните композитни никелови покрития са получени по безтокова химическа технология „ЕФТТОМ-НИКЕЛ", разработена в Техническия университет-София [3].

Уякчаващата компонента в покритията представлява частици от силициев карбид (SiC) със среден размер на частиците $35 \div 40$ nm. Концентрацията на частиците в разтвора е в границите от 5 до 7 об. % .

Изследват се пет серии покрития: образец от базовия материал без покритие, никелово покритие без частици (Ni): никелово покритие с наночастици ($Ni - SiC$). Покритията без и с наночастици са подложени на термообработка. Термичната обработка се осъществява в продължение на 6 часа при 300°C. От всяка серия се изследват по 2 броя образци и се вземат средно-аритметични стойности от измерваните параметри.

Микротвърдостта на покритията е определена по метода на Knoop при натоварване $0{,}5$ [N]

Изследваните образци представляват дискове с дебелина 3 mm и диаметър 100 mm.

В таблица 1 са представени данни за химическия състав на базовия материал (подложката), върху която са нанесени никеловите покрития.

Таблица 1:Химичен състав на материала на подложката

Химически състав, %							
C	S	Mn	P	Si	Cr	Ni	Fe
0,4	**0,045**	**0,55**	**0,45**	**0,20**	**0,30**	**0,30**	**баланс**

Дебелината на покритията се измерва с уред Pocket LEPTOSKOP 2021 Fe в 10 точки от повърхнината и се взема средноаритметичната стойност на измерените показания. Средната дебелина на покритията е 24 μm.

В таблица 2 са представени данни за изследваните образци.

Таблица 2: ***Данни за покритията: съдържание на наночастици, термообработка, микротвърдост и грапавост***

№	**образци**	**Термообработка**	**Микротвърдост НК 0,02**	**Грапавост Ra**
1.	Без покритие	-	370	0,418 μm
2.	Ni – без термообработка	-	450	0,418 μm
3.	Ni + с термообработка	300°C, 6 часа	860	0,418 μm
4.	NI*SIC- без термообработка	-	473	0,418 μm
5.	NI*SIC+ с термообработка	300°C, 6 часа	980	0,418 μm

3.ТЕОРИЯ НА ЕРОЗИЙНОТО ИЗНОСВАНЕ ОТ ВЪЗДУШНО-АБРАЗИВНА СТРУЯ

Въздушна струя, носеща абразивни частици с определен дебит на въздушната и твърдата фази, попада върху повърхнината на образеца В резултат на периодичните ударни въздействия на абразивните частици покритието постепенно се разрушава и образецът губи от

своята маса. Този вид износване е известно като «струйно-абразивна ерозия» или «струйно-ерозийно износване».

При разработване на теорията на ерозийното износване от въздушно-абразивна струя в настоящата работа се изхожда от закона за контактното взаимодействие в трибологията, който в общия случай в диференциална форма има вида [6]:

$$\frac{dR}{R} = \eta \frac{dA}{A} \tag{1}$$

където dA/A представлява относителното смущение, действащо върху покритието; dR/R е относителната на покритието, а η представлява комуникативният потенциал на контактното взаимодействие между смущението (акцията) и реакцията.

В разглеждания случай на износване комуникативният потенциал е постоянен, т.е. $\eta = 1$; относителното смущение (акцията) се представя чрез въздействието на абразивната фаза в струята, по-конкретно чрез нейния масов дебит - m_a, т.е.

$$\frac{dA}{A} = \frac{dm_a}{m_a} \tag{2}$$

където $m_a = m_a(t)$ е законът за изменение на ударната маса на абразивните частици, атакуваща покритието чрез въздушна струя, и

$$\frac{dR}{R} = \frac{dm}{m} \tag{3}$$

представлява относителната реакция на покритието, представена чрез относителното му масово износване.

Тук $m = m(t)$ е законът за масовото износване на покритието.

Отчитайки формули (2) и (3), законът за к8онтактното взаимодействие във форма (1) се редуцира до вида:

$$\frac{dm}{m} = \frac{dm_a}{m_a} \tag{4}$$

Интегрира се израза (4)

$$\ell nm = \ell nm_a + \ell nk \tag{5}$$

или

$$\ell n\frac{m}{k} = \ell nm_a \tag{6}$$

След антилогаритмуване се намира връзката между двата закона – закона на износването $m = m(t)$ и закона на ударната абразивна маса $m_a = m_a(t)$, т.е.

$$m(t) = k.m_a(t) \tag{7}$$

След отчитане на получените формули и заместване във формула (1) се получава *законът за скоростта на струйно-абразивната ерозия* във вида:

$$\frac{dm}{dt} = k\frac{dm_a}{dt} \quad \text{или} \quad \dot{m} = k\dot{m}_a \tag{8}$$

От закона (8) се определя *интензивността на ерозийното износване*:

$$i_e = \frac{\dot{m}}{\dot{m}_a} = k \tag{9}$$

Интензивността на ерозията i_e представлява отношение на скоростта на масовото износване и масовия дебит на абразивната фаза в струята и е бездименсионно число.

Ерозийната износоустойчивост на покритието I_e се определя като реципрочна стойност на интензивността на износване i_e, т.е. тя представлява бездименсионна величина

$$I_e = \frac{1}{ie} = \frac{\dot{m}_a}{\dot{m}} \tag{10}$$

Ако се запише отношението на износоустойчивостта на покритието към износоустойчивостта на материала без покритие, приет за еталон, то се получава *относителната износоустойчивост при струйно-абразивна ерозия* или относителната ерозийна износоустойчивост, т.е.

$$E_{ie} = \frac{I_e^i}{I_e^o} \tag{11}$$

Относителната ерозийна износоустойчивост E_i^e представлява бездименсионно число, което показва колко пъти се увеличава или намалява износоустойчивостта на повърхностния слой на даден материал в условия на ерозия, ако върху него се нанесе покритие, т.е. влиянието на покритието върху износоустойчивостта на подложката, върху която е нанесено.

Разработени са устройство и методика, които се основават на описаната теория на струйно-абразивната ерозия.

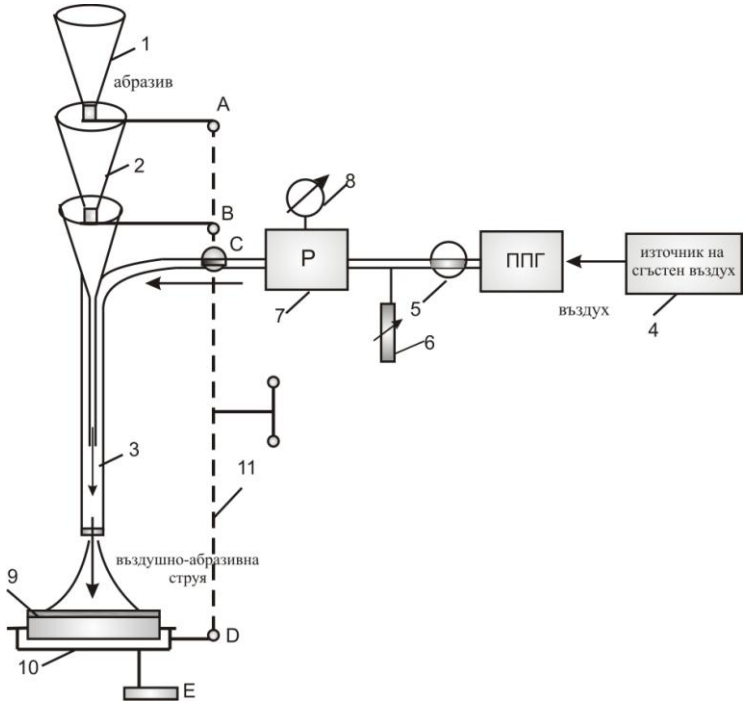
4.УСТРОЙСТВО И МЕТОДИКА ЗА ИЗСЛЕДВАНЕ НА ЕРОЗИЙНО ИЗНОСВАНЕ

Изследването на ерозийно износване на покрития с въздушно-абразивна струя се осъществява с устройство, разработено в научно-приложната лаборатория „Трибология" – катедра МТМ - МТФ при ТУ-София. Параметрите на устойството са съобразени с изискванията на международните стандарти [5].

Функционалната схема на устройството е представена на фиг. 1.

Предназначението на устройството е да се формира въздушна струя, носеща абразивни частици като се задават два самостоятелни независими стационарни потока – въздушен и абразивен.

Стационарният, свободно падащ абразивен поток, се формира с помощта на три камери: захранваща камера (1), която се запълва с работния абразивен материал; стабилизираща камера (2), запълнена със същия вид абразив и работна камера (3), която е предназначена за ускоряване абразивните частици и смесването на въздушния и абразивния поток. Абразивният материал преди поставяне в камери (1) и (2) се пресява през комплект от сита и се подсушава в сушилен шкаф за отнемане на влагата от частиците.



Фиг. 1: *Функционална схема на лабораторна уредба за изследване и изпитване на повърхностни слоеве и покрития в условия на струйно-абразивно износване*

Въздушният поток се подготвя последователно от източник на сгъстен въздух (4); пневмо-подготвяща група (ППГ) за пречистване на въздуха от механични частици, влага и маслени пари; превключвател (5) и регулатор на налягане (6) за захранване и стабилизиране на

фиксираното въздушно налягане P в камера (7). Налягането P се измерва по скалата на манометър (8), включен към камера (7).

Формирането на работната двуфазна струя, като краен продукт от смесването, се осъществява на изхода на работната камера (3).

Изпитваният образец (10) се позиционира в държача (11), свързан с реверсивен механизъм (12), с помощта на който се регулират следните параметри: разстояние ℓ между дюзата и повърхнината (9), ъгъл на взаимодействие α между оста на струята и нормалата към повърхнината (9) на образеца.

Последователността на работа с устройството е следната: подходящо подготвеният образец (9) се поставя в държача (10) като с реверсивния механизъм (11) се позиционира на определено разстояние ℓ и ъгъл на взаимодействие α.

Смесителната работна камера (3) се захранва с пречистен въздух чрез отваряне на превключвателя (5) като се задава стационарно работно налягане P с регулатора (6).

Работното количество абразивен материал се поставя в захранващата камера (1) при запълнена стабилизираща камера (2) със същия вид абразив при затворен механизъм (11).

С отваряне на механизма (11) започва процесът на струйно-абразивно облъчване на покритието (9) на образеца и продължава до момента на изчерпване на абразивния материал в камера (1). В този момент се превключва механизъм (11), с което едновременно се прекратява изтичането на въздушния поток от камера (7) и на абразивния поток от работната камера (1) и стабилизиращата камера (2).

Методиката за изследване на ерозийно износване с описаното устройство се състои в измерване на масата на образеца преди облъчване и след облъчване с двуфазна струя при фиксирани параметри: разстояние ℓ и ъгъл на взаимодействие α, работно налягане P, масов дебит на абразива $\dot{m}_a$.

Масата на образците се измерва с електронна везна WP-S-180/C/2 с точност до $0{,}1\ mg$. Преди всяко измерване с везната образецът се почиства с разтвор, неутрализиращ статичното електричество и се подсушава.

Масовият дебит на абразива $\dot{m}_a$ се определя предварително чрез измерване с хронометър на времето t, за което изтича количеството абразивен материал m_a от камерата (2) през изходната дюза, без наличие на въздушна фаза, т.е. $\dot{m}_a = m_a / t$

В таблица 3 са представени параметрите на експеримента.

Таблица 3: Параметри на струйно-абразивното облъчване

№	Параметър	Стойност
1.	Ъгъл на взаимодействие	$\alpha = 0^o$
2.	Работно налягане на въздушната фаза	$P = 10^5\ Pa$
3.	Масов дебит на абразивната фаза	$\dot{m}_a = 166{,}7\ g/\min$
4.	Абразивен материал	Корунд черен
5.	Среден размер на абразивните частици	$d_a = 500\ \mu m$
6.	Разстояние между дюзата и повърхнината	$\ell = 10\ mm$
7.	Продължителност на облъчването	$t = 6\ \min$

5. ЕКСПЕРИМЕНТАЛНИ РЕЗУЛТАТИ

С описаните методика и устройство е проведено изследване на пет серии никелови покрития и на материала на основата без нанесено покритие. Получени са експериментални резултати за масовото ерозийно износване m, скоростта на масовото износване $\dot{m}$, интензивността i_e и износоустойчивостта I_e, определени по формули (9) и (10). Резултатите са представени в таблица 3.

Таблица 4: Експериментални резултати

№	образци	маса преди ерозия, g	маса след ерозия, g	износване g	Скорост на износва-не $mg/\min$	Интензив-ност i_e	Износо-устойчивост I_e
1.	Без покритие	64,6202	64,6197	0,0005	0,008	3.10^{-3}	$0,33.10^{3}$
2.	Ni – без термообра ботка	63,6215	63,6192	0,0023	0,38	$2,3.10^{-3}$	$0,43.10^{3}$
3.	Ni + с термообра ботка	64,5753	64,5715	0,0038	0,63	$3,8.10^{-3}$	$0,26.10^{3}$
4.	NI*SIC- без термообра ботка	75,0376	75,0264	0,0112	1,87	11.10^{-3}	$0,09.10^{3}$
5.	NI*SIC+ с термообра ботка	73,1352	73,1215	0,0137	2,28	$13,7.10^{-3}$	$0,07.10^{3}$

В таблица 5 са представени стойности за относителната ерозийна износоустойчивост, определена по формула (11).

Таблица 5: Относителна износоустойчивост на покритията пристуйно-абразивната ерозия

$E_{ie} = I_e^i / I_e^o$			
E_{21}	E_{31}	E_{41}	E_{51}
1,3	0,79	0,27	0,21

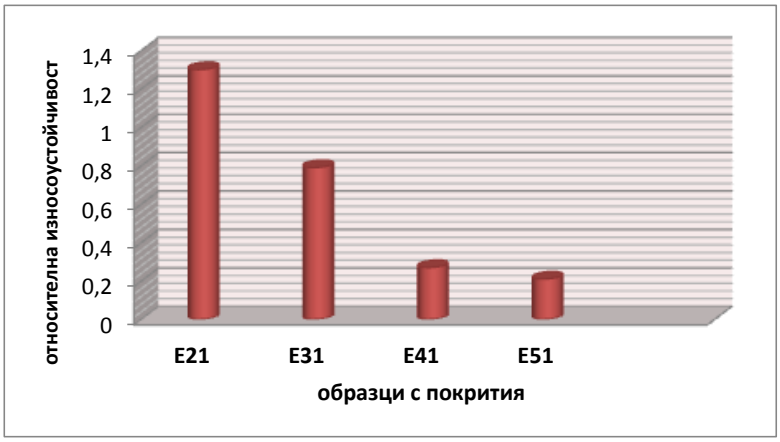
На фиг. 2, фиг. 3 и фиг. 4 са представени диаграми на масовото износване, износоустойчивостта и относителната износоустойчивост за изследваните образци при струйно-абразивна ерозия.



Фиг. 2: Диаграма на масовото ерозийно износване на покритията



Фиг. 3: Износоустойчивост на покритията при струйно-абразивна ерозия



Фиг. 4: Относителна износоустойчивост при струйно-абразивна ерозия

Анализът на получените експериментални резултати води до следните основни констатации и изводи:

1. Най-висока износоустойчивост имат никелови покрития без наночастици и без термообработка. Иносоустойчивостта им е 1,3 пъти по-висока от тази на подложката и 1,65 пъти по-висока от тази на никелово покритие без частици с термообработка.
2. Присъствието на наноразмерни частици от силициев карбид като уякчаваща фаза в химически никеловите покрития най-общо води до понижаване на ерозийната им износоустойчивост. Най-ниска износоустойчивост имат термообработените никелови покрития

с наночастици от SiC и износоустойчивостта им е 6,14 пъти по-ниска от тази на никелово покритие без частици и без термообработка.

3. Допълнителната термообработка на композитните покрития с наночастици влошава допълнително ерозийната износоустойчивост с около 120%.

6. ЗАКЛЮЧЕНИЕ

В заключение може да се обобщи, че никеловите покрития, съдържащи наночастици от силициев карбид не са подходящи за повърхнини, подложени на ударно въздействие от твърди частици. Тяхната малка устойчивост на динамични ударни въздействия вероятно се дължи на намаляване на пластичните свойства на композитното покритие от присъствието на силиций и повишаване на крехкостта.Такова предположение ще бъде проверено в бъдещи системни изследвания на ерозийното износване на никелово покритие с наноразмерни частици от други нетвърди метали като мед, калай и др.

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RECEIPT OF Ni-Cr COATINGS ON POLYMER SUBSTRATES BY DC MAGNETRON SPUTTERING

Polina MILUSHEVA, Nikola NIKOLOV, Nikolai IVANOV, Dimitar DECHEV

Abstract: *The object of this paper is the ability to obtain Ni-Cr coatings on polymer substrates by DC magnetron sputtering in a vacuum. Processing is economically and environmentally viable, as it combines the recovery of precious metal, with mitigation of environmental impacts. Alloy targets used are the result of recovery of nickel and chromium from industrial wastewater. And using vacuum deposition technology for coating is removed harmful working conditions, waste pollution.*
Key Words: *Ni-Cr, polymers, thin layers, cathode sputtering*

ПОЛУЧАВАНЕ НА Ni-Cr ПОКРИТИЯ ВЪРХУ ПОЛИМЕРНИ ПОДЛОЖКИ ЧРЕЗ ПОСТОЯННОТОКОВО МАГНЕТРОННО РАЗПРАШВАНЕ

Полина МИЛУШЕВА, Никола НИКОЛОВ, Николай ИВАНОВ, Димитър ДЕЧЕВ

Резюме: *Обект на настоящата работа е възможността за получаване на Ni-Cr покрития върху полимерни подложки, чрез постояннотоково магнетронно разпрашване във вакуум. Обработката е икономически и екологично целесъобразна, тъй като комбинира възстановяването на ценен метал, със смекчаване на въздействието върху околната среда. Използваните сплавни мишени са резултат от възстановяването на никел и хром от промишлени отпадни води. А чрез използването на вакуумните технологии за отлагане на покритията, се премахват вредните условия на труд, отпадъците, замърсяването на околната среда.*
Ключови думи: *Ni-Cr, полимери, покрития, катодно разпрашване*

1.УВОД

Производството е неизменна част от живота на човешкото общество като цяло и представлява комбинация от фактори, позволяваща ефективно използване на стопанските ресурси и оптимална реализация на поставените цели. Основният проблем за оптималното използване на ресурсите (суровини, материали, оборудване, капитал), е тяхната ограниченост. В последните години голямо приложение намира рециклирането, т.е. възвръщане на полезните компоненти обратно в производството за повторна употреба. Това е свързано и с проблема за опазване на околната среда, което е отговорност на всеки един от нас. С всеки изминал ден изчерпването на ресурсите на планетата и постоянно растящите източници на замърсяване застрашават бъдещето на човечеството. Затова трябва да се предприемат мерки за опазване на природата. Важна стъпка в тази насока е разделното събиране и рециклирането на отпадъците [1].

Обект на настоящата работа е възможността за получаване на Ni-Cr покрития върху полимерни подложки, чрез постояннотоково магнетронно разпрашване във вакуум.

Металният слой, нанесен върху полимерен материал, защитава същият от УВ-лъчението, топлинните потоци, намалява проницаемостта на влага и кислород. Тези свойства на металните покрития предпазват полимерните материали от бързо стареене и се съчетават с отличен декоративен ефект. Използването на метализация разширява с повече от 300 хиляди асортимента пластмасови изделия, позволява тяхното целенасочено използване.

2.ИЗБОР НА МАТЕРИАЛИ

2.1.Материал за покритие

Използваните мишени са сплави на основата на никел и хром. Те са резултат от възстановяването на никел и хром от промишлени отпадни води. Обработката е икономически и екологично целесъобразна, тъй като комбинира възстановяването на ценен метал, със смекчаване на въздействието върху околната среда. Избрани са *Ni80Cr20* и *Ni50Cr50*. Те са немагнитни и могат да се използват при магнетронно разпрашване във вакуум [8]:

2.2.Подложки

За целите на настоящето изследване за подложки са избрани полимерите Polipom POM (Турция) и ПС БС 793 удароустойчив (България). Изборът на тези полимери, е повлиян от възможността за лесното им обработване, ниската им цена и масовото им приложение в автомобилостроенето, машиностроенето, електротехниката и др. отрасли [2, 3, 4].

3.ЕКСПЕРИМЕНТАЛНА ЧАСТ

3.1.Подготовка на повърхността преди нанасяне на покритието

Качеството на металното покритие зависи от вида на повърхността на полимера, от неговата химична природа, над молекулната му структура и начина на подготовка на повърхността преди нанасяне на покритията.

Грижливото предварително почистване на повърхността и нейната допълнителна обработка, е от съществено значение за получаване на покритие с определени експлоатационни характеристики. Резултат от предварителни експериментални проучвания, е следната последователност за почистване на полимерните подложки [7, 9]:

за подложки от POLIPOM®-POM:

механично почистване – шлифоване с шкурки Р600 и Р1500;

химическо почистване – измиване с повърхностно активно вещество – миещ препарат „Medix", последващо обилно изплакване с вода (50°C), последващо изплакване с дестилирана вода и изсушаване при стайна температура;

йонно почистване – почистване във вакуум, в тлеещ разряд, в работна среда от аргон, без допълнителен окисен слой.

Параметрите на режима на почистване са:

- работно налягане – *6 Pa;*
- работно напрежение – *1200 V;*
- разряден ток – *0,15 A;*
- времетраене на процеса – *300 s;*

за подложки от ПС БС 793 удароустойчив:

механично почистване – шлифоване с шкурки Р600 и Р1500;

химическо почистване – измиване с повърхностно активно вещество – миещ препарат „Medix", последващо обилно изплакване с вода (50°C), последващо изплакване с дестилирана вода и изсушаване при стайна температура;

йонно почистване – без катодно почистване, с допълнителна обработка с кислород – t = *240 s;* $p = 6.10^{-2}$ *Pa;* U = *390 V;* I = *0,8 A.*

Катодното почистване се извършва в същата камерата, в която ще бъде получено покритието, непосредствено преди неговото нанасяне. Използва се постояннотокова схема, при която почистваният образец се поставя върху анода, а се почиства страната, обърната към катода. След приключване на катодното почистване, без да се нарушава вакуума и променя остатъчната атмосфера, се нанася покритието.

3.2.Процес на отлагане на покритията

Нанасянето на тънкослойните *Ni-Cr* покрития, е осъществено чрез постояннотоково магнетронно разпрашване във вакуум. Използването на вакуумните технологии за отлагане на покрития, игнорират вредните условия на труд, отпадъците, замърсяването на околната среда.

Процесът на отлагане**,** се извършва в камерата на вакуумна инсталация „ТИТАН - 22" (България), преустроена за нанасяне на многослойни покрития. Тя е оборудвана с четири плоски магнетрона с диаметър *100 mm* и захранващ блок с максимална мощност *15 kV*. Общият вид на инсталацията е показан на фиг. 1.



Фиг. 1. Вакуумна инсталация „ТИТАН - 22”

Техническите данни на съоръжението са:

- размери на камерата – *560/560/500 mm*
- пределна стойност на разреждане - $p_{пр}$*= 1,5.10*$^{-3}$ *Pa*
- захранващ източник за магнетрон: U_{max}*=1000 V,* I_{max}*= 20 A*
- потенциал на електрода за катодно почистване U_{max}*= 1200 V*

Прибори за измерване на вакуум:

- за нисък вакуум - *TERMOWAC TM 220S2*
- за висок вакуум - *PENNINGVAC PM 310*

Вакуумен помпен агрегат на база на две помпи:

- за нисък вакуум - *DK 200 – 200 m*^{3}*/h*
- за висок вакуум - паромаслена дифузионна помпа тип *DI6000 (LEYBOLD - HERAEUS) – 6000 l/s.*

При получаване на слоевете са избрани такива технологични параметри на разпрашване, при които горенето на разряда е устойчиво и стабилно. Нанесени са покрития при режим, параметрите на който, са представени в табл. 1.

Таблица 1. Параметри на режимите на отлагане на покритията

Мишена	Ni80Cr20		Ni80Cr20	
Работен газ	O_2	Ar	O_2	Ar
Налягане на работния газ, *Pa*	0,04	0,15	0,04	0,06
Ток, *A*	1	1	1	1
Напрежение, *V*	410	540	450	540
Време за отлагане, *s*	180	600	180	600
Разстояние мишена-подложка, *mm*	160	160	160	160
Температура на работната маса, *^{o}C*	22±3	22±3	22±3	22±3

Напрежението и тока на магнетронния разряд, се определят непосредствено по вградените в захранващите блокове прибори. Налягането на работния газ в камерата, може да се регулира плавно и се измерва с вграден в инсталацията вакууммер. Парциалното налягане на реактивния газ (кислород) се регулира и контролира със система за едновременно натичане на два газа „СНА-2” (Украйна). Разстоянието между мишената и подложката, както и времето за отлагане, не се променят.

След приключване на процеса на нанасяне, образците се изкарват от вакуум-камерата и се оставят при стайна температура [5, 6].

3.3.Контрол на получените покрития

Една от основните експлоатационни характеристики на материалите с покрития е адхезията на слоя към подложката. Когато е необходим бърз контрол за измерване на адхезионната връзка в системата слой-подложка, се използва метода на „лепнещата лента”. Този метод дава качествени резултати, но те са първия сигнал за качествено покритие **[10, 11].**

За получените тънкослойни *Ni-Cr* покрития, се поставя лепнеща лента със стандартизирано усилие на отлепяне, притиска се, за да се осъществи добър контакт, след което се прилага нормална сила и лентата се отлепя. Адхезията е добра, а това е предпоставка за по-нататъшно оптимизиране на технологичните параметри на режима на отлагане.

4.ЗАКЛЮЧЕНИЕ

Проведените експерименти по отлагане на покрития, дават основание да се направят следните обобщения и изводи:

- Създадена е технология за получаване на тънкослойни покрития от Ni80Cr20 и Ni80Cr20, върху подложки от полимерите POLIPOM®-POM и ПС БС 793 удароустойчив.
- Предварително експериментално са определени стойностите на технологичните параметри на режима на катодно почистване.
- Определени са технологичните параметри на режимите на получаване на покритията.
- Получените покрития са равномерни, с добра адхезия, позволяваща допълнително оптимизиране на технологичните параметри на режима на отлагане.

БЛАГОДАРНОСТИ

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ИЗСЛЕДВАНЕ ИЗНОСВАНЕТО НА ИНСТРУМЕНТИ С ЕЛЕКТРОИСКРОВИ ПОКРИТИЯ ОТ ВИСОКОЕНЕРГИЕН ИЗТОЧНИК ПРИ ПРЕКЪСНАТО РЯЗАНЕ

Тодор ПЕНЯШКИ

STUDY OF THE WEAR OF CUTTING TOOLS WITH ELECTRO-SPARKING COATINGS FROM HIGH ENERGY SOURCE WITH UNINTERRUPTED CUTTING

Todor PENIASHKI

Abstract: *For electro-sparking coating (ESC) they are used in Bulgaria sources with impulse energy from 10^{-4} to 10^{-3},J. Received in these conditions coatings with thickness 5-6 μ m are mix from the anode and cathode materials. With purpose for receiving of layers with higher level of dispersion, thickness and quantity of carbides of piles up electrode (and in this way higher hardness, wearing quality and durability) are made attempts for ESC of coatings from source with higher energy. In the work process are investigated parameters of received coatings with purpose of selection of appropriate energy for piles up. The paper analyzed the parameters of the resulting coatings depending on electrode material and energy for lamination. They are covered coatings of cutting plates from HSS steel and are made comparative studies of their wear in the milling. The received results show a significant increase of the durability of the tools in comparison with not layered and layered up with conventional sources of energy. Are derived statistical models to determine the durability of the layered tools. Are definite technical and technological conditions, which is received minimum wear, respectively maximum durability of piled up tools.*

Key Words: *electrospark alloying, impulse energy, coating, cutting plates from HSS steel, milling, increasing to wear capability.*

Известно е, че при използване на най-разпространените у нас машини за електроискрово напластяване ***/ EH/*** „Елфа" с увеличение на енергията на единичния импулс /***Ee***/ и на електрическата мощност, нараства количеството пренесен върху катода материал, монотонно нарастват грапавостта / ***Ra /***, дебелината / ***δ*** / и микротвърдостта /***Hv/*** на нанесените покрития [1,2,3]. Структурата им постепенно издребнява и при режимите с максималната за машините енергия /10^{-2} J/ достига до състояние близко до аморфното[3]. При ръчните вибрационни установки за ***EH*** , където се използват източници с по-висока енергия, / ***Ee*** до 5 и повече J/, при напластяване на стомани с твърдосплавни електроди в получения слой има ясно разграничение на отделните зони :

– горна– състояща се предимно от карбиди от напластяващия електрод /***HE/*** ,

- подслой – смес от двата материала, съставена от мартензит–аустенитна матрица, наситена с карбиди от напластяващия електрод, видоизменени карбиди от електрода и съединения на двата материала и елементите от обкръжаващата среда, получени в процеса на напластяване.

- долна - дифузионна зона – с намаляваща концентрация на карбидите в дълбочина към основата и намалено съдържание на въглерод поради дифузията му в посока към по-горните зони. При ***EH*** с машините „Елфа", най- горния карбиден слой липсва – нанесеното покритие по строеж и структура е аналогично на подслоя, получен при вибрационните методи. Това е причина която води често до противоречиви и недостатъчно удовлетворяващи резултати при използване на инструменти с ***EH*** покрития. От практическа и теоретична гледни точки е очевидно, че по- нататъшното увеличение на ефекта от ***EH*** чрез машините „Елфа" е свързано с увеличение на енергията на единичния импулс, което ще доведе до получаване на покрития с

по-големи дебелина, твърдост, степен на дисперсност, количество на карбидите в слоя и съответно по-добри експлоатационни свойства. С цел получаване на покрития с по-голямо количество на карбиди в горния слой и по- висока степен на аморфност са използвани източници с енергия на единичния импулс до 2 J и съответно по-висока мощност. В работите [3,4] е изследвано изменението на качествените характеристики /***Ra***, ***δ***, ***Hv/,*** състава и структурата на нанесени с твърдосплавни електроди върху бързорежеща стомана покрития в зависимост от параметрите на режима за ***ЕН*** и ***Ее*** на горните източници. Установено е, че при ***Ее>*** 10^{-2} *J* се получава бял слой с високодисперсен хетерогенен строеж, близък до аморфния, като увеличението на енергията води до нарастване на степента на аморфност, и при ***Ее>*** *0,2 J* цялото покритие е аморфно. Използването на по-висока енергия позволява получаване на покрития с дебелина ***δ*** до 40 -50 μm - повече от три пъти по-голяма от получената с конвенционалния генератор на машините „Елфа" , но и значително по-висока грапавост– ***Ra*** до 2,5-3 μm***.***

В [4] е изследвано износването на инструменти с покрития, нанесени с висока енергия при непрекъснато рязане. Задачата на настоящата работа е да се изследва влиянието на по-високата енергия и получените "псевдоаморфни" структури върху износването на напластените инструменти при прекъснато рязане и да се определят най-подходящите от гледна точка на износването режими и условия за нанасяне на покритията.

ПОСТАНОВКА НА ЕКСПЕРИМЕНТИТЕ

Условия на рязане

Използвани са моделни инструменти - челна фреза с диаметър *D=125 mm* с механично закрепени режещи пластини от бързорежеща стомана Р6М5 от типа SPGN150412 /ISO/ с геометрични параметри: преден ъгъл $\gamma_0 = 6^0$, главен заден ъгъл $\alpha_0 = 6^0$, главен установъчен ъгъл $\chi_r = 75^0$, спомагателен установъчен ъгъл $\chi_r' = 15^0$, ъгъл на наклона на главния режещ ръб $\lambda_s = 6^0$. На фрезата се закрепва само една режеща пластина с цел избягване влиянието на биенето на зъбите върху износването. Опитите са проведени на фреза "ФУ 321" при пълно симетрично челно фрезоване на заготовки от стомана 45/0.45%С/ , с дължина 500 и широчина 120mm., скорости на рязане 39 и 49 m/min, подаване на зъб *Sz = 0,2 u 0,4 mm* и дълбочина на рязане 2 mm. Инструментите се напластяват по предната повърхнина, като за увеличение на достоверността на резултатите, всеки режещ ръб е напластяван при различен режим. Използвано е непрекъснато охлаждане с 5% - тен разтвор на борьол. Провеждат се еднофакторни и многофакторни експерименти. За многофакторните експерименти се използват модели от типа $T= C\, V^x.S_z{}^y$ *u* $T= C\, V^x.S_z{}^y.Ra^q$, където ***Ra*** е грапавостта на покритията. която се приема като комплексен параметър, характеризиращ техните свойства.

Условия за ЕН

Материал на ***НЕ*** – твърдосплавни електроди със състав {*Ti, Ta, Nb}C, WC u Co* с условно означение ***Р25***; WC и Co – с условно означение ***ВК***; *TiN, Ni u Mo* – с условно означение ***ТН***.
Режими за ***ЕН*** - Режимите за ***ЕН*** , както и стойностите на параметрите на получените с тях покрития за ***НЕ ВК*** са дадени в Таблица1. За сравнение е приет и един режим от машините "Елфа" - №20.

Методика на измерванията

Износване на инструментите – През определени интервали от време се измерва износването по предната /Кт/ и главната задна повърхнина/VB/ до достигане на избрания критерий VB=0.5мм. За обективност са измервани и следните параметри на износването:

- $h_{з\ мах}$ – максимално износване по главната задна повърхнина;
- $h_{з.сп.}$ - широчина на лентата на износване по спомагателната задна повърхнина;
- $h_{з.сп..}$ - максимално износване по спомагателната задна повърхнина.

Измерванията се извършват с инструментален микроскоп БМИ и индикаторен часовник- /0.01мм./. Провеждат се четири паралелни опита. Получените резултати се обработват като се определят средноквадратичното отклонение и средноаритметичната стойност на доверителния интервал - *S* *u* Δx. Рязко отделящите се стойности се отхвърлат по метода на Грубс [5] - $\theta = \frac{x_{\max} - \bar{x}}{S} > \theta_{кр}$.

Грапавост и дебелина на покритията – Измерват се с Профилограф-профилометър “Pertometer PS5”.Резултатите са от 5 паралелни опита. Тук също се определят *S, ∆x и Θ*, като рязко отделящите се стойности се отхвърлят.

Микротвърдост на покритията – Измерва се с микротвърдомер “Laitz”, като резултатите са средно аритметично от 5 измервания.

АНАЛИЗ НА ПОЛУЧЕНИТЕ РЕЗУЛТАТИ

В Таблица1 са дадени режимите за ***ЕН*** , както и стойностите на параметрите на получените с тях покрития за ***НЕ ВК*** . Аналогични са и резултатите, получени с останалите два електрода, с

Таблица1.

№	**I,A**	**τ**	**Ti,** μs	**Ee,** J	**Ra,**μm	**δ,** μm	**Hv**,GPa
1.	30	0.04	5	0.015	1.28	5.33	13.87
2.	30	0.08	5	0.015	1.23	5.74	14.23
3.	30	0.04	10	0.03	1.48	6.33	14.8
4.	40	0.04	2	0.008	1.04	5.54	12.8
5.	40	0.04	5	0.02	1.25	5.67	14.28
6.	40	0.04	10	0.04	1.70	6.24	15.45
7.	40	0.08	10	0.04	1.64	6.76	15.33
8.	40	0.04	20	0.08	1.83	9.45	15.67
9.	40	0.04	50	0.2	2.27	14.5	17.87
10.	50	0.04	2	0.01	1.26	6.03	12.74
11.	50	0.04	5	0.025	1.42	6.9	13.99
12.	50	0.04	10	0.05	1.72	7.68	15.36
13.	50	0.04	10	0.2	1.85	8.68	17.12
14.	50	0.04	20	0.1	1.93	10.75	18.15
15*.	50	0.02	50	0.25	2.46	16.66	18.47
16*.	60	0,1	20	0,12	2,53	25	12,84
17*.	60	0,1	50	0,3	2,62	29,15	14,29
18*.	80	0,1	50	0,4	2,88	35,43	12,19
19*	60	0,1	100	0,6	3,06	55	12,03
20.	14.4	0.1	12	0.01	1.36	5.84	15.45

тази разлика, че при напластяване с електрод ***ТН*** грапавостта и дебелината на получените покрития са с около 20% по-ниски. От параметрите на режима за ***ЕН*** най- силно влияние върху изменението на грапавостта и дебелината на покритията оказва продължителността на импулсите ***Ti***. При сравнението на грапавостта и дебелината на покритията, получени при различни комбинации на електрическите параметри на режима за ***ЕН*** на използваните източници - напрежението ***U,*** тока ***I,***продължителността на импулсите ***Ti,*** капацитета ***C,*** коефициента на запълване на импулсите ***τ,*** се установява, че покрития, нанесени с еднаква енергия могат да имат различни по стойности дебелина и грапавост. / Например, при ***I=****20 А,* ***τ*** *= 0,08* и ***Ti*** *= 10 μs, -* ***Ra*** *= 1,44μm и* ***δ*** *= 6,2 μm* . При същата енергия, но при при ***I=****50 А,* ***τ*** *= 0,08 и* ***Ti*** *= 2 μs, -* ***Ra*** *= 1,23μm и* ***δ*** *= 5,5 μm /.* По-ниските стойности на ***Ra*** са получени при по-ниски стойности на ***Ti***. В резултат на проведени планирани многофакторни експерименти при основни нива на факторите ***I=****20 - 50 А* ***Ti*** *= 2 - 20 μs,* ***τ*** *=0,02 - 0,08* са получени следните зависимости:

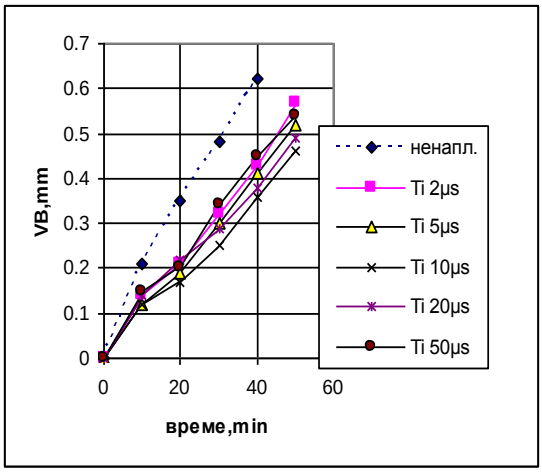
- за твърдосплавен електрод *ВК –* ***Ra*** *= 0,56+0,012****I*** *+0,115****Ti*** *– 1,5****τ*** *– 0,001* ***I. Ti*** *(1)*
- за твърдосплавен електрод *Р25 -* ***Ra*** *= 0,45+0,01****I*** *+0,11****Ti*** *–* ***τ*** *– 0,008* ***I. Ti*** *(2)*

Както се вижда, коефициентите пред двете уравнения са близки, което е обусловено от факта, че и двата електрода са на основа *WC*. Тъй като при ***ЕН*** с определен електрод на всяка определена стойност на ***Ra*** съответстват и определени стойности на дебелината ***δ*** , а също и на степента на дисперсност, аморфност и количеството на карбидите, то ***Ra*** може да се възприеме като комплексен параметър, характеризиращ свойствата на покритието. По такъв начин получените модели дават реални възможности за предварителен подбор на режимите за ***ЕН*** и получаване на покрития с предварително зададени дебелина, грапавост и експлоатационни свойства, съответстващи на вида и условията на експлоатация на инструмента.

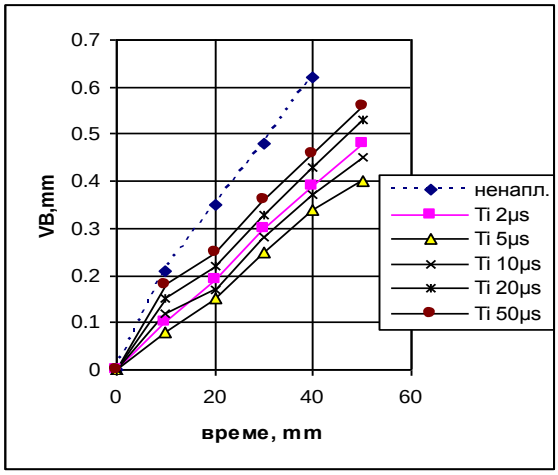
От горните резултати е видно, че получаване на покрития с по-голяма дебелина /респ. по-голямо количество на карбидите в слоя и по-висока степен на аморфност/ и по-ниска грапавост е възможно чрез използване на по-ниски стойности на ***Ti*** – 2, 5 и евентуално 10 μs , при високи стойности на тока /***I>*** 30 А/ и коефициента на запълване на импулсите /***τ >*** 0,04/. Грапавостта

на покритията, получени при стойности на ***Ti>*** *10 μs* и ***I>*** *40 A* е непригодна за ***ЕН*** на металорежещи инструменти. Използването на тези по-дебели и по-износоустойчиви покрития е възможно единствено след допълнителна обработка – шлифоване, или притриване с цел намаляване стойностите на ***Ra***.

Резултатите от изследванията на износването на напластени с ***НЕ ВК*** инструменти са изобразени графично на фигури 1-7. От изследваните режими е възможно да се изяви влиянието на коефициента на запълване на импулсите τ, продължителността на импулсите ***Ti*** и тока ***I*** върху износването на напластените инструменти.На фиг.1,2 и 3 е показано изменението на износването VB във времето в зависимост от продължителността на импулсите ***Ti***, съответно за ток ***I*** 30, 40 и 50 А. От фигурите се установява, че с увеличение на ***Ee*** до определени стойности износването намалява до минимум. С по-нататъшното увеличение на енергията износването на напластените инструменти постепенно нараства.



Фиг.1. Зависимости"време -износване" за инструменти,напластени при ток I=30A, τ=0.04; V=39 m/min, S_z = 0,2 mm/зъб, t = 2mm

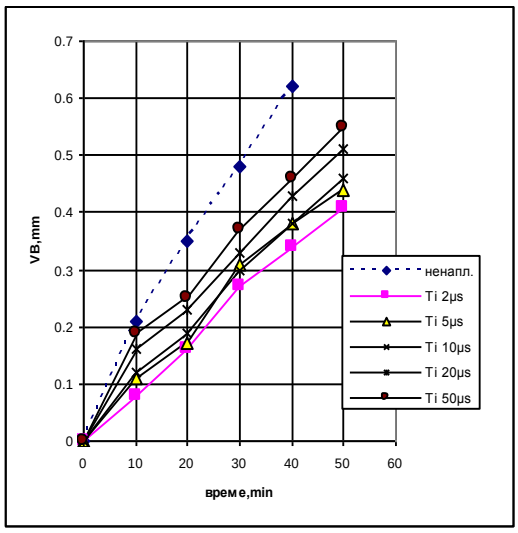


Фиг.2. Зависимости "време -износване" за инструменти,напластени при ток I=40A, τ=0.04; V=39 m/min, S_z = 0,2 mm/зъб, t = 2mm

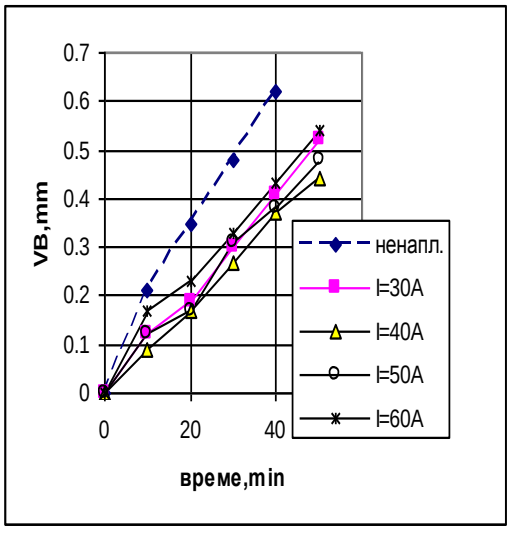
- При ***I*** = *30 A* – фиг.1 – с увеличение на ***Ti*** до 20μs, износването намалява, а при ***Ti***=50μs нараства, но е с по-ниски стойности от това при **Ti**=2μs;

- При ***I*** =*40 A* – фиг.2. - най-ниски стойности на износването *VB* са получени при ***Ti*** 2 и 5 μs, а при ***Ti>*** 5μs *VB* постепенно нараства, но е с по-ниски стойности от това при ***Ti***=2μs и от това на инструментите с покрития, нанесени при ток 30А;

- При ***I*** =*50 A* – фиг.3.– най-малко износване имат инструментите напластени при ***Ti*** = *2μs*, с увеличаване на ***Ti*** износването постепенно нараства.



Фиг.3. ток I=50A, τ=0.04; V=39 m/min, S_z = 0,2 mm/зъб, t =2mm



Фиг.4. Зависимости "време -износване" за инструменти, напластени при τ=0.04, Ti=5 μs ; V=39,m/min, S_z = 0,2 mm/зъб.

На фиг.4 е дадено изменението на износването *VB* във времето в зависимост от тока ***I*** при ***Ti*** = *5μs*. Констатира се, че увеличението на ***I*** до 40А води към намаляване на *VB*. При ***Ti*** › 5μs тази зависимост ще бъде друга , както може да се установи от горните фигури – нарастването на износването ще започва от по-ниски стойности на тока. Това явление се обяснява с взаимното влияние на ***I*** и ***Ti***, както върху грапавостта на покритията, така и върху степента на отгряване и обезвъглеродявана на подповърхностния слой. От фигурите се установява, че минимално износване *VB* се получава при режимите с висок ток и ниски стойности на ***Ti*** и ***τ, / Ti*** *< 10 μs,* ***τ*** *<0,06/*, при които грапавостта на покритията ***Ra<*** 1,4μm; или при режими с по-нисък ток ***I*** *= 20-40A*, но по-високи стойности на ***Ti*** и ***τ - Ti*** *>10 μs,* ***τ*** ***>****0,06* , т.е. – при режимите с възможно максимална енергия, но по-ниска грапавост и степен на отгряване на покритията. Това сложно изменение се дължи на съвместното влияние на **Ti** и **I** върху качествените характеристики и най-вече върху грапавостта на покритията. До определена степен на увеличение на ***Ee*** – /стойностите на ***Ti*** и ***I/-*** по-високата грапавост на получените покрития се компенсира от по-високите дебелина и твърдост на слоя, степен на дисперсност и аморфност и количеството на карбидите [3], след което грапавостта ***Ra*** поради по-високия коефициент на триене в резултат на който нарастват температурата и силите на рязане, започва да влияе отрицателно върху износването.

Износването по предната повърхнина на инструментите – Кт намалява с увеличение на ***Ee*** ***I*** респ. на **Ti** и **I/** .

Аналогични зависимости са получени и за останалите електроди и посочените в Таблица 1 режими.

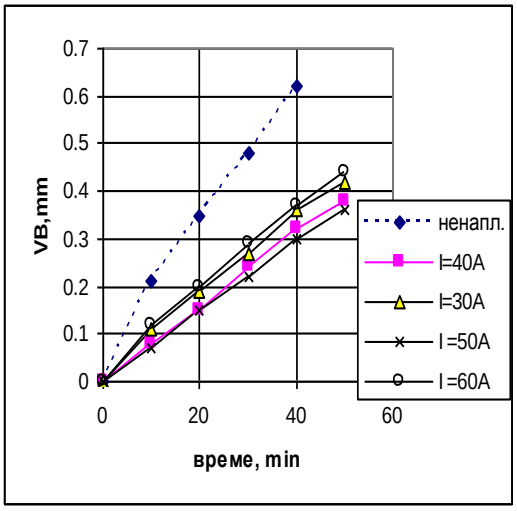
За установяване влиянието на грапавостта на покритията върху износването са извършени опити с напластени при висока енергия *0,1 – 1J* инструменти *-/* ***I*** *= 40-60A и* ***Ti*** *=10 - 100 μs/*, като нанесените покрития са притривани с диск с диамантена паста и натиск 0,5 N до получаване на грапавост ***Ra<*** *1,3μm* – като тази на покритията, довели до най-ниско износване. Получените резултати са дадени на фиг.5. Сравнението с фиг.1-4 показва, че всички притрити покрития имат до 20% по-малко износване от непритритите, износването по предната повърхнина Кт също е по-ниско. Това показва следното:

-по-високата грапавост е основната причина за нарастването на износването;

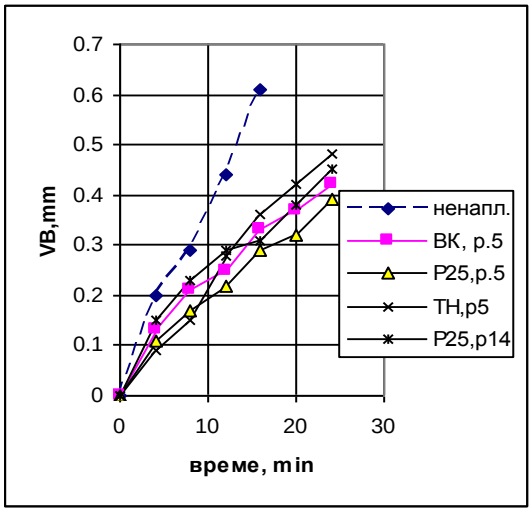
– грапавостта на покрития, нанесени при режими с ***Ti*** *>20μs* е непригодна за металорежещи инструменти. Използването на такива покрития е възможно само след допълнителна обработка до стойности ***Ra<*** *1,3μm*, което води до максимален ефект от ***ЕН*** ;

-увеличението на ***Ee*** –/респективно степента на дисперсност и аморфност на покритието/ води до намаляване на износването;

- допълнителната обработка позволява да се увеличи трайността на напластените инструменти с 5 до 15 min;



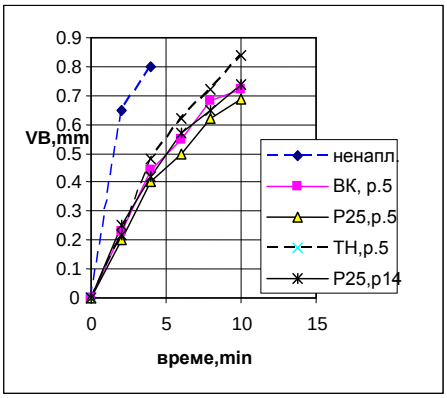
Фиг.5. Криви "време -износване" за инструменти с притрити покрития V=39,m/min, S_z = 0,2 mm/зъб, t =2mm



Фиг.6. Криви „време-износване" при ЕН с електроди ВК, Р25 и ТН, V =49 m/min, S_z = 0,2 mm/зъб, t =2mm

При режимите с ***Ee****> 0,3 J* обаче отново се установява тенденция към нарастване на износването. Това се дължи на термичното влияние на по-високата енергия и отгряването на тънките и остри режещи ръбове, поради невъзможност за отвеждане на по-голямото количество топлина. Увеличението на ***Ee*** до 0,3 J дава възможност не само за повишаване на

трайността на напластените инструменти до 2,5 – 3 пъти, но и за повишаване на производителността на процеса до 2mm^2/s.



Фиг.7. Криви „време-износване" при ЕН с електроди ВК, Р25 и ТН, V =49 m/min, S_z = 0,4 mm/зъб, t =2mm

Сравнението на износването на инструменти с покрития от електроди ВК, Р25 и ТН – фиг.6 и 7 показва, че по-ниско износване имат инструментите, напластени с Р25 и ВК. По-високото износване на напластените с ТН инструменти се дължи на промените, които *TiN* претърпява в процеса на преноса и получаването на видоизменени нитриди и карбонитриди от типа TiN_{1-x}, $TiCN_{1-x}$, които влошават износоустойчивостта му. По-здравата дифузионна връзка с основата в резултат на смесените интерметалоидни карбиди от типа: Fe_3W_3C и Me_xW_yC при напластяване с електродите на основа *WC* е предпоставка и за по-високата износоустойчивост на напластените инструменти.

Таблица 2.

№	Режим, електрод				Трайност Т, min		Трайност Т, min	
	I,A	Ti, μs	***τ***	НЕ	VB= 0,2mm	Повишение на Т, пъти	VB= 0,4mm	Повишение на Т, пъти
1	30	2	008	Р25	18	2	38	1,65
2	30	10	0,04	Р25	22	2,44	42	1,82
3	40	2	0,06	Р25	20	2,22	40	1,73
4	40	5	0,04	Р25	25	2,77	48	2,08
5	40	10	0,04	Р25	22	2,44	43	1,86
6	40	20	0,04	Р25	19	2,11	39	1,69
7	40	50	0,04	Р25	16	1,77	36	1,56
8	50	2	0,04	Р25	24	2,66	49	2,13
9	50	10	0,04	Р25	22	2,44	43	1,86
10	40	20/притриване	0,04	Р25	26	2,88	48	2,08
11	40	50/притриване	0,04	Р25	28	3,11	54	2,34
12	50	20/притриване	0,04	Р25	28	3,11	55	2,39
13	60	100/притриване	0,02	Р25	20	2,22	45	1,95
14		**ненапластени**			**9**	-	**23**	-
15*	40	5	0,04	ТН	8	2,28	19	1,72
16*	40	5	0,04	ВК	9	2,57	22	2
17*	40	5	0,04	Р25	11	3,14	25	2,27
18*	**Ненапластени***				3,5	-	11	-

От фигурите се установява, че ефекта от ***ЕН*** при по-тежкия режим на рязане –фиг.7. е по-висок, т.е. с увеличение на температурата и натоварванията, ефектът от ***ЕН*** се увеличава.

В Таблица 2 е дадена трайността на някои от напластените инструменти при критерии на износване *VB=0.2mm* и *VB=0.4mm*, *V=39m/min,Sz=0,2mm/зъб.*

Означените със „ * „ резултати са получени при *V49 mm/min* и *Sz0,2 mm/зъб*

От таблицата се вижда, че при всички случаи на ***ЕН*** трайността на инструментите в зависимост от избрания критерий на износване се увеличава 1,5 до 3 пъти, като по-висока степен на повишението на трайността е получена при критерий на износване 0,2 mm.

За изменението на износването по главната задна повърхнина *VB* във функция на времето в зависимост от коефициента на запълване на импулсите τ при двете двойки режими с номера

1 и 2 и 6 и 7 - Таблица1, се констатира, че по-ниските стойности на τ водят до по-малко износване. При режимите с по-висока енергия ***Ee*** **-** №6 и 7, износването има по-ниски стойности, а влиянието на τ при режими №1 и 2 е по-слабо изразено отколкото при режими 6 и 7. Това се обяснява с отгряването на подповърхностния слой, което е по-силно изразено при по-високите стойности на ***Ee*** и τ.

На базата на получените за износването данни за режима с най-ниско износване - №5 от Таблица1 е изведена скорост-трайностната зависимост за скоростен диапазон 39-49m/min, подаване *Sz – 0,2 и 0,4 mm/зъб* и критерии на износване *VB= 0,2 и 0,4 mm*. Стойностите на трайността при двете стойности на скоростта и подаването за съответните критерии на износване са определени от фиг.1-7. Получени са следните зависимости:

- за *Sz=0,2* и критерий на износване *VB=0,4mm* – $T= 2,3.10^5/V^{2,33}$, *min - (3)*
- за *Sz=0,4* и критерий на износване *VB=0,4mm* – $T= 4,9.10^{10}/V^{5,9}$, *min – (4)*

При използване на режим №5, или други със същата енергия, чрез горните зависимости може да бъде предварително определена трайността на напластените инструменти, или да бъде определена максималната скорост /производителност/ при зададена трайност.

За изследване влиянието на режима на рязане и грапавостта на нанесените покрития върху износването и трайността и получаване на обобщена скорост-трайностна зависимост: $T=C_t. V^x . S^y. Ra^z$ е проведен пълен факторен експеримент от вида №=2^4 . Сравняват се ненапластени и напластени инструменти с електрод Р25 и режими №1 и №11 / със съответна грапавост на покритията ***Ra****=1 и 1,4*μm с условни означения $\boldsymbol{Ra}_1$ и $\boldsymbol{Ra}_{2/}$ при нива на останалите фактори – *V=39 и 49m/min, Sz= 0,2 и 0,4* mm/зъб. Износването може да се представи като модел от вида: $VB= Ct.V^x.S^y.t^z.Ra^q.$ След съответната обработка на резултатите и проверките за значимост на коефициентите и адекватност [5], декодиране и антилогаритмуване, уравнението добива вида:

$VB= 4,9.10^{-6}.V^{2,57}.S_z^{0,7}.T^{0,77}.Ra^{-1,33}$ *,mm. – (5)*

От горното уравнение при критерий *VB=0,4mm* е получен модела на трайността –

$T= 2,4.10^6.V^{-3,33}.S_z^{-0,7}.Ra^{1,73}$, *min. - (6) .*

От уравнението се установява, че за изследвания диапазон при постоянен режим на рязане максимална трайност ще се получи при при максимално възможната стойност на грапавостта на нанесените покрития. При ЕН на инструменти с остри и тънки режещи ръбове, поради влошените условия за топлоотвеждане и опасност от отгряването им обаче следва да се използват режими с по-ниска енергия. Полученият модел позволява да се изчисли предварително трайността на напластените инструменти, а чрез заместване на ***Ra*** с изразите (1)и (2) дава възможности за едновременно оптимизиране на параметрите на режимите на рязане и напластяване.

ИЗВОДИ

1. Изследвано е влиянието на ***Ee*** и параметрите на режима за ***ЕН*** при използване на генератори с ***Ee*** до 2 J върху износването на напластените инструменти и е получено на над 3 пъти увеличение на трайността им спрямо ненапластените и 1.1 - 1.5 пъти в сравнение с тази , получена при ***ЕН*** с конвенционалните машини “Елфа”.

2. Грапавостта на нанесените покрития съществено влияе върху износването и трайността на инструментите. Получените резултати позволяват да се установи, че с увеличение на ***Ee*** – нараства степента на дисперсност и аморфност на покритието,а износването на напластените инструменти намалява до режимите, при които стойностите на ***Ra*** достигат до 1.3 – 1.4μm. По- нататъшното увеличение на ***I*** респ. на **Ti** и **I**/ води до нарастване на ***Ra*** и на износването VB. За получаване на по-малко износване следва да се подбират режими с възможната максимална енергия, но при стойности на грапавостта на получените покрития по-ниски от1,3-1,4 μm.

3. Грапавостта на покритията, получени при стойности на ***Ti>*** *10 µs и* ***I>*** *40 A* е непригодна за ***ЕН*** на металорежещи инструменти. Използването на тези по-дебели и по-износоустойчиви покрития е възможно единствено след допълнителна обработка – шлифоване, или притриване с цел намаляване стойностите на ***Ra***.

4. Последващата обработка след ***ЕН*** с цел намаляване на грапавостта на покритията позволява да се увеличи трайността на напластените инструменти с 5 до 15 min спрямо тази на непритритите такива.

5. Установено е, че при прекъснато рязане по-подходящи са твърдосплавни електроди от типа Р25 и ВК, при които се получава най-висока трайност на ***ЕН*** инструменти. Влиянието на ***Ee*** върху трайността е по-голямо от това на напластяващите електроди. Определени са и режимите за ***ЕН***, при които се получава максимално увеличение на трайността на напластените инструменти.

6. Получени са математико-статистически модели за грапавостта на нанесените покрития и трайността на напластените инструменти, които дават възможност за предварителен подбор на режимите за напластяване и получаване на максимална трайност за конкретните условия на рязане.

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ПРЕПОРЪЧИТЕЛНИ ОБЛАСТИ НА ИЗПОЛЗВАНЕ НА ЕЛЕКТРОИСКРОВОТО НАПЛАСТЯВАНЕ И ЕФЕКТИВНОСТ ОТ ПРИЛОЖЕНИЕТО МУ

Тодор ПЕНЯШКИ

SUGGESTED AREAS OF USE AND EFFICIENCY ELEKTROSPARKING LAMINATION OF ITS APPLICATION

Todor PENIASHKI

Abstract: *The present work shows the location/ the place/ of Eletrospark alloying among other methods of coating. Disclosed its technological capabilities, advantages and disadvantages compared with existing methods. An increase is of wear resistance of tools, machine parts and equipment plating by Electrospark alloying stratification. Indicated possible areas for its practical application, in which the method is the most beneficial, economically and technologically the most effective.*

Key Words: *electrospark alloying, the electrospark protection method, vibrating electrode, increasing to wear capability, increase for difference materials.*

Електроискровото напластяване/Е.Н./ е един от най-простите, евтини и ефективни физични методи, който се използва в различни отрасли на промишлеността за нанасяне на износоустойчиви покрития върху работната повърхност на различни детайли и инструменти.

Методът се основава на явлението електрическа ерозия в газова среда и се състои в насочено в пренасяне на материал от напластяващия електрод(анод) върху повърхността на напластяваното изделие(катод), под действието на електрически разряди. Получените покрития са със здрава дифузионна връзка с материала на основата, висока плътност, равномерност и добра повтаряемост на качествените характеристики, не деформират и не изменят геометричните параметри на обработвания детайл. Широките технологични възможности на метода са предпоставка за успешното му прилагане в най-различни области за повърхностна модификация и уякчаване на всякакви бързоизносващи се инструменти и детайли и електрически елементи от метални материали. Използването на този високоуниверсален и икономичен метод у нас обаче е необосновано ограничено и недостатъчно ефективно. Това е свързано главно с недоброто познаване на метода и възможностите му, на факторите способстващи за увеличението на износоустойчивостта, и липсата на технологична документация по използването му. Целта на настоящата работа е да се разкрият възможностите и универсалността на Е.Н., да се покажат предимствата и недостатъците му в сравнение със съществиващите методи, мястото му сред тях, да се представят възможните области за прилагането му, в които той е най-изгоден, икономически и технологично най-ефективен, и да се посочи ефекта от използването му.

ПРЕДИМСТВА И НЕДОСТАТЪЦИ НА ЕЛЕКТРОИСКРОВОТО НАПЛАСТЯВАНЕ

Основните предимства на Е.Н. в сравнение със съществуващите методи за нанасяне на износоустойчиви покрития са разкрити в [1,2,3,4,5,6,8,9,13,14,17] и се свеждат до следното:

- Възможност за локално формиране на покрития от всякакви и върху всякакви токопроводящи материали включително и многослойни покрития. Покритията може да се нанасят в зададени места без да се защитава останалата повърхност;
- Една от най-здравите връзки с материала на основата в сравнение с другите методи – на нивото на границата на якост на самия материал;
- Широкоуниверсална, максимално проста и достъпна технология, която не изисква предварително третиране на обработваната повърхност и може да се използва във всяко едно предприятие, което разполага, или не с термично и галванично оборудване;
- Просто, евтино, компактно, надеждно, мобилно и достъпно оборудване, позволяващо да се напластяват детайли на място – без демонтаж;
- Простота на експлоатацията и обслужването на оборудването – то е малогабаритно и ремонтопригодно, позволява всеки работник в рамките на 1-2 часа да се запознае и работи с него;
- Добра плътност, равномерност, сравнително ниска грапавост на нанесените покрития и повтаряемост на качествените им показатели;
- Слабо термично въздействие и отсъствие на нагряване и деформация на материала на напластяваното изделие. Тази възможност широко се използва при ремонтно-възстановителните работи;
- Възможност за пълна автоматизация на процеса на напластяване;
- Висока ефективност при малки разходи на материал и енергия –ниска енергоемкост при ръчните и механизирани процеси - 0,3 –5 kW
- Възможност за увеличение на повърхностната твърдост на стоманите до 20GPa, на титана – до 18, на медта – до 10 GPa.

Основен недостатък на метода е ниската производителност, която го прави по-малко пригоден за големи серии детайли в сравнение с PVD, електрохимичните и газопламъчните методи.

УСТАНОВКИ ЗА ЕЛЕКТРОИСКРОВО НАПЛАСТЯВАНЕ

В практиката са известни най-различни по вида си и начина на действие съоръжения и установки за ЕН [2,3,4,5,8,9,17], а в литературата се предлагат различни класификации , но най-пълна е предложената от Верхотуров и Муха [4], които разделят ЕН в зависимост от използваното оборудване, режимите за обработка, отличителните признаци на напластяващите електроди и междуелектродната среда. От началото на внедряване на метода в промишлеността най-голямо разпространение е получило напластяването с компактен електрод в газова среда (въздух), при което се използват главно ръчните преносими установки с вибрации на напластяващия електрод и механични контакти между анода и катода в процеса на напластяването и българските безконтактни механизирани и автоматизирани установки с поддържане на междуелектродно разстояние. Най-разпространените вибрационни установки са показани на фиг.1. От тях най-популярни са молдовските „Элитрон”, руските UR-121, ИНТАЛ, японските „Depositron”, германските и швейцарските “CARBIDOR” и “TUKADUR”, американските “Elektroarc”. Използваната в различните видове и модели установки енергия на импулса най-често е от 0.1 до 5 J, а дебелината на получените с тях покрития - 3 – 750 μm. Микротвердостта на повърхностния слой - 1200-2000 HV. В близкото минало у нас се използваха главно българските «Искропласт» , който дават възможност за получаване на покрития с дебелина 3- 60 μm В табл.1 са дадени основните технологични характеристики на някои от най-популярните установки.

Основен представител на безконтактнто Е.Н. е българският метод локално електроискрово напластяване, получил в близкото минало широко разпространение. Методът представлява качествено нова стъпка в развитието на ЕН и дава възможност за механизация и автоматизация на процеса, повишаване на производителността и подобряване на качествените показатели на покритията [6,7,8], което е причината за широкото му внедряване у нас и в чужбина . Възможността за механизация и автоматизация е намерила израз в доскоро произвежданите универсални машини “Елфа 541”, полуавтомати “Елфа 911” и “Елфа 921” и машините с ЦПУ “Елфа – 731 и“Елфа 741”. Дебелината и грапавостта на получените покрития могат да се изменят в граници съответно от 2 до 12 μm и Ra от 0,32 до 1,6 μm, като се варира с параметрите на

режима за ЕН и материала на напластяващия електрод. Принципната схема на метода му осигурява определени предимства [7,8,9,13], които му дават приоритет пред вибрационните методи за напластяване на всякакви инструменти и детайли с високи изисквания към качеството на работната повърхност.

Разполагайки с установените зависимости на качествените показатели от параметрите режима за ЕН[5,6,7,8,10] е възможно получаването на покрития с предварително зададени качествени характеристики. Трябва да се има в предвид, че ако е необходимо получаването на покритие от определен електроден материал с по-ниска грапавост, то дебелината му ще бъде също по-ниска и обратно, ако е необходимо покритие с по-голяма дебелина – грапавостта му ще бъде по-висока. На фиг.2 е показана микроструктурата на покритие, нанесено с твърдосплавен електрод върху въглеродна средно легирана стомана. Най-висока твърдост има повърхностният бял слой. Белият слой има неравновесна мартензит-аустенитна структура, наситена с дребнодисперсни видоизменени анодни карбиди. Полученият аустенит е легиран с елементи от анодния материал като количеството му и степента на легиране нарастват с увеличение на енргията за обработка. В дълбочина концентрацията на карбидите намалява, микротвъдостта също намалява до изравняването й с тази на основата. ЕН дава възможност за получаване на тънки, средни и дебели често се използват електроди К10 (ВК6М); Р25 (Т5К10); Р10 (Т15К6), а също и графит, релит, стелити, чисти и благородни метали и др. Безволфрамовите твърди сплави от типа ТН, ТНМ, КНТ, КХН, обезпечават покрития с по-ниски характеристики отколкото тези от първата група. Влиянието на материала на Н.Е. върху трайността трябва да се разглежда комплексно заедно с влиянието на енергията за обработка и условията на работа на напластеното изделие. Електроден материал, който при определени условия на експлоатация е най-ефективен, при други условия може да не доведе до същото повишение на трайността. По общото си предназначение електроискровите покрития могат да бъдат: за защита от химическа корозия причинена от агресивни течности или газови среди**,** за намаляване на износването, породено от триене и абразивно въздействие, за температурна защита на напластените изделия, за пободряване на електропроводимостта, за повишаване на химическата устойчивост, и като цяло - за повишаване на трайността и работоспособността на инструменти и детайли.











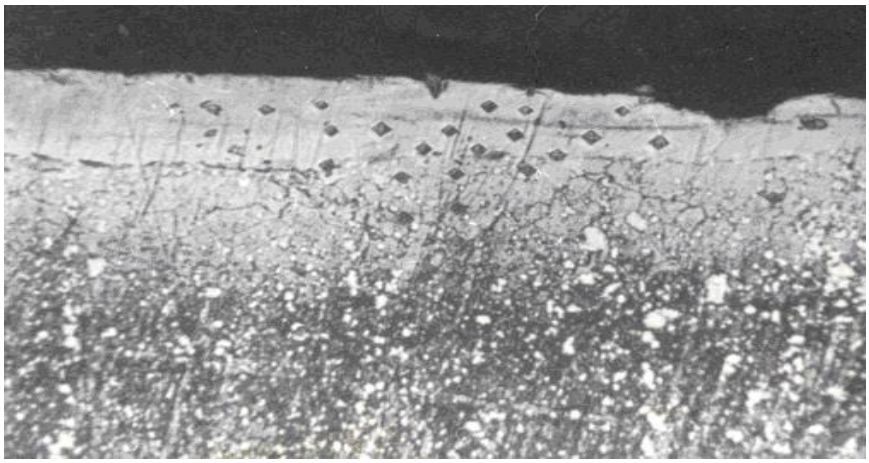
Рис. 4. Установки ЭИЛ

Фигура 1. Ръчни вибрационни установки за ЕН [10,14,17,Рекламни материали на ОАО-Пэлм, Интал.]

Fig. 1. AutoClean Installations for ESA

Модел	Мощност Вт/ кVA,	Грапавост на покритията-Ra, μm	Дебелина на покритията, μm
ИЛ100 - 2 С ултразвуков инструмент	120	-	5- 80
Элитрон-17	0,4 кVA	2,5 -8	10 - 50
Элитрон-21Б	0,25 кVA	1,2-6	5-30
Элитрон-22А	0,3 кVA	2,5 - 18	10-80
Элитрон -52Б	4,5 кVA	2,5 - 65	10 - 750
БИГ-1	0,45 кVA	2,5-30	10-150
БИГ-4	0,5 кVA	2,5-50	10-500
ИНТАЛ-3000	До10,5 кVA	-	10-600
DEPOSITRON	0,2 кVA	1,25- 6	10-30
UR-121	0,11 кVA	1,2 -6	5 -20
ИСКРОПЛАСТ	0,3 кVA	1,25 - 10	5 - 50
ЕЛФА	0,2 кVA	0,32 – 2	2-15

Таблица1. Технологични характеристики на вибрационните установки



Фиг.2 Структура на електроискрово покритие от твърдосплавен електрод върху въглеродна стомана

Fig. 2. Structure of electrospark coverage of hardmetal electrode on carbon steel *

ОСНОВНИ ОБЛАСТИ НА ИЗПОЛЗВАНЕ НА ЕН И ПОЛУЧЕНИ РЕЗУЛТАТИ

Чрез Е.Н. могат да се изменят и модифицират в зададено направление физико-химическите и геометрически характеристики на повърхностния слой за придаване на определени свойства – повишение на износоустойчивостта, повишение, или намаление на твърдостта и коефициента на триене, повишение на якостта на умора, на корозионната устойчивост, температуроустойчивостта, намаляване съпротивлението на електрически контакти, възстановяване на размерите на износени изделия и др. Качеството на нанесените покрития и универсалността на технологията обуславят широкото приложение на метода за нанасяне на покрития с различно предназначение в различии отрасли на промишлеността: металообработване и машиностроене, електроника и електротехника, дървообработваща, мебелна, целулознохартиена, стъклена, хранителна, лека и химическа промишлености и много други. Конкретните предназначения на ЕН покритията са за:

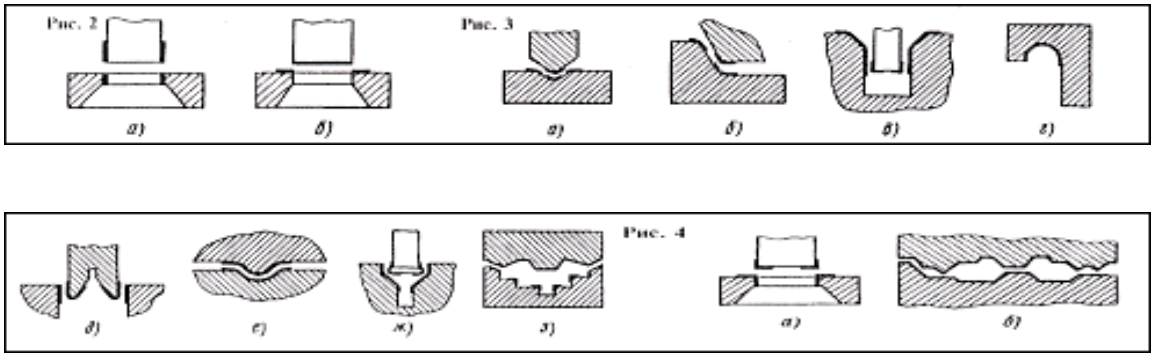
- ***Повишаване на трайността на инструменти***

Една изключително широка област на приложение на метода ЕН е за повишаване на износоустойчивостта на различни по вид и предназначение инструменти, изработени от инструментални стомани. Предположенията, че широкото използване на ЕН ще доведе трайността на инструментите до нивото на твърдите сплави не се сбъднаха. Поради по-ниската си износоустойчивост и производителност методът не може да се конкурира с PVD методите и затова мястото му е основно в машиностроителните и ремонтни организации, потребители на инструменти, където Е.Н. може да се използва за инструменти с различно предназначение.

Трайността на инструментите и детайлите напластени по метода ЕН, се увеличава средно от 1,5 до 3,5 пъти и зависи от качествените показатели, състава и структурата на покритията, технологичната схема за нанасянето им, условията за експлоатация, вида размерите и геометричните им параметри.

-Металорежещи инструменти Методът е приложим не за серийно и масово производство с използване на големи количества универсални металорежещи инструменти, повечето от които излизат с покрития направо от производителите, а за отделни специализирани такива, работещи при тежки условия на рязане, или при труднообработваеми материали /например твърди стомани и чугуни, закалени стомани, обработване на повърхности след заваряване и др./ – Това са: свредла, метчици, зъбодълбачни колела, зъбонарезни ножове, комбинирани свредла, двуперести фрези и зенкери, челни и канални фрези, профилни фрези и ножове главно за груба и получиста обработки с ударни натоварвания. Ножове с различна конфигурация и предназначение, циркуляри, отрезни ленти, ножове за абканти и гилотини и др., чиято трайност по данни на потребителите се увеличава 1,3-3 пъти.

- Щанцови и щампови инструменти Особено ефективно се явява напластяването на щампи,огъващи, изтеглящи отсичащи, комбинирани щанци, матрици, пресформи и леярски форми, в това число и оборудване за пресоването на пластмасови, гумени и праховометалургични изделия, щампи за гореща обработка – протегляне, изтегляне, огъване, пресоване и др. Тези инструменти се изработват главно от хромови инструментални стомани.



Фиг. 3.[10,14,15] – Схеми за ЕН на щанцови и формообразуващи инструменти
Fig. 3. [10,14,15] Electrospark stratification - schemes of stamping shape forming tools

Нанасянето на твърдосплавни покрития на основа WC върху тези стомани води до подобряване на работните им свойства и увеличаване на трайността им 1,5 до 3 и повече пъти. Покритията се нанасят локално само на работните ръбове на инструментите - фиг.3, по предната, задната или предната и задна повърхнини в зависимост от вида на инструмента и условията на експлоатация, като след презаточване, напластяването може да се осъществи отново. Целесъобразно и икономически изгодно се явява нанасянето на покрития и върху работната част на инструменти за горещо щамповане, на поансони и матрици–Фиг3а,б, трайността на които се увеличава 2-6 пъти[10] и формообразуващи инструменти, при които се напластява цялата работна повърхност – фиг.3., а ресурса им нараства до 10 пъти[10,11,14,15,]. Положителен ефект от ЕН на щампи може да се получи и с графитен напластяващ електрод, с който се получават покрития с най-ниска грапавост.

- Леярски, валцуващи и изтеглачни инструменти – валцуващи ролки за кръгли и профилни изделия от от мед, стомана , алуминий, дюзи за екструзия, и др, трайността на които се увеличава 1,5 до 3 пъти.

- Дървообработващи инструменти Електроискровото напластяване позволява да се повиши трайността на всякакви дървообработващи инструменти – профилни фрези, ножове,свредла, за раздробяване на дървесина, за рязане на хартия, триони и верижни триони, дискови ножове, циркуляри и други от три до 8 пъти [14,17]

- Инструменти за селскостопански машини и техника – ножове за рязане на растителни суровини и за косене, инструменти за рязане и раздробяване на растителни стъбла, за издребняване на зърно, лекарствени растения, фураж, работни органи на машини за различни обработки на почвата /лемежи, длета, накладки и др./, чиято трайност нараства 1,5 - 3,5 пъти.

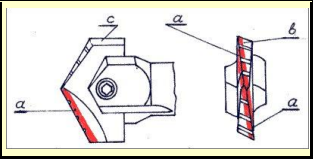
- Инструменти за хранителновкусовата и леката промишленост – обкатяващи, захващащи и водещи ролки в консервната промишленост, фингери и ютии за подаване и нагнетяване на тютюневата смес, формовъчни ролки за стъклената промишленост, инструменти за рязане на хартия, картони и течно стъкло, литейни форми за стъклени изделия, форми за обувната промишленост, форми, ножове всякакви: за опаковки, дозаторни, обкатяващи, обрезни и отрезни, матрици и пуансони, издребнители, раздробители, ударни и изправящи и навиващи устройства, захватни устройства.

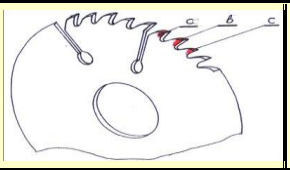
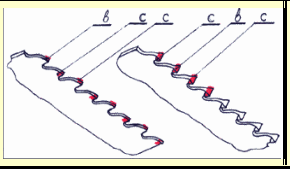
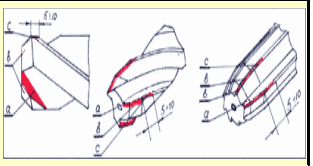
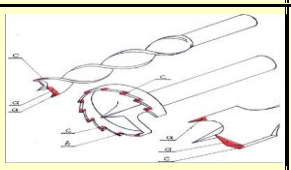
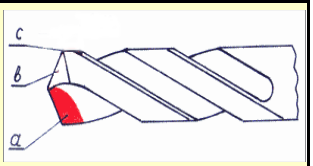
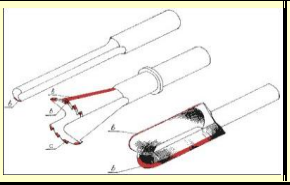
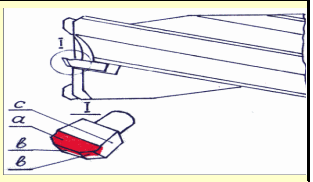
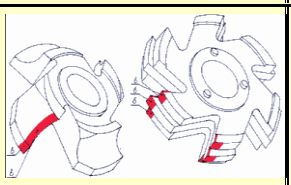
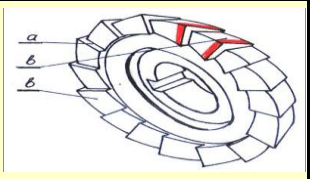
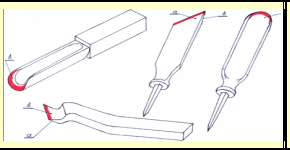
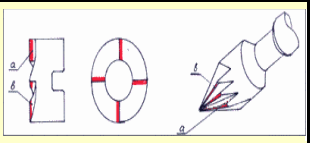
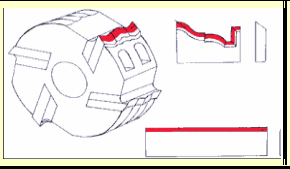
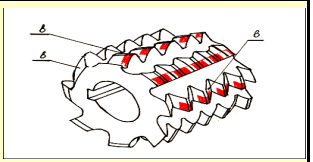
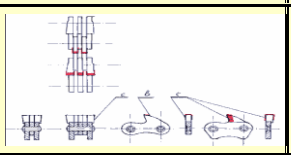
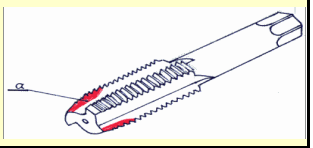
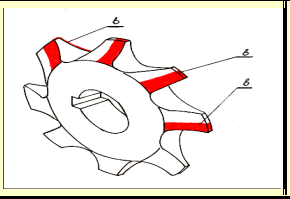
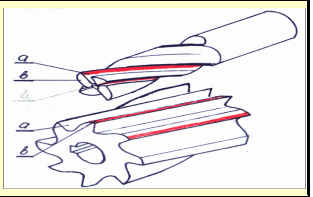
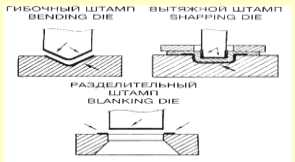
В Таблица 2 е дадено повишението на трайността и схемите за нанасяне на покритията на метало- и дървообработващи инструменти. Таблицата е съставена по данни от [2,3,4 ,5,7,9,10,11,12,13,14,15,16,17]

- ***Повишаване на трайността и работоспособността на бързоизносващи се детайли.***

-Детайли от различни машини с двигатели с вътрешно горене – трактори и автомобили, компресори, селскостопански, пътностроителни, железопътни и други машини– мотовилки, клапани, гърбици, шийки и лостове на разпределителните валове, колелата на синхронизатори на скоростни кутии,предварително напластяване, или възстановяване на износени шийки на колянови валове и много други, валове на помпи и вентилатори, бутални пръстени,превключващи вилки и лостове, детайли от газоразпределинелни механизми и горивни помпи, трансмисионни валове и оси, бутални пръти и плунжери от хидросистемите, и др.

Таблица 2. Трайност и схеми за напластяване на инструменти
Table 2. Durability and schemes for stratification of tools

Инструмент дървообработващи/металорежещи	**Повишаване на трайността, пъти.**		
		Дървообработващи инструменти	**Металорежещи инструменти,**
/Двуперести инструменти	/1,5-2,5		

Циркуляри – всички видове и изпълнения	**3 /2**		
Режещи гребени /Зенкери и райбери	**3 /1,3-3, 5**		
Свредла – всички видове и изпълнения	**1,5-3/ 1,5-3**		
Фрези палцеви	**3/ до2,5**		
Фрези профилни/ Фрези канални	**3/ 2**		
Ножове профилни, фуговъчни/ зенковки, цековки	**3/ 1,3-2,5**		
Фрезови глави – цели и съставни/червячни фрези	**3/ 2**		
Режещи вериги/Метчици	**3/ 1,5-3,5**		
/Фрези, всички видове и изпълнения	**/1,3-2,5**		
Инструменти за селскосто пански машини и техника	**1,5-3,5**		
Валцуващи и водещи ролки за меден валцдрат	**1,3-1,8**		
/Щанци и Щампи всякакви видове и изпълнения	**1,3-3**		

-Увеличение на износоустойчивостта на триещи се повърхности на работните органи на металообработващи, селскостопански, строителни, подемни, транспортни машини, апарати и други изделия с различно предназначение:

--в машиностроенето: шийки на валове на машини, помпи, ротори, леещи и валцуващи машини, скоростни кутии и редуктори и много други; лагерни гнезда, шпонкови и шлицеви канали , колела, втулки, лостове, гърбични и храпови механизми, лагерни шийки ; лагерни гнезда на капаци от ел. двигатели, корпуси; лопатки от работни колела, работни повърхнини от лагерни шийки на валове и оси; детайли от скоростни кутии; направляващи и центри на стругове, калибри, стъпкови и подаващи механизми, шнекове.



Фиг.4. Е.Н. на дегайли от двигатели с вътрешно горене
Fig.4. Elektrospark alloying details of internal combustion engines

-- в строителството, минното дело, нефтената промишленост – работни органи на подемни механизми, детайли от нефто пренасящото оборудване, от транспортьори за насипни материали, машини за смесване, раздробяване и смилане, ролки от ролгангове и др.

-- лека , химическа промишленост и битова техника - детайли от намотаващи, тъкачни и предачни машини, транспортьори, дюзи, дорници, направляващи и водещи втулки и ролки, дозиращи механизми и ротационни работни елементи на помпи, работни повърхнини от транспортиращи шнекове, лопатки на компресорни машини и помпи, повърхности под уплътнителни и механични уплътнители, стержени за шибърни кранове – различна номенклатура, бутални пръти за компресори, , кожуси на термодвойки, машини за смесване, раздробяване и смилане, детайли от автоклави и много други.

--в електротехническа промишленост – вентилационни лопатки на турбогенератори, шийки на валове и ротори, лагерни гнезда на капаци от ел. двигатели, челни уплътнения за електрически

машини, ролки за телоподаващи устройства, сопла на заваръчни установки, и др.

- ***Възстановяване на формата и размерите на износени детайли и инструменти***

Възможността за нанасяне на здраво свързано с основата покритие без нагряване широко се използва при ремонтно-възстановителните операции. Възстановяването на износени детайли се явява енерго- и ресурсоспестяващ процес. Методът се използва за възстановяване на формата и размерите на износени инструменти и детайли – щанци, щампи, направляващи, колонки, втулки, шийки на валове, плоски изделия със сложна геометрична форма, ротационни триещи се повърхности, плъзгащи лагери, шийките на колесни двойки, клапани с износени фаски и стержени, вилки, полуоси, лопатки на турбини, гърбични и храпови механизми, колянови и разпределителни валове и др. в границите на дебелината на отложения слой. Независимо от различните цели при уякчаването и при възстановяването на размерите, и в двата случая налице е значително увеличение на трайността. В подхода към двата случая няма принципни разлики, освен дебелината на нанесеното покритие.

- ***Нанасяне на токопроводящи покрития***

Общ недостатък на използуваните в съвременната контактна техника методи е значителния разход на благородни метали и техни сплави. С прилагането на ЕН се намалява рязко разходът на тези материали като се заместват плакирането, нитоването или галваничното покриване на контактните площи с покриване само на работната контактна повърхност. Заедно с високото качество, здравата връзка с основния материал, гаранцията за най-икономично изразходване на благородни метали и сплави методът обезпечава висока износоустойчивост и ниско електрическо съпротивление. При това разходите на сребро и злато за различните контактни изделия намаляват от 10 до 150 пъти. С нанасянето на токопроводящи покрития върху изделия с различно предназначение /контактни пера, комутатори, контактни пластини, захвати за

тролеен, влаков проводник и др./ се постига двоен ефект – икономия на благородни метали и повишение на износоустойчивостта в сравнение с галваничните методи.

- ***Други области на използване***

-Запълване на микропори и други повърхностни дефекти на различни детайли и изделия;
-Получаване на декоративни повърхности /шагрен, пчелна клетка и др./ на пресформи и леярски форми за гума и пластмаси;
-Надписване и маркировка на детайли от закалени стомани и други твърди и труднообработваеми материали;
-Нанасяне на различни материали за подобрение на адхезията;
-Увеличение на коефициента на триене, чрез увеличение на грапавостта на повърхностите.

- ***Примери за използване***

Областите за използване на метода са многобройни и многообразни. По-нататък се прилагат няколко примера от различни области, за да се добие представа за размера на икономически ефект от приложението на ЕН. В [10,11,12,13,14,15,16,17] е даден годишния икономически ефект от приложението на метода, който за различни инструменти и детайли е в граници от 50-150 хил.лв.– например за детайли за тютюневата промишленост в завод „Ю.Гагарин" – 48 хил. лв., за специализирани инструменти за производство на зъбни колела в завод „Искър"-55 хил.лв. При ЕН на пресформа за твърдосплавни цилиндрични заготовки, трайността и се увеличава 1,8 пъти. Годишният брой на използваните пресформи след ЕН намалява на 3, с което само от този вид инструмент заводът реализира икономически ефект от 10840лв.[13]. В таблица 3,[11] са дадени резултатите за трайността на щанци в завода за електронни и полупроводникови елементи – София, от които се вижда, че Е.Н. увеличава трайността на щанците 1,4-3,5 пъти. Това води до икономии на инструменти, енергия, труд и материали за монтаж, демонтаж и ремонт и презаточване на щанцата и по- висока производителност в резултат на намаляване на броя на престоите. Общият годишен брой на презаточванията на горните щанци е бил 140, а след Е.Н. презаточванията намаляват до 79. Цената на еднократно напластяване на горните 6 броя щанци е била 14,88 лв. Годишният икономически ефект от внедряването на метода за горните щанци по данни на завода е бил над 66 хиляди лева, при натоварване на машината „Елфа 541" само 21 работни дни. Това показва, че полученият ефект е само една малка част от този, който би се получил при пълно натоварване на машината.

В Салдинския металургичен завод – Русия - от 1980г. до сега се извършва Е.Н. на матрици за прошиване на отвори в релсовите подложки. Матриците и поансоните се напластяват само по
челните повърхности, при което трайността им се е увеличава 1,4-2 пъти. [16].

Възстановяването на пресови сглобки на голямогабаритни детайли - валове с диаметри 220, 700 и 900 мм, се прилага от 1990г. във Серовския феросплавен завод и води до 2 пъти увеличение на трайността им. От 2008г в комбинат «Магнезит», «Богословское рудоуправление», са възстановени шийките на четири вала на фирма "Sandvik" с диаметър 710 мм., които още не са се износили. [12,16]. Икономическият ефект от приложението на метода се определя от: повишението на трайността и надеждността на изделията и намаляването на количеството инструменти /детайли/, необходими заизпълнение на определена производствена програма, намаляване на загубите за изработване /закупуване / на резервни части, увеличение на продукцията в резултат на намаляването на престоите и разходите за смяна и ремонт на износените изделия, възможност за работа с по-производителни режими при по-висока или еднаква трайност с тази на неналластените изделия, повишаване на качеството и количеството на произведената продукция.

Общата цена на ЕН е значително по-ниска в сравнение с тази при използване на другите методи за нанасяне на покрития. Единствено при електрохимичните и PVD методите цената на напластяването е по-ниска в случай, че се напластяват едновременно големи количества /десетки и стотици броя/ от едно и също изделие.

Ниските разходи за напластяването, простотата и достъпността на технологията и обслужването, екологичната чистота и универсалността на оборудването, възможността за локално нанасяне на покритието позволяват да се решат цял комплекс въпроси от производствените и ремонтно-възстановителни дейности на предприятията от повечето производствени области.

Таблица 3. Трайност на щанци след електроискрово напластяване
Table3. Durability of electrospark hardenes dies after Plating

Щанца, материал	Щанцуван материал, дебелина	Критерий за износване	Режим,-енергия на единичния импулс,J	Напластяващ електрод	Брой удари.10^3 преди ЕН	Брой удари.10^3 след ЕН	Повишение на трайността, пъти
Щанца за изтегляне, Х12	Алпака, 0,3мм	Чеплък, 0,05мм	10^{-4}	Р25	10	14	1,4
			10^{-3}	Р25		15	1,5
			10^{-2}	Р25		21	2,1
			10^{-4}	ВК6М		15	1,5
			10^{-3}	ВК6М		16	1,6
Щанца комбинирана, Х12	Покалаена ламарина, 0,25мм	Чеплък, 0,04мм	10^{-4}	Р25	200	600	3
			10^{-3}			800	4
			10^{-2}			700	3,5
Щанца за изрязване, Х12М	Алпака, 0,35мм	Чеплък, 0,1мм	10^{-4}	Р25	250	430	1,7
			10^{-3}			580	2,2
			10^{-2}			500	2
Щанца за изрязване, Р18	Ст.65Г, 0,15мм	Чеплък, 0,04мм	10^{-3}	Р25	120	380	3,2
			10^{-2}			340	2,8
			10^{-3}	ВК6М		360	3
Щанца комбинирана, Х12	Алуминиево многопластово фолио	Чеплък, 0,04мм	10^{-4}	Р25	110	196	1,8
			10^{-3}			245	2,5
			10^{-2}			260	2,7
			10^{-3}	ВК6М		220	2
			10^{-2}			246	2,5

Щанца за изрязване на изолационни подложки, Х12	Прешпан, 0,1мм	Чеплък, 0,04мм	10^{-4}	Р25	500	900	1,8
			10^{-3}			800	1,7
			10^{-2}			800	1,7
			10^{-3}	ВК6М		800	1,7
			10^{-2}			800	1,7

Този метод може да бъде полезен и ефективен в условията на всяко промишлено предприятие, тъй като е най-лекият, прост и универсален метод за локално нанасяне на износоустойчиви покрития с високи експлоатационни свойства, даващ възможност без особени технически усилия да се решат и най-сложните проблеми по повишаването на трайността на всякакви детайли и инструменти. Внедряването му позволява значително да се намалят разходите за производство и обслужване на оборудването, да се повиши качеството и количеството на произведената продукция.

ИЗВОДИ

1. Показани са технологичните възможности на електроискровото напластяване, предимстватаи недостатъците на метода и оборудването и е определено мястото му сред другите съществуващи подобни методи и областите на приложението му в индустрията.
2. Представени са качествените характеристики, свойствата и предназначението на ЕН покрития, нанесени чрез най-разпространените установки и и закономерностите при формирането им.
3. Посочени са препоръчителните области на използване на метода и оборудването и резултатите за различни конкретни случаи на приложение.
4.Въз основа на икономическия ефект са посочени ползите от приложението на метода за всяко промишлено предприятие.

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INFLUENCE OF CBN NANOSIZED ADDITIVES ON THE DUCTILE CAST IRON MICROSTRUCTURE AND WEAR RESISTANCE

Julieta KALEICHEVA

Abstract: *The microstructure, hardness and wear resistance of ductile cast irons with nanosized cubic boron nitride cBN additives are investigated. The metallographic analysis by means of an optical metallographic microscope and hardness testing by the Brinnel Method are performed. The wear in friction conditions of a fixed abrasive is examined. The nanosized additives influence on the cast iron microstructure, hardness and tribological properties is studied.*
Keywords*: nano modifiers, ductile cast irons, hardness, wear resistance, microstructure.*

ВЛИЯНИЕ НА НАНОРАЗМЕРНИ ДОБАВКИ ОТ CBN ВЪРХУ МИКРОСТРУКТУРАТА И ИЗНОСОУСТОЙЧИВОСТТА НА ЛЯТИ СФЕРОГРАФИТНИ ЧУГУНИ

Жулиета КАЛЕЙЧЕВА

Резюме: *Изследвана е микроструктурата, твърдостта и износоустойчивостта на леяти сферографитни чугуни, съдържащи наноразмерни добавки от кубичен боров нитрид cBN. Проведен е металографски анализ с оптичен металографски микроскоп GX41 OLIMPUS и изпитване на твърдост по метода на Бринел. Проведено е експериментално изследване на износването при триене по закрепен абразив. Изучено е влиянието на наноразмерните добавки върху микроструктурата, твърдостта и трибологичните свойства на чугуните.*
Ключови думи: *наномодификатори, леяти сферографитни чугуни, твърдост, износоустойчивост, микроструктура*

1. ВЪВЕДЕНИЕ

Сферографитният чугун е конструкционен материал, който се характеризира с висока якост, жилавост и износоустойчивост. Широкото му използване в машиностроенето е свързано с уникалното съчетание на физико-механични и леярски свойства, превъзхождащи свойствата на легираните и модифицирани сиви и ковки чугуни , а така също и на много стомани. Графитът, присъстващ в чугуна, обезпечава съпротивление срещу механично износване и подобрява неговата обработваемост. Наноразмерни частици, добавени в стопилката на чугуните в малки количества, могат да увеличат количеството на графита и да променят неговата морфология. Този ефект, в съчетание с промените в структурата на металната основа, постигнати чрез термична обработка, повишават износоустойчивостта на чугуните [1-4].

Целта на този доклад е да се изследват микроструктурата, твърдостта и износоустойчивостта на образци от лят сферографитен чугун, съдържащи наноразмерни добавки от кубичен боров нитрид *cBN.*

2. МАТЕРИАЛ И МЕТОДИКИ НА ИЗСЛЕДВАНЕ

Изследвани са образци от два състава лят сферографитен чугун, съдържащи наноразмерни частици от кубичен боров нитрид *cBN* (табл. 1). Химичният състав на сферографитните чугуни е следния:
Състав 1 - Fe-3,55C-2,67Si-0,31Mn-0,009S-0,027P-0,040Cu-0,025Cr-0,08Ni-0,06Mg wt%.
Състав 2 – Fe-3,54C-2,47Si-0,66Mn-0,02S-0,03P-0,04Cu-0,02Cr-0,08Ni-0,048Mg wt%.

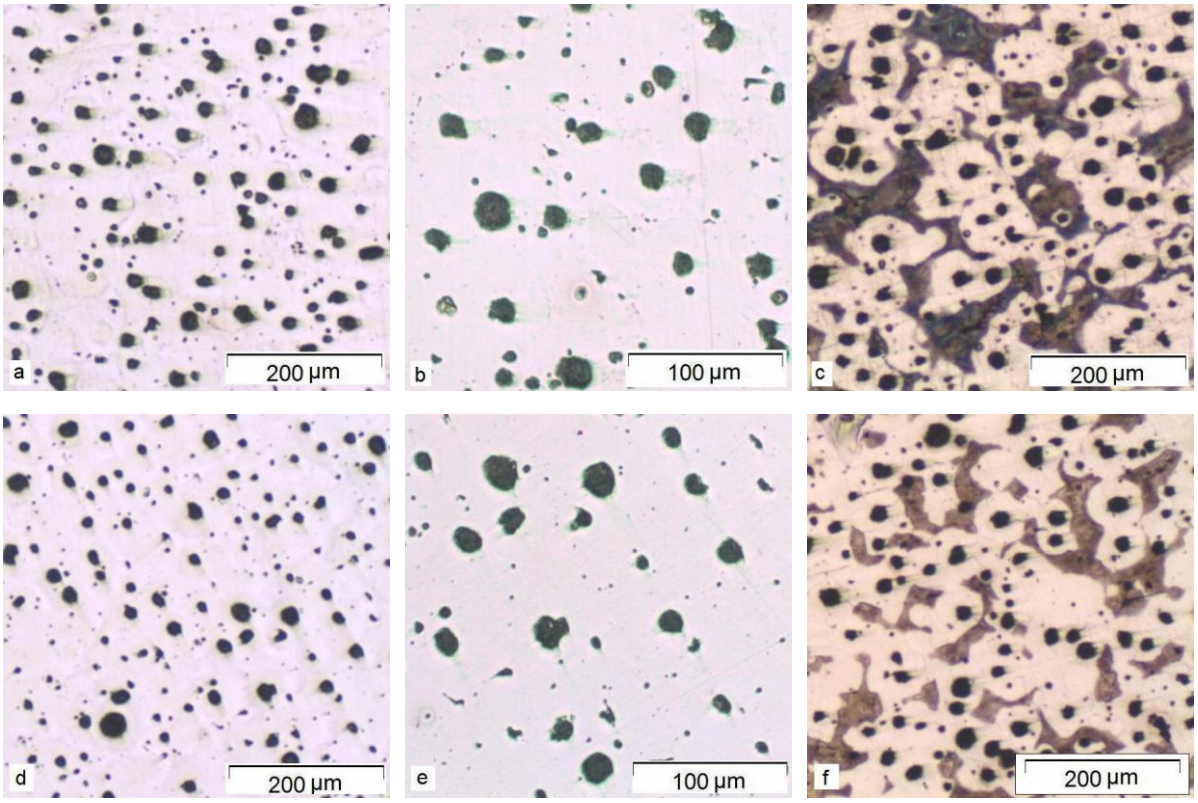
Таблица 1. Наномодификатори, твърдост HB, трибологични свойства.

№ на обра -зеца	Нано модифи-катор	Твърдост HB	Масово износване m [mg]	Скорост на износване dm/dt [mg/min]	*Интензивност на износване i*	Износо-устойчивост *I*
1	-	185	32	2,72	$0{,}124.10^{-6}$	$8{,}06.10^{6}$
2	*cBN*	170	17	1,45	$0{,}066.10^{-6}$	$15{,}15.10^{6}$
3	-	203	29,6	2,52	$0{,}114.10^{-6}$	$8{,}77.10^{6}$
4	*cBN*	190	16,4	1,39	$0{,}063.10^{-6}$	$15{,}87.10^{6}$

Преди да бъдат добавени в стопилката, наноразмерните частици са покрити с никел по метод за отлагане на безтоково никелово покритие ЕФТТОМ – НИКЕЛ [5]. Покритие от никел, желязо и др. [6,7]. върху наноразмерните частици позволява тяхното омокряне в стопилката и по-равномерното им разпределение в обема на отливката.

Изследвана е микроструктурата на образци от два състава ляти сферографитни чугуни с оптичен металографски микроскоп GX41 OLIMPUS. Образците са проявени с реактив: 2% разтвор на азотна киселина в етилов спирт. Проведено е изпитване на твърдост по метода на Бринел.

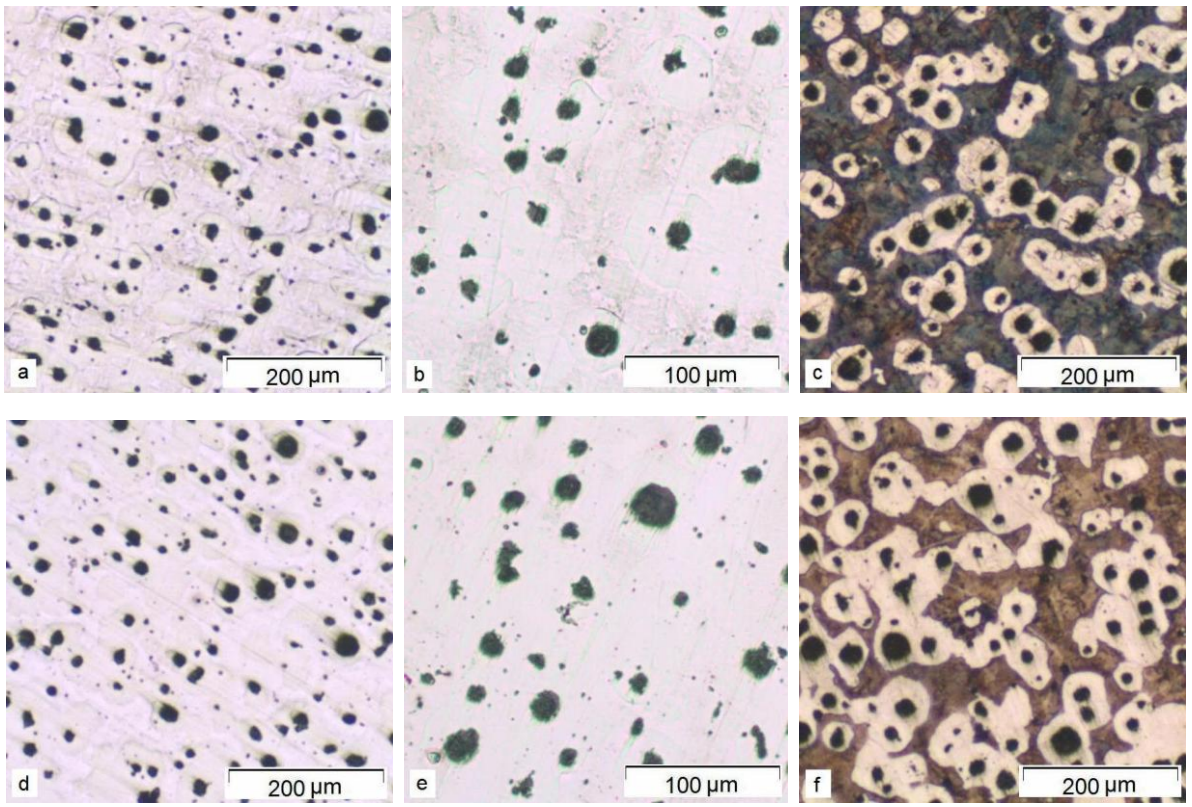
Проведено е експериментално изследване на износването на образци от изотермично закален сферографитен чугун по методика и с устройство за ускорени изпитания по кинематичната схема „палец - диск" при триене по закрепен абразив [3].



Фиг. 1. Микроструктура на непроявени (a,b,d,e) и проявени с 2% р-р на HNO_3 в етилов спирт (c,f) образци от лят сферографитен чугун (състав 1) без и с наномодифика-тори:a÷c-без наномодификатор(образец №1);d÷f-с наномодификатор cBN(образец №2)

3. Експериментални резултати и Анализ

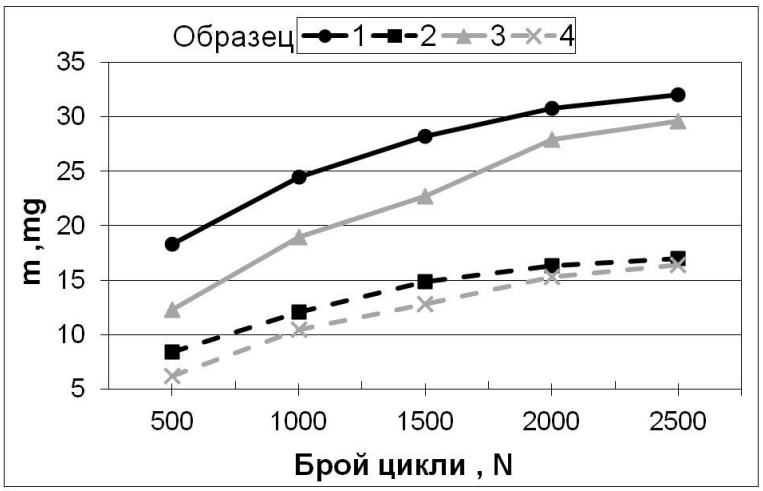
Структурата на изследваните чугуни в лято състояние се състои от ферит, перлит и графит (фиг.1 и 2). Наноразмерните добавки не променят формата на графита, наблюдава се известно увеличаване на количеството графитна фаза в чугуна от състав 2 (фиг. 2). Количеството на



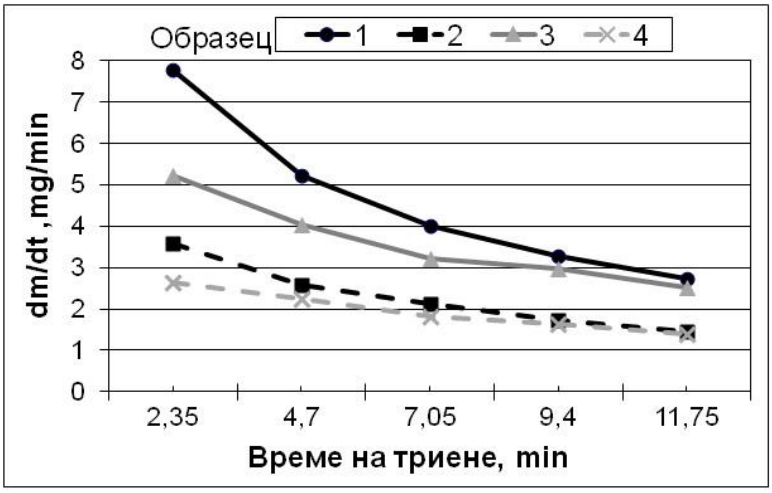
Фиг. 2. Микроструктура на непроявени (a,b,d,e) и проявени с 2% р-р на HNO_3 в етилов спирт (c,f) образци от лят сферографитен чугун (състав 2) без и с наномодификатори:a÷c-без наномодификатор(образец №3); d÷f-с наномодификатор cBN(образец №4)

Таблица 2. Експериментални резултати за масовото износване m, скоростта на износване dm/dt, интензивността на износване i и износоустойчивостта I.

Път на триене, *S* [m]		140	280	420	560	659
Брой цикли , *N*		500	1000	1500	2000	2500
Време ,t [min]		2,35	4,7	7,05	9,4	11,75
Масово износване, m [mg]	образец 1	18,3	24,5	28,2	30,8	32
	образец 2	8,4	12,1	14,9	16,3	17
	образец 3	12,3	19	22,7	27,9	29,6
	образец 4	6,2	10,5	12,8	15,3	16,4
Скорост на износване, dm/dt [mg/min]	образец 1	7,79	5,21	4	3,28	2,72
	образец 2	3,57	2,57	2,11	1,73	1,45
	образец 3	5,23	4,04	3,22	2,97	2,52
	образец 4	2,64	2,23	1,81	1,63	1,39
Интензивност на износване, *i*	образец 1	$0,071.10^{-6}$	$0,095.10^{-6}$	$0,109.10^{-6}$	$0,119.10^{-6}$	$0,124.10^{-6}$
	образец 2	$0,014.10^{-6}$	$0,047.10^{-6}$	$0,058.10^{-6}$	$0,063.10^{-6}$	$0,066.10^{-6}$
	образец 3	$0,048.10^{-6}$	$0,073.10^{-6}$	$0,088.10^{-6}$	$0,108.10^{-6}$	$0,114.10^{-6}$
	образец 4	$0,024.10^{-6}$	$0,041.10^{-6}$	$0,05.10^{-6}$	$0,059.10^{-6}$	$0,063.10^{-6}$
Износо-устойчивост, *I*	образец1	$14,08.10^{6}$	$10,53.10^{6}$	$9,17.10^{6}$	$8,4.10^{6}$	$8,06.10^{6}$
	образец 2	$71,43.10^{6}$	$21,28.10^{6}$	$17,24.10^{6}$	$15,87.10^{6}$	$15,15.10^{6}$
	образец 3	$20,8.10^{6}$	$13,7.10^{6}$	$11,36.10^{6}$	$9,26.10^{6}$	$8,77.10^{6}$
	образец 4	$41,67.10^{6}$	$24,39.10^{6}$	20.10^{6}	$16,95.10^{6}$	$15,87.10^{6}$



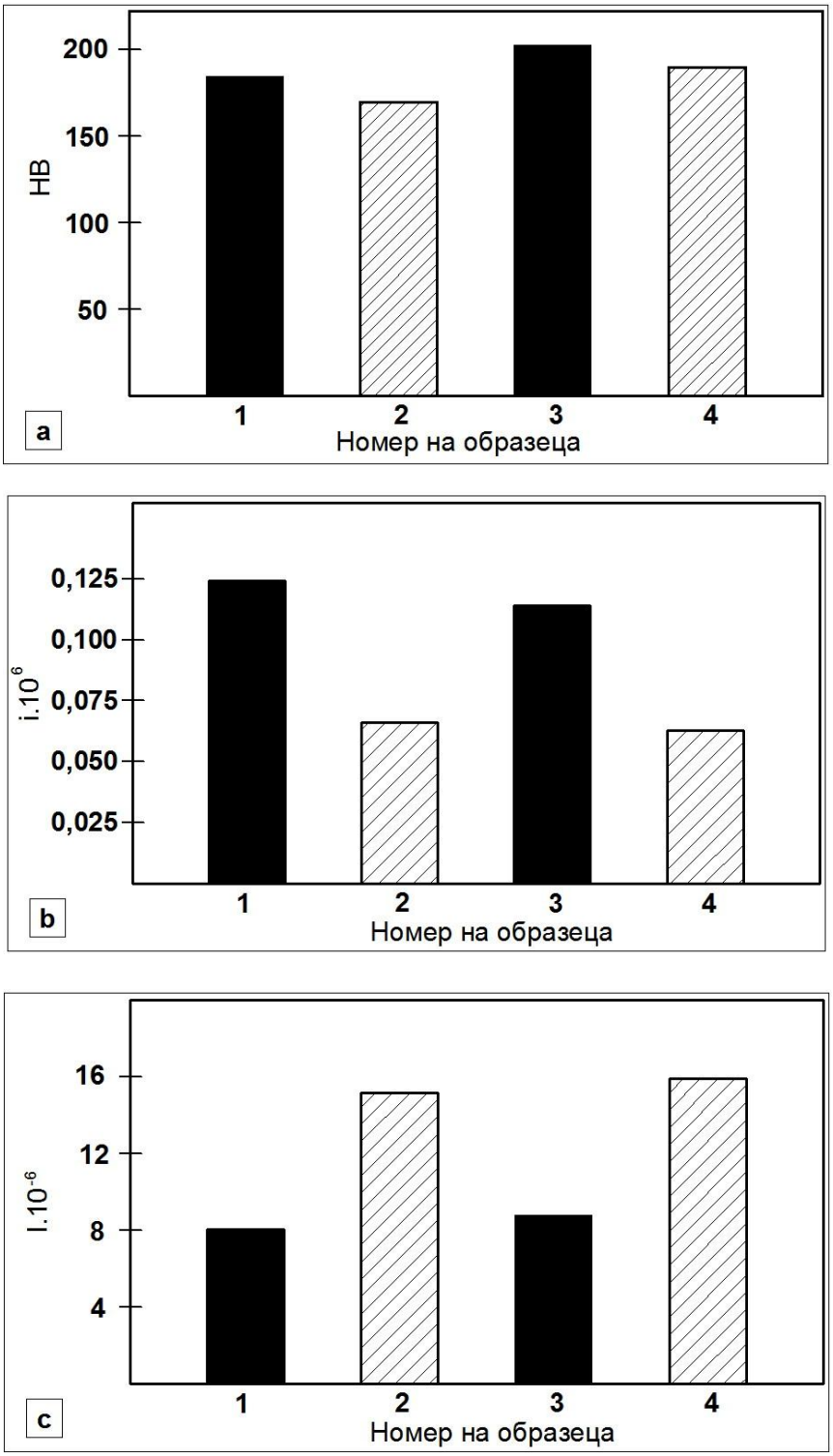
Фиг. 3. Зависимост на масовото износване m от броя цикли N.



Фиг. 4. Зависимост на скоростта на износване dm/dt от времето на триене .

перлита в структурата на чугуните от състав 2 (фиг. 2 c,f) е по-голямо от това на чугуните от състав 1 (фиг. 1 c,f). Това е свързано с по-голямото количество манган в чугуна от състав 2 (0,66 %) в сравнение с това в състав 1 (0,31 %). В чугуните с наноразмерни добавки от кубичен боров нитрид *cBN* количеството на ферита в структурата е по-голямо от това в чугуните без нанодобавки (фиг.1 f и фиг.2 f в сравнение с фиг.1 c и фиг.2c). Съвместното влияние на мангана и наномодификатора изменят количественото съотношение между структурни елементи с различна твърдост (перлит, ферит, графит), което влияе върху общата твърдост на изследваните чугуни(табл.1; фиг. 5 a).

Получени са експериментални резултати за масовото износване m, скоростта на износването dm/dt, абсолютната интензивност на износване i и абсолютната износоустойчивост I на образците и тяхното изменение във времето на контактно взаимодействие (табл. 2). Представените трибологични свойства в табл. 1 са за един и същи път на триене $S = 659\,[m]$.На фиг. 3 са изобразени графично зависимостта на масовото износване m от броя цикли N (пътя на триене), а на фиг. 4 зависимостта на скоростта на масовото износване dm/dt от времето на триене *t*. На фиг. 5 са представени таболограми на твърдостта *HB* (a), интензивността на износване *i* (b) и износоустойчивостта *I* (c) на образци от лят сферографитен чугун без (обр. 1, 3) и с наноразмерни добавки от кубичен боров нитрид *cBN* (обр. 2, 4).



Фиг. 5. Твърдост HB (a), интензивност на износване i (b) и износоустойчивост I (c) на образци от лят сферографитен чугун без (1,3) и с (2,4) наномодификатор.

От проведеното експериментално изследване на износването бе установено, че износоустойчивостта на чугуните без наномодификатор е I = 8,06.10^6 за състав 1 и I = 8,77.10^6 за състав 2 . За чугуните с наномодификатор кубичен боров нитрид *cBN* износоустойчивостта (I = 15,15.10^6 за обр. 2 и I = 15,87.10^6 за обр. 4) се учеличава с 82 % за състав 1 и с 89 % за състав 2 в сравнение с чугуните без наномодификатор (табл. 1, фиг. 5 c).

4. ЗАКЛЮЧЕНИЕ

Изследвана е микроструктурата, твърдостта и поведението при износване на ляти сферографитни чугуни без и с наноразмерни добавки от кубичен боров нитрид *cBN*. Наноразмерните добавки не променят формата на графита. Те променят количественото съотношение между перлита и ферита в структурата на чугуна. Интензивността на износване на чугуните с наномодификатори намалява, а износоустойчивостта им се увеличава с 82÷89 % в сравнение с тази на чугуните без наномодификатор.

БЛАГОДАРНОСТИ:

Настоящите изследвания са свързани с проблематиката и са финансирани по договор ДУНК - 01/3 на ТУ – София с МОН на тема: „Създаване на „Университетски научно-изследователски комплекс" (УНИК) за иновации и трансфер на знания в областта на микро/нано технологии и материали, енергийна ефективност и виртуално инженерство".

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MECHANICAL AND TRIBOLOGICAL PROPERTIES OF DUCTILE CAST IRON STRENGTHENED WITH NANOSIZED ADDITIVES

Julieta KALEICHEVA

Abstract: *The microstructure, mechanical properties and wear resistance of ductile cast irons strengthened with nanosized additives of titanium nitride TiN, titanium nitride + titanium carbonitride (TiN + TiCN) and cubic boron nitride cBN .are studied. The metallographic analysis by means of an optical metallographic microscope GX41 OLIMPUS is carried out. The hardness testing by Brinnel Method and tensile testing are performed. The influence of the nanosized additeves on the microstructure, mechanical properties (hardness HB, tensile strength R_m, Yield stress $R_{p0,2,,}$ specific elongation A, relative contraction Z) and wear resistance of ductile cast irons is determined.*

Keywords: *nanosized particles, ductile cast irons, hardness, mechanical properties, wear resistance*

МЕХАНИЧНИ И ТРИБОЛОГИЧНИ СВОЙСТВА НА ЛЯТИ СФЕРОГРАФИТНИ ЧУГУНИ С НАНОРАЗМЕРНИ ДОБАВКИ

Жулиета КАЛЕЙЧЕВА

Резюме: *Изследвани са микроструктурата, механичните свойства и износоустойчивостта на ляти сферографитни чугуни, съдържащи добавки от наноразмерни частици – титанов нитрид TiN, титанов нитрид + титанов карбонитрид (TiN + TiCN) и кубичен боров нитрид cBN . Проведен е металографски анализ на оптичен металографски микроскоп GX41 OLIMPUS. Проведено е изпитване на твърдост по Бринел и изпитване на опън. Установено е влиянието на наноразмерните добавки върху микроструктурата, механичните свойства (твърдост HB, якост на опън R_m, граница на провлачане $R_{p0,2}$,относително удължение A, относително свиване Z) и износоустойчивостта на ляти сферографитни чугуни.*

Ключови думи: *наноразмерни частици, ляти сферографитни чугуни, твърдост, механични свойства, износоустойчивост*

1.ВЪВЕДЕНИЕ

Сферографитният чугун е ефективен конструкционен материал, съчетаващ добра технологичност с комплекс от високи физико-механични свойства. Износоустойчивостта и антифрикционните свойства на сивите чугуни са добре известни и са свързани с присъствието на графит в структурата им. При еднакви форма, размер, количество и разпределение на графитната фаза, износоустойчивостта на чугуна зависи от структурата на металната матрица. Морфологията на графита и структурата на металната основа определят механичните свойства на сивите чугуни. Те могат да бъдат променяни чрез термична обработка и чрез легиране [1-3]. Наноразмерни частици, добавени в стопилката в малки количества, променят морфологията на графита от пластинчата във вермикулярна, както и структурата на металната матрицата, което води до повишаване износоустойчивостта на чугуните [4,5].

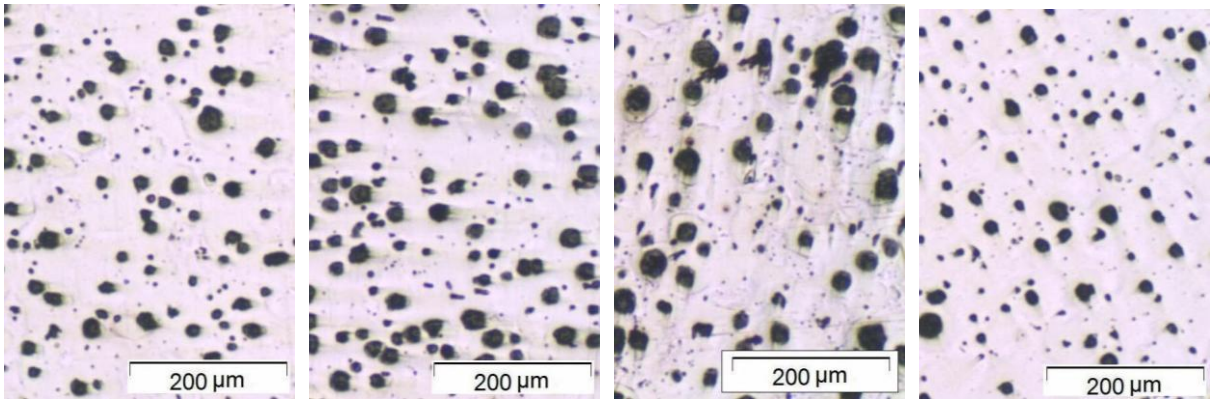
Целта на този доклад е да се изследва влиянието на различни наноразмерни добавки върху механичните свойства, микроструктурата и поведението при износване на образци от два състава лят сферографитен чугун.

2.МАТЕРИАЛ И МЕТОДИКИ НА ИЗСЛЕДВАНЕ

Изследвани са образци от два състава лят нелегиран сферографитен чугун, съдържащи наноразмерни частици от титанов нитрид TiN, титанов нитрид + титанов карбонитрид (TiN + TiCN) и кубичен боров нитрид cBN (табл. 1).

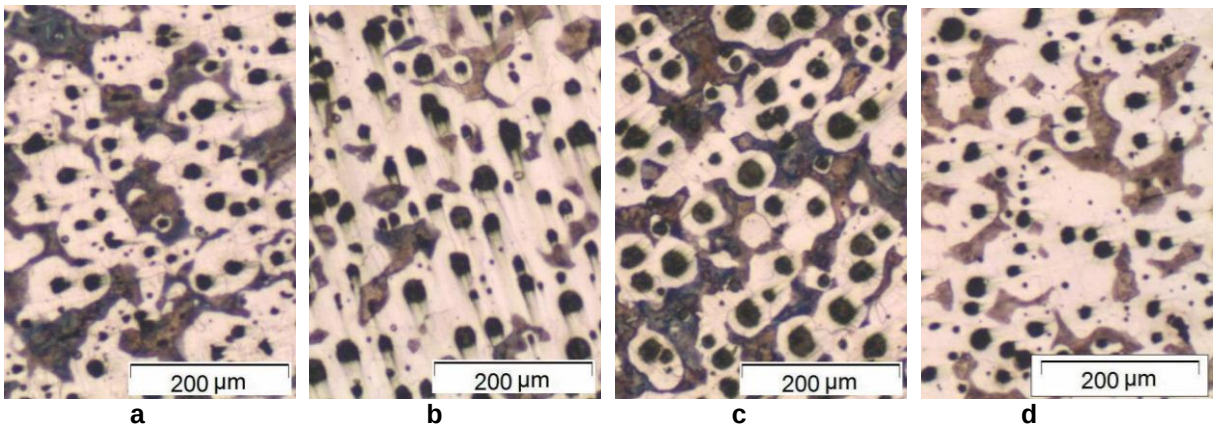
Таблица 1: Състав на чугуна, наномодификатори.

№ на образеца	Състав на сферографитния чугун	Нано модификатор
1	Fe-3,55C-2,67Si-0,31Mn-0,009S-0,027P-0,040Cu-0,025Cr-0,020Ni-0,039Mg wt % (състав 1)	-
2		*TiN*
3		*TiCN+ TiN*
4		*cBN*
5	Fe-3,54C-2,47Si-0,66Mn-0,02S-0,03P-0,04Cu-0,02Cr-0,008Ni-0,048Mg wt % (състав 2)	-
6		*TiN*
7		*TiCN +TiN*
8		*cBN*



a **b** **c** **d**

Фиг. 1. Микроструктура на непроявени образци от лят сферографитен чугун (състав 1):a - без наномодификатор; b - с наномодификатор TiN; c - с наномодификатор (TiCN + TiN); d - с наномодификатор cBN



a **b** **c** **d**

Фиг. 2. Микроструктура на проявени с 2% разтвор на HNO_3 в етилов спирт образци от лят сферографитен чугун (състав 1): a - без наномодификатор; b - с нано-модификатор TiN; c - с наномодификатор (TiCN+TiN); d - с наномодификатор cBN

Преди да бъдат добавени в стопилката, наноразмерните частици са покрити с никел по метод за отлагане на безтоково никелово покритие ЕФТТОМ – НИКЕЛ [6]. Покритието върху наноразмерните частици позволява тяхното омокряне в стопилката и по-равномерното им разпределение в обема на отливката [7,8].

Изследвана е микроструктурата на ляти образци от сферографитен чугун с оптичен металографски микроскоп GX41 OLIMPUS. Образците са проявени с реактив: 2% разтвор на азотна киселина в етилов спирт. Проведено е изпитване на твърдост по метода на Бринел и изпитване на микротвърдост с натоварване 100 g.

Проведено е изпитване на опън за ляти чугунени образци и са определени следните механични характеристики: якост на опън R_m, граница на провлачване $R_{P0,2}$, относително удължение *A* и относително свиване *Z*.

Проведено е експериментално изследване на износването на образци от лят сферографитен чугун по методика и с устройство за ускорени изпитания по кинематичната схема „палец - диск" при триене по закрепен абразив [9].

Таблица 2. Твърдост НВ , микротвърдост HV0,1 и трибологични свойства на сферографитни чугуни с наномодификатори.

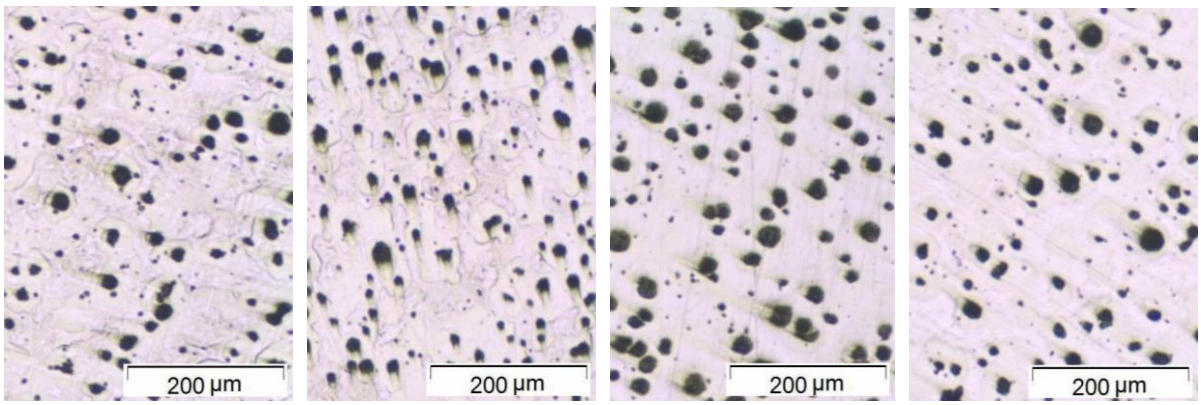
№ на образеца	Нано модификатор	Твърдост НВ	Микротвърдост HV0,1		Интензивност на износване *i*	Износо устойчивост *I*
			ферит	перлит		
1	-	185	189	329	$0,124.10^{-6}$	$8,06.10^{6}$
2	*TiN*	165	171	274	$0,074.10^{-6}$	$13,6.10^{6}$
3	*TiCN + TiN*	180	178	311	$0,08.10^{-6}$	$12,5.10^{6}$
4	*cBN*	170	181	340	$0,066.10^{-6}$	$15,15.10^{6}$
5	-	203	207	357	$0,114.10^{-6}$	$8,77.10^{6}$
6	*TiN*	195	178	287	$0,065.10^{-6}$	$15,38.10^{6}$
7	*TiCN + TiN*	201	192	338	$0,071.10^{-6}$	$14,08.10^{6}$
8	*cBN*	190	189	344	$0,063.10^{-6}$	$15,87.10^{6}$

Таблица 3: Механични свойства на сферографитни чугуни с наномодификатори.

№ на образеца	Нано модификатор	R_m, *MPa*	$R_{p0,2}$, *MPa*	A, *%*	Z, *%*
1	-	583	427	16	18
2	*TiN*	530	396	19	18
3	*TiCN + TiN*	511	373	15	16
4	*cBN*	560	411	10	14
5	-	617	466	14	12
6	*TiN*	574	444	12	15
7	*TiCN + TiN*	604	445	14	14
8	*cBN*	561	418	13	16

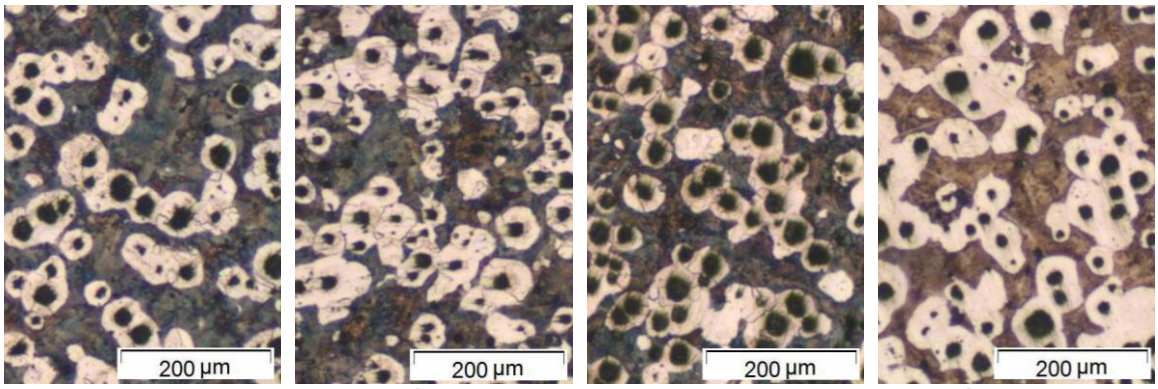
3.ЕКСПЕРИМЕНТАЛНИ РЕЗУЛТАТИ И АНАЛИЗ

На фиг. 2 и фиг. 4 са представени микроструктурите на изследваните чугуни в лято състояние, които се състоят от ферит, перлит и графит. Количеството на перлита в структурата на чугуните от състав 2 (фиг. 4) е по-голямо от това в състав 1 (фиг. 2). Чугуните от състав 2 съдържат повече манган (0,66 %) в сравнение с тези от състав 1 (0,31 %), което увеличава перлита в структурата.Това определя и по-високата трърдост (190 ÷ 203 НВ) на образците от състав 2 в сравнение с твърдостта (165 ÷ 185 НВ) на образците от състав 1 (табл. 2). Наноразмерните добавки променят количественото съотношение между перлита и ферита. Те не променят формата на графита, но увеличават количеството и размера на графитната фаза (фиг.1 и 3). В най-голяма степен оказват влияние върху размера и количеството на графита нанодобавките от титанов нитрид + титанов карбонитрид (TiN + TiCN) и от титанов



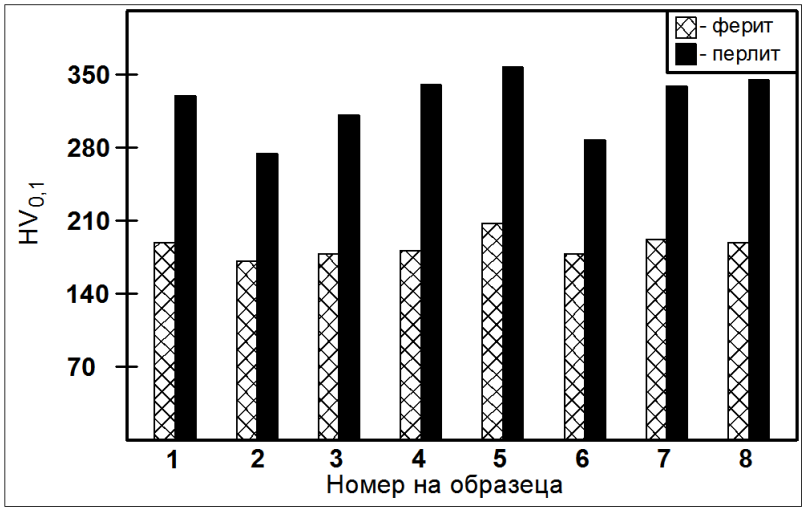
a b c d

Фиг. 3. Микроструктура на непроявени образци от лят сферографитен чугун (състав 2):a - без наномодификатор; b - с наномодификатор TiN; c - с наномодификатор (TiCN + TiN); d - с наномодификатор cBN

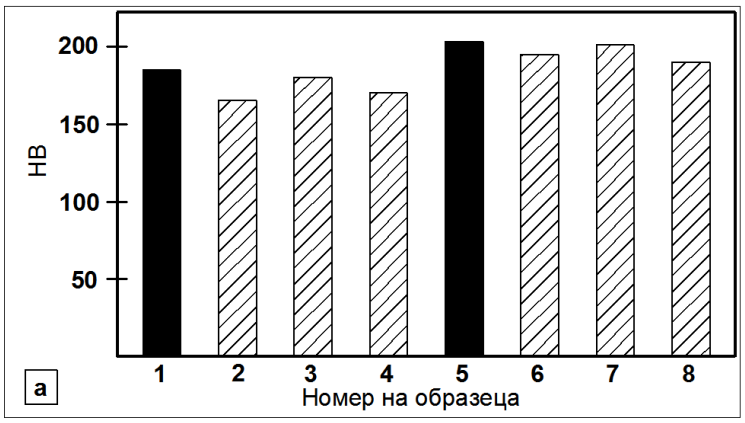


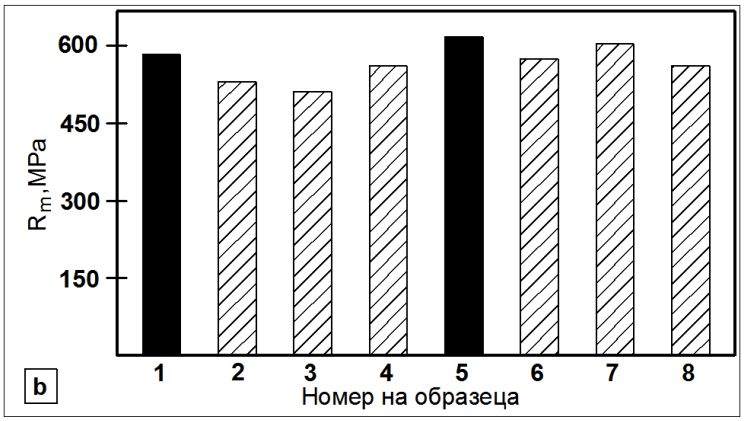
a b c d

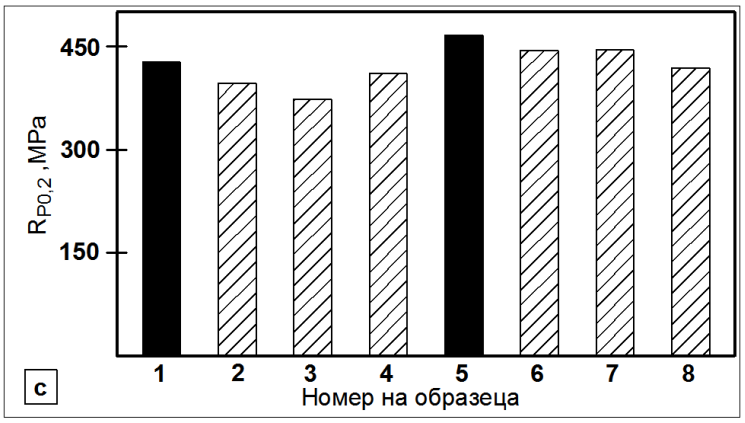
Фиг. 4. Микроструктура на проявени с 2% разтвор на HNO_3 в етилов спирт образци от лят сферографитен чугун (състав 2): a - без наномодификатор; b - с нано-модификатор TiN; c - с наномодификатор (TiCN + TiN); d - с наномодификатор cBN



Фиг. 5. Микротвърдост $HV_{0,1}$ на образци от лят сферографитен чугун без (1,5) и с (2,3,4,6,7,8) наномодификатори.







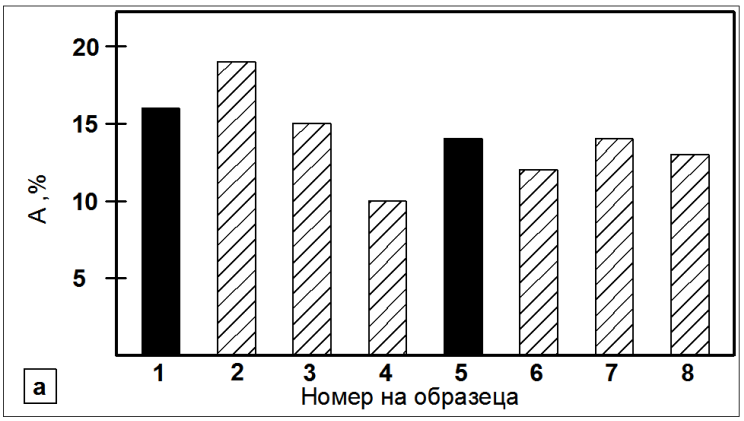
Фиг. 6. Твърдост HB (a), якост на опън R_m (b) и граница на провлачане $R_{p0,2}$ (c) на образци от лят сферографитен чугун без (1,5) и с (2,3,4,6,7,8) наномоди

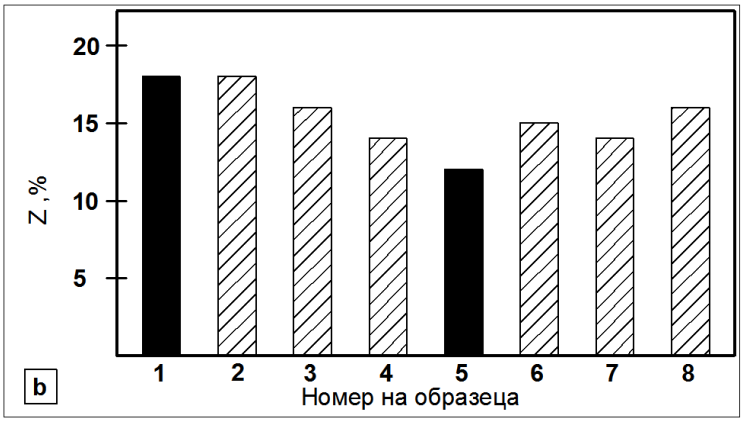
нитрид TiN (фиг.1 b,c и фиг.3 c). Изменя се количественото съотношение между структурни елементи с различна твърдост, което влияе върху общата твърдост на чугуните. Твърдостта на

чугуните с нанодобавки е малко по-ниска от тази на чугуните без наноразмерни частици (фиг. 6 а).Измерената микротвърдост за структурата перлит е 274÷357 $HV_{0,1}$, а за структурата ферит - 171÷207 $HV_{0,1}$ (табл. 2). Микротвърдостта на ферита в образците с нанодобавки е по-ниска от тази в изходнити образци (фиг. 5).

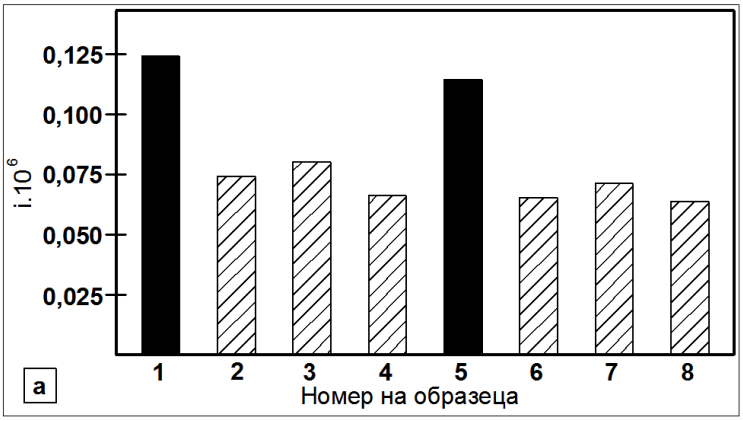
Резултатите от изпитването на опън (табл. 3) показаха известно понижаване на якостните характеристики – якост на опън R_m и граница на провлачане $R_{p0,2}$ (фиг. 6 b,c). Не се установява закономерност в изменението на пластичните характеристики - относителното удължение *A* и относително свиване *Z* , за образците без и с наноразмерни добавки (фиг. 7).

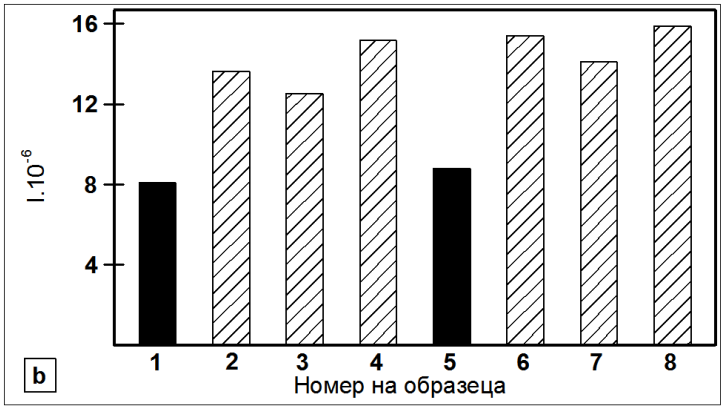
От проведеното експериментално изследване на износването бе установено, че интензивността на износване на лятите чугуни с нанодобавки намалява, а износоустойчивостта им се увеличава (табл. 2 и фиг. 8). Графитът в структурата на сивите чугуни определя в значителна степен поведението им при износване. Защитните свойства на повърхностния слой с графит се подобряват при намаляване разстоянието между графитните сфери и износоустойчивостта на чугуна се увеличава. Установено е, че наноразмерните добавки от титанов нитрид TiN повишават износоустойчивостта на чугуните с 69÷75 %, от титанов нитрид + титанов карбонитрид (TiN + TiCN) – с 55÷61 % и от кубичен боров нитрид cBN с 88 ÷ 81 % в сравнение с износоустойчивостта на чугуните без нанодобавки от състав 1 и 2.





Фиг. 7. Относително удължение A (a) и относително свиване Z (b) на образци от лят сферографитен чугун без (1,5) и с (2,3,4,6,7,8) наномодификатори.





Фиг. 8. Интензивност на износване i (a) и износоустойчивост I (b) на образци от лят сферографитен чугун без (1,5) и с (2,3,4,6,7,8) наномодификатори.

5. ЗАКЛЮЧЕНИЕ

- Установено е понижаване на якостните характеристики – твърдост HB, якост на опън R_m и граница на провлачане $R_{p0,2}$ в изследваните образци от ляти сферографитни чугуни с наноразмерни добавки от TiN, (TiN + TiCN) и cBN.

- Наноразмерните добавки от TiN, (TiN + TiCN) и cBN оказват влияние върху количественото съотношение между ферита и перлита в лятата структура на чугуните. Те не променят формата на графита, но увеличават количеството и размера на графитната фаза.

- Установено е, че наноразмерните добавки от TiN, (TiN + TiCN) и cBN повишават износоустойчивостта на лятите чугуни от състав 1 с 69, 55 и 88 %, а на лятите чугуните от състав 2 с 75, 61 и 81 % в сравнение с чугуните без нанодобавки.

БЛАГОДАРНОСТИ:

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WEAR RESISTANCE OF AUSTEMPERED DUCTILE IRON WITH NANOSIZED ADDITIVES

J. KALEICHEVA, M. KANDEVA, V. MISHEV, Z. KARAGUIOZOVA

***Abstract**: Samples of austempered ductile irons with nanosized titanium nitride + titanium carbonitride (TiN + TiCN), titanium nitride TiN and cubic boron nitride cBN additives are investigated. The thermal treatment process is performed at two stages: heating at 900 °C, 1 h and austempering at 380 °C, 2 h.The upper bainite structure obtained is observed by means of an optical metallographic microscope GX41 OLIMPUS. The hardness measurements by Vickers Method and the wear examination in friction conditions of a fixed abrasive by a cinematic scheme „pin - disc" are carried out. The nanosized additives' influence on the austempered ductile irons microstructure, hardness and tribological properties are determined.*

***Keywords**: nanosized particles, austempered ductile irons, upper bainite, hardness.*

ИЗНОСВАНЕ НА ИЗОТЕРМИЧНО ЗАКАЛЕНИ СФЕРОГРАФИТНИ ЧУГУНИ С ДОБАВКИ ОТ НАНОРАЗМЕРНИ ЧАСТИЦИ

Ж.КАЛЕЙЧЕВА, М. КАНДЕВА, В. МИШЕВ, З. КАРАГЬОЗОВА

***Резюме:** Изследвани са образци от изотермично закалени сферографитни чугуни, съдържащи добавки от наноразмерни частици – титанов нитрид + титанов карбонитрид (TiN + TiCN), титанов нитрид TiN и кубичен боров нитрид cBN. Режимът на термичната обработка включва нагряване при температура 900 °C, 1 h и изотермично закаляване при 380 °C, 2 h. Получената микроструктура горен бейнит е изследвана с оптичен металографски микроскоп GX41 OLIMPUS. Проведено е изпитване на твърдост по метода на Викерс и изследване на износването по кинематичната схема „палец - диск" при триене по закрепен абразив. Установено е влиянието на наноразмерните добавки върху микроструктурата, твърдостта и трибологичните свойства на изотермично закалените сферографитни чугуни.*

***Ключови думи:** наноразмерни частици, изотермично закалени сферографитни чугуни,горен бейнит, твърдост*

1. ВЪВЕДЕНИЕ

Сферографитните чугуни се характеризира с висока якост, жилавост и износоустойчивост и са конструкционен материал, който се използва широко в машиностроенето [1]. Графитът, присъстващ в чугуна, обезпечава съпротивление срещу механично износване и подобрява неговата обработваемост. Легирането, темичното въздействие или съчетанието на тези два процеса са ефективни решения при обработването на желязо-въглеродните сплави с цел получаване на оптимални свойства [2].Сферографитните чугуни с бейнитна структура на металната основа, получена чрез изотермично закаляване, притежават висока якост и повишена пластичност и жилавост [3-5]. Наноразмерни частици, добавени в стопилката на чугуните в малки количества, увеличават количеството на графита и променят неговата морфология, което в съчетание с промените в структурата на металната основа повишава износоустойчивостта на чугуните [6-8].

Целта на този доклад е да се изследва микроструктурата, твърдостта и трибологичните свойства на образци от изотермично закалени сферографитни чугуни, съдържащи наноразмерни добавки.

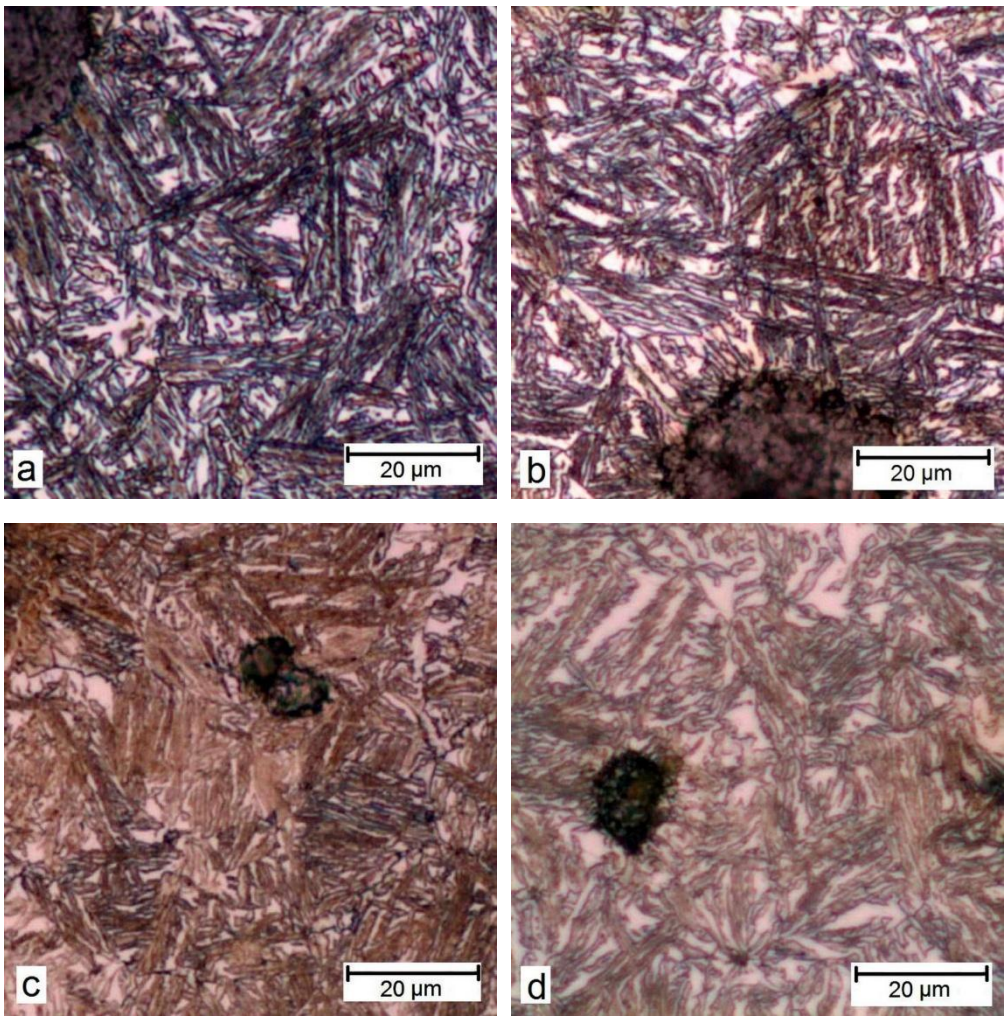
2. МАТЕРИАЛ И МЕТОДИКИ НА ИЗСЛЕДВАНЕ

Изследвани са образци от два състава сферографитен чугун, съдържащи наноразмерни частици от титанов нитрид + титанов карбонитрид (TiN + TiCN), титанов нитрид TiN и кубичен боров нитрид *cBN* (табл. 1). Химичният състав на сферографитните чугуни е следния:
Състав 1 - Fe-3,55C-2,67Si-0,31Mn-0,009S-0,027P-0,040Cu-0,025Cr-0,08Ni-0,06Mg wt%.
Състав 2 – Fe-3,54C-2,47Si-0,66Mn-0,02S-0,03P-0,04Cu-0,02Cr-0,08Ni-0,048Mg wt%.

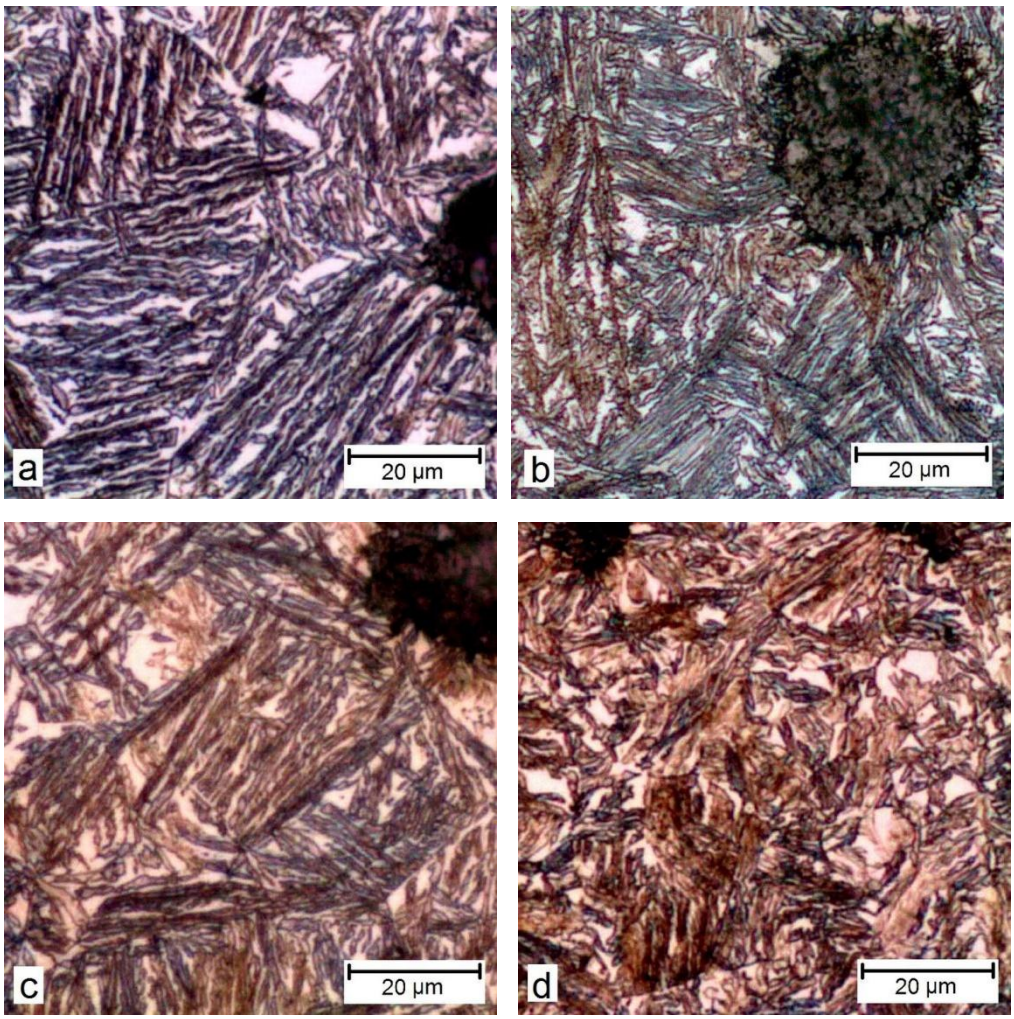
Таблица 1. Наномодификатори и твърдост по Викерс HV10.

№ на образеца	Нано модификатор	Микроструктура	Състав на чугуна	HV10	Състав на чугуна	HV10
1	-	горен бейнит	1	314	2	316
2	*TiCN + TiN*			319		312
3	*TiN*			317		302
4	*cBN*			312		299

Преди да бъдат добавени в стопилката, наноразмерните частици са покрити с никел по метод за отлагане на безтоково никелово покритие ЕФТТОМ – НИКЕЛ [9]. Покритието върху наноразмерните частици позволява тяхното омокряне в стопилката и по-равномерното им разпределение в обема на отливката.
Образци от двата състава сферографитен чугун, съдържащи различни наноразмерни добавки, са подложени на изотермично закаляване, включващо нагряване при температура 900 ^{o}C, 1 h и изотермично задържане при температура 380 ^{o}C, 2h.



Фиг. 1. Микроструктура горен бейнит на изотермично закален сферографитен чугун (състав 1) без наномодификатор (a), с наномодификатор TiCN + TiN(b), TiN(c) и cBN(d).



Фиг. 2. Микроструктура горен бейнит на изотермично закален сферографитен чугун (състав 2) без наномодификатор(a), с наномодификатор TiCN + TiN(b), TiN(c) и cBN(d).

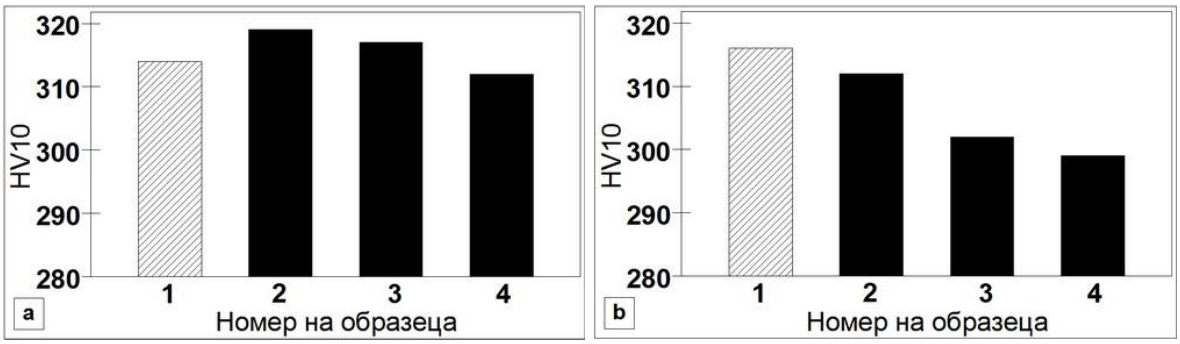
Изследвана е микроструктурата на изотермично закалените чугунени образци с оптичен металографски микроскоп GX41 OLIMPUS. Образците са проявени с реактив: 2% разтвор на азотна киселина в етилов спирт. Проведено е изпитване на твърдост по метода на Викерс с натоварване 10 kg.

Проведено е експериментално изследване на износването на образци от изотермично закален сферографитен чугун по методика и с устройство за ускорени изпитания по кинематичната схема „палец - диск" при триене по закрепен абразив [8]. В експеримента се използва импрегниран материал *Корунд 220*. В работата се изследва износването на 8 броя образци от чугун със структура горен бейнит,съдържащи наноразмерни добавки(табл. 1). Основните параметри на експеримента за изследване на износването са: *Номинално контактно налягане* $p_a=0,4.10^6$ *[Pa]; Средна скорост на плъзгане,* V *= 24,5 [cm/s]; Номинална контактна площ,* A_a *= 50,24 [mm^2]; Плътност* $\rho=7,80.10^3$ *[kg/m^3].*

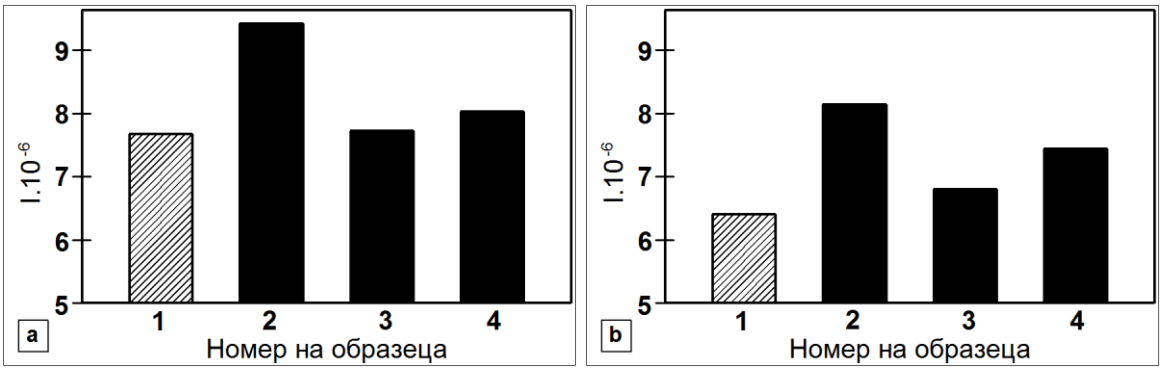
3. Експериментални резултати и Анализ

Структурата на изследваните чугуните след изотермично закаляване при температура 380^{o}C в продължение на 2 часа се състои от горен бейнит . Горният бейнит се образува в температурния интервал 350 – 450 ^{o}C на бейнитната област и след охлаждане до стайна температура в структурата присъства бейнитен ферит, карбиди и остатъчен аустенит $A_{ост.}$. (фиг.1, 2). Бейнитът е ориентирана структура, състояща се от игли α – фаза (бейнитен ферит), карбиди и непревърнат аустенит. α-фазата се образува по мартензитен механизъм от аустенитните области с ниско въглеродно съдържание [3,5].При охлаждане от температурата на изотермата до стайна температура, част от непревърнатият аустенит претърпява мартензитно превръщане, а друга част от него остава в структурата като остатъчен аустенит $A_{ост.}$. Наноразмерните добавки променят морфологията на бейнитния ферит от ориентирана

към переста (фиг.1c,d; фиг 2d).Твърдостта на изотермично закалените образци от състав 1 се изменя от 312 до 319 HV10 (фиг.3a), а на тези от състав 2 – от 299 до 316 HV10 (фиг.3b). Твърдостта на изотермично закалените образци от състав 2 е по-ниска в сравнение с твърдостта на образците от състав 1, което се обяснява с различната степен на превръщане на преохладения аустенит в двата състава.

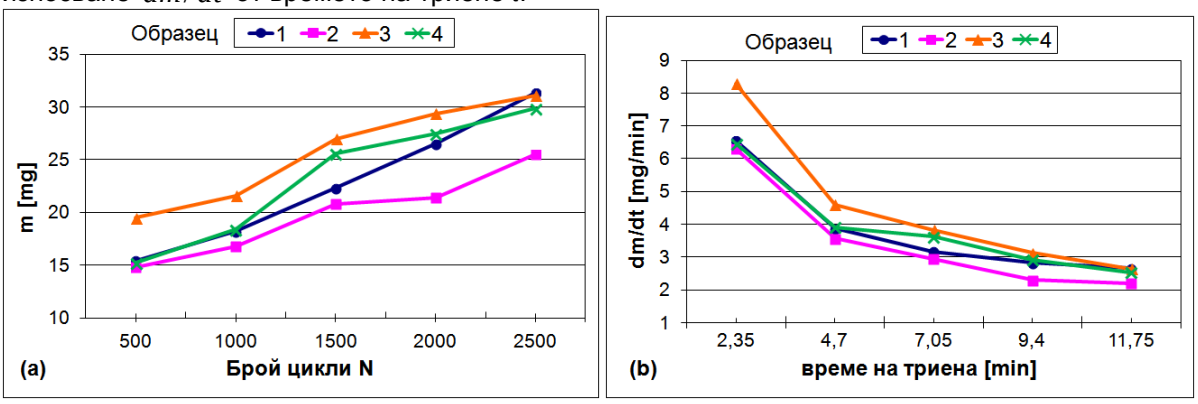


Фиг. 3. Твърдост HV10 на бейнитни чугуни без наномодификатор (обр.1) и с нано-модификатор TiCN + TiN (обр.2), TiN (обр.3) и cBN (обр.4). a - състав 1; b - състав 2.



Фиг. 4. Износоустойчивост I на бейнитни чугуни без наномодификатор (обр.1) и с наномодификатор TiCN + TiN (обр.2), TiN (обр.3) и cBN (обр.4).a - състав 1; b - състав 2.

Получени са експериментални резултати за масовото износване m, скоростта на износването dm/dt, абсолютната интензивност на износване i и абсолютната износоустойчивост I на образците и тяхното изменение във времето на контактно взаимодействие (табл.2 и 3). На фиг. 4 и 5 са изобразени графично зависимостта на масовото износване m от броя цикли N (пътя на триене) и зависимостта на скоростта на масовото износване dm/dt от времето на триене t.



Фиг. 5. Зависимост на масовото износване m от броя цикли N (a) и на скоростта на износване dm/dt от времето на триене t (b) за образци от изотермично закален сферографитен чугун (състав 1).

Таблица 2. Експериментални резултати за масовото износване m, скоростта на износване dm/dt, интензивността на износване i и износоустойчивостта I (състав 1).

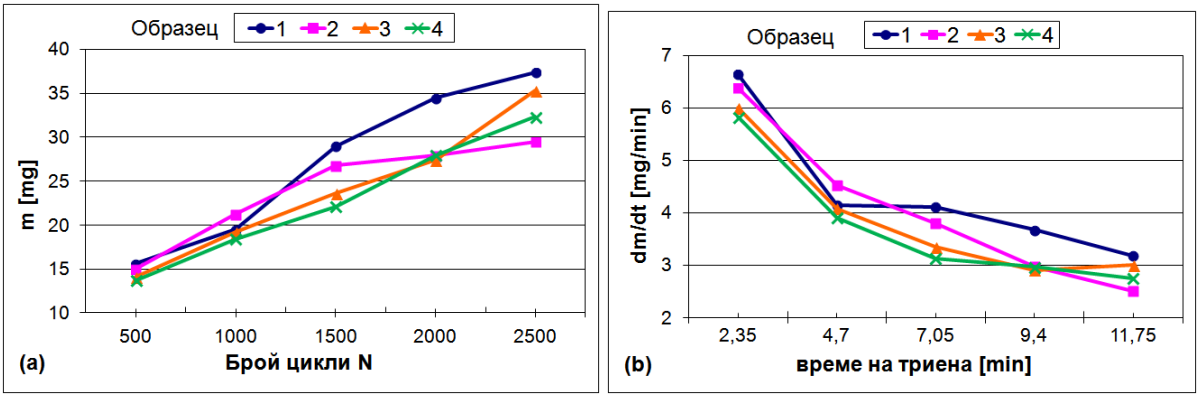
Път на триене, *L* [mm]		122,5	245	367,5	490	612,5
Брой цикли , *N*		500	1000	1500	2000	2500
Време , *t* [min]		2,35	4,7	7,05	9,4	11,75
Масово износване, *m* [mg]	образец 1	15,4	18,2	22,3	26,5	31,3
	образец 2	14,8	16,8	20,8	21,4	25,5
	образец 3	19,5	21,6	27,0	29,4	31,1
	образец 4	15,2	18,4	25,6	27,5	29,9
Скорост на износване, *dm/dt* [mg/min]	образец 1	6,55	3,87	3,16	2,82	2,66
	образец 2	6,30	3,57	2,95	2,30	2,20
	образец 3	8,30	4,60	3,83	3,13	2,65
	образец 4	6,47	3,91	3,63	2,92	2,54
Интензивност на износване, *i*	образец 1	$0{,}32.10^{-6}$	$0{,}19.10^{-6}$	$0{,}15.10^{-6}$	$0{,}14.10^{-6}$	$0{,}13.10^{-6}$
	образец 2	$0{,}30.10^{-6}$	$0{,}17.10^{-6}$	$0{,}14.10^{-6}$	$0{,}11.10^{-6}$	$0{,}10.10^{-6}$
	образец 3	$0{,}40.10^{-6}$	$0{,}22.10^{-6}$	$0{,}19.10^{-6}$	$0{,}15.10^{-6}$	$0{,}13.10^{-6}$
	образец 4	$0{,}32.10^{-6}$	$0{,}19.10^{-6}$	$0{,}18.10^{-6}$	$0{,}14.10^{-6}$	$0{,}12.10^{-6}$
Износоустойчивост, *I*	образец1	$3{,}12.10^{6}$	$5{,}28.10^{6}$	$6{,}46.10^{6}$	$7{,}25.10^{6}$	$7{,}67.10^{6}$
	образец 2	$3{,}25.10^{6}$	$5{,}72.10^{6}$	$6{,}93.10^{6}$	$8{,}98.10^{6}$	$9{,}42.10^{6}$
	образец 3	$2{,}46.10^{6}$	$4{,}45.10^{6}$	$5{,}34.10^{6}$	$6{,}54.10^{6}$	$7{,}72.10^{6}$
	образец 4	$3{,}20.10^{6}$	$5{,}22.10^{6}$	$5{,}63.10^{6}$	$6{,}99.10^{6}$	$8{,}03.10^{6}$

Таблица 3. Експериментални резултати за масовото износване m, скоростта на износване dm/dt, интензивността на износване i и износоустойчивостта I (състав 2).

Път на триене, *L* [mm]		122,5	245	367,5	490	612,5
Брой цикли , *N*		500	1000	1500	2000	2500
Време , *t* [min]		2,35	4,7	7,05	9,4	11,75
Масово износване, *m* [mg]	образец 1	15,6	19,5	29,0	34,5	37,4
	образец 2	15,0	21,3	26,8	27,9	29,5
	образец 3	14,1	19,2	23,6	27,4	35,3
	образец 4	13,7	18,4	22,1	27,9	32,3
Скорост на износване, *dm/dt* [mg/min]	образец 1	6,64	4,15	4,11	3,67	3,18
	образец 2	6,38	4,53	3,80	2,97	2,51
	образец 3	6,00	4,08	3,35	2,91	3,00
	образец 4	5,83	3,91	3,13	2,97	2,75
Интензивност на износване, *i*	образец 1	$0{,}32.10^{-6}$	$0{,}20.10^{-6}$	$0{,}20.10^{-6}$	$0{,}18.10^{-6}$	$0{,}16.10^{-6}$
	образец 2	$0{,}31.10^{-6}$	$0{,}22.10^{-6}$	$0{,}186.10^{-6}$	$0{,}145.10^{-6}$	$0{,}12.10^{-6}$
	образец 3	$0{,}29.10^{-6}$	$0{,}2.10^{-6}$	$0{,}16.10^{-6}$	$0{,}14.10^{-6}$	$0{,}146.10^{-6}$
	образец 4	$0{,}29.10^{-6}$	$0{,}19.10^{-6}$	$0{,}15.10^{-6}$	$0{,}145.10^{-6}$	$0{,}13.10^{-6}$
Износоустойчивост, *I*	образец1	$3{,}08.10^{6}$	$4{,}93.10^{6}$	$4{,}96.10^{6}$	$5{,}57.10^{6}$	$6{,}40.10^{6}$
	образец 2	$3{,}20.10^{6}$	$4{,}51.10^{6}$	$5{,}37.10^{6}$	$6{,}89.10^{6}$	$8{,}14.10^{6}$
	образец 3	$3{,}40.10^{6}$	$5{,}00.10^{6}$	$6{,}10.10^{6}$	$7{,}01.10^{6}$	$6{,}80.10^{6}$
	образец 4	$3{,}50.10^{6}$	$5{,}22.10^{6}$	$6{,}52.10^{6}$	$6{,}89.10^{6}$	$7{,}44.10^{6}$

На фиг. 6 са представени таболограми на износоустойчивостта *I* (b) на образци от изотермично закален сферографитен чугун без (обр.1) и с (обр. 2,3,4) наномодификатори. Представените трибологични свойства на фиг. 6 са за един и същи път на триене $L = 612{,}5\,[m]$.

Износоустойчивостта *I* на изотермично закалените образци с наноразмерни добавки от състав 1 се увеличава с 5÷24 % в сравнение с износоустойчивостта на образеца без добавки от наноразмерни частици. Износоустойчивостта *I* на чугуните от състав 2 с нанодобавки е с 6÷27 % по-висока от износоустойчивостта на чугуна без нанодобавки.



Фиг. 6. Зависимост на масовото износване m от броя цикли N (a) и на скоростта на износване dm/dt от времето на триене t (b) за образци от изотермично закален сферографитен чугун (състав 2).

4. ЗАКЛЮЧЕНИЕ

Изследвана е микроструктурата, твърдостта и трибологичните свойства на изотермично закалени сферографитни чугуни без и с наноразмерни добавки от титанов нитрид + титанов карбонитрид (TiN + TiCN), титанов нитрид TiN и кубичен боров нитрид *cBN*. Наноразмерните частици променят морфологията на бейнитния ферит в структурата на изотермично закалените сферографитни чугуни. Най-висока е износоустойчивостта (I = 9,42.10^6 и I = 8,14.10^6) на чугуните (състав 1 и състав 2) с нанодобавка *TiCN + TiN*.

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INVESTIGATION ON SURFACE FATIGUE LIFE OF COATED GEARS

Zdravka KARAGUIOZOVA

Abstract: *The hard Nickel-ultra dispersed diamond powder (Ni-UDDP) coating is deposited on spur gears and investigation of the surface fatigue live is carried out. The deposition of Ni- UDDP coating on the gears is performed using electroless EFTTOM-Nickel method with addition of UDDP strengthening particles. The highest value in a maximum Hertzian contact stress required to remove coating of 1800 Mpa is received for the Ni + UDDP coatings thermally treated at 290°C for 6 hours.*

Key Words*: electroless coating**, fatigue life, UDDP, gears, prolong surface life.*

1.INTRODUCTION

The creation of a new generation gears is of a great importance for the automotive industry increasing requirements for gears' reliability, noise and efficiency (environmental and energy impact) improvement. The main failure mechanism limiting the gears' performance is surface fatigue failure (micropitting, pitting or spalling). Development of methods for the surface hardening of the gears is one way to manufacture high performance gears. The most commonly used hardening processes that result in the reduction of macro-pitting are carburizing, nitriding and induction annealing [1,2]. Hard coatings have also a potential for increasing gear surface fatigue lives. The comparison of the surface fatigue lives of coated and uncoated gears in [3] proves the improved life owing to the coating, approximately a six-fold increase. Namely for uncoated gears, all of fifteen tests result in fatigue failure before completing 275 million revolutions, for coated gears, eleven of the fourteen tests are suspended with no fatigue failure after 275 million revolutions. The metalcontaining, carbon-based diamond-like (Me-DLC) coating selected for this study are designed specifically for the aerospace gearing applications.Thin hard coatings have potential for improving gear performance. In fact, coatings are reported to have some successful applications [4-6] where product durability improvements have been achieved by the application of thin hard coatings to gears. Co deposition of hard particles to the coating leads to new unique surface properties achieved due to the synergism of the matrix and the surprising properties of the added particles [7,8] The great diversity of possibilities to co deposit different hard particles of different sizes ensures a wide variety of the coatings' applications. Naik et all [9] report promising results in reference to the adherence and toughness of two coatings. Others authors Alanou, et al [10] get mixed results for the scuffing load capacity of rolling and sliding coated disks used to simulate aerospace gearing contacts. For tungsten carbon carbide and amorphous boron carbide coatings laboratory tested Joachim, Kurz and Glatthaar receive improved results, but the results achieved for such coatings applied to commercial applications are also mixed.

The purpose of the present study is to prolong the surface fatigue lives of gears using a novel technology for electroless coating deposition to create a new generation of gears applied in the automotive industry. The electroless coating selected for this investigation is composite Ni- UDDP coating characterized by

- Exceptional wear resistance
- Excellent hardness
- Enhanced corrosion resistance
- Perfect conformity to complex geometries
- Increased thermal transfer
- Applicability to all common metals and alloys
- Coverage of entire surfaces or selected critical areas.

2.MATERIAL AND INVESTIGATION METHOD

2.1. Manufacture of test samples

The disc samples are manufactured using 17CrNiMo6 steel, which chemical composition is given in table 1:

Table 1. Chemical composition of 17CrNiMo6 steel samples.

C	Si	Mn	Cr	Ni	Mo
0.18%	0.20%	0.70%	1.65%	1.55%	0.30%

The samples are carburised, hardened and tempered and finish ground in the axial direction (i.e. to replicate the grinding lay on meshing gear teeth) with 30μm of crowning. The thermal treatment process cycle conditions are: soak for 30 minutes at 930°C; gas carburise for 120 minutes at 930°C and 1.2% C diffuse for 60 minutes at 930°C; fast cool to 830°C and hold for 60 minutes at 0.75% C; direct oil quench (standard speed 22 grade quench oil); temper for120 minutes at 180°C.

The results of the metallographic analysis carried out after finish grinding are summarised in Table 2.

Table2. Material properties

Case hardness (at d = 0.05m)	686Hv
Case depth (at 550Hv)	1.08mm
Core hardness (at d = 3mm)	435Hv

2.2. Coating procedure

The nanocomposite nickel coatings are obtained by electroless nickel plating method EFTTOM-NICKEL. This method is developed at Technical University of Sofia [11]. The ultra dispersed diamond powder (UDDP) is used as a strengthening material. The particle size is between 4-6 nm. The nanosized diamond powder is produced by a detonation method developed at SRTI-BAS [12] using conical and cylindrical explosives. The technology for nanostructured coating deposition is developed at BAS-SRTI [13]. The coatings are composed of deposited consecutively two layers: electroless nickel followed by Ni-UDDP. The UDDP quantity in the composite coating is 5 vol.%-7 vol.%. The coatings are thermally treated at the following temperature modes:

1. at 200°C for 10 hours
2. at 290°C for 6 hours.

The microstructure observations before and after the tests are carried out by means of the optical metallographic microscope GX41 OLIMPUS at magnifications x100. The samples are treated with 3% HNO3-C2H5OH solution before the examination. The microhardness of the coating is determined by Vickers Method. The used loading is 300gf.

2.3.Test procedure

The contact fatigue tests are carried out using the 60mm centre distance disc rig. Two tests are performed on each coating and a summary of the operating conditions is shown in Table 3. The discs are run for 1x106 cycles at each of the load stages shown in Table 4 until the coating has been removed. It is noted that a Hertzian contact stress of 1200MPa is selected for load stage 1 as the base steel would be expected to perform without concern under such conditions.

Table 3: Operating conditions for contact fatigue tests on coated disc samples.

Lubricant:	100cSt mineral oil + 4% Anglamol A99 EP additive
Lubricant temperature:	70°C
Lubricant flow rate:	1.4l/min (into and out of mesh)
Speed:	1100rpm
Slide roll ratio:	0.33
Load cycles:	$1x10^6$ (per load stage)

Table 3: Loading conditions for contact fatigue tests on coated disc samples.

Load stage	Applied load (N)	Hertzian contact stress (MPa)
1	143	1200
2	182	1300
3	227	1400
4	280	1500
5	339	1600
6	407	1700
7	483	1800
8	568	1900

3. EXPERIMENTAL RESULTS

3.1. Metallographic analysis

Micro-hardness measurements are carried out on the discs to determine if the coating process has adversely affected the properties of the substrate material. The micro-hardness profiles measured on each disc are plotted in Figure 1. The micro-hardness profile measured on an uncoated disc in the carburised and finish ground condition is also included for comparison. The Ni + UDDP coated discs that are thermally processed at temperatures of 200 and 290°C give a reduction in case hardness of approximately 5 to 65Hv relative to the carburised and finish ground reference condition. However, these reductions in case hardness are not unexpected given that the thermal processing is carried out at temperatures of between 20 and 110°C higher than the typical tempering temperature of the steel from which the discs are manufactured.

Despite the observed reductions in case hardness, the values measured on the Ni + UDDP coated discs that are thermally processed at temperatures of 200 and 290°C would not be deemed unacceptable for carburised gears. In each case, the hardness values measured at a depth of 0.05mm are greater than the minimum case hardness of 660Hv recommended for carburised gears.

The coatings applied show good adhesion to the surface of the gear teeth and there is no evidence to suggest that the microstructure of the substrate material has been modified during the coating process. Ni+ UDDP coatings can also be applied without modifying the gear geometry and surface finish present after finish grinding.

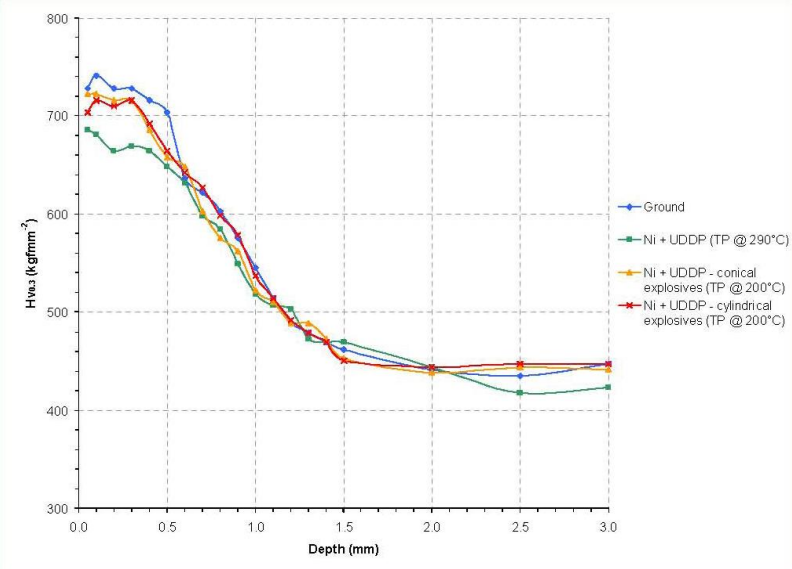


Figure 1: Microhardness profile measured on coated samples

3.2. Contact fatigue test

The results of the contact fatigue tests on the Ni + UDDP coated disc samples are summarised in Figures 2-4. The minimum Hertzian contact stresses at which the coatings are seen to be removed during testing are shown in Table 5.

Table 4: Summary of results from contact fatigue tests on coated disc samples.

Coating	**Thermal processing**	**Hertzian contact stress required to remove coating, σH (MPa)**	
		Test 1	**Test 2**
Ni + UDDP	200°C, 10 hours	≤ 1200	≤ 1200
Ni + UDDP	290°C, 6 hours	1700…1800	1200…1300



a **b**

Figure 2: Optical micrograph showing: a. Ni + UDDP coating on Ø50mm disc prior to testing and b. removal of Ni + UDDP coating and micro-pits on Ø50mm disc after N = 1x106 at σH = 1200MPa - coating thermally processed at 200°C for 10 hours. (x100 magnification), – UDDP prepared using conical explosives, coating thermally processed at 200°C for 10 hours.



a **b**

Figure 3: Optical micrograph showing: a. Ni + UDDP coating on Ø50mm disc prior to testing and b. removal of Ni + UDDP coating on Ø50mm disc after N = 1x106 at σH = 1200MPa -coating thermally processed at 200°C for 10 hours. (x100 magnification), – UDDP prepared using cylindrical explosives, coating thermally processed at 200°C for 10 hours.



a **b**

Figure 4: Optical micrograph showing: a. Ni + UDDP coating on Ø50mm disc prior to testing and b. localised removal of Ni + UDDP coating and micro-pitting on Ø50mm disc after ΣN = 2x106 at σH = 1300Mpa (x100 magnification) – coating thermally processed at 290°C for 6 hours.

In each case, the removal of the coating appears to be related to delamination of the Ni plate applied prior to deposition of the UDDP. The test results indicate that increasing the thermal processing temperature can significantly improve the adhesion of the Ni plate although the observed variability in performance of Ni-UDDP coating, thermally processed at 290°C for 6 hours, would give cause for concern if this type of coating was to be considered for use in gearing applications.

It is determined that the inconsistent performance of the coatings is most likely to have been caused by temperature fluctuation in the furnace used for the thermal processing. Therefore, if this problem can be resolved, the results suggest that Ni + UDDP coating combined with thermal processing at 290°C has the potential to achieve contact fatigue performance approaching this one of the high performance gears.

CONCLUSIONS:

Based on the results of the metallurgical analysis and contact fatigue tests carried out on the coated disc samples, it is concluded that:

• The temperature at which the Ni + UDDP coatings are thermally processed can be increased to 290°C without causing excessive tempering of the substrate material.

• The contact fatigue performance of the Ni + UDDP coatings can be significantly improved by increasing the temperature at which thermal processing is carried out.

• Improved control of the thermal processing temperature is required to reduce the variability in the contact fatigue performance of the Ni + UDDP coatings.

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STUDY OF FRICTION IN CONTACT SYSTEMS WITH DISTRIBUTED PARAMETERS

Mara KANDEVA

Abstract: *Friction in systems with distributed parameters depends on the law of contact pressure distribution, which is dependent on the law of wear rate in stationary regime of joint operation.*

The paper presents theoretical results about the value and the position of the integral friction force, the reduced friction coefficients under starting and dynamic regime in the system „journal bearing" in three cases of contact pressure distribution – constant, linear and hyperbolic. The obtained results could be used as basis for development of a procedure for measurement of friction force and friction coefficients in systems with distributed parameters.

Key Words: *tribology, friction, friction coefficients,contact systems with distributed parameters*

ИЗСЛЕДВАНЕ НА ТРИЕНЕТО В КОНТАКТНИ СИСТЕМИ С РАЗПРЕДЕЛЕНИ ПАРАМЕТРИ

Мара КАНДЕВА

Резюме: *Триенето в системи с разпределени параметри зависи от характера на разпределение на контактното налягане. Разпределението на контактното налягане от своя страна се определя от закона за разпределение на скоростта на износване в стационарен режим на работа на съединението.*

В настоящата работа са получени теоретични резултати за големината и местоположението на интегралната сила на триене, редуцирания коефициент на триене при стартов и динамичен режим в трибосистема „петов лагер" при три случая на разпределение на контактното налягане – постоянно, линейно и хиперболично.

Ключови думи: *трибология, триене, коефициент на триене, системи с разпределени параметри*

1.ВЪВЕДЕНИЕ

Контактното тяло като функционален елемент в трибосистемите има дискретна структура. Външното натоварване и съответното фактическо контактно налягане в контактните съединения на машините се осъществява в контактните петна [1 ÷ 4].

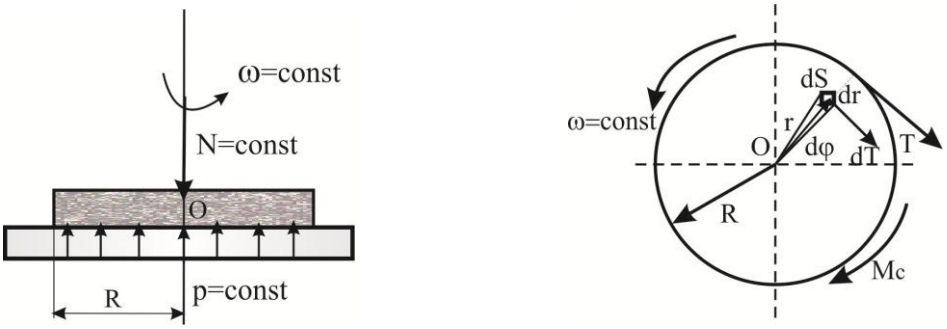
Характерът на разпределение на контактните петна, тяхната интензивност и изменението им във времето определят динамиката на триенето и износването в условия на плъзгане, търкаляне и търкаляне с плъзгане [5 ÷ 9].

Целта на настоящата работа е да се изследва влиянието на характера на разпределение на контактното налягане върху големината и местоположението на интегралната сила на триене във връзка с разработване на методики за измерване на статичния и динамичен коефициент на триене.

Изследват се няколко случая на разпределение на налягането.

2.ТРИЕНЕ В СИСТЕМА С РАВНОМЕРНО РАЗПРЕДЕЛЕНИЕ НА КОНТАКТНОТО НАЛЯГАНЕ

Разглежда се трибосистема, състояща се неподвижна опора и хоризонтален диск, ротиращ около вертикална централна ос с постоянна ъглова скорост $\omega = const$ с централно нормално натоварване N ($p = const$). Такава трибосистема в специализираната литература се нарича още „петов лагер”. Системата е само кинематично разпределена (фиг.1)



Фиг. 1. Схема на контактна система с равномерно разпределение на контактното налягане $p = const$

Елементарната сила на триене dT в елементарна площадка $dS.dr$ се представя с израза:

$$dT = \mu.p.dS.dr = \mu.p.r.d\varphi.dr \tag{1}$$

където $p = N / \pi R^2$ е контактното налягане.

След интегриране на уравнение (1):

$$T = \int_0^{2\pi}\int_0^{R} \mu pr.d\varphi = \mu p \frac{R^2}{2} 2\pi = \mu R^2 \pi \frac{N}{\pi R^2} = \mu N$$

се намира интегралната сила на триене:

$$T = \mu N \tag{2}$$

Местоположението на интегралната сила на триене спрямо центъра *O* се определя от условието: моментът на силата T да бъде равен на интегралния момент M_c на всички разпределени сили на триене, т.е.

$$T.r_x = M_c \tag{3}$$

Съпротивителният момент M_c на разпределените сили на триене се получава чрез интегриране на елементарните моменти на разпределените сили на триене, т.е.

$$dM_c = dT.r \tag{4}$$

От уравнение (1) и след интегриране на (4) за интегралния съпротивителен момент следва:

$$M_c = \int_0^{2\pi}\int_0^{R} \mu pr^2.d\varphi.dr = \mu p \frac{R^3}{3} 2\pi = \frac{2}{3}\mu R^3 \pi \frac{N}{\pi R^2}$$

или

$$M_c = \frac{2}{3}\mu RN \tag{5}$$

След заместване на изразите (2) и (5) в уравнение (3) се определя разстоянието r_x от оста на въртене, на което трябва да се намира интегралната сила на триене T, за да притежава същия съпротивителен момент M_c, какъвто е този на разпределените сили на триене, т.е.

$$\mu N.r_x = \frac{2}{3}\mu RN$$

откъдето за местоположението на интегралната сила на триене следва

$$r_x = \frac{2}{3}R \qquad (6)$$

Периферната тангенциална сила F_o, с която се преодолява статичното състояние на диска при нормално натоварване N и динамичната сила F, с която се преодолява въртеливото му движение със скорост ω определят съответно статичният коефициент на триене μ_o и динамичният коефициент на триене μ при равномерно разпределение на контактното налягане $p = const$.

От сравняването на двата момента - този на периферната сила F_o и на интегралната сила на триене T_o се получават съответно коефициентите на стартово и стационарното динамично триене, съответно:

$$\mu_o = \frac{3}{2}\frac{F_o}{N} \qquad (7) \qquad\qquad \mu = \frac{3}{2}\frac{F}{N} \qquad (8)$$

които чрез редуцирания коефициент на триене μ_r се представят във вида:

$$\mu_o = \mu_r \frac{F_o}{N} \qquad (9) \qquad\qquad \mu = \mu_r \frac{F_o}{N} \qquad (10)$$

От уравнения (7), (8), (9) и (10) за редуцирания коефициент на триене се получава:

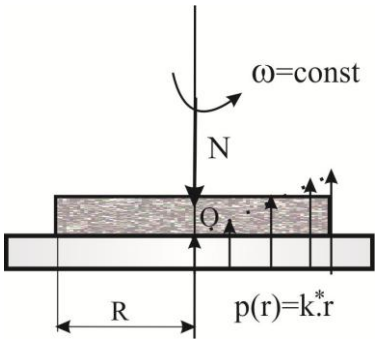
$$\mu_r = \frac{3}{2} \qquad (11)$$

Методиката за експериментално определяне на двата коефициента на триене μ_o и μ се свежда до измерване на съответните периферни сили F_o и F.

3.КОНТАКТНА СИСТЕМА С ДИНАМИЧНО И КИНЕМАТИЧНО РАЗПРЕДЕЛЕНИЕ

Разглежда се линейният случай на разпределение на контактното налягане:

$$p(r) = k.r \qquad (12)$$



Фиг. 2. Схема на контактна система с линейно разпределение на контактното налягане $p(r) = k.r$

Коефициентът на пропорционалност k се определя от условието за равновесие на вертикалните сили:

$$\sum_i N_i = 0$$

Елементарната dN и интегрална N нормални сили се определят съответно с изразите:

$$dN(r) = p(r).dr.d\varphi.r \; ; N(R) = \int_0^{2\pi}\int_0^{R} k.r^2 dr.d\varphi = N$$

от които се получава:

$$k\frac{R^3}{3}.2\pi = N$$

Или за коефициента на пропоционалност следва:

$$k = \frac{3}{2}\frac{N}{\pi R^3} \tag{13}$$

Законът за изменение на контактното налягане в съответствие с (12) и (13) приема вида:

$$p(r) = \frac{3}{2}\frac{r}{\pi R^3}N \tag{14}$$

След заместване на (14) в (1) за елементарната и интегрална сили на триене се получава:

$$dT = \mu.p.dS.dr = \mu\frac{3}{2\pi}\frac{r^2}{R^3}N.d\varphi.dr\ ;\quad T = \int_0^{2\pi}\int_0^{R}\mu\frac{3}{2}\frac{N}{\pi R^3}.r^2 d\varphi.dr = \frac{3}{2}\frac{\mu N}{\pi R^3}\frac{R^3}{3}.2\pi = \mu N$$

Съпротивителният момент се определя след заместване в условието (4), т.е.

$$M_c = \int_0^{2\pi}\int_0^{R}\mu\frac{3}{2}\frac{r^3 N}{\pi R^3}d\varphi.dr = \frac{3}{2}\frac{R^4 N}{4\pi R^3}2\pi$$

или

$$M_c = \frac{3}{4}\mu RN \tag{15}$$

Аналогично за местоположението r_x на интегралната сила на триене се получава:

$$r_x = \frac{3}{4}R \tag{16}$$

Коефициентите на триене при стартов и стационарен динамичен режим са съответно:

$$\mu_o = \frac{4}{3}\frac{F_o}{N} \qquad (17) \qquad\qquad \mu = \frac{4}{3}\frac{F}{N} \qquad (18)$$

или за коефициентите на триене, изразени чрез редуцирания коефициент μ_r следва:

$$\mu_o = \mu_r\frac{F_o}{N} \qquad (19) \qquad\qquad \mu = \mu_r\frac{F}{N} \qquad (20)$$

от където се получава:

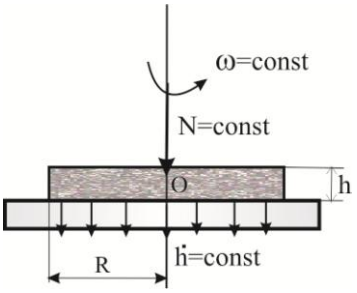
$$\mu_r = \frac{4}{3} \tag{21}$$

Редуцираният коефициент на триене μ_r е фактор, който характеризира влиянието на разпределението на налягането върху стандартизираната методика за измерване на коефициентите на триене.

4.КОНТАКТНА СИСТЕМА С РАВНОМЕРНО РАЗПРЕДЕЛЕНА СКОРОСТ НА ИЗНОСВАНЕ

Законът за износване по презумция се определя от закона за разпределение на налягането. Това твърдение по принцип е вярно за стационарния режим на износване, т.е. при стационарна скорост на износване.

Разглежда се случай на постоянна скорост на линейно износване $\dot{h}$ и хомогенно разпределение на износването – фиг.3.



Фиг. 3. Схема на контактна система с равномерно разпределена скорост на линейно износване $\dot{h} = k.p.v$

Скоростта на износване се представя във вида:

$$\dot{h} = k.p.v \tag{22}$$

където скоростта на плъзгане е $v = r.\omega$.

Тъй като $\dot{h} = const$ и $k = const$, то $p.v = p.r.\omega = const$, откъдето за изменението на контактното налягане се записва

$$p(r) = \frac{k\omega}{r} = \frac{k_o}{r}; \quad k_o = k.\omega$$

т.е. законът за контактното налягане има хиперболичен характер:

$$p(r) = \frac{k_o}{r} \tag{23}$$

От формула (23) за $p(R) = \infty$ следва $p(r) = \frac{k_o}{R}$.

Константата k_o се определя от условието за равновесие на вертикалните сили

$$\sum_i N_i = 0; \qquad N = \int_0^{2\pi}\int_0^R \frac{k_o}{r} d\varphi.r.dr = k_o R.2\pi,$$

откъдето се получава:

$$k_o = \frac{N}{2\pi R} \tag{24}$$

След заместване на (24) в (23) се получава законът за разпределение на контактното налягане, който гарантира равномерно износване на диска:

$$p(r) = \frac{N}{2\pi r R} \tag{25}$$

За няколко стойности на радиуса R по формула (25) се получават съответните стойности на налягането, представени в таблица 1.

Таблица 1. Контактното налягане при различни стойности на радиуса.

R	0	0,25R	0,5R	0,75R	R
p(R)	∞	$2N/\pi R^2$	$N/\pi R^2$	$0,67N/\pi R^2$	$0,5N/\pi R^2$

От (1) и (25) за елементарната и интегрална сила на триене се получава съответно:

$$dT = \mu.p.dS.dr = \mu\frac{N}{2\pi R.r}.r.d\varphi.dr; \; T = \int_0^{2\pi}\int_0^R \mu\frac{N}{2\pi R}.d\varphi.dr = \mu\frac{N}{2\pi R}2\pi R = \mu N \tag{26}$$

За съпротивителния момент от условието (4) следва:

$$M_c = \int_0^{2\pi}\int_0^R \mu\frac{N.r^2}{2\pi R.r} d\varphi.dr = \mu\frac{N}{2\pi R}\frac{R^2}{2}2\pi: \; M_c = \frac{1}{2}\mu R.N \tag{27}$$

За местоположението на интегралната сила на триене се получава:

$$r_x = \frac{1}{2}R \tag{28}$$

При измерване на периферната сила F_o за преодоляване на статичното триене и силата F при движение се получават съответните статичен и динамичен коефициент на триене:

$$\mu_o = 2\frac{F_o}{N} = \mu_r\frac{F_o}{N} \qquad (29) \qquad \mu = 2\frac{F}{N} = \mu_r\frac{F}{N}, \qquad (30)$$

откъдето редуцираният коефициент на триене е

$$\mu_r = 2 \tag{31}$$

В таблица 2 са представени стойности за редуцирания коефициент на триене μ_r и за местоположението r_x на интегралната сила на триене на факторите при различни форми на закона за разпределение на контактното налягане – постоянна, линейна и хиперболична.

Таблица 2. Стойности на редуцирания коефициент на триене и местоположението на силата на триене при различна форма на разпределение на контактното налягане

Разпределение на контактното налягане	$p(r)=const$	$p(r)=k.r=\frac{3}{2}\frac{N}{\pi R^3}.r$	$p(r)=\frac{k_o}{r}=\frac{N}{2\pi R}.\frac{1}{r}$
Редуциран коефициент на триене	$\mu_r=\frac{3}{2}$	$\mu_r=\frac{4}{3}$	$\mu_r=2$
Местоположение на силата на триене	$r_x=\frac{2}{3}R$	$r_x=\frac{3}{4}R$	$r_x=\frac{1}{2}R$

5.ЗАКЛЮЧЕНИЕ

Триенето в контактни системи с разпределени параметри зависи от закона за разпределение на контактното налягане, който от своя страна се променя и се определя от закона за разпределение на скоростта на износване в стационарен режим на работа на съединението.

В настоящата работа са получени теоретични резултати за големината и местоположението на интегралната сила на триене и за редуцирания коефициент на триене при стартов и динамичен режим в трибосистема „петов лагер” при три случая на разпределение на контактното налягане – постоянно, линейно и хиперболично.

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ABRASIVE WEAR IN DRY FRICTION OF CORROSION-RESISTANT STEELS

Galina KLITCHEVA

Abstract: *The comparative study on wear and wear resistance in dry abrasive friction of two types of different heat – treated cast details from stainless steels for use in pulp and paper industry was conducted. The behavior of both details in these conditions outside of the tribosystem as well as in the quality of a tribocouple was found and explained.*

Key Words: *wear resistance, abrasive friction, corrosion resistance steels*

ИЗНОСВАНЕ НА СТОМАНИ ТИП 1Х13 И 3Х13 ПРИ СУХО АБРАЗИВНО ТРИЕНЕ

Галина КЛИЧЕВА

Резюме: *Проведено е сравнително изследване относно износването и износоустойчивостта при сухо абразивно триене на два вида различно термообработени ляти детайли от корозионноустойчиви стомани тип 1Х13 и 3Х13 , предназначени за работа в целулозно – хартиената промишленост.Установено и обяснено е поведението на двата детайла в посочените условия извън трибосистемата и в качеството им на триводвойка.*

Ключови думи: *износоустойчивост, абразивно триене, корозионноустойчиви стомани*

ВЪВЕДЕНИЕ

Изследвани са детайли от корозионноустойчиви стомани (феритно – мартензитен и мартензитен клас), работещи при температури до 973К и продължителност на експлоатация до100000 часа, предназначени за целулозно – хартиената промишленост [1].

Целта на работата е да се проведе сравнително изследване на износването и износоустойчивостта на различно термообработени ляти детайли («ринг» и «ролка»), за машини за безкрайно хартиено платно, съответно от стомани 12Х13НМЛ (тип 1Х13) и 30Х13НМЛ (тип 3Х13) при сухо триене по повърхност със закрепен абразивървият ред на всеки абзац трябва да бъде на разстояние 0.7mm. Шрифт на основния текст – 10pt Arial, Justified. Междуредово разстояние - Single. Не се допускат празни редове между отделните абзаци. Заглавията на разделите трябва да бъдат отделени от текста с по един ред преди и след. Препратките към литературни източници трябва да се означават в квадратни скоби, както е показано[1, 2, 3].

I. ЕКСПЕРИМЕНТАЛНА ПРОЦЕДУРА

Химичният състав на стоманите в тегловни проценти, е даден съответно в таблици 1 и 2.

Таблица 1. *Химичен състав на стомана 12Х13НМЛ*

C	Si	Mn	Cr	Ni	V	Mo
0.15	0.36	0.66	12.92	1.60	0.06	0.55

Таблица 2. *Химичен състав на стомана 30Х13НМЛ*

C	Si	Mn	Cr	Ni	V	Mo
0.29	0.41	0.65	13.10	1.60	0.05	0.50

Термообработката по режим Т1 представлява отгряване при температура 1123К, задържане в продължение на 3 часа и охлаждане с пещта. Термообработката по режим Т2 представлява нормализация (нагряване до температура 1293К, задържане в продължение на 4 часа и охлаждане не въздух), с последващо отвръщане (нагряване до температура 723К, задържане в продължение на 2 часа и охлаждане с пещта) [2].

За целта на експеримента бяха изработени цилиндрични образци с размери ∅ = 8 mm и h = 15 mm.

Описанието на образците е представено в таблица 3.

Таблица 3: *Описание на изследваните образци*

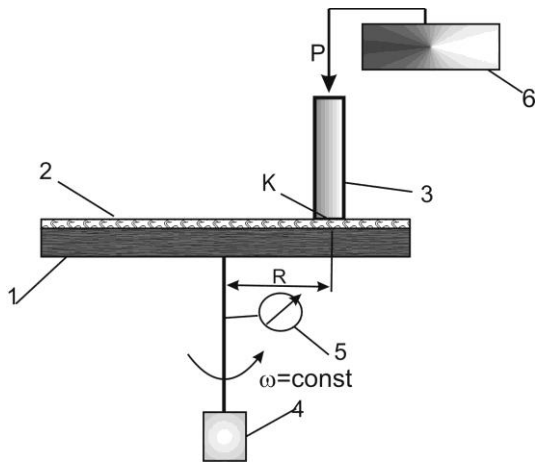
№ на образеца	Обозначения	Технология
1.	**Ro**	Ринг, ст. 1Х13 без термообработка
2.	**RT1**	Ринг, ст. 1Х13 Термообработка Т1
3.	**RT2**	Ринг, ст. 1Х13 Термообработка Т2
4.	**Bo**	Ролка, Ст 3Х13 без термообработка
5.	**BT1**	Ролка, ст. 3Х13 Термообработка Т1
6.	**BT2**	Ролка, ст. 3Х13 Термообработка Т2

II. УСТРОЙСТВО И МЕТОДИКА ЗА ИЗСЛЕДВАНЕ

Експерименталното изследване се осъществява по методика и с устройство за ускорени изпитания по кинематичната схема „палец-диск", разработени в центъра по трибология в МТФ – ТУ-София [3].

Функционалната схема на устройството е представена на фиг. 1.

Изследваният цилиндричен образец 3 (тяло) се монтира неподвижно в натоварващата глава 6 по такъв начин, че челната му плоска повърхност контактува с абразивната повърхност 2 на хоризонтален диск 1 (противотяло). Противотялото 2 се върти с постоянна ъглова скорост $\omega = const = 6{,}28\ [s^{-1}]$ около вертикалната си ос. Броят на оборотите се отчита с оборотомера 5. Устройството позволява изменение на скоростта на плъзгане на образеца. Това може да се осъществи по два начина: чрез изменение на ъгловата скорост на диска от управляващ блок 4 и чрез изменение на разстоянието R между оста на въртене на противотялото 1 и оста на образеца 3 спрямо оста на въртене на диска. В настоящия експеримент $R = 3{,}12\ [cm]$, а скоростта на плъзгане е $V = 19{,}6\ [cm.s^{-1}]$.



Фиг. 1: *Функционална схема на устройство за изследване на износването при твърдо закрепен абразив*

Абразивната повърхност 2 на противотялото 1 представлява импрегниран корунд с твърдост 60% по-висока от твърдостта на изпитваните материали в съответствие с изискванията на действащите стандарти [4].

Методиката включва следните последователни операции:

1. Подготовка на повърхността на цилиндричните образци 3 чрез шлайфане и полиране до еднаква грапавост, като се вземат мерки за предотвратяване на структурни и физико-химични промени в повърхностния слой на образците. Описанието на образците е представено в таблица 1. Грапавостта е $R_a = 0{,}25\ [\mu m]$, измерена с профилограф **TESA Rugosurf 10G**;

2. Измерване на масата на образците преди и след изминаване на определен брой цикли (път на триене L) с помощта на електронна везна **WPS 180/C/2,** с точност $0{,}1\,[mg]$. При всяко измерване образците се почистват с подходящ разтвор за предотвратяване на статичното електричество;

3. Образецът 3 се монтира в натоварващата глава, задава се желаното нормално натоварване P и път на триене L чрез брояч на обороти 5;

4. Пресмята се абсолютното масово износване $m\ [mg]$ като разлика между масата на образеца преди и след определен брой цикли N (път на триене L).

Основните показатели на износването са следните:

1. Абсолютно масово износване, $m\ [mg]$ - разлика между масите на образеца преди и след определен път на триене L;

2. Скорост на масовото износване dm/dt [*mg/min*] - разрушената маса от повърхността на образеца за време една минута;

3. Абсолютна интензивност на износване i - разрушената дебелина h на повърхностния слой за единица път на триене. В настоящата методика разрушената дебелина h на повърхностния слой, изразена чрез износването m, представлява бездименсионно число, което се пресмята по формулата:

$$i = \frac{m}{\rho . A_a . L}\ , \qquad (1)$$

където: ρ е плътността на материала на образеца - $\rho = 7{,}8.10^3\ \left[kg/m^3\right]$; A_a е номиналната контактна площ на взаимодействие, а L е пътят на триене, който се пресмята чрез съответния брой цикли N на контактно взаимодействие, по формулата:

$$L = 2\pi RN \qquad (2)$$

4. Абсолютна износоустойчивост I - пресмята се като реципрочна стойност на интензивността на износване и съответно също е бездименсионна величина, т.е.:

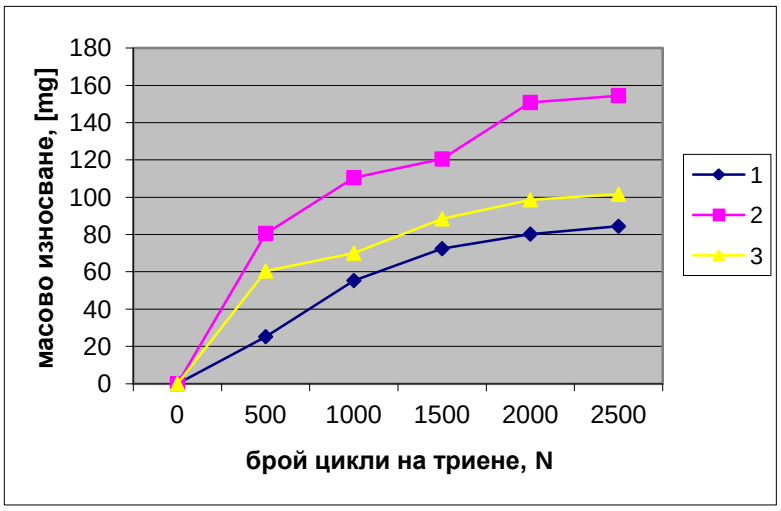
$$I = \frac{1}{i} = \frac{\rho . A_a . L}{m} \qquad (3)$$

Данните от експеримента са представени в таблица 4.

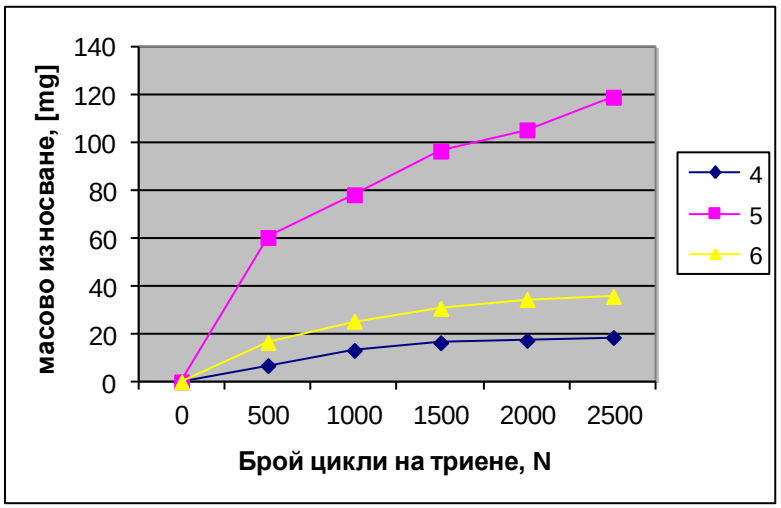
***Таблица 4**: Параметри на експеримента*

Параметри	**Стойности**
Номинално контактно налягане, p_a	$20{,}6\ [N/cm^2]$
Средна скорост на плъзгане, V	$19{,}6\ [cm.s^{-1}]$
Номинална контактна площ, A_a	$50.10^{-6}\ [m^2]$
Контратяло	Корунд Р 320
Нормално натоварване	10,3 [*N*]

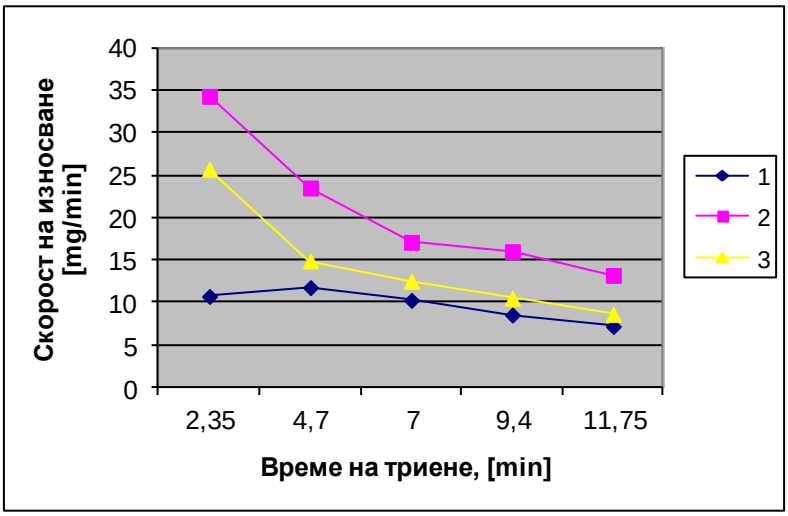
III. ЕКПЕРИМЕНТАЛНИ РЕЗУЛТАТИ



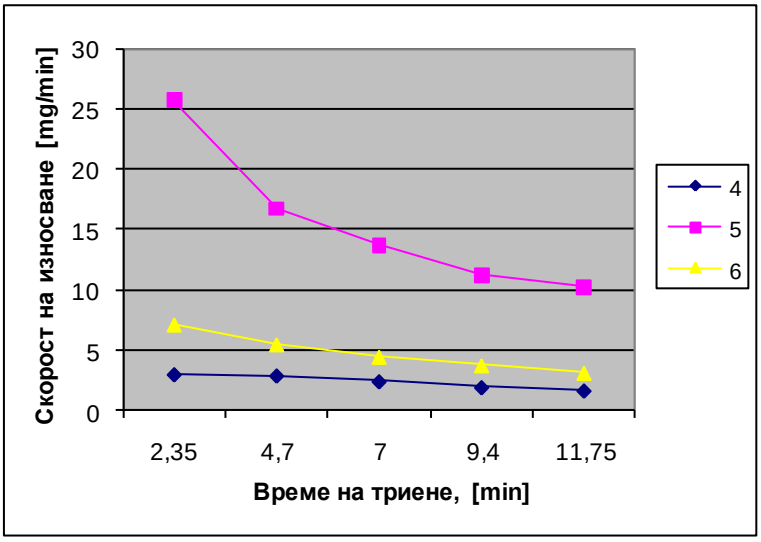
Фиг. 2: *Зависимост на масовото износване от броя цикли на триене на образци № 1, 2, 3*



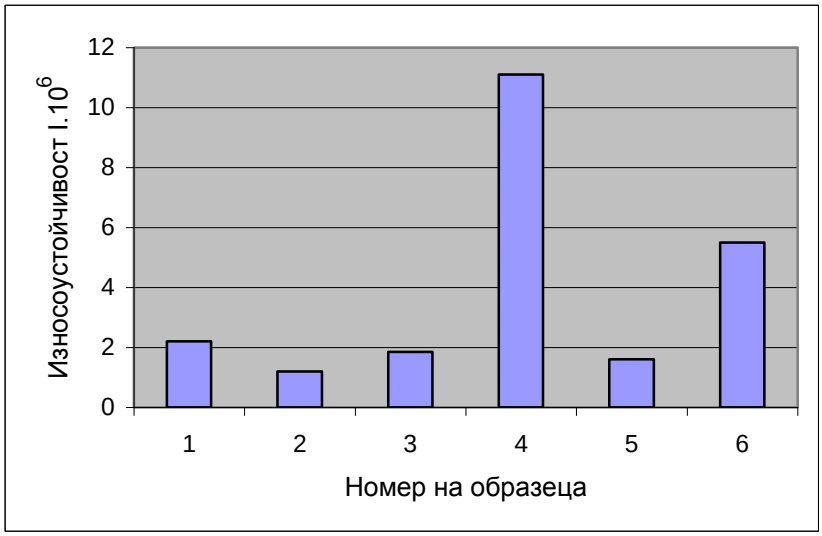
Фиг. 3: *Зависимост на масовото износване от броя цикли на триене на образци № 4, 5, 6*



Фиг. 4: *Изменение на скоростта на масовото износване от времето на образци № 1,2,3*



Фиг. 5: *Изменение на скоростта на масовото износване от времето на образци № 4,5,6*



Фиг. 6: *Износоустойчивост на образците при* $N = 2500$

IV. АНАЛИЗ И ИНТЕРПРЕТАЦИЯ НА ЕКСПЕРИМЕНТАЛНИТЕ РЕЗУЛТАТИ

На фиг. 2 се виждат зависимостите на масовото износване от броя на циклите на триене при образци от детайл „ринг” (ст. 1Х13) без термообработка (Ro) и термообработени по режими Т1 и Т2 (съответно RT1 и RT2). Прави впечатление, че независимо от броя на циклите, образците от детайл „ринг” без термообработка показват най- малко масово износване, а най – силно се износват образците от детайл „ринг”, подложени само на отгряване (режим Т1). Междинно положение по този показател заемат образците от детайл „ринг”, преминали термообработка по режим Т2 (нормализация и отвръщане).

На фиг. 3 са показани зависимостите на масовото износване от броя на циклите на триене при образци от детайл „ролка” (ст. 3Х13) без термообработка (Во) и термообработени по режими Т1 и Т2 (съответно ВТ1 и ВТ2). Ходът на кривите е аналогичен, както при образците от детайл „ринг” (фиг. 2), но тук масовото износване е забележимо по – ниско, т.е., детайл „ролка” се износва по- слабо от детайл „ринг” при едни и същи условия.

На фиг. 4 е представено изменението на скоростта на масовото износване от времето на триене при образци от детайл „ринг” (съответно Ro, RT1 и RT2). Вижда се, че и по този показател, образците без термообработка (Ro) имат най – благоприятно поведение, следвани от образците, преминали термообработка по режим Т2 (RT2) - (нормализация и отвръщане), а най – висока скорост на износване показват образците, подложени само на отгряване (режим Т1) – (RT1).

Аналогично, на фиг. 5 наблюдаваме най – ниска скорост на износване при образците от детайл „ролка” без термообработка (Во), най- висока скорост на износване отново показват образците от детайл „ролка”, преминали термообработка по режим Т1 (ВТ1), а образците от детайл „ролка”, подложени на нормализация и отвръщане (режим Т2) – (ВТ2), заемат междинно положение и по този показател. Скоростта на износване при образците от детайл „ролка”, обаче, като цяло е по- ниска от тази при образците от детайл „ринг”.

На фиг. 6 е показана износоустойчивостта на всички изследвани образци при брой цикли на триене N = 2500. Логично, при така представените резултати, износоустойчивостта на образците от детайл „ролка” е забележимо по – висока от тази на образците от детайл „ринг” при едни и същи условия, като най – добра е тя при тези от тях, които са без термообработка (с около 80%), следвани от такива, преминали термообработка по режим Т2 (нормализация и отвръщане) – с около 30%. Детайл „ринг” без термообработка показва с около 15% по- висока устойчивост срещу абразивно разрушаване от същия детайл, преминал термообработка по режим Т2. Детайл „ролка” без термообработка показва с около 50% по- висока устойчивост при тези условия от същия детайл, подложен на термообработка по режим Т2.

V. ЗАКЛЮЧЕНИЕ

Проведени са изследвания за износване и износоустойчивост при сухо абразивно триене на два вида детайли от корозионноустойчиви стомани (тип 1Х13 и 3Х13), работещи като трибодвойка в съоръжения за целулозно – хартиената промишленост.

От анализа на експерименталните данни е установено, че самостоятелното поведение (извън трибосистемата) на детайл „ролка” (ст. 3Х13) в посочените условия е по- благоприятно от това на детайл „ринг” (ст. 1Х13) за всички изследвани показатели.

В зависимост от термообработката най – висока износоустойчивост (съответно най – малко износване) при едни и същи условия показват детайли „ринг” и „ролка” без термообработка, като за детайл „ролка” стойностите на тези показатели са по – добри.

Детайлите и от двата вида, подложени само на отгряване, имат най – лоши качества (извън трибосистемата), а детайлите, преминали пълен цикъл на термообработка (нормализация и отвръщане) заемат междинно положение по отношение на износването и износоустойчивостта. По – ниската износоустойчивост на детайлите „ринг” и „ролка” след пълен цикъл на термообработка (режим Т2) в сравнение с нетермообработените детайли, вероятно се дължи на по-ниската пластичност на повърхностния слой (поради уякчаващата термообработка), което води до по-слаба демпфериращa способност на материала. Като резултат, абразивните зърна на контратялото предизвикват „надраскване” на повърхността, т.е. увеличават абразивното износване.

В термообработено състояние по режим Т2 двата детайла са подходящи за работа като контактна система, тъй като е намерен подходящ баланс между твърдост, якост и пластичност на контактуващите материали.

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T R I B O L O G Y
A BRIEF HISTORICAL OVERVIEW

Tzonka KOSTEVSKA

Abstract: *This report provides a brief historical overview of the development of tribology, as a science that spread knowledge from antiquity to the present day and their application in practice.*

Key Words: *Tribology, principles and history.*

Tribology is the science of the mechanisms of the contact and friction between bodies which are capable of relative motion with respect to one another, including when the object moves in a gaseous or liquid medium. It involves the study and application of nature, principles and application of friction, lubrication and wear of the elements make contact. Applied Tribology called tribotechnology /tribotechnics/.There are also tribochemistry and tribophysics.

The word tribology is composed of the Greek radix τριβο (friction) and λογος (word, speech, science). British physicist Professor David Tabor (1913 - 2005) He offers it in 1966 [1]. He is head of the Laboratory "Cavendish", Cambridge, UK, where he deals with the study of physics and chemistry of solids. Worked as assistant to Gonville and Caius College, Cambridge, in 1957, he has won several awards for his research, and the first gold medal for his work in the field of tribology, which is proposed by the Institution of Engineers in 1972. [1]

Tribology should be seen not only as a system of knowledge about the contact structure and interaction of material, but also as a complex system of production and implementation of information theory, materials, products and technologies in the scientific - technical area. Processes friction and wear and lubrication as well as those that are associated with them, have been used in time and studied for various uses in the production and development of scientific theories.

The man known for more than 100,000 years how by rubbing two pieces of wood - hard inside the soft, receive fire.

Objects, buildings and monuments from ancient times show that the wheel and later the carriage was invented about 4000 BCE Wheels were used from 4000 - 3500 BC It is thick, and sometimes consists of several parts assembled together. Rays wheel was invented around 2500 - 2000 BC година initially with 4 beam (spokes), and later with six or eight of them, which makes it significantly harder.

Scientists believe that the first steps made towards greater use of friction in everyday life were found in Mesopotamia and dates back 2500 years BC It is found stone elements (hinges) for doors that were used as such timber through shaft which rotates in a hollow tree or rock drilled. [5]

Man has used carts on wheels to carry heavy loads on tree trunks. Egyptians are sliding heavy loads on roads, probably made of wood, which were very well lubricated before the object can be moved by them.

Transportation of large stone blocks for construction of buildings and monuments, military equipment and troops required to reduce the friction in the process of moving. Materials such as water, fats and oils are used as lubricants in vehicles of that time - for example, the road a head sleds.

There are reliefs as those of Saqqara tomb of 2,400 years n.e etc. that show the movement of a statue of you and in front of her on the road, a man who poured liquid - water or oil to facilitate sliding. This is the first known example of the performance of lubrication. Relief from 1880 BC (Fig. 1), on the other tomb shows the same method of transport statuya.Chovekat who poured water here is already on the pedestal of the statue and not on the road - a place where it can be crushed.

This shows that our ancestors had respect on reducing friction rectilinear motion. The importance of lubrication is recognized.

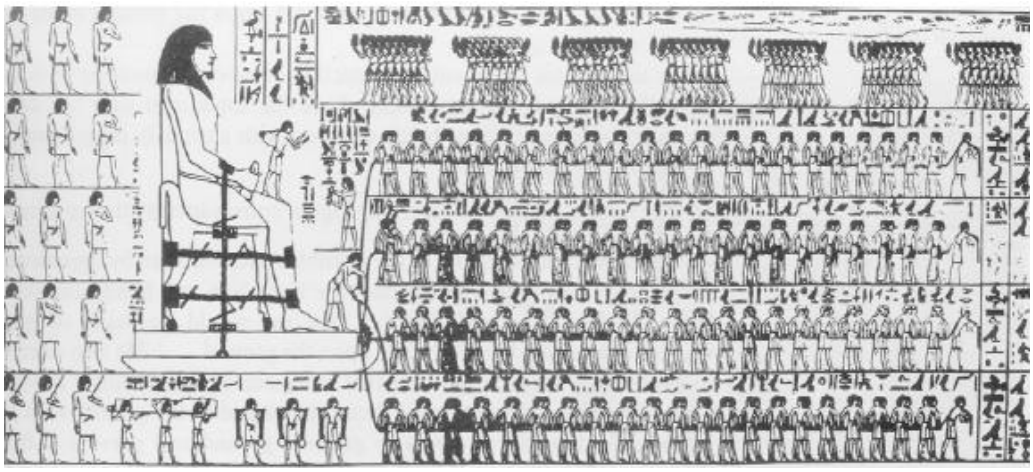


Fig.1.*Transport a statue, grave Tchuti Hetep, El-Lersheh, Egypte, 1880 h*.

We see that in this transport were used 172 slaves to be dragged sled with large statue weighing 600 kN and a wooden path. This is probably one of the earliest engineering of humanity, respectively, and such an attempt to make the process "lubrication". Some modern scholars have calculated that each man exercise the pull of about 800 N.Vaz on this common effort should at least force equal to the friction force becomes 172 x 800 N.Koefitsientat friction is about 0.23. Chariot found in an Egyptian tomb provides evidence for the use of lubricants - Original animal fat used to grease the bearings.

Egyptians used vehicles (some authors call them trucks) on wheels for transport during the war to 1400 BC Sheep or beef tallow were used to lubricate the wheels.

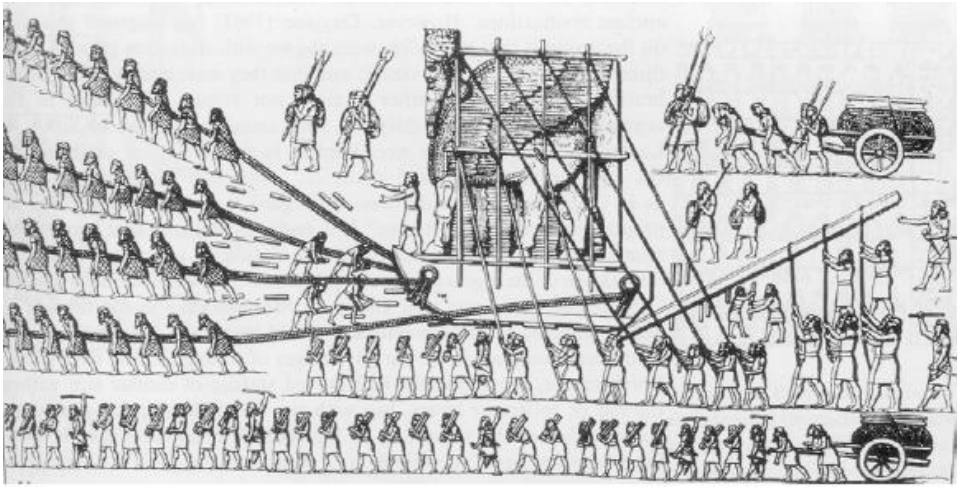


Fig.2 *Bas - relief 'estaure a Kouynjik, Assyrie, / bas-relief of Koiyumdzhik, Asiriya/700 years bc*

Relief from Kouynjik, Assyrie, dating from 700 g.pr. n is (Fig. 2) clearly shows the movement on wooden rollers (boards) of a sled on which is placed a statue. There are four human figures in front of the statue, which pour liquid over it. This technical solution shows that the people were well aware of friction process and the fact that lubrication by fluid (water or oil) replaced friction plazgane.Tova is osiguryavapo rapid movement of large objects - in this case the carriage. Wheel spokes appeared in India around 2,500 BC and in China in 1500 years BC The wheels of iron dates back to 255 years BC in China (Figure 3)

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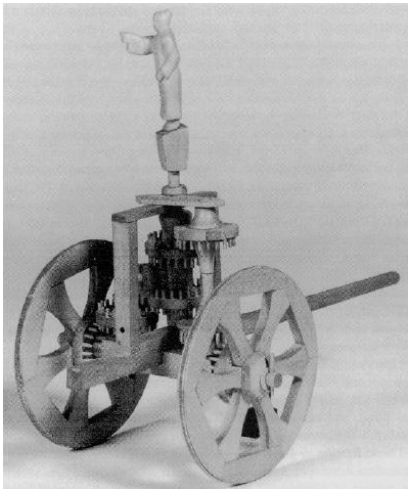


Fig. 3 *Trolleys Guidance, China, 255 years bc*

There are historical documents which can be seen vehicle (truck) loaded with a very special statue that rotates through two related wheel gears and differential. The distance between the wheels is equal to their diameter and the ratio of the two gears is equal to 1. Hand of the statue remains constantly out in the same direction (south) and thus, regardless of the path traveled by carriage of flat, provided that there is no slip between the bearing wheels and the ground. This truck probably was used by the Chinese to move when crossing the Gobi Desert. [3]

The Greeks and Romans used wheel. They are known animal and vegetable oils as lubricants. Greeks invented the screw gear. Aristotle, Archimedes, and other lesser-known authors describe the principle of operation of various equipments.They are using in Alexandria the same camshaft. In fact, the Greeks had all the elements needed for a great technical progress, but ..... Crank, angled leve, serves to initially enforce the motor was invented in the fourteenth century. However, there was no real development of machines for different reasons. The main reasons may be the lack of wood and energy, problems in the hydraulic transport associated with inadequate road network, the existence of slavery and foremost way of thinking, which recognizes only pure thinking and rigorous evidence leaving no room for experimental logic.

Romans are using and are developing techniques developed by the Greeks. They have made significant progress in the production of olive oil and grind grain. Water mills were used to 120 BC.

Leonardo da Vinci (1452-1519) was the first that deals with the study of the laws of friction, but unfortunately his records are not well understood and many authors do not dare to offer his research to the attention of modern scholars.

Charles Augustin de Coulomb (Charles Augustin de Coulomb 1736-1806) is French physicist and military engineer officer, one of the founders of the electrostatics. He doing research in the field of friction. He published them in 1779 in " Theorie des machines simples" with analysis of friction in mashines. He is writening 25 articles between 1781 and 1806 on topics from the fields of electricity, magnetism, friction and twists.

Amonton Guillaume (Fr. Guillaume Amontons; 1663-1705) - French engineer and physicist and member of the French Academy of Sciences, one of the pioneers in the field of tribology. He studied mathematics, geodesy, applied mechanics and celestial mechanics alone, as has been deaf from birth. It is known for developing Coulomb's law Amonton-author and labor «Remarques et experiences physiques sur la construction d'une nouvelle clepsydre, sur les baromètres, thermomètres et hydromètres» (Paris, 1695), as well as many other developments in the field mechanics, thermometers and molecular physics, reflected in the memoirs of the French Academy of Sciences in 1699.

Law Amonton - Coulomb

The basic equation in makrotribology expressed by the law of Amonton - Coulomb. It connects proportional friction and normal reaction force / normal load /. [4] The force of friction, as - the general case and the normal load (or under normal reaction) are associated with the inequality:

$$|F| \leqslant \mu N_{normal}\,, \tag{1}$$

where μ, the coefficient of friction and without dimensional edinitsa.Tova ratio turns to draw only in the presence of relative movement. This ratio is called the law of Amonton – Coulomb. The main feature of friction is μ, the friction coefficient, which is determined by the materials making up the surfaces of the interacting bodies. He carries all the information about tribology. Depends on many factors, some of which have a thickness of the surface layer, the temperature, humidity, velocity and relative movement. It exists law Amonton - Coulomb which adhesion has been reported: The value of the coefficient of friction μ, of not more than 1 and is located in the range 0.1 to 0.5 for the majority of couples interacting materials. When the friction coefficient is greater than 1 $(\mu > 1)$, this means that the contact between the bodies is a force of adhesion $N_{adhesion}$ and the formula for calculating the coefficient of friction changes as follows:

$$\mu = \frac{F}{N_{normal} + N_{adhesion}} \tag{2}$$

Today, many researchers based on their research have reached the knowledge that the simplified representation of the friction force as a function of normal load proved untenable theoretically and experimentally. It was found that the frictional force is not a function of the normal load and the operator of the process which occurs at one or another combination of the normal load, the sliding speed and the parameter vector of friction. [2]
Problems that arise in friction by reducing wear, lubrication, tightness, and thus the quality and reliability of the plant and equipment to achieve energy savings, materials and labor leads generally to achieve greater economic impact on the holding of the state.
Tribology is a kind of art of applying operational analysis of problems of great economic importance of reliability, maintenance and wear of equipment, covering products from spacecraft to household appliances.
Surface interactions in the field of tribology are complex and their understanding requires knowledge of different disciplines - physics, chemistry, applied mathematics, mechanics of solids, fluid mechanics, thermodynamics, heat transfer, materials science, rheology, lubrication, machinery design, performance and reliability.
The friction between bodies at their point of contact, there is an electronic nature. The main source of friction in the superconducting state, the phonons are, as the coefficient of friction can be reduced several times. Phonon means "voice" in Greek. Phonon is a formal object-like quasiparticles, which are used in various areas of theoretical physics and viewed in terms of solid state physics, describes the quantum oscillation (quantum mode of vibration), which occurs in the solid crystal structures, atomic lattice of the solid bodies. Processes occurring at the atomic lattice of solids explain some of their basic properties, such as thermal and electrical conductivity. The phonons whose frequency is determined by the wave length, are responsible for the emergence of the "sounds" in solids.
The man is understood in antiquity that discovering friction is complicated. It can partly be achieved through comprehensive research. It self rubbing bodies accompany the existence of the whole of nature. Its presence allows us to move on the surface of the Earth. Walking is a process which is impossible without friction. We go up because our only contact is touching the surface of which we reject, and overcoming friction. Friction is accompanied by different, their physical nature, phenomena such as exelektronics emission luminescence, spectroscopy statistical discharges, thermal or chemical processes. Existing continuous mechanism of destruction and formation adhesion connections in the area of contact friction in the process, creates mechanical vibrations in a very wide range of frequencies. The latter starts from the sound frequencies that we know as grinding or music and ends with ultrasonic frequencies, which represents friction ultra sound emision.Ultrasound is sound with a frequency of about 20 kNz.That frequency greater than the upper limit of human hearing. Some animals, such as dogs (up to 45 kHz), dolphins (up to 150 kHz) and bats (up to 110 kHz) have a higher limit than that of the human ear and can hear ultrasound and possibly a special way to mark progress friction.
Every human being daily encounter with the forces of friction. What will our world is no traction and hence no friction, no action is not accompanied by resistance? We know with certainty that a world without friction is more unbearable than the world where there is friction and accompany our lives.
Tribology as science is taught too little for a number of reasons. Is often ignored as a separate subject in educational programs as it weaves a thin thread of knowledge in many other areas of science and technology, such as metalworking, lubrication action is today and everyday duty in engineering, the study of contact as undeniable process from reality, the use of ultrasound in many areas of our lives

and others.

We know that trivial problems have not received a satisfactory solution to this day. We can very well solve many problems of everyday life, when she met the manifestations of friction and whoever finds a solution will probably be free the misery for centuries.

Knowledge from the field of engineering, chemistry, physics and tribology today offer extensive fields of development and implementation in technology, as well as alleviate the problems of the everyday life associated with friction and the world economy as a whole.

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MONITORING OF TECHNOLOGY PROCESSES WITH CAQ-QMSYS - PROCESS CAPABILITY INDEX AND RATIO

Olga KARAKOSTOPULO

Abstract: *The use of statistical methods is a way to ensure a production process with minimum rejects. The paper presents process capability index and process performance index and how they are used for monitoring of* technology processes*. The use of quality assurance software to ensure quality is present.*

Key Words: *process capability index, process performance index*

КОНТРОЛ НА ТЕХНОЛОГИЧНИЯ ПРОЦЕС С ИЗПОЛЗВАНЕТО НА QMSYS -СТАБИЛНОСТ И НАСТРОЕНОСТ НА ТЕХНОЛОГИЧНИЯ ПРОЦЕС

Олга КАРАКОСТОПУЛО

Резюме: *Използването на статистически методи за контрол е средство за осигуряване на производствен процес с минимален брак. В статията се представени коефициентите характеризиращи процесите и тяхното приложение. Показано е и приложението на софтуер за управлението на качеството при този контрол.*

Ключови думи: *коефициент на способност, коефициент на настроячност.*

1.ВЪВЕДЕНИЕ

В съвременния свят всички фирми, които искат да са конкурентно способни на пазара трябва да се сертифицират по ISO 9001. Този сертификат е гаранция, че това, което се произвежда във фирмата отговаря на документация/изискванията на клиента и че фирмата може достатъчно адекватно и своевременно да реагира при възникнали "проблеми" при производството и да идентифицира смущенията в производствения процес.

Използването на контролните карти дава възможност да се следят контролираните размери от дадена серия детайли или при дребно серийно производство състоянието на процеса.

Преди да се избере определен вид контролна карта, е необходимо чрез предварителни изследвания да се анализира качествената способност на процесите. Това изследване се извършва при реални условия на производствения процес, при които въздействат всички възможни фактори.

От разпределението на стойностите на параметрите при предварителните изследвания се съди и за разпределението им за общата съвкупност. При това е необходимо да се оцени разпределението на параметрите и тяхната промяна във времето.

2.ХАРАКТЕРИСТИКИ НА ПРОЦЕСА

Когато имаме един процес на производство върху него действат случайни и систематични грешки. В резултат от това размерите на детайла се отклоняват от номиналната стойност. Целта на производството, а по специално на отдела по качество е да гарантира такъв процес, че отклонението от номинално положение да е в границите на допуска на детайлите. Това се постига с помощта на статистическите методи - на статистическия контрол на процесите.

Следенето на размерите с контролните карти започват след като сме настроили системата. Това означава всички звена, които участват в производствения процес да са настроени така, че да гарантират производството на годни детайли. Също така при този процес на настройка трябва да се осигури достатъчен запас, за да може "системата" да бъде дълго време в

стабилно състояние без да се поднастройва. Всяка една поднастройка е свързана със средства - разходи и спиране на процеса за известно време.

Процесът може да се определи като овладян, когато резултатите, които получаваме са стабилни и възпроизведими. Стойностите не се изменят или се изменят само в допустими познати граници.

Факторите, които характеризират един процес са два: точност и стабилност на процеса. Точността не се поддава на влияние и зависи само от качеството на самия процес. Характеризира се с разсейване, дължащо се само на случайни колебания и се определя от технологичното оборудване и от организацията на управление на производствените процеси.

Стабилността се определя от постоянство на средната стойност на даден процес. Влияние указват външни причини - различни партиди материал, настройване на машината, оператори и др. Стабилността може да бъде повлияна и управлявана на производствено ниво. Тя може да бъде визуализирана и контролирана с контролни карти

Тези две величини се оценят статистически, като се приема, че процесите имат нормално разпределение. Различава се показатели определящи процесите и такива характеризиращи машината.

Коефициентът на разсейване C_P (C_m за машина) Нарича се още коефициент на точност. Характеризира ширината на разсейване на стойностите на процеса (машината) в сравнение с ширината на зададения допуск

$$C_p = \frac{T}{V} = \frac{T_Г - T_Д}{6\sigma} \quad (1)$$

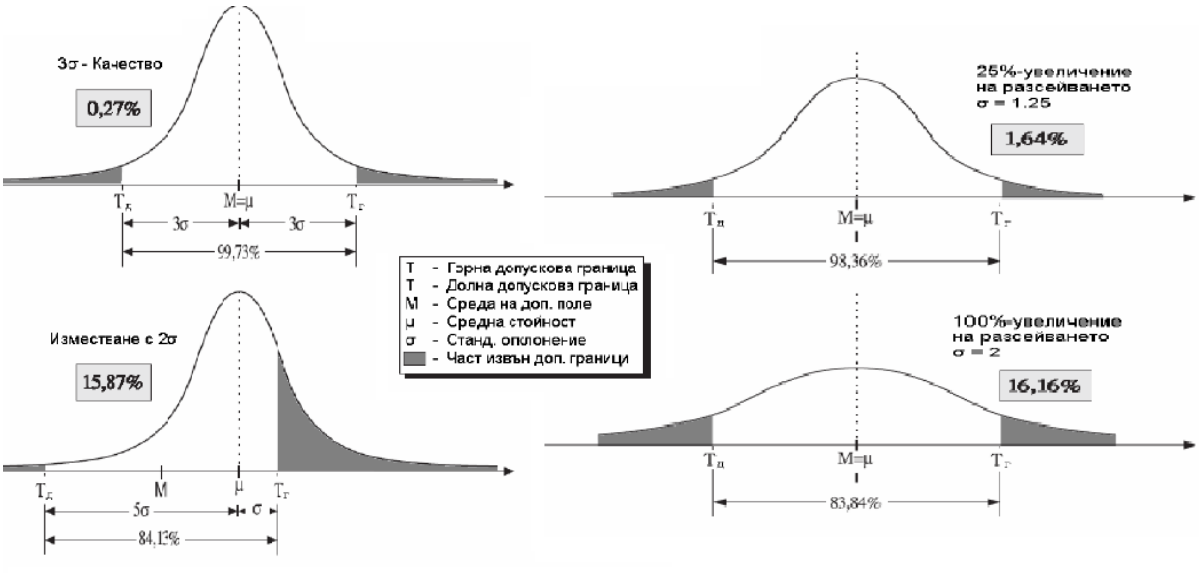
където T е допуска, а σ - стандартно отклонение на извадковите средни стойности

Стремежът е да се постигне разсейване, което е по-малко от ширината на допуска на контролируемият параметъра.

Коефициентът на положение $C_{Pк}$ ($C_{mк}$ за машина). Характеризира положението на средните стойности на процеса (машината) спрямо границите на допусковото поле. Определя се по следната зависимост:

$$C_{pк} = \frac{T_Г - \overline{X}}{3\sigma}(\frac{\overline{X} - T_Д}{3\sigma}) \quad (2)$$

където $T_Г$ и $T_Д$ са горната и долната гранични стойности, а X е средна стойност на общата съвкупност.



Фиг. 1. Процент детайли извън допусковото поле в зависимост от големината на изместване на центъра на групиране

Средната стойност на процеса трябва да е настроена да съвпада със средата на допуска, за да се избегне попадане на стойности извън границите на допусковото поле. На фиг.1 [6]е представено влиянието на измесването на центъра на групиране спрямо средата на допусковото поле върху качеството на произвежданите детайли. Когато средната стойност съвпада със средата на допуска и разсейването на размерите е ±3σ, то вероятността да имаме

детайли извън допуск е 0,27 %. Ако се запази разсейването ±3σ, а центъра на групиране се измести с 3σ към долната допускова граница, то вероятността за получаване на негодни детайли нараства до 15,87%. При промяна на разсейването на ±2σ при съвпадане средната стойност съвпада със средата на допуска вероятността за получаване на негодни детайли нараства до 16,16%.

3.ПРИЛОЖЕНИЕ НА КОЕФИЦИЕНТИТ

Стойностите, които заемат коефициентите на разсейване и на способност дават информация какъв процент от изделията, излезли от дадено производство са годни. По такъв начин една фирма, проверявайки и измервайки регулярно тези коефициенти може да гарантира пред клиента си какво е качеството на производството й. Измерването, при входящ контрол, в процедура, която е свързана с време, за осъществяване на този процес и също така със средства. Има детайли, при които контрола е разрушаващ. Начин за избягване на входящия контрол е подържането на тези коефициенти в предписани граници, което е едно от изискванията за доставчиците напр. на автомобилната промишленост.

3.1. ИЗСЛЕДВАНЕ И ДОКАЗВАНЕ СПОСОБНОСТТА НА МАШИНАТА

Този вид изследване се извършва при инсталиране на нова машина или преспособление, след текущ ремонт, подмяна на обработващи инструменти и други събития, влияещи върху разсейването на параметрите на продуктите.

Взема се голяма извадка от 50-100 изделия. Целта е да се изследва способността на машината или приспособлението и затова трябва да се избягва влиянието на различни външни фактори – оператор, материал, режим на работа и други. Препоръчително е да се измерват детайли, произведени от една смяна, от един доставчик на материал (една партида).

Таблица 1. Минимални изисквания за способност на машината

Машина	Показател	Допуск	Стойности извън допуска
Способна	$C_m \geq 2,00$ $C_{mk} \geq 1,67$	$T \geq 12\sigma$	< 0,6 PPM <0,00006%
Условно способна	$2,00 > C_m \geq 1,67$ $1,67 > C_{mk} \geq 1,33$	$12\sigma > T \geq 10\sigma$	< 63,4 PPM <0,0063%
Неспоспособна	$C_m < 1,67$ $C_{mk} < 1,33$	$T < 8\sigma$	> 63,4 PPM >0,0063%

Способността на машината се доказва с показателите за положение и разсейване на параметрите Cm , Cmk. В табл.1 [6] са представени различни стойности на тези коефициенти и процента брак на 1000000 (PPM), за различните случай.

3.2. ИЗСЛЕДВАНЕ И ДОКАЗВАНЕ СПОСОБНОСТТА НА ПРОЦЕСИТЕ

Този вид изследване се извършва при въвеждане на нов процес или нов продукт или когато изискването на клиента е да се следи и документират тези коефициенти. За проверката се вземат от 20 до 50 малки извадки (3-10 изделия) за продължителен интервал от време. Необходимо е да отчете влиянието на повече фактори, заради това извадките се вземат от различни смени и оператори, за няколко машини и материали.

Таблица 2. Минимални изисквания за способност на процесите

	Показател	Допуск	Стойности извън допуска
Способна	$C_P \geq 1,67$ $C_{pk} \geq 1,33$	$T \geq 10\sigma$	< 63,4 PPM <0,0063%
Условно способна	$1,67 > C_p \geq 1,33$ $1,33 > C_{pk} \geq 1,00$	$10\sigma > T \geq 6\sigma$	< 2700 PPM <0,27%
Неспоспособна	$C_p < 1,67$ $C_{pk} < 1,33$	$T < 6\sigma$	> 2700 PPM >0,27%

Способността на процеса се доказва с показателите за положение и разсейване на параметрите Ср , Cpk. При анализ на процесите в предварителна пробна серия преди започване на серийното производство се използват показателите Pp и Ppk , които се изчисляват аналогично Ср и Cpk. В табл.2 [6] са представени стойностите, които трябва да заемат тези коефициенти, когато искаме да имаме способен процес. При специални изисквания на клиенти тези коефициенти могат да заемат и по високи стойности.

4.ПРИЛОЖЕНИЕ НА СОФТУЕРА

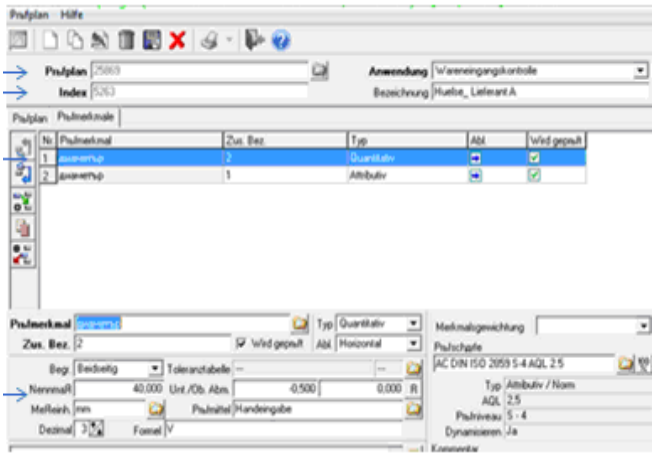
За да се оцени способността на един процес или една машина е необходимо извършването на голям брой измервания и последващата статистическа обработка на резултатите. Необходимо е дори да се оцени достоверността на зададените данни (стойности). Използването на специализиран софтуер QMSys улеснява извършването на изчислителната работа, спестява време, като дава възможност и автоматично да се получава необходимата документация. При използването на електронен шублер (или друг измервателен уред) данните могат да се въвеждат автоматично в системата - софтуера.

Първо в програмата се въвежда детайла, като артикул. Системата задава автоматично номер и се очаква от потребителя да се въведат данни за: размерите, които ще проверяват, какви измервателни уреди ще се използват, името на служителя, който ще измерва и датата. На базата на този артикул се генерира и план за измерване.

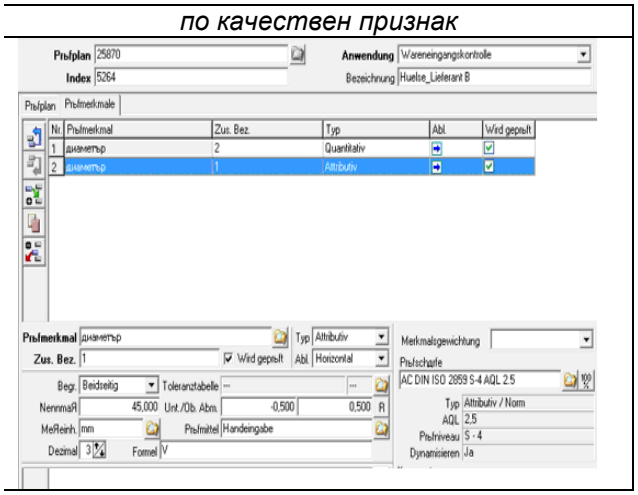
На фиг.2 е показан прозорец от системата QMSys, на които е показан измервателния план на входящ контрол на втулка. Единият диаметър има зададен допуск ø40 $_{-0}^{+0,5}$, а другия е със свободен размер ø45. За диаметъра с допуск се извършва проверка по качествен признак, а за свободния размер - по количествен, тъй като в този случай е достатъчно да се оцени размера като годен или негоден.

За извършване на пресмятанията е необходимо да се зададе и приемателното равнище на контрол, с което се определя рискът на производителя и потребителя и да се зададе допуска на размерите. В този прозорец се дефинира, дали измерването ще се извършва он-лайн (автоматично) или данните ще се въвеждат ръчно от оператора. С така въведените данни се извършва и построяването на разпределението на размерите за измерваната извадка (фиг.3).

по количествен признак



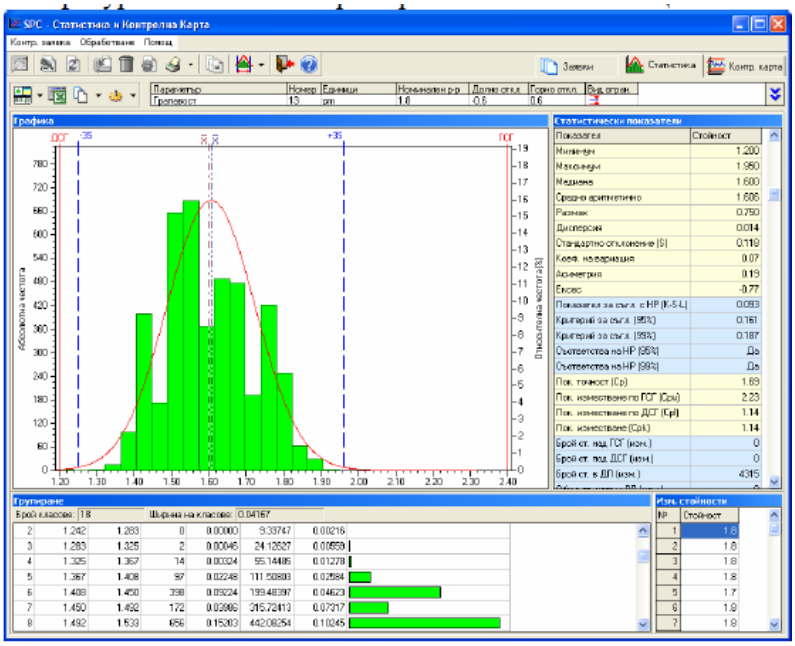
по качествен признак



Фиг.2 Необходими изходни данни за изчисляване на параметрите при проверка на размерите

Софтуерът QMSYS ни дава информация за всички важни статистически параметри: стандартно отклонение, дисперсия, показател на точността и показател на изместването. Тези показатели дават информация за наличието на систематични и случайни грешки, които оказват влияние върху точността на процесите.

На фиг.3 се вижда, че софтуера дава информация и за стойността на коефициента на настоячност и точност на процесите и диагрма на нормалното разпределние на измерените стойности. Тази информация е необходима, ако искаме да извършим изследване на способността на процесите, или ако приемателния ни контрол се извършва само на базата на тези коефициенти. В този случай е необходимо да се представят портоколи от измервания и определяне на коефициентите, което може да се получи-разпечата директно от програмата.



Фиг.3 Прозорец от софтуера QMSYS след изчисляване на въведените дани за проверка по качествен признак

5.ЗАКЛЮЧЕНИЕ

Използването на софтуер за управление на качеството QMSys има следните предимства:
- измерените стойности могат в режим он-лайн да се прехвърлят в системата
- извършва се оценка на размерите по качествен и количествен признак
- получава се оценка за всички статистически показатели
- извършва се изследване и доказване способността на процесите
- извършва се изследване и доказване способността на машината
- на базата на въведените входящи данни и резултати от измерването се получават автоматично контролните планове.

БЛАГОДАРНОСТИ

Статията е създадена със съдействието по материали на фирма Квалисис, разработили софтуера QMSys. Специални благодарности на управителя г-н Големанов за помощта и сътрудничеството.

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MONITORING OF TECHNOLOGY PROCESSES WITH CAQ-QMSYS - CONTROL CHARTS

Olga KARAKOSTOPULO

Abstract: *The control charts are the most familiar methods for monitoring of technological process. They are several types depending of type the monitoring parameters, statically value and production plan. The work present the CAQ QMSys for different opportunity.*
Key Words: *control charts, QMSys*

КОНТРОЛ НА ТЕХНОЛОГИЧНИЯ ПРОЦЕС С ИЗПОЛЗВАНЕТО НА QMSYS - КОНТРОЛНИ КАРТИ

Олга КАРАКОСТОПУЛО

Резюме: *Статистическият метод за контрол на точността на технологичния процес чрез контролни карти намира най-голямо приложение в практиката. Известни са няколко вида такива в зависимост от типа на контролеруем параметър, статистическия параметър и видът на производство. В статията е представена систематика при използването на софтуер QMSys за различните случай.*
Ключови думи: *контролна карта, контролни граница, QMSys*

1.УВОД

Фирмите, които се занимават с производство на детайли, без значение дали са дребно серийно, едросерийно или единично производство, трябва да осигуряват спазване на предписаните размери, дописки, качество на повърхнините т.е. всички технически изисквания и да се в състояние да доставят изделията в срок.

Използването на контролните карти дава възможност да се следят контролираните размери от дадена серия детайли или при дребно серийно производство състоянието на процеса при типове детайли.

Контролните карти за управление на процесите могат да се класифицират в две основни групи . Shewhart - контролни карти по опитни данни, които се използват за управление на способни процеси, когато е необходимо да се запази това състояние на процеса. Тези карти дават сигнал, когато състоянието на процеса се промени и е необходимо той да се пренастройва.

Контролните карти по спецификационни изисквания се прилагат, когато даден процес трябва да се контролира по отношение на предварително зададени гранични стойности. Този случай се среща често, когато в процеса на производство съществуват систематични изменения, или при преход от една партида към друга. Типичен случай за приложение на този вид карти са процесите с бързо износване на обработващия инструмент.

2.СТАТИСТИЧЕСКИ ПАРАМЕТРИ ИЗПОЛЗВАНИ ПРИ КОНТРОЛНИТЕ КАРТИ

2.1. Показатели при контролните карти

Контролните карти са метод за статистическо регулиране на технологичните процеси. Те се използват за оценка на процеса и за следене на промяната на неговата настройка. Регулирането на процеса на производство се извършва чрез следенето на две характеристики - разсейването на размерите и изменението на положението на средната стойност. За построяването им се използват статистически характеристики.

Показателите за положението на разпределението са средна стойност x; медиана x и екстремни стойности. При еднакви обеми на извадките контролните карти на средните стойности x са по-чувствителни към измененията в настроеността на процеса.

Показатели за разсейването на параметрите - стандартно отклонение s и размах R

2.2. Проверка на закона на разпределение

Всеки статистически анализ започва със събирането на данни т.е. с наблюдения. На базата на информацията и резултатите от тези наблюдения се построяват характеристики или разпределение. Най-общо така получаваме информация колко стойности в какъв интервал попадат, като интервала съвпада с допуска на детайла.

В машиностроенето най-често при обработка се работи с нормален закон на разпределение т.е приема се, че обработваните детайли имат такъв характер на разпределение на размерите. Необходимо е обаче преди прилагането на статистически методи за контрол е да се провери дали обработваните детайли наистина имат такъв характер. За целта се използват някои универсални методи за проверка на хипотезите за закона на разпределение.

Тест на Kolmogorov-Smirnov-Lilliefors - това е статистически тест за проверка на съгласуваност на две разпределения . Необходимо е да се вземат две извадки и на тази база да се провери дали те имат еднакъв закон на разпределение или дали едната извадка има същото разпределение като това, което сме допуснали.

Тест на Пирсън - определя зависимостта между две променливи, най-често се търси линейна зависимост. Коефициента на Пиърсън или на корелация се бележи с r и е в интервала между (-1;1). Чрез този коефициент може да се определи дали две извадки са с нормално разпределение, като изискването е те да имат приблизително нормално разпределение.

Тест на Shapiro-Wilks е статистически тест, с който се проверява, че дадена извадка има нормален закон на разпределение. Нулевата хипотеза H_0 е, че извадката е с нормално разпределение, а обратната хипотеза H_1.

2.3. Видове контролни карти

Контролните карти съдържат две граници - предупредителни и контролни. Двата типа граници се определят на базата на извършени измервания на детайли и последващата им статическа обработка. Прилагането на контрол с контролни карти е възможно само след като имаме един стабилен и настроен процес. Използват се най-често следните двустранно ограничени доверителни интервали:

От предварителна серия извадки с n = 100 (20 x 5 бр.) се определят границите на регулиране и се отбелязват в картата.

α = 95% за предупредителните граници

α = 99% за контролните граници.

2.3.1.Контролни карти по качествен признак

Тези карти се използват за качествено оценяване на дадена величина. Пример за това когато се прави оценка дали даден размер е в граница или не е, дали даден детайл, които се боядисва или поцинкова

Границите са така подбрани, че броят на дефектните единици (дефектите) в случайна извадка с обем n от настроен и стабилен процес да лежи с вероятност 99% между контролните граници и с вероятност 95% между предупредителните граници.

При процес под статистически контрол броят на дефектните единици в извадката се подчинява на биномния закон за разпределение. В този случай p е броят на дефектните единици в общата съвкупност, $g_{bin}(x)$ е вероятността в извадката да има точно x на брой дефектни единици, $G_{bin}(x)$ е сумарната вероятност в извадката да има максимум x на брой дефектни единици.

Необходимо е обема на извадката да се подбере така, че $n.p > 1$. Определянето на контролните граници за различните видове карти са дадени таблица 1.

Таблица1. Видове контролни карти по качествен признак

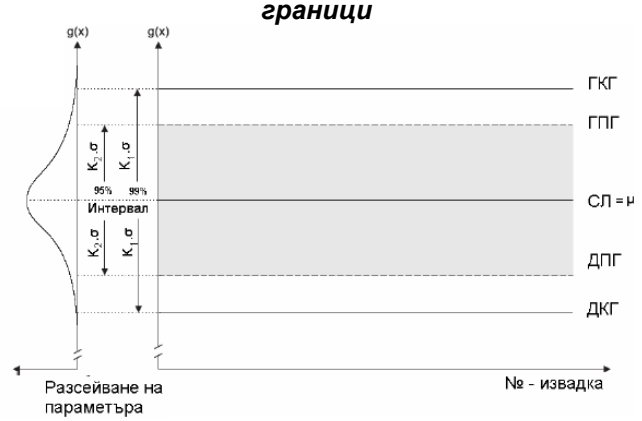
	контролна карта за брой несъотв.. единици (np)	Контролна карта за относителна. част на несъотв. единици (p)	контролна карта за несъотв. единици в % (p%)
ГКГ	X+0.5 за Gbin(X;P;N) ≥ 99.5% > Gbin(X-1 P;N)	(x+0.5)/n за Gbin(x;p;n) ≥ 99.5% > Gbin(x-1 p;n)	100.(x+0.5)/n за Gbin(x;p;n) ≥ 99.5% > Gbin(x-1 p;n)
ГПГ	x+0.5 за Gbin(x;p;n) ≥ 97.5%> Gbin(x-1 p;n)	(x+0.5)/n за Gbin(x;p;n) ≥ 97.5%> Gbin(x-1 p;n)	100. (x+0.5)/n за Gbin(x;p;n) ≥ 97.5%> Gbin(x-1 p;n)
СЛ	p.n	p	100.p
ДПГ	x-0.5 за Gbin(x;p;n) > 2.5% ≥ Gbin(x-1 p;n	(x+0.5)/n за gbin(x;p;n) > 2.5% ≥ gbin(x-1 p;n	100. (x+0.5)/n за Gbin(x;p;n) > 2.5% ≥ Gbin(x-1 p;n
ДКГ	x-0.5 за Gbin(x;p;n) > 0.5% ≥ Gbin(x-1 p;n)	(x+0.5)/n за Gbin(x;p;n) > 0.5% ≥ Gbin(x-1 p;n)	100. (x+0.5)/n за Gbin(x;p;n) > 0.5% ≥ Gbin(x-1 p;n)

2.3.1.Контролни карти по количествен признак

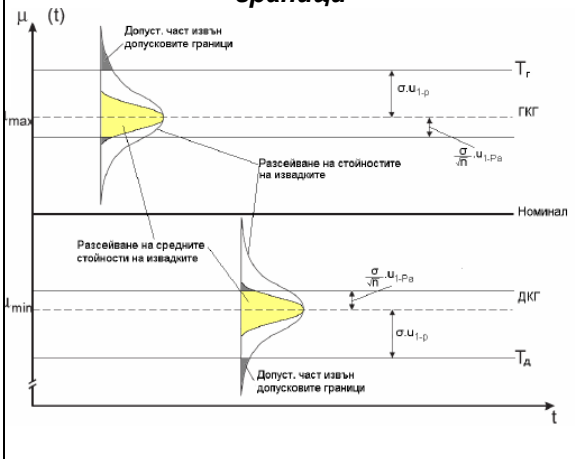
Контролни карти за положението на процеса без отчитане на спецификационните граници

На фиг.1 е представена такъв тип контролна карта. Вземат се извадки с обем n ≥ 5. В този случай разпределението на извадковите средни стойности се подчинява на нормалния закон дори и за параметри, които в генералната съвкупност не се подчиняват на нормалния закон на разпределение. Поради тази причина е възможно регулирането с контролни карти за средната стойност и на параметри с разпределение, различно от нормалното. Определянето на контролните граници за различните видове карти са дадени таблица 2.

без отчитане на спецификационните граници



С отчитане на спецификационните граници



Фиг. 1. Контролна карта

Таблица2. Контролна карта без отчитане на спецификационните граници

Видове граници	Контролна карта за средната стойност на извадките	Контролна карта за медианата на извадките	Контролна карта за индивидуални стойности
ГКГ	μ + KS1.σ	μ + KS3.σ	μ + KS5.σ
ГПГ	μ + KS2.σ	μ + KS4.σ	μ + KS6.σ
СЛ	μ	μ	μ
ДПГ	μ - KS2.σ	μ - KS4.σ	μ - KS6.σ
ДКГ	μ - KS1.σ	μ - KS3.σ	μ - KS5.σ

Контролни карти за положението на процеса с отчитане на спецификационните граници

Границите са така подбрани, че средната стойност на случайна извадка с обем n от настроен и стабилен процес да лежи с вероятност 99% между контролните граници и с вероятност 95% между предупредителните граници. Такава контролна карта е представена на фигура 1. Коефициентите за границите са дадени в литературата [4,6]. Определянето на контролните граници за различните видове карти са дадени таблица 3.

Таблица3. Контролна карта без отчитане на спецификационните граници

Видове граници	Контролна карта за средната стойност на извадките	Контролна карта за медианата на извадките	Контролна карта за индивидуални стойности
ГКГ	Тг - K_A.σ	Тг - K_A .K_{A2}.σ	Тг - K_{A3}.σ
ГПГ	Тд + K_A.σ	Тд + K_A .K_{A2}.σ	Тд + K_{A3}.σ
СЛ	(Тд +Тг)/2	(Тд +Тг)/2	(Тд +Тг)/2

Коефициентът K_A зависи от обема на извадката n, броя на дефектните единици p, при превишаване на който е необходимо да се пристъпи към регулиране на процеса. Коефициентът може да се избере от съответните стандарти или от номограмите на Wilrich.

Коефициентите K_A и K_{A3} , с които се въвеждат съответните корекции при контролна карта за медианата и за индивидуални стойности, са дадени в литературата [4,6].

Единично производство

По горе споменатите карти се използват когато имаме серийно производство на детайли.

Когато обработваме подобни детайли в малки партиди, също можем да използваме статистически контрол. Използва се като база контролната карта по средна стойност и размах. За да може да се използва една и съща контролна карта за различните партиди се работи с отклонението от номинална стойност, което за всички видове детайли ще е в един и същи порядък. Като оценка на разсейването се използва размаха.

Построява се контролна карта подобна на тази по средна стойност и размах. Като на диаграмата за средната стойност се нанася разликата

$$\delta\overline{X} = \overline{X} - \overline{\overline{X}}$$

За всяка партида се определя средната стойност $\overline{\overline{X}}$, за всяка извадка се определя средната стойност $\overline{X}$ В зависимост от разликата в разсейването на отделните серии типове детайли се използват два вида карти:

контролни карти за малки партиди от подобни детайли

Друг вид контролни карти се използват когато обработваме малки партиди детайли, с близки малки размери, на една машина. Ако разгледаме процеса на струговане, то разликата в диаметрите на различните детайли не трябва да е много голяма и диаметрите на обработваните детайли също да е малък. В този случай разсейването на отделните партиди ще бъде еднакво

Определянето на контролните граници на картата за средните стойности е по зависимост:

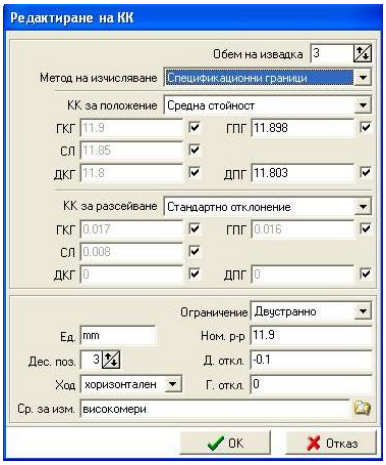
$$K_{\Gamma} = +A_2\overline{R} \text{ и } K_{Д} = -A_2\overline{R}$$

а контролните граници на картата за размаха е:

$$K_{\Gamma} = D_4\overline{R}$$

3.СОФТУЕР QMSYS

Построяването на контролните карти е процес свързан с много голям обем изчислителна работа. Необходимо е събиране на опитните данни, изчисляване на контролните граници, проверка на различни хипотези. Фирмите, сертифицирани по ISO 9000 са задължени да изготвям и съхраняват документацията, която доказва качеството на тяхното производство. Използването на



Фиг. 2.

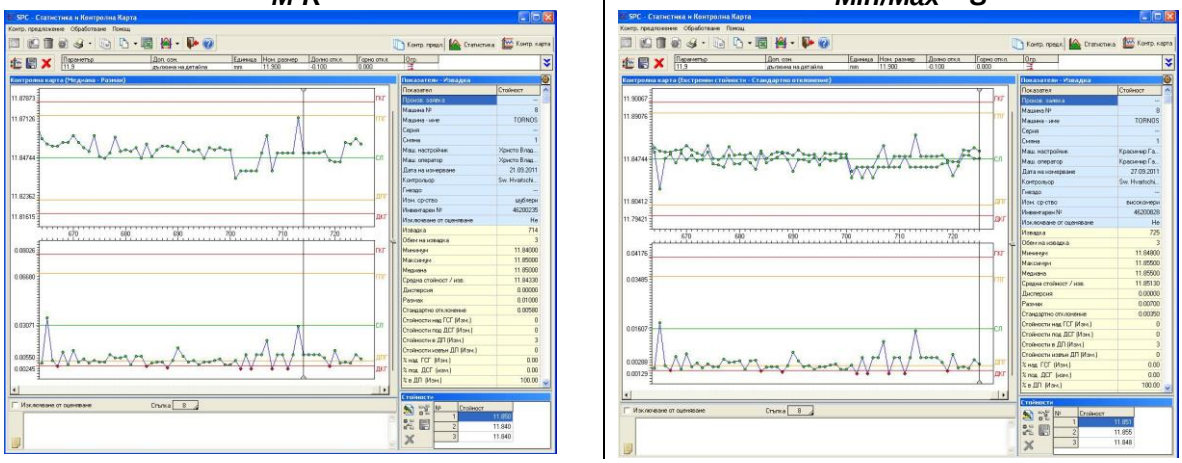
софтуер за управление на процесите значително намалява изчислителната работа и грешките в резултат от човешки фактор.

Софтуерът QMSYS има модул SPC, който подпомага изготвянето и построяването на контролни карти. Със софтуера се изготвят карти по количествен и качествен признак, по всички горепосочени показатели.

На фиг. 2 е даден диалогов прозорец, в който се дефинират необходимите данни, за да се построй една контролна карта. След като се избере типа на картата се избират параметрите, по които ще се следи разсейването и положението. При контролни карти с отчитане на спецификационните граници за определяне на границите е необходимо да се зададе и допуска на контролеруемия размер. Проверка на хипотезата за нормален закон на разпределение се извършва с тест на Hakolmogorov-Smirnov-Lilliefors.

На фиг.3 е даден прозорец на контролна карта без отчитане на спецификационните граници. Освен характера на разпределение на точките, на графиката се дава информация за: спецификационни данни, статистически параметри, тест за нормално разпределение, показатели за способност на процеса, стойности и % спрямо допуска– от измерване и по нормален закон.

M-R ***Min/Max – S***

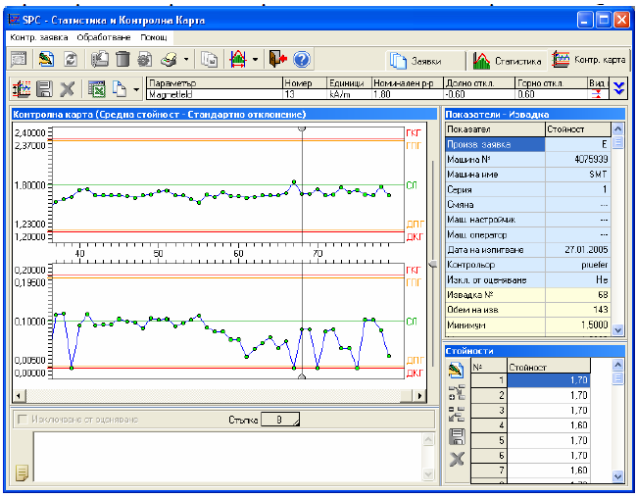


Фиг. 3. без отчитане на спецификационните граници

Софтуерът може да се използва за управление на процесите с контролни карти както за серийно производство, така и за единично и дребно серийно.

За серийно производство се използват картите с и без отчитане на спецификационните граници. При втория вид карти допусковото поле се намалява с коефициент * средноквадратичното отклонение. Тези карти използват при процеси с малки разсейване в

извадките, но при които е възможен тренд на средната стойност на извадката или непостоянство на средната стойност на извадката [6].



Фиг. 4. X-S, отчитане на спецификационните граници

При контролни карти със спецификационни граници – контролните граници са равни на допуска. Това се използва при карти по индивидуални стойности или когато се започва нова контролна карта и няма данни за разсейването на процеса[6].

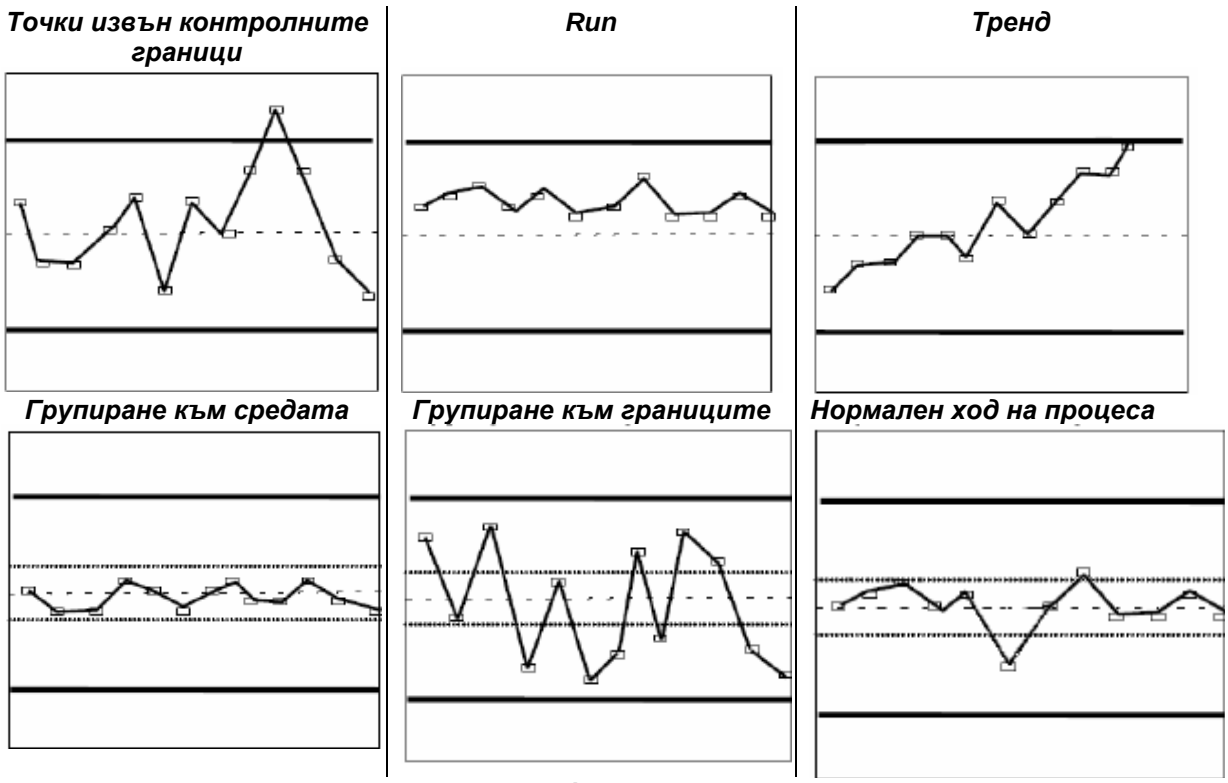
В QMSys SPC за дребно-серийно и единично производство се използва и карта по индивидуални стойности (извадки с обем 1) и се контролира само положението на процеса.

4.ИНФОРМАЦИЯ ОТ КОНТРОЛНИТЕ КАРТИ

Характера на разпределение на точките от контролните карти дават информация за стабилност на процеса и за мероприятията, които трябва да се предприемат, за да се стабилизира той отново. Можем да получим информация и за наличие на систематични или случайни грешки.

При управление на процеса с контролна карта са възможни следните ситуации, указващи нарушаване на стабилността на протичане на процеса:

- Точки извън контролните граници – показват систематично увеличаване на разсейването или на изместване на настройката на процеса поради смяна на инструмент, параметри на работа и др. Необходимо е пренастройване на процеса.
- Run– 7 или повече последователни точки над/под средната линия на картата - показват систематично постоянно изместване на настройката на процеса. Необходимо е пренастройване на процеса. Вероятността за грешка на критерия е под 1%.
- Тренд – 7 или повече точки в нарастваща или намаляваща последователност - показват систематично изместване на настройката на процеса поради износване на инструмент, нов материал, смяна на контролен уред и др. Необходимо е пренастройване на процеса. Вероятността за грешка на критерия е под 1%.
- Над 23 от 25 последователни точки (над 90%) попадат в “средната трета” от диапазона на контролната карта - показват систематично намаляване на разсейването на процеса поради подобряване на процеса, или поради фалшифициране на измерванията, грешка при изчисления и др. При стабилен и центриран процес по нормално разпределение в “средната трета” трябва да попадат 68% от точките. Необходимо е да се провери верността на данните. Вероятността за грешка на критерия е под 1%.
- Под 10 от 25 последователни точки (под 42%) попадат в “средната трета” от диапазона на контролната карта - показват систематично увеличаване на разсейването на процеса. Необходимо е да се провери верността на данните и състоянието на процеса. Вероятността за грешка на критерия е под 1%.



Фиг. 5.

5.ЗАКЛЮЧЕНИЕ

Използването на специализиран софтуер подпомага фирмите при съставянето, отпечатването и съхраняването на информацията свързана с регулирането на процесите с контролни карти. Модулът QMSys SPC позволява да се използват контролни карти за:

1. Контролни карти по количествен признак:

средна стойност, медиана, екстремни стойности; стандартно отклонение, размах и индивидуални стойности

2. Контролни карти по качествен признак

брой несъответстващи единици в извадката; относителна. част на несъответстващи единици в извадката; %-част на несъответстващи единици в извадката.

3. Изготвяне на контроли карти за единично производство

За определянето на контролните граници се използват следните методи:

- по нормален закон с отчитане на спецификационни граници
- по нормален закон без отчитане на спецификационни граници
- по нормален закон (КК по качествен признак)
- въвеждане на границите

Документите, които се генерират от програмата се:

- планове за контрол на процесите и продуктите
- записи и протоколи от проверките и мониторинга
- документи за идентификация на партидите

БЛАГОДАРНОСТИ

Статията е създадена със съдействието по материали на фирма Квалисис, разработили софтуера QMSys. Специални благодарности на управителя г-н Големанов за помощта и сътрудничеството.

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INFLUENCE OF ENVIRONMENT FOR TRIBOFILMS FORMATION IN FRICTION BETWEEN METALS

Tinka GROZDANOVA

Abstract *: The results of a tribological study on the surface of a self-lubricating antifrictional material in vacuum and in ambient air are presented. Pictures of formed tribofilm in result of dry friction of a tin tribocouple are shown.*

Keywords *: Vacuum, friction, self- lubricating antifrictional material.*

ВЛИЯНИЕ НА ОБКРЪЖАВАЩАТА СРЕДА ЗА ФОРМИРАНЕТО НА ТРИБОФИЛМИ ПРИ ТРИЕНЕ НА МЕТАЛИ

Тинка ГРОЗДАНОВА

Резюме: *В статията са представени резултатите от трибологично изследване на повърхността на самосмазващ се композитен антифрикционен материал на медна основа, изпитан в условията на вакуум и в атмосферна среда. Показани са снимки на формиращ се трибофилм при сухо триене на трибодвойка от калай.*

Ключови думи: *Вакуум, самосмазващ се композитен антифрикционен материал, трибофилм.*

1. ВЪВЕДЕНИЕ

При взаимодействието на две тела, участващи в трибопроцес, контактните повърхности претърпяват изменения, в резултат на които се образува нов веществен продукт, наричан понякога „трето контактно тяло" [1]. Формирането и съставът на този продукт зависят както от вида на материалите, така и от условията, при които протича процесът – обкръжаваща среда, сила на взаимодействие, скорост на движение, времетраене и т.н. Контактното тяло съчетава в себе си комплекса от изменения и трансформации на основните материали в контактната област.

Някои автори наричат този продукт „формиращ се трибофилм" и изследват връзката между механизма на адхезионно износване и химичните реакции [2, 3].

Триенето на метални повърхности, съвместно с механичната енергия, стимулира появата на физични процеси и последващо възбуждане на химични реакции с молекулите на обкръжаващата среда. Измененията на материала и енергийното състояние на трибоконтакта, появата на елестични, пластични и деструктивни деформации се изследват в различни диапазони: на макро-, микро-, нано-, мезо- и ултра - ниво. Трибодеформациите, предизвикани от изменения в кристалната решетка, водят до разкъсване на кристало-химични връзки, електронна емисия и разрушаване на материалите [1].

Тези процеси се проявяват в по-голяма степен, ако материалите се използват в екстремни условия – в откритото космическо пространство, във вакуум или при сухо триене [4, 5].

2. ИЗЛОЖЕНИЕ

По съвместна научна програма между Института за космически изследвания и технологии към БАН и Института по проблеми на материалознанието към Националната Академия на Науките на Украйна беше разработена серия самосмазващи се композитни антифрикционни материали под общото название ИПМ. Те се отличават с това, че притежават хетерогенна структура и съставните компоненти имат разпределени функции. Разработени са на медна основа, легирана с фосфор и никел, манган или калай. Съдържат изолирани глобуларни

образувания на оловото, което практически не взаимодейства с медта. Основният технологичен принцип при създаването им е постигане на оптимални трибопараметри: нисък коефициент на триене, висока износоустойчивост, голяма товароносимост и защита срещу образуване на центрове на зацепване и задиране в контактната област. Медта и нейните сплави изграждат носещата матрица, а оловото реализира антифрикционните функции [6, 7].

Материалът ИПМ -304 (Cu – P – Sn – Pb) беше изследван при сухо триене във вакуум и на въздух. На повърхността се образува оловен смазочен слой, вследствие на повишаването на температурата в контакта, на разликите между коефициентите на дифузия и термично разширение на матрицата и на оловото, както и на пластичната деформация. Равномерното разпределение и стабилността на този слой зависят от много фактори като структурните промени в повърхностния слой, разпределението на оловото в обема на материала, температурата в контактната зона и режима на триене. От тях се определят антифрикционните параметри на композита, неговата адаптивност и ефектът на самосмазване.

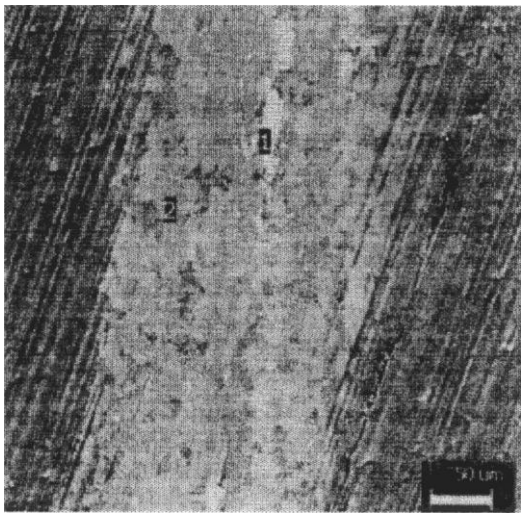
С увеличаването на скоростта на триене и силата на натоварване, температурата в контакта се покачва и количеството на оловната смазка се увеличава. При по-леките режими на работа (товар 2N) снабдяването на повърхността с олово се отнася към процеса на дифузия. При по-тежките режими (товар10N) обогатяването с олово е по-интензивно и оловният слой е с по-голяма плътност [8]. Това се дължи, както на повишената температура (до 170^{o}C), така и на избутване на олово към повърхността под действието на товара.

3. ЕКСПЕРИМЕНТАЛНИ РЕЗУЛТАТИ

3.1. Изследване на триещата се повърхност на материала ИПМ-304 във вакуум.

Изследването е извършено с трибосистема „pin-on-disk” (палец-диск) във вакуум 1.10 $^{-3}$ Pa при натоварване 2 N и скорост на движение 0,2 m/s. Движещият се диск е изработен от изследвания материал. Палецът, който се явява контратяло, е изработен от стомана AISI 52100 (100 Cr 6) с твърдост 740 HV [9].

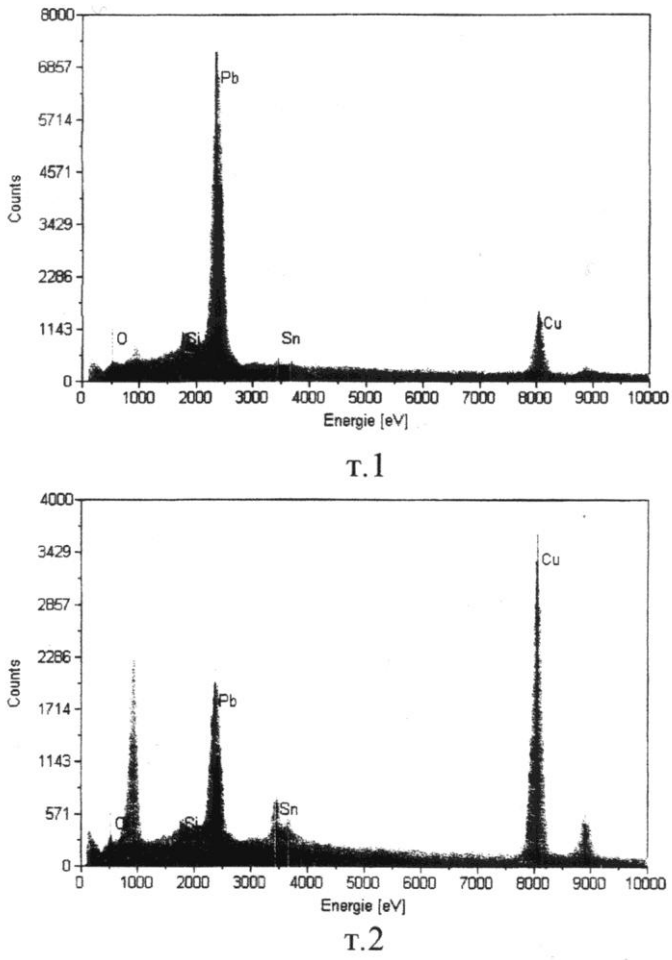
На фиг. 1 е показано изображение на повърхността на диска, направено със сканиращ електронен микроскоп.



Фиг. 1. Морфология на повърхността на ИПМ -304 след сухо триене във вакуум.

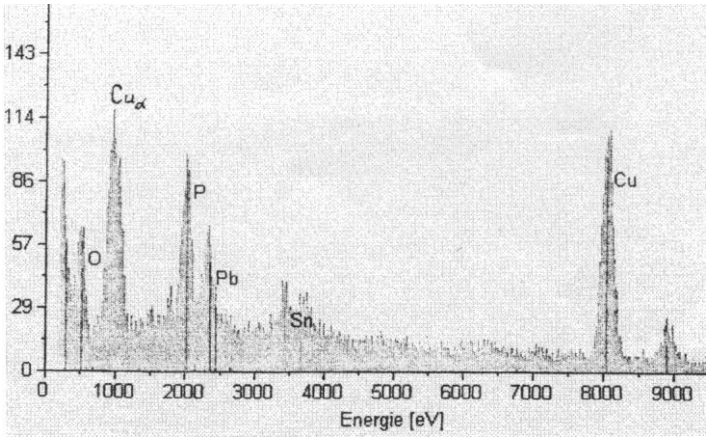
Вижда се добре оформеният оловен смазочен слой.

На фиг. 2 е показана снимка от анализа на елементния състав в точките 1 и 2 на обработваната повърхност, извършена с рентгенова микросонда. Количеството на оловото е значително и преобладава в сравнение с другите компоненти, особено в т.1 – най-светлата област.



Фиг. 2. Спектри на елементния състав в две точки на повърхността.

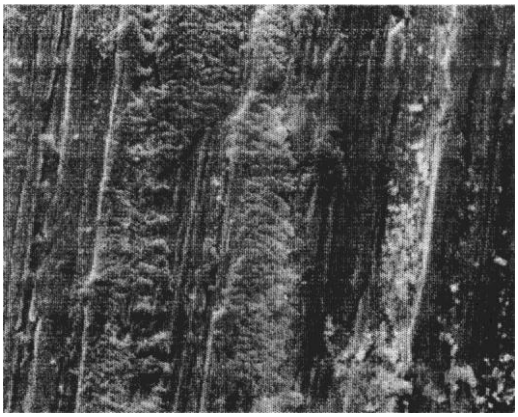
На фиг. 3 е показан спектърът на елементния състав на продукта от износването. Спектърът съдържа компоненти от матрицата – мед, фосфор, калай и олово.



Фиг. 3. Спектър на продукта от износването при сухо триене във вакуум.

3.2. Изследване на триещата се повърхност на материала ИПМ-304 в атмосферна среда.

На фиг. 4 е показан видът на повърхността след триене на въздух.



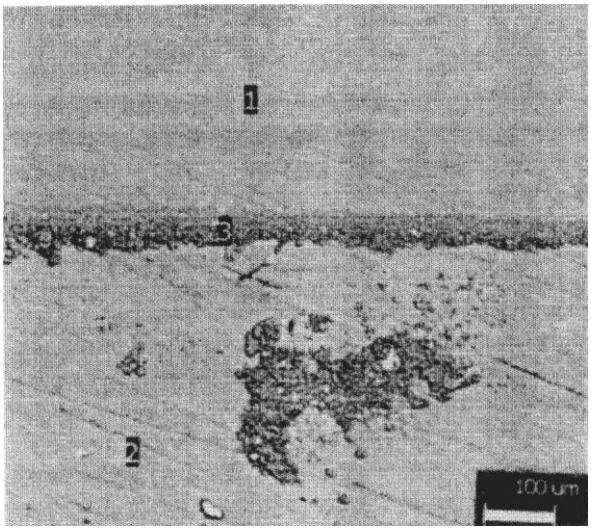
Фиг. 4. Морфология на повърхността на ИПМ -304 след сухо триене на въздух.

Образувалият се оловен слой се окислява, което го прави по-крехък. Получава се нарастване на коефициента на триене и интензитета на износване. Това би могло да се компенсира частично с увеличение на натоварването и скоростта. В този случай повърхностният слой е обогатен с олово, но в по-малка степен и самосмазването е по-слабо ефективно.

3.3. Изследване на повърхността на контратялото и елементния състав на продукта от износването при триене на въздух.

Това изследване е проведено по същия метод, както и предните случаи, но палецът е изработен от материала ИПМ-304, а контратялото е стоманен диск.

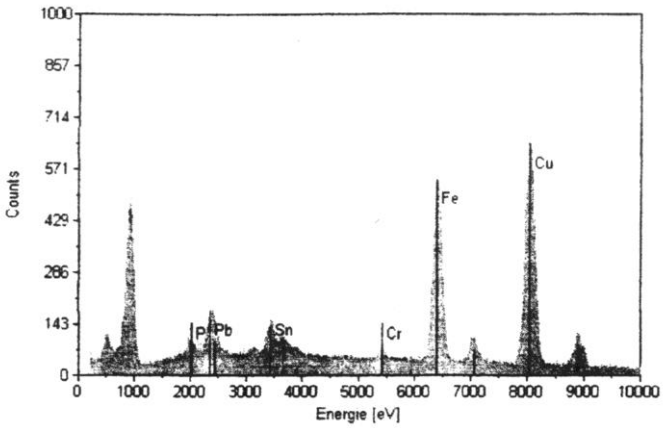
На фиг. 5 е показана снимка на повърхността на контратялото.



Фиг. 5. Повърхност на контратялото след триене на въздух.

Ясно се очертават три зони : зона 1 – повърхността на диска извън контактната област, зона 2 – следата от триенето и зона 3 – продуктът от износването.

На фиг. 6 е показан спектърът на елементния състав на продукта от износването.

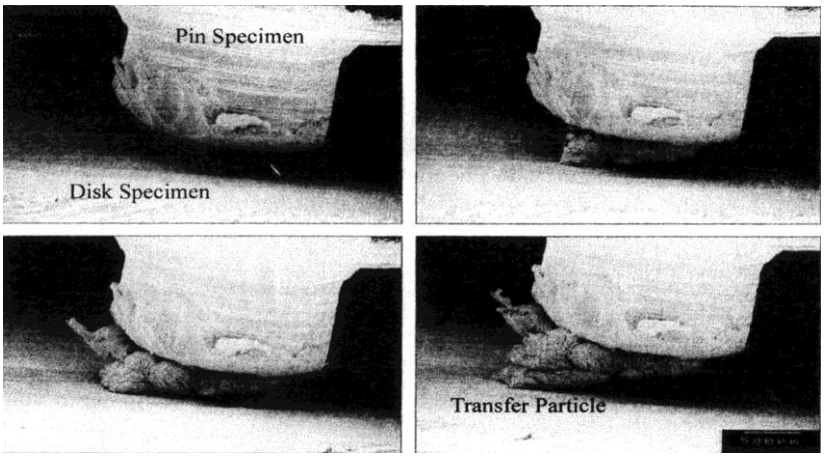


Фиг. 6. Спектър на продукта от износването при сухо триене на въздух.

Частиците на продукта от износването са разположени на границата на зони 1 и 2, а част от тях и върху следата от триене. От спектралния анализ се вижда, че в него се съдържат елементите на композитния материал – Cu, Sn, P, Pb и елементи от стоманата - Fe, Cr. Съдържанието на олово е 2,5 пъти по-голямо, в сравнение с това при триенето във вакуум, където, освен металното олово, е регистрирано и присъствие на неговия окис. По-силното триене води до износване на повърхността на стоманения диск, въпреки голямата твърдост на материала.

3.4. Изследване на образувания трибофилм при трибодвойка от калай.

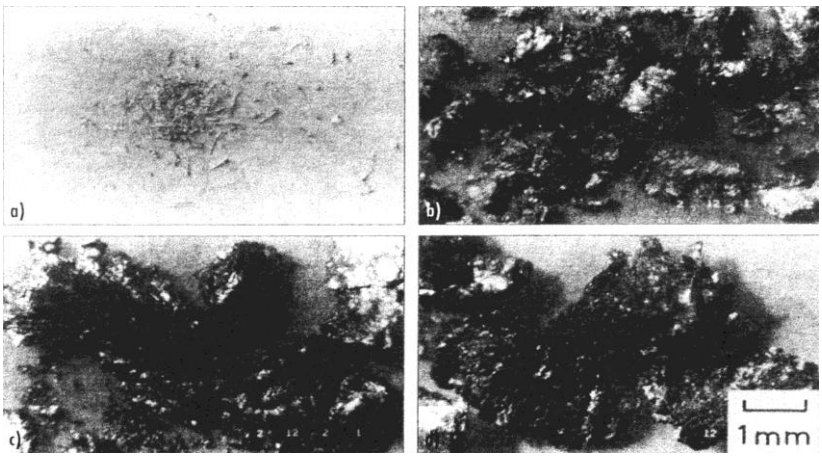
Известните учени-триболози Кен'ичи Хирацука и Чеслав Кайдас извършват изследване на трибодвойка от калай във вакуум и на въздух. Тяхната цел е да установят връзка между механизма на адхезионно износване и химичните реакции със зоабикалящата среда, от гледна точка на формирането на трибофилм, и в зависимост от времетраенето на процеса [2]. На фиг. 7 са показани снимки, направени със сканиращ електронен микроскоп при триене във вакуум.



Фиг. 7. Израстване на преносна частица при триене във вакуум [2].

След всеки 375 мм разстояние след триенене експериментът е бил спиран, вакуумната камера е била прочиствана и е снимана картината около взаимодействащите повърхности. В този случай можем да видим образуването на „третото тяло".

На фиг. 8 е показана триещата повърхност и частиците от износване на калай при различно налягане на кислород.



Фиг. 8. Частици от износването на калай при различно налягане [2]:
a) 1.10 $^{-4}$ Pa Vac. ; b) 1.10 $^{-1}$ Pa Vac. ; c) 1.10 ^{4} Pa O_2 ; d) 1.10 ^{5} Pa O_2.

Количеството на износените частици е различно, както и техният размер. В случаите с по-голямо съдържание на кислород се измерва и по-голяма твърдост на частиците.

4. ЗАКЛЮЧЕНИЕ

От снимките се вижда, че повърхността на изследвания самосмазващ се композитен антифрикционен материал ИПМ-304 се обогатява с олово в процеса на сухо триене във вакуум и на въздух.

При триене във вакуум образуваният смазващ оловен слой е плътен и износоустойчив. Продуктът от износването съдържа предимно елементи на композитния материал.

При триене на въздух полученият оловен слой е неравномерен и по-лесно се износва. Прилагането на по-голямо натоварване в контакта и увеличаването на скоростта на движение могат да компенсират частично тези недостатъци, но биха довели до по-голяма консумация на енергия. Продуктът от износването съдържа както елементи от изследвания материал, така и елементи от стоманеното контратяло.

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STUDY OF THE WEAR-RESISTANCE OF LAYERS, OBTAINED BY PLASMA MELTING

Manahil TONGOV, Tatiana SIMEONOVA

Abstract: *The report is devoted to the study of the microstructure and wear properties of layers obtained by applying a mixture of powder and a binder on a sample and subsequent scanning of the working surface with plasma transferred arc to melt lead paint and partial melting of the substrate. The preparation technology of samples prior to scanning and abrasive wear testing is described. The microstructure and abrasive wear behavior of the layers is analyzed and the resistance against abrasive wear is determined.*

Key words: *layers, plasma, microstructure, abrasive wear*

ИЗСЛЕДВАНЕ ИЗНОСОУСТОЙЧИВОСТТА НА СЛОЕВЕ, ПОЛУЧЕНИ ЧРЕЗ ПЛАЗМЕНО ПРЕТОПЯВАНЕ

Манахил ТОНГОВ, Татяна СИМЕОНОВА

Резюме: *Докладът разглежда микроструктурата и износоустойчивостта на слоеве, получени чрез нанасяне на смес от прахообразен материал и свързващо вещество върху образци и последващото им сканиране с плазмена дъга. Описана е подготовка на образците за нанасяне на покритието и изследване на степента на износване. Анализирана е получената микроструктура на слоя и са направени изпитвания за определяне на износоустойчивостта срещу абразивно триене.*

Ключови думи: *слоеве, плазма, микроструктура, абразивно износване*

1. УВОД

През последното десетилетие се е наложила тенденцията за все по-често използване на плазмените технологии и процеси както за възстановяване на износени детайли, с цел да се удължи експлоатационния им живот, така и при производството на нови. По този начин детайлите могат да се изработят от по-евтин материал, а повърхностните характеристики да се подобрят чрез нанасяне на слоеве с необходимите специални свойства (твърдост, износоустойчивост, корозионна устойчивост и др.). За повишаването на износоустойчивостта на покритията, особено работещите в агресивни среди и при високи температури, обикновено се използват сплави на основата на кобалт или никел, като според [1] вторите са по-евтината алтернатива. Обикновено сплавите на никелова основа съдържат легиращите елементи хром (със съдържание между 1 и 29%), бор и силиций (чието съдържание обикновено е в рамките на 1-4%), които повишават твърдостта и износоустойчивостта на наваряваните слоеве. Тези сплави са особено подходящи за работа в условията на триене , като имат добра износоустойчивост (при стайна и повишена температура), топлоустойчивост и корозионна устойчивост срещу. В практиката обикновено се използват сплави на основата на Ni-Cr-Si-B-C, нанесени чрез различни технологични процеси, като термично напръскване (плазмено [2÷6], пламъчно [7÷11] и високоскоростно [5, 12, 13]), лазерно наваряване [7, 9, 10, 14÷18], плазмено наваряване [19÷24], течна цементация [8, 25, 26] и хибридни процеси [27÷29].

Настоящият доклад разглежда микроструктурата и износоустойчивостта на слоеве с дебелина в диапазона от 1 до 2 [mm] реализирани с помощта на плазмено – дъгов процес на наваряване.

2. ЕКСПЕРИМЕНТАЛНА МЕТОДИКА

2.1. Изходни материали

За изработване на опитните образци са използвани планки от нелегирана конструкционна стомана S275JR с размери 4x100x100 [mm] и карбидообразуваща прахообразна смес на основата на никел. Химичният състав на материалите е показан в табл. 1, а размерът на частиците варира в границите 45÷180 [μm]. В качеството на свързващо вещество, за получаване на паста се използва разтвор на водно стъкло. Получената паста се нанася върху планките [30].

Таблица 1. Химичен състав на подложката S275JR и на праховата сплав Surfit 1560, %

Елемент	Ni	Fe	Cr	Si	B	O	C	Mn	P	S	N	Cu
S275JR	-	-	-	-	-	-	0.22	1.5	0.04	0.04	0.012	0.55
Surfit 1560	Bal.	4.0	14.95	4.40	3.18	0.025	0.75	-	-	-	-	-

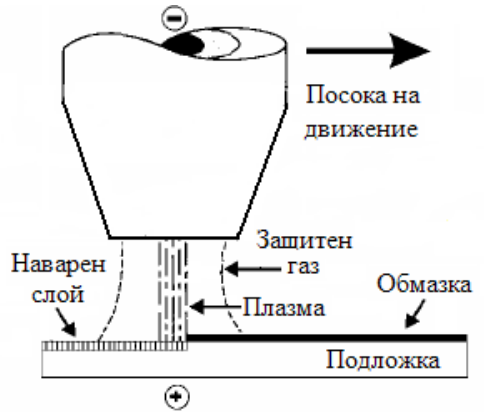
2.2. Технология на нанасяне на обмазката [30].

От прахообразната смес е приготвена обмазка със свързващо вещество разтвор на водно стъкло във вода при обемни съотношения 1:5. Подготовката на образците за сканиране и претопяване на нанесения слой с плазмена дъга е следната: предварително подгряване на планката; нанасяне на пастата; изсушаване при 90°C. Върху всички образци е нанасяна обмазка с дебелина в границите 1,3÷1,5 [mm].

2.3. Технологични параметри на плазменото претопяване.

С цел стопяване на обмазката и частично разтопяване на подложката подготвените образци са подложени на сканиране с плазмена дъга.

На фиг.1 схематично е представен процеса на плазмено претопяване. При експериментите в качеството на плазмообразуващ и защитен газ е използван Ar, а основните параметри на процеса са: ток на дъгата $I_н$ = 50÷80 [A]; стъпка (разстояние между две съседни ивици) $S_н$ = 3 [mm]; скорост на дъгата $V_н$ = 85 [mm/min]; дебит на плазмообразуващ газ $Q_{ПГ}$ =0,8[l/min]; дебит на защитен газ $Q_{ЗГ}$ = 5 [l/min];



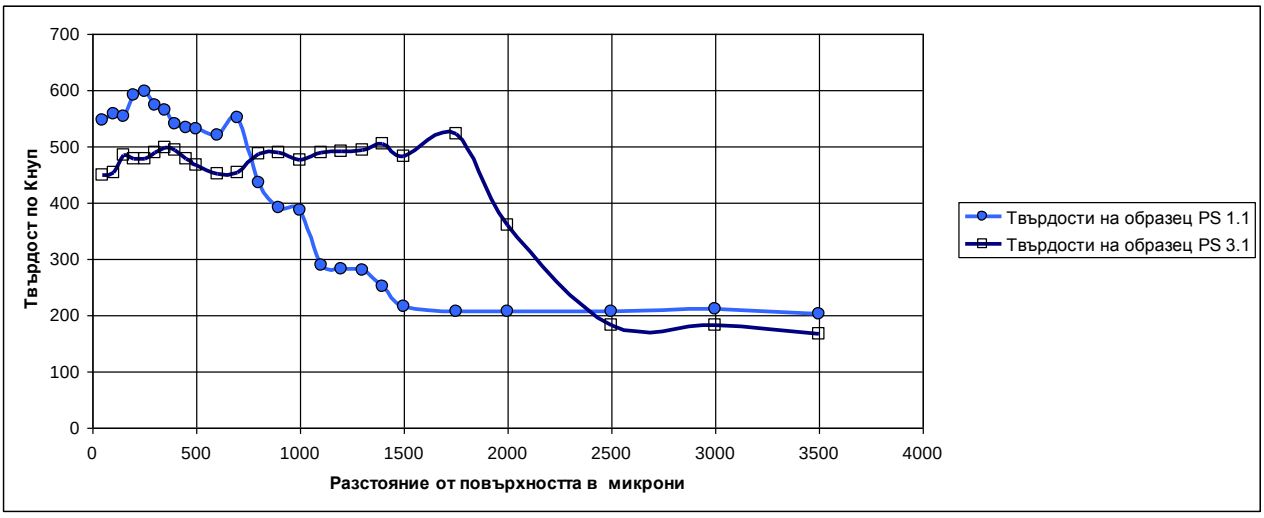
Фиг.1. Схема на процеса

На базата на предварителни изследвания относно получаваната твърдост във формираните слоеве [30] за настоящото изследване на износоустойчивост бяха избрани образци ***PS 1.1*** и ***PS 3.1***. Параметрите на технологичния процес за посочените образци са показани в табл.2 .

Таблица 2 . Параметри на процеса.

Образец	***Iн,*** *A*	***Vн,*** *mm/min*	***Sн,*** *mm*	***$Q_{ПГ}$,*** *l/min*	***$Q_{ЗГ}$,*** *l/min*
PS 1.1	*65*	*85*	*3*	*0,8*	*5*
PS 3.1	*80*	*85*	*3*	*0,8*	*5*

Микротвърдостта на образците е изследвана по метода на Кнуп, като е използван твърдомер „Zwick Materialprufung" Mod. 3212. Използваното натоварване е 50[g]. Направени са по три профила на твърдостта за всеки от изследваните образци. Осреднени резултати от измерванията са представени в графичен вид на фиг. 2. Получените резултати показват, че слоя за образец ***PS 1.1*** има твърдост 500-600 $HK_{0.05}$, която се запазва сравнително постоянна до дълбочина 0,8-0,9 [mm] от повърхността и след това пада. За дълбочината на слоя може да се каже, че е в диапазона 0,7÷1.3 [mm]. Основното, което трябва да се отбележи за образец ***PS 3.1*** е по-голямата дълбочина на слоя, достигаща до 2 [mm], като разсейването в диапазона на резултатите е подобно (1,7÷2,2 [mm]). Това е нормален резултат поради по-големият ток на дъгата и по-голямата линейна енергия. Разликите в изпъкналостта и дълбочината на провара в мястото на измерване водят до съответните разлики в дебелината на слоя. Сравнявайки резултатите от ***PS 1.1*** и ***PS 3.1*** се вижда, че в първият случай твърдостта в рамките на слоя е по-висока. Това се дължи на по-голямата концентрация на елементите, въвеждани чрез обмазката поради по-малката дълбочина на провара.



Фиг. 2. Осреднени профили на твърдост на образците

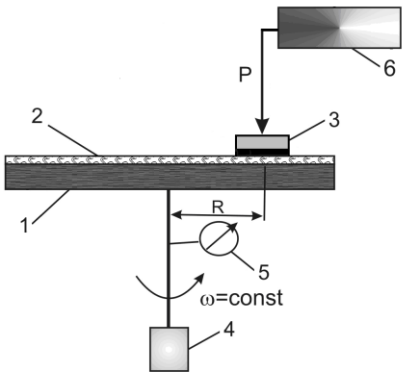
2.4. Металографски анализ на микроструктурата

От образците с претопен слой са направени шлифове за изследване на микроструктурата. Шлифоването е извършено със шкурки №№ от 400 до 2000, а полирането с диамантена паста 1 [μm]. Структурите са проявени с 2% разтвор на азотна киселина. Металографските изследвания са проведени с оптичен металографски микроскоп „ Olympus GX41", с дигитална цветна камера „Altra 20".

2.5. Подготовка на образци и методика за изследване на абразивно износване

От планките с формирани слоеве се изрязват образци с формата на квадрат с дължина на страната 15,8 [mm], които се подлагат на абразивно износване. Експерименталното изследване се осъществява по методика и с устройство за ускорени изпитания по кинематичната схема „палец-диск", разработени в центъра по трибология в МТФ – ТУ-София. Функционалната схема на устройството е представена на фиг. 3.

Изследваният призматичен образец 3 (тяло) се монтира неподвижно в натоварващата глава 6 като челната му повърхнина контактува с абразивната повърхнина 2 на хоризонтален диск 1 (противотяло). Дискът 1 се върти с ъглова скорост ω (в рамките на проведените експерименти $\omega = \text{const} = 6{,}28 \quad [\text{s}^{-1}]$) около вертикалната си ос. Броят на оборотите се отчита с брояча 5. Устройството позволява промяна на скоростта на плъзгане чрез настройване на ъгловата скорост на диска от управляващ блок и/или изменение на разстоянието R между оста на въртене и оста на образеца 3. Методиката за изследване на абразивно износване включва последователност от следните операции: подготовка на повърхнината на образците 3 чрез шлайфане и полиране до еднаква грапавост, като се вземат превантивни мерки за предотвратяване на структурни и физико-химични промени в повърхностния слой на образците; измерване на масата на образците преди и след изминаване на определен път на триене S (брой цикли) с помощта на електронна везна WPS 180/C/2 с точност 0,1[mg]; монтиране на образеца 3 в натоварващата глава; задаване на желаното нормално натоварване P (в случая P=5,76[N]) и път на триене S чрез брояча 5; пресмятане на абсолютното масово износване Δm [mg] като разлика между масата на образеца преди и след определен брой цикли N (път на триене S).

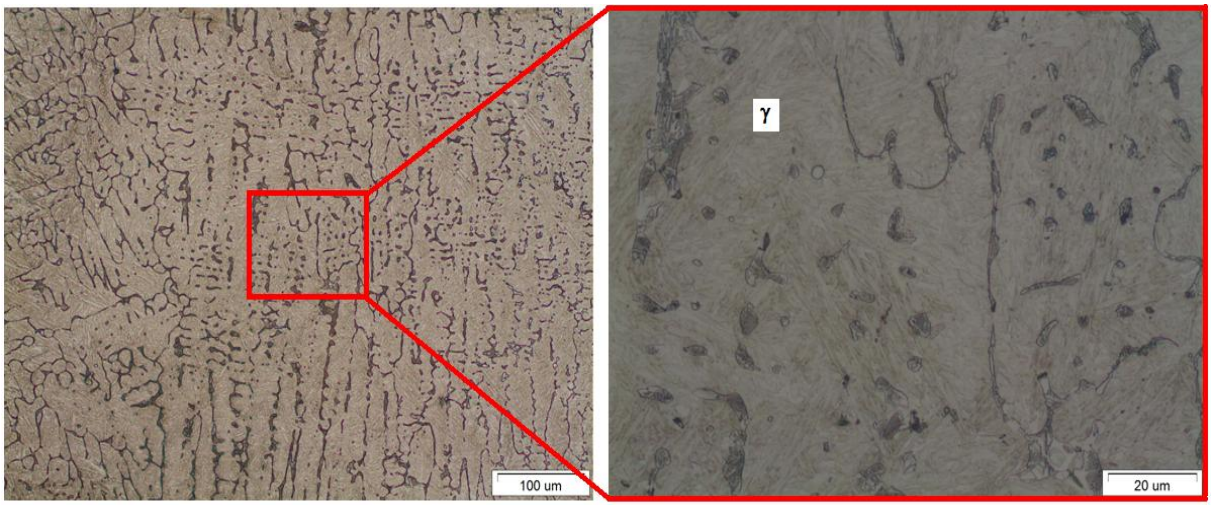


Фиг. 3: Функционална схема на устройство за изследване на износването в условия на твърдо закрепен абразив

3. ЕКСПЕРИМЕНТАЛНИ РЕЗУЛТАТИ

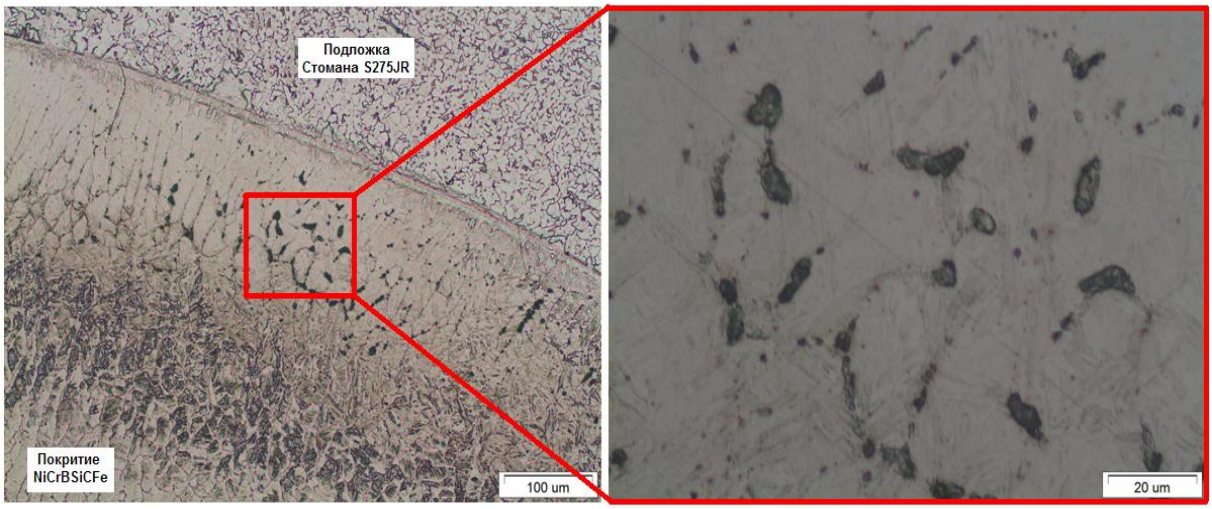
3.1. Анализ на микроструктурата на слоевете

На фиг.4 е показана микроструктурата на слоя, образуван при претопяването на образец **PS1.1.** Вижда се образуването на дендритна структура в процеса на кристализация в претопения метал. На базата на разгледаните в литературата изследвания на NiCrBSi покрития става ясно, че наблюдаваните дендрити представляват γ-твърд разтвор на хром и желязо в никел [18, 20, 21], докато получаваните отделяния по границите на зърната са основно съставени от карбиди (Cr_7C_3), бориди (Cr_2B, CrB) [19, 20, 21] и силициди (Ni_3Si) [21, 23]. Според направените в [22] електронно-микроскопски изследвания (сканираща електронна микроскопия SEM и Оже (Auger) спектрален микроанализ AES) в междудендритното пространство се наблюдават Cr_3C_2, Cr_7C_3, CrB, и Ni_3B фази, а според [7] се образува и комплексен карбид $(Cr,Fe)_7C_3$.



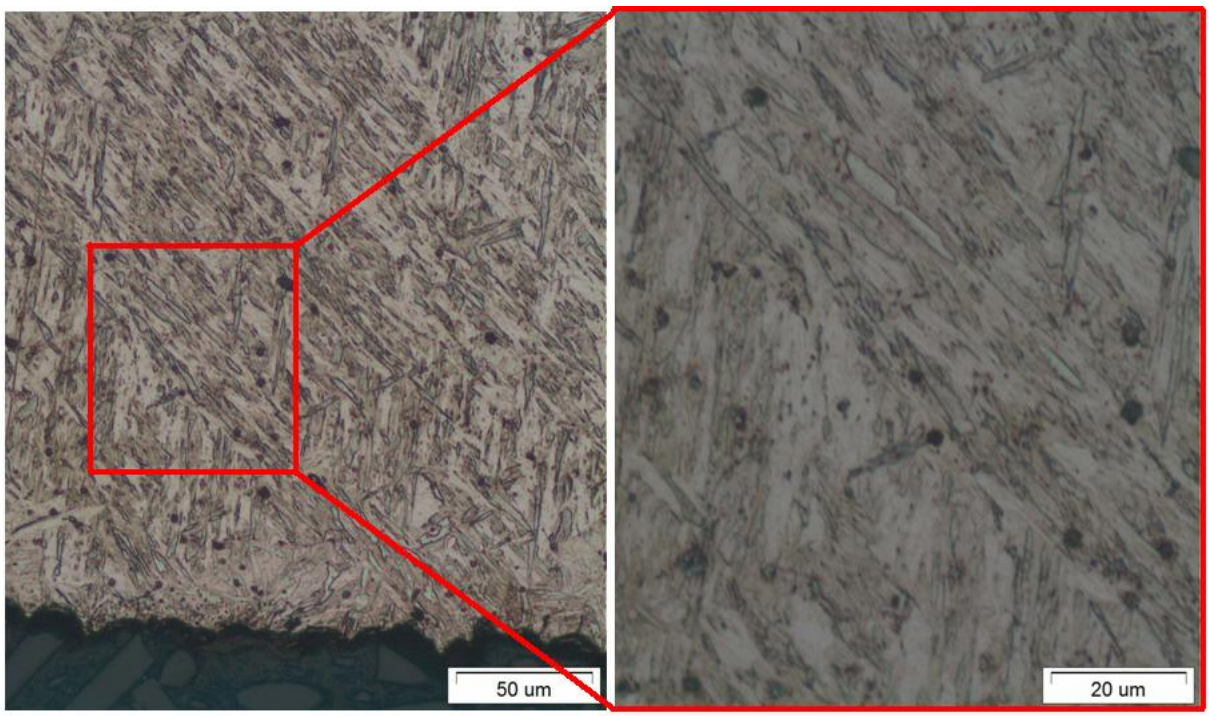
Фиг. 4. Микроструктура на слоя на образец PS1.1.

На фиг.5 е показана зоната на сплавяване при образец **PS1.1**. Тази област е по-богата на желязо поради частичното затопяване на кристалите на подложката. Поради тази причина тук се очаква образуване на комплексни карбиди от вида M_7C_3 и $M_{23}C_6$ [7, 33].



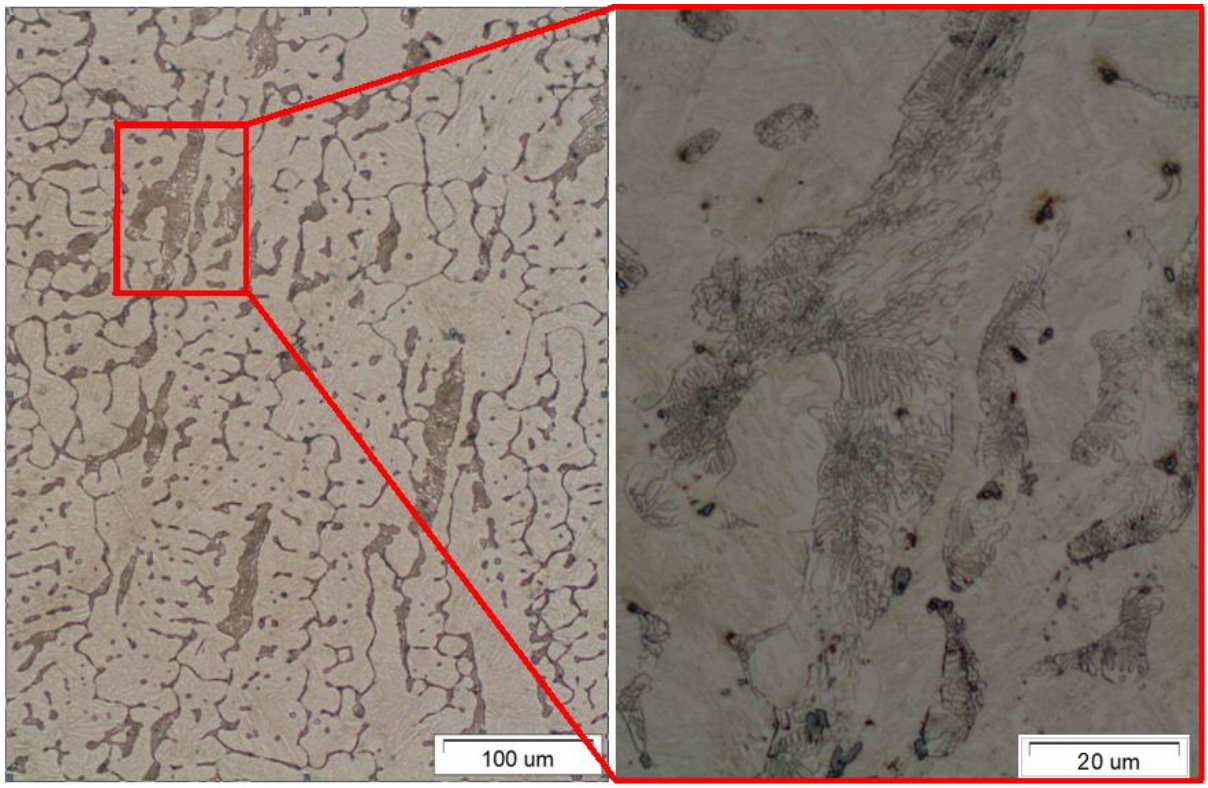
Фиг. 5. Зона на сплавяване за образец PS1.1.

Микроструктурата на повърхността на слоя е представена на фиг.6. По данни от енергийно дисперсивния рентгеноспектрален анализ, проведен в [20], наблюдаваните частици са карбиди и бориди.



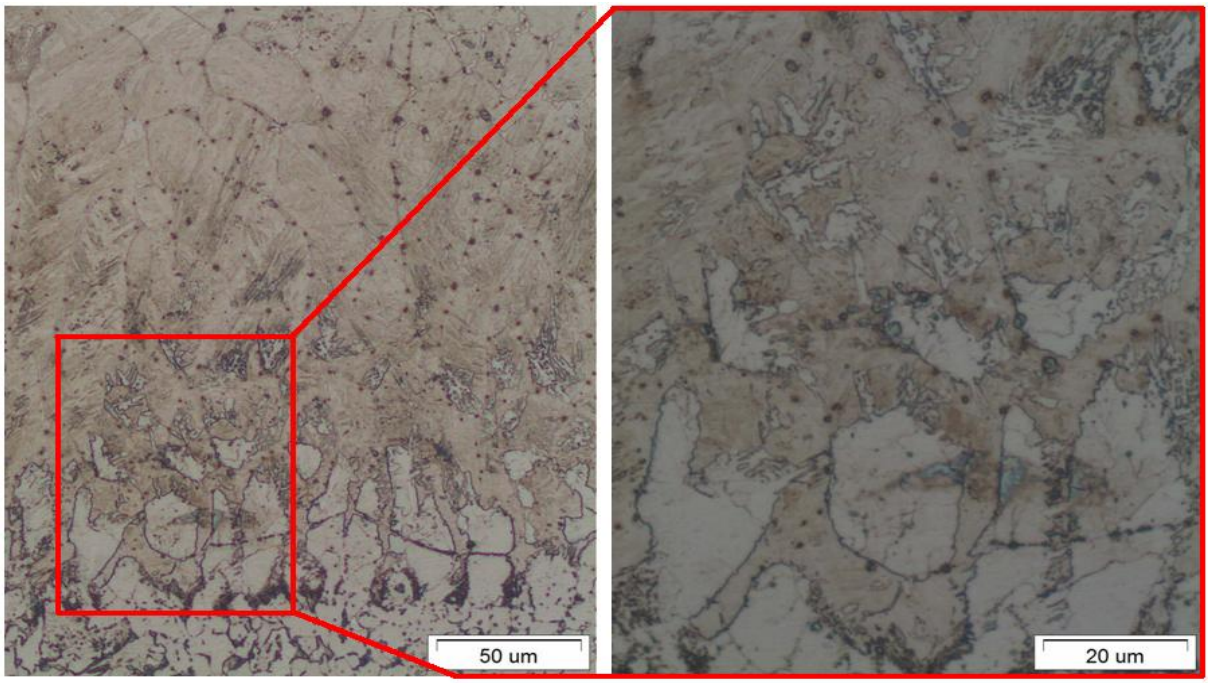
Фиг. 6. Микроструктура на повърхността на слоя на образец PS1.1.

Микроструктурата на слоя на образец **PS3.1** е показана на фиг.7**.** Наблюдава се характерната дендритна структура, получена в процеса на кристализация в претопения метал. В отделни участъци остатъчната стопилка между дендритите кристализира под формата на евтектика, която по данни на [21] е тройна карбидо-боридна (γ-твърд разтвор, Cr_7C_3 и Cr_2B (CrB)).



Фиг. 7. Микроструктура на слоя на образец PS3.1.

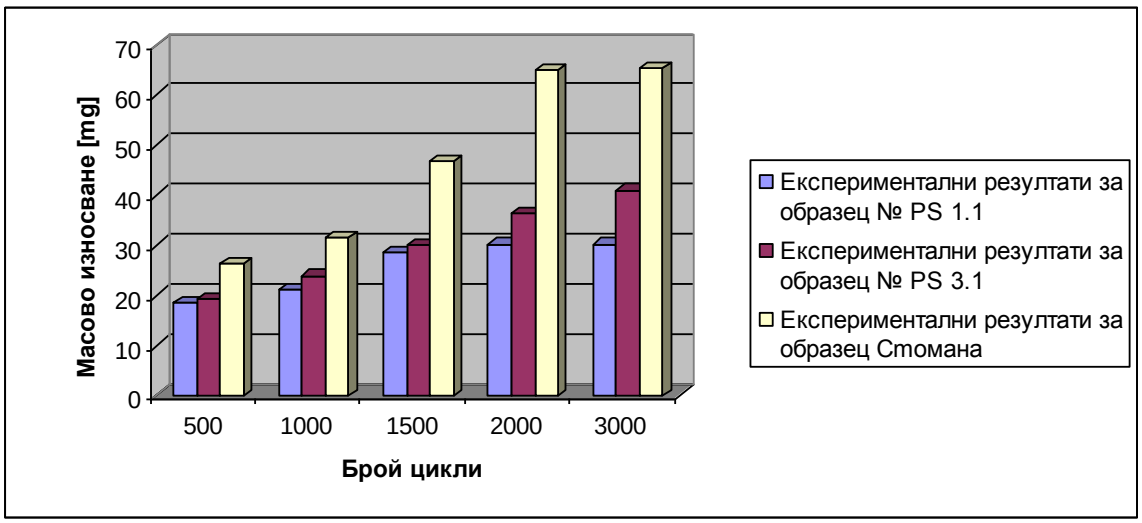
Зоната на сплавяване за образец **PS3.1** е показана на фиг.8. Наред с посочените по-горе карбидни, боридни и силицидни фази, в богатата на желязо зона на смесване непосредствено над основата се наблюдава формиране на двуфазна структура, за която се предполага че съдържа α и γ твърди разтвори.



Фиг. 8. Зона на сплавяване за образец PS3.1.

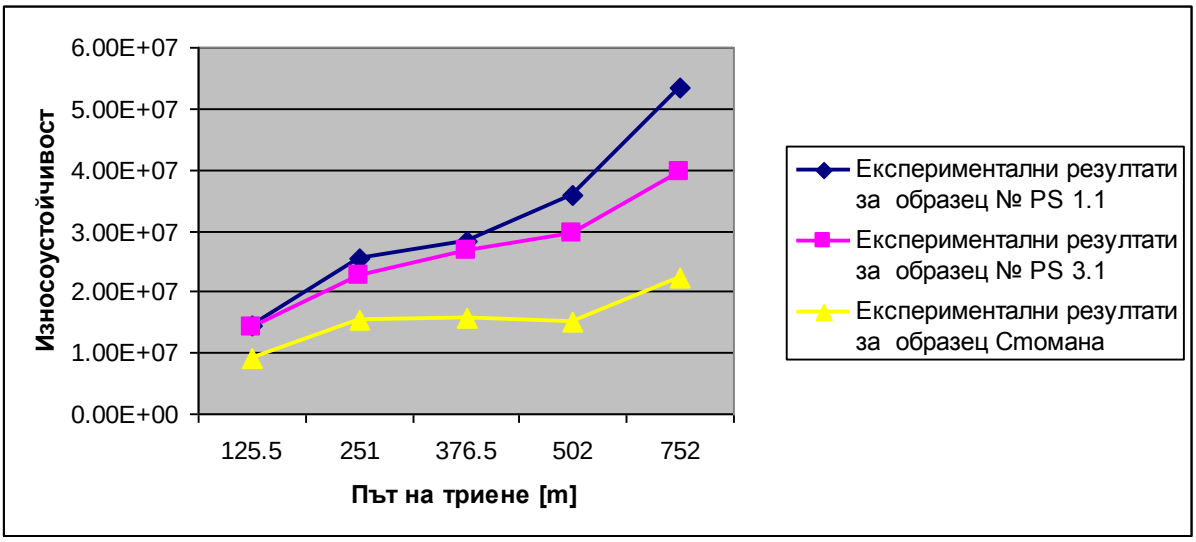
3.2. Изследване на износоустойчивостта на слоевете

На фиг. 9 е показано масовото износване на изследваните образци. Най-добри резултати се наблюдават при образец **PS1.1** в диапазона 1500-3000 цикъла, като количеството на износения материал за този участък е почти постоянно, което може да бъде обяснено с високата концентрация и равномерното разпределение на уякчаващите частици в рамките на нанесения слой. При образец **PS3.1** също са получени добри резултати, като за масовото износване се наблюдава плавно повишаване на стойностите, което се свързва с получената по-голяма дълбочина на провара, а оттам и по-ниска концентрация на допълнителния прахов материал от обмазката в наварения слой. Получените резултати за основния метал потвърждават очакванията за най-високо масово износване в целия диапазон на проведеното изследване.



Фиг. 9. Масово износване на изследваните образци

Износоустойчивостта на изследваните образци е показана на фиг. 10. Ясно се вижда получаваната при образец **PS1.1** най-висока износоустойчивост, като наблюдаваното повишаване в края на изследването се свързва с износване на меката матрица на покритието и протичане на процес на абразивно триене по доста по-твърдите уякчаващи фази на слоя, което е характерно за композитните материали. Образец **PS3.1** също показва висока износоустойчивост, която запазва нарастващия си характер за целия период на изследването. Поведението на образеца говори за равномерно разпределение на уякчаващите фази в целия обем на слоя, които както е споменато най-вероятно са карбиди, бориди и силициди. Полученото нарастване на износоустойчивостта на стоманата след прилагане на 2000 цикъла на абразивно триене най-вероятно се дължи на уякчаването на материала в следствие на протичащата пластична деформация в зоната на контакта между образеца и абразивния диск.



Фиг. 10. Износоустойчивост на изследваните образци

И при двата наварени образеца се наблюдава двукратно увеличение на износоустойчивостта спрямо основата, като малко по-високите стойности на износоустойчивостта при образец **PS1.1** спрямо **PS3.1** се дължат на по-голямата концентрация на уякчаващите елементи в слоя, който при еднакво количество на нанесената обмазка има по-малка дълбочина.

4. ИЗВОДИ

От настоящото изследване могат да се направят следните основни изводи:

1. Плазменото наваряване позволява получаване на слоеве чрез претопяване на предварително нанесения върху образеца допълнителен материал под формата на обмазка, при постигане на желаната дебелина от 1÷2 [mm].
2. Слоевете, получени чрез плазмено наваряване се формират равномерно, без зони на несплавяване и имат повишена твърдост по цялата дълбочина на провара.
3. Направената оптична микроскопия показва образуването на характерната за покритията на основата на никела дендритна структура, съставена от γ-твърд разтвор, като получаваните отделяния по границите на зърната са основно съставени от карбиди, бориди и силициди.
4. Плазмено наварените NiCrBSiCFe слоеве имат висока износоустойчивост, което се дължи на равномерното разпределение на уякчаващите фази в обема на покритието
5. Малко по-високите стойности на износоустойчивостта при образец **PS1.1** спрямо **PS3.1** се дължат на по-голямата концентрация на уякчаващите елементи в слоя, който при еднакво количество на нанесената обмазка има по-малка дълбочина.

Тук трябва да бъде отбелязано, че поради финно дисперсния характер на посочените при микроструктурния анализ фази и многокомпонентния състав на обмазката за изясняване на конкретния вид и състав на образуваните фази се налага следващо провеждане на сканираща електронна микроскопия и рентгеноспектрален или Оже спектрален микроанализ на структурата.

БЛАГОДАРНОСТИ

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ON THE MICROSTRUCTURE AND STRENGTHENING OF ALUMINIUM AND ALUMINIUM ALLOYS

Adelina MITEVA

Abstract: *We study the possibilities for strengthening of Aluminium and Aluminium alloys on the basis of analysis of their microstructure properties. Two types of additives are considered: nanodiamonds and SiC. We review the main crystal structure defects responsible for strengthening of Aluminium alloys. A critical discussion is presented. Possible extensions of this work in the future are considered.*

Key Words: *Aluminium alloys, crystal structure defects, tribology, SiC, nanodiamonds.*

МИКРОСТРУКТУРА И УЯКЧАВАНЕ НА АЛУМИНИЯ И НЕГОВИТЕ СПЛАВИ

Аделина Митева

Резюме: *Чрез анализ на микроструктурата са изследвани възможностите за уякчаване на алуминия и неговите сплави. Разгледани са три типа уякчаващи добавки, а именно SiC, диамант и нанодиаманти. Разглеждат се основните дефекти отговорни за уякчаването в алуминиевите сплави – дислокациите. Дискутират се резултатите, правят се изводи и се разглеждат бъдещи изследвания.*

Ключови думи: *алуминиеви сплави, дефекти на кристалната структура, трибология, SiC, нанодиаманти.*

1.ВЪВЕДЕНИЕ

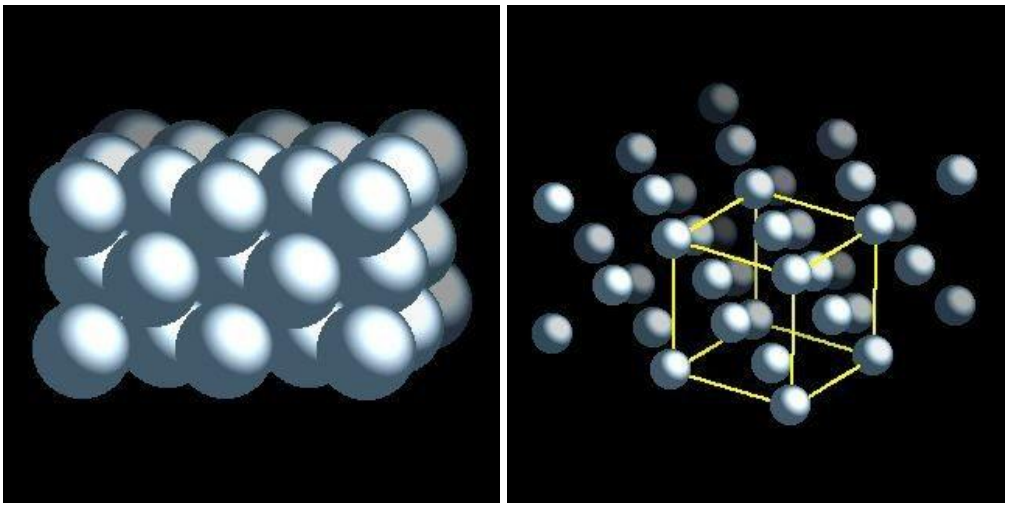
Докладът е мотивиран от много модерните днес нанонаука, нанотехнологии, нанокомпозити и трибология. Тяхната приложна, инженерна реализация е непосредствено свързана с развитието на фундаменталните аспекти на нанотехнологиите (нанонауката) и с начините на изследване на съдържащите наноструктури обекти. Наноструктурираните обекти, а най-вече наноструктурираните метали, сплави и композити, днес се изследват активно от много чужди и наши автори [1,2,3]. Тук предмет на изследването е алуминият и неговите сплави, и композитите на тяхна основа, с оглед на възможностите за уякчаването им с различни легиращи, и нелегиращи добавки.

Сега се разглеждат три добавки, а именно диамант, нанодиамант и силициев карбид (SiC). В нанонауките и в трибологията, компютърните симулации и моделиране (които са важна съставна част от съвременната наука) са особено полезни. Те допълват, развиват и свързват теорията с експеримента и технологията. Разбира се, чистата теоретична наука не винаги може да реши напълно техническите проблеми, тъй като методите ú са свързани със систематично опростяване на процесите и явленията. Но днес науката може да предскаже много от свойствата на веществата от състава им. Тук са разгледани и възможностите за прилагане на компютърно моделиране към упоменатите вече структури.

2.СВОЙСТВА И АНАЛИЗ НА СТРУКТУРАТА НА АЛУМИНИЯ

В тази работа представяме данните за структурата на алуминия (Al) и сплавите му съвсем накратко, тъй като тези данни присъстват практически във всички учебници, справочници и монографии, посветени на метали и материали. Алуминият е сребристо-бял, лек метал, който се отличава с достатъчна химическа (корозионна) устойчивост, ниска якост и твърдост, висока

пластичност. Има температура на топене 658.7^{o}C. За алуминия (метал от трета А група на периодичната система на химичните елементи) и неговите сплави са характерни високи електро- и топлопроводност. Алуминият е един от най-достъпните и относително евтини метали. Най-често Al е в алуминиеви сплави с мед, цинк, магнезий, манган и силиций. Al е метал с ГЦК структура на кристалната си решетка (стенно центрирана кубична кристална решетка или fcc; виж фиг. 1), структурен тип A1, пространствена група Fm3m, координационно число 12, параметър на решетката 4.0496 Å, междуатомни разтояния 2.863 Å, плътност 2.698 г/см^3, атомен радиус 1.43 Å, обем на един атом 16.60 Å^3. Високояките деформируеми алуминиеви сплави са с висока якост (600-700 МПа), но не са така пластични, а и при температури над 150 ^{o}C, падат стойностите за якостта им и за корозионната им устойчивост.



Фиг. 1. Структура на Al

Интересът към тези ГЦК метали е най-голям, тъй като по-голямата част от експерименталните данни е получена за тези метали. Дефектите на кристалния строеж и механичните/трибологични свойства се разглеждат заедно, въпреки че тези дефекти определят не само механичните/трибологични свойства на металите и сплавите, но и редица важни физични характеристики. Например с увеличаването на плътността на дислокациите нараства вътрешното триене, променят се оптичните свойства, повишава се електросъпротивлението на металите. Дислокациите увеличават средната скорост на дифузия в кристалите, ускоряват стареенето и други процеси свързани с дифузията, намаляват химическата им устойчивост. Механичните и трибологични свойства са част от физичните свойства на веществата. Наличието на определени механични/трибологични свойства е едно от основните изисквания към металите и сплавите, което се обяснява със способността им да служат за конструкционни материали в различни области. Например алуминиевите сплави, които намират приложение като материали в авиационната техника, трябва да могат да издържат на следните условия: високи скорости, бързо променящи се външни силови въздействия, циклични пикови натоварвания, големи температурни разлики.

Дислокациите в кристалите са едни от най-важните структурни дефекти, които имат отношение към тяхното уякчаване. Например в ГЦК кристалите действително устойчивите пълни дислокации са с: вектор на Бюргерс 1/2<110>; направление на хлъзгане <110>; най-често наблюдавани равнини на хлъзгане {111} [4,5]. Често, но не винаги, равнините на хлъзгане са най-плътно опакованите равнини.

Едни от най-важните свойства и особенности на структурата са дефектите на кристалната решетка – ваканции, дислокации, дефекти на опаковката, примесни атоми и др. Когато говорим за влияние на структурата върху свойствата, ние имаме предвид преди всичко зависимостта им от дефектите на структурата. Почти всички свойства са структурно чувствителни. А всички свойства са зависими от фазовия състав, т.е. състав и фази.

Примесните компоненти в чист вид са изовалентни, а имат атомен обем различен от този на матрицата. Примесните атоми се разпределят в кристалната решетка неравномерно и се концентрират върху структурните дефекти.

Дислокациите, освен че са възможен вид дефект в кристалната решетка, са и от изключителна важност за редица практически проблеми. Плътността на дислокациите се

определя като: количеството на дислокациите, които пресичат произволно сечение на кристала на площ от 1 $см^2$. Или по друг начин: плътността на дислокациите може да се определи като сумата от дължините на дислокационните линии в 1 $см^3$.

Механичната якост и пластичност на твърдите тела зависи главно именно от дислокациите. Влиянието на дислокациите върху якостта на материала най-лесно се обяснява чрез анализ на диаграмата напрежение-деформация (диаграмите на опън/разтягане) [5]. При прилагане на натоварване имаме два процеса свързани с дислокациите: генерация на нови дислокации и преместване/движение на съществуващи и новосъздадени дислокации. Макроскопическата скорост на деформация на даден кристал се определя от плътността на движещите се дислокации и от усредената им скорост при дадено натоварване [4,5].

3.КОМПОЗИТИ НА АЛУМИНИЕВА (AL) ОСНОВА

Композиционните материали (к.м.) или композити са многокомпонентни материали, състоящи се от основа/матрица, армирана с запълнители (които могат да са влакна, нишки, частици и др.). Чрез подбор на състава и свойствата на матрицата и на запълнителя се получават материали с необходимото съчетание от експлуатационни и технологични свойства.

Тук ще се спрем на метален к.м. на основата на Al. Като добавки могат да се използват различни вещества (графитни частици [6,7], B, нанодиамант, SiC, диамант и SiC [8], TiC, Al_2O_3, ZrO_2, покрити с молибден нанотръби и др.), но тук разглеждаме само три от възможностите: нанодиамант [3], SiC (силициев карбид) [2] и диамант с SiC [8]. По-добри качества има к.м. на Al основа с добавка SiC, отколкото този с нанодиамант. Добавката от SiC е за предпочитане пред ултрадисперсния детонационен нанодиамант, когато става дума за повишаване на якостните характеристики на Al композит.

Например, ще сравним температурите им на топене, които са: Al (660^oC), SiC (2540 ^oC), нанодиамант (около 600 ^oC). Ясно е, че за работа при по-високи температури е за предпочитане по труднотопим запълнител. В случая това е SiC.

От гледна точка на съчетанието на микротвърдост и чупливост, отново трябва да се спрем на SiC. Нанодамантите са твърди, но чупливи при натоварване, за разлика от SiC. SiC е с микротвърдост 33 ГПа.

Като плътност са приблизително еднакви и следователно теоретически равностойни: SiC (3,2 $г/см^2$) и нанодиаманта (около 3 $г/см^2$).

Параметрите на решетките на Al, SiC и на нанодиаманта са съответно равни на: 0,4 nm; 0,44 nm и 2,5 nm. По принцип нанодиамантите са с размери от 4 до 6 nm. Но нанодиамантите са конгломерати от отделни диамантени атоми. Не е ясно как да става тяхното вграждане в матрицата на Al, така че да бъде съхранена напълно цялостта им. Вграждането им зависи от прилаганата технология на получаване на композита. А при всички случаи с увеличаване на размерността на по-твърдата фаза, се затруднява повече движението на дислокациите в матрицата. Това води от своя страна до повишаване на якостта.

Следва да се подчертае, че колкото са по-малки отделните кристалчета на Al матрица, толкова по-голяма е твърдостта на композита.

В литературата има достатъчно данни за такова уякчаване на Al с нанодиаманти (ND), с диаманти и с SiC.

Например (виж фиг. 2 на [3]) в [3] с нарастването на концентрацията на нанодиаманта в алуминиевия композит, твърдостта на металния композит също расте.

Например (на фиг. 3 [2]) в [2] са показани вариациите на общия обем на износването при нормално приложени натоварвания. Загубата на обема се увеличава с увеличаване на нормалните натоварвания. Загубата на обема е максимална за чист алуминий и след това намалява с увеличаването на процента (%) на SiC до 20%. Отново тази тенденция се променя за 25% съдържание на SiC, поради нееднаквото смесване.

В [8] са докладвани получените и изследвани диамант/SiC/Al композити с големи обемни части на подсилващите материали (диамант и SiC) и голямо съотношение на размерите на частиците на диаманта към SiC (7,8:1). Резултатите показват, че малките SiC частици се локализират около едрите диамантени частици. Наблюдавано е крехкото счупване на диаманта в тези композити, което показва голямата якост на граничната връзка между двете фази. Резултатите показват, че диамант/SiC/Al композитите с 80% и 66,7% обемна фракция на диамант като подсилващ/армиращ материал в заякчаването на Al (с две армиращи фази с различна големина), показват по-голямо обемно разрушение в армиращия материал и по-нисък коефициент на топлинно разширение в сравнение с диамант/Al композита.

4.ЗАКЛЮЧЕНИЕ И БЪДЕЩА РАБОТА

Направено е въведение в темата по уякчаването на Al и неговите сплави, с нанодиамант и SiC. При направеното сравнение по параметрите твърдост, температура на топене, плътност и параметър на елементарната клетка, се вижда, че: от двата варианта (SiC или нанодиамант) по-подходящ за уякчаването на Al и сплавите му е SiC. Разбира се, всяка от двете разгледани добавки, SiC или нанодиамант, подобрява якостните свойства на алуминиевата матрица. Но в бъдеще биха могли да се разгледат нови и още неосъществени комбинации от тези две армиращи добавки, взети поотделно или участващи съвместно.

Направено е въведение и в темата по уякчаването на Al и неговите сплави с две армиращи фази, диамант и SiC. Работата може да продължи с разглеждането и на три армиращи фази.

Продължението на тази работа е в ход, т.е. разглеждането на всички възможни вещества за запълнители в Al матрица на композита, на алуминиева основа; сравняването им по параметри и избор на най-подходящ за космически и други приложения. Предстои пресмятане на характеристиките им от структурните данни и планиране на експеримент за потвърждение на направените пресмятания. Теоретичните пресмятания могат много да допринесат за определянето на оптималните параметри за различните комбинации на армиращите фази, за получаване на желаните свойства на композита. Както например е докладвано в [9], където са приложени ANOVA и ANN моделиращи техники за оптимизация на параметрите на Al/SiC композити.

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MICROSTRUCTURE AND TRIBOLOGY OF NICKEL AND NICKEL ALLOYS

Adelina MITEVA

Abstract: *The present study reports the effects of the microstructure parameters on the mechanical and tribological properties of nanostructured nickel. We study the possibilities for strengthening of nickel on the basis of analysis of the microstructure properties. Two types of additives are considered: nanodiamonds and SiC. We review the main crystal structure defects responsible for strengthening of nickel alloys. A critical discussion is presented. Possible extensions of this work in the future are considered.*

Key Words: *nickel alloys, crystal structure defects, tribology, composites, nanostructured nickel.*

1.INTRODUCTION

Currently one of the priorities of modern material science are nanomaterials and nanotechnology. Nanostructured objects, and especially nanostructured metals, alloys and composites (nano-composites), are nowadays intensively investigated by many foreign and bulgarian authors [1-12]. Here the subject of the publication is nickel and its alloys, and composites based on nickel, in view of the possibilities of strengthening them with various substances as reinforcements. The possibilities of their tribological investigation are also discussed. The information contained in this study has been compiled from the literature. It is presented as a first part of a guide to the use of nanostructured nickel and its alloys, and its properties in materials selection, in view of the possibilities of strengthening them with various reinforcements, and in view of the future investigations. Here we also examine the possibilities for the application of computer modeling of the structures already mentioned.

2.PROPERTIES AND ANALYSIS OF THE NICKEL STRUCTURE

In this work we briefly present data on the structure of nickel and its alloys, since these data are virtually found in all textbooks, reference books, and even monographs dedicated to metals and materials. Nickel is a chemical element with the chemical symbol Ni and atomic number 28. It is a silvery-white lustrous metal with a slight golden tinge. Nickel belongs to the transition metals and is hard and ductile. Pure nickel shows a significant chemical activity that can be observed when nickel is powdered to maximize the exposed surface area on which reactions can occur, but larger pieces of the metal are slow to react with air at ambient conditions due to the formation of a protective oxide surface. Even then, nickel is reactive enough with oxygen so that native nickel is rarely found on Earth's surface, being mostly confined to the interiors of larger nickel–iron meteorites that were protected from oxidation during their time in space. On Earth, such native nickel is always found in combination with iron, a reflection of those elements' origin as major end products of supernova nucleosynthesis. An iron–nickel mixture is thought to compose Earth's inner core. Because of nickel's slow rate of oxidation at room temperature, it is considered corrosion-resistant. Historically this has led to its use for plating metals such as iron and brass, to its use for chemical apparatus, and its use in certain alloys that retain a high silvery polish, such as German silver. About 6% of world nickel production is still used for corrosion-resistant pure-nickel plating. Nickel is one of four elements that are ferromagnetic around room temperature. Alnico permanent magnets based partly on nickel are of intermediate strength between iron-based permanent magnets and rare-earth magnets. The metal is chiefly valuable in the modern world for the alloys it forms; about 60% of world production is used in nickel-steels (particularly stainless steel). Other common alloys, as well as some new superalloys, make up most of the remainder of world nickel use, with chemical uses for nickel compounds consuming less than 3% of production. Nickel has a melting point 1455°C. Nickel is a transition metal of a group 10 of the periodic system of elements. Ni has a metal structure with a fcc crystal lattice

(face centered cubic crystal lattice, see fig. 1 [13]), structural type A1, space group Fm3m, coordination numbers 12, lattice parameter of 3.524 Å, interatomic distances 2.492 Å, 8.96 g/cm^3 density, atomic radius of 1.24 Å.



Fig. 1. Highly purified nickel spheres [13]

The reason of the greatest interest in these metals is that most of the experimental data were obtained for these metals. The crystal structure defects and the mechanical, and tribological properties are considered together, as these defects determine not only mechanical/tribological properties of metals and alloys, but also a number of important physical characteristics. For example, the increase in the density of dislocations increases internal friction, changes optical properties, increases electrical resistance of the metals. Dislocations increase the average speed of diffusion in crystals, accelerated aging and other processes related to diffusion, reduce chemical resistance. Mechanical and tribological properties are an important part of the physical properties of substances. The presence of certain mechanical/tribological properties is one of the main requirements for metals and alloys, which is explained by their ability to serve as a structural material in various fields.

Dislocations in crystals are one of the most important structural defects that are relevant to their strengthening. For example, in fcc crystals the full really resistant dislocations are those with: Burger vector 1/2<110>; slip direction of <110>; the most commonly observed slip planes of {111} [7,8]. Often, but not always, the slip planes are the most densely packed planes.

One of the most important properties and peculiarities of the structure are the defects of the crystal lattice - vacations, dislocations, stacking faults, impurity atoms, etc. When we talk about the influence of the structure on the properties, we mean above all dependence on the structure defects. Almost all of the properties are structurally sensitive and they depend on the phase composition.

Impurity components in their pure form are with the same valence and have atomic volume different from that of the matrix. Impurity atoms in the crystal lattice distributed unevenly and concentrate on structural defects.

Dislocations, besides being the possible type of defects in the crystal lattice, are extremely important for a number of practical problems.

Mechanical strength and plasticity of solids depends mainly on the dislocations. The influence of dislocations on the strength of the material is most easily explained by analyzing the stress-strain diagram (diagram strength/stretching) [6]. In the application of load we have two processes associated with the dislocations: generation of new dislocations and relocation/movement of existing and newly created dislocations. Macroscopic speed of crystal deformation is determined by the density of moving dislocations and their average speed at a given load [7,8].

3.NICKEL BASED COMPOSITES

Composite materials (KMs) are multicomponent materials consisting of a base/matrix reinforced with the fillers/reinforcement (which may be fibers, particles, etc.). By selecting the composition and the properties of the matrix and the reinforcement/s, one receives materials with the necessary combination of operating and technological properties.

Here we concentrate on metallic KM based on Ni. We can distinguish two types of nickel based nanostructured KMs: bulk or surface nanostructured (nanostructured nickel based coatings). In both types of nickel KMs, one can use various substances as reinforcements (B, BN, nanodiamond, SiC, graphite, diamond and SiC, TiC, TiN, TiCN, Al_2O_3, ZrO_2, TiO_2, etc.). Nanostructured Ni based coatings are widely spread and used, and very popular in surface modification, giving rise to production of coatings with new, improved, desirable, high quality and tailoring surface properties for various applications.

Some of the techniques used to produce nanostructured materials (some used specially for Ni based KMs) are electrodeposition, ion implantation, laser beam treatments, electron beam vapor deposition, mechanical alloying, molecular beam epitaxy, rapid solidification from the liquid state, electrochemical deposition processes, PVD (Physical Vapor Deposition), CVD (Chemical Vapor Deposition), electroless Ni plating.

Now let's consider the possibilities to increase the strength characteristics of Ni composite by adding to nickel nanodiamond or SiC (silicon carbide). These reinforcements are used for production of corrosion and wear resistance surfaces.

For example, we will compare their melting temperatures, which are as follows: Ni (1455 °C) (for bulk Ni), Ni (approximately 880 °C) (for electroles Ni), SiC (2540 °C) nanodiamond (600 °C). It is clear that to operate at higher temperatures is preferable to choose SiC.

In terms of the combination of micro hardness and brittleness, must again look into SiC. Nanodiamonds are hard but brittle under load, unlike SiC. SiC microhardness is 33 GPa.

As to the densities, they are approximately equal and therefore theoretically equivalent: SiC (3,2 g/cm2) and nanodiamond (about 3 g/cm2).

Lattice parameters of Ni, SiC and nanodiamond are respectively equal to: 0.352 nm; 0.44 nm and 2.5 nm. Basically nanodiamond sizes are from 4 nm to 6 nm. But nanodiamonds are conglomerates of atoms. It is not clear how to do their incorporation into the Ni matrix, so as to preserve their integrity. Embedding depends on the applied technology of obtaining composite. And in all cases, increasing the dimensionality of the solid phase is making more difficult the movement of dislocations in the matrix. And this in turn leads to the increase of the strength.

It should be noted that the smaller are individual crystals of Ni matrix, the greater is the hardness of the composite.

In the literature there are sufficient data for such a strengthening of Ni with nanodiamonds (ND) and SiC.

The [5] study reports the effects of electroplating parameters on the microstructure and thus, the mechanical and tribological properties of nanostructured nickel. Results show that electroplating produced thick, dense and uniform nickel deposits with grain size down to 10's of nm and a length/width ratio around 1.8. The grain size and distribution were found to significantly affect hardness and elastic properties with the smallest grain size possessing a hardness that was at least three times higher than that of bulk nickel. Nanostructured nickel showed lower coefficients of friction and wear rates compared to that of bulk nickel and the nanostructured nickel with the smallest grain size exhibited the lowest coefficient of friction and wear rate. These differences were attributed to different wear mechanisms. Bulk nickel showed extensive cracking and evidence of material removal under a wear fatigue mechanism. On the contrary nanostructured nickel exhibited a fine abrasive wear mechanism. This study presents results that suggest a consistent relationship between processing parameters, grain size and distribution, hardness, and wear behavior in electroplated nickel. Understanding of this relationship can be applied to tailor properties and improve behavior of MEMS components. In this study nanostructured nickel samples were electrodeposited under various conditions and characterized by microstructural, mechanical and tribological properties in an effort to develop a better understanding of processing-structure-property relationship.

Fundamental investigations on the origins of friction at the nanoscale were carried out in [9] using both theoretical and experimental approaches. A model was developed that analytically solves for friction by the motion of dislocations at atomically flat crystalline interfaces. It combines known concepts from dislocation drag, grain boundary theory, and contact mechanics into a single model which accurately predicts a wide range of friction phenomena, including static and kinetic friction, friction anisotropy, transfer layers and velocity dependence. In addition, values for friction coefficients calculated by inputting only basic materials constants yield reasonable agreement with comparable ultrahigh vacuum friction results.

The paper [10] reviews the properties of the electroless nickel deposits and describes successful applications. Some of the unique properties of electroless nickel, such as thickness uniformity, hardness, corrosion Properties and applications of electroless nickel resistance and magnetic response have resulted in its use in many different industries. In spite of this, not all designers, engineers, metallurgists and others responsible for materials selection are aware of the value of electroless nickel as an engineering or functional coating. However, it is firmly established as a

functional coating in the electronics, oil and gas, chemical, aerospace and automotive industries, for instance. It is also recognized and used effectively in many others and the number of applications continues to grow.

The many useful properties of these deposits should lead to continued growth in the industry. Of significant interest has been the opportunity presented as a result of the environmental concerns associated with chromium and cadmium plating. The successful replacement of chromium by electroless nickel has frequently been reported and cost savings described. In these applications, thickness uniformity, hardness, corrosion resistance and wear resistance have been major factors. In addition, corrosion resistance enables electroless nickel to compete with other alternatives to cadmium plate. The information contained in Appendix 4 [10] provides an indication of the widespread use of electroless nickel in various industries. It also shows the properties that are of importance in these applications and the versatility of the coating is clearly evident. Through a greater knowledge of the properties of electroless nickel it is hoped that engineers, designers, metallurgists and others involved in materials selection will become more familiar with the many ways in which it can be used to resolve materials problems.

Computer modelling can lend valuable support to experimental and theoretical research on fracture mechanisms. The paper [11] describes examples of the modelling of brittle .tracture in bcc metals, where the preference for the {100} cleavage plane can be explained, and various applications of computer modelling to the mechanisms of toughening brittle materials by ductile inclusions. Computer modelling is beginning to make important contributions to the understanding of fracture processes in metals and composite materials, in the sense that it has become possible to predict the behaviour of materials in microregions which are not, or not completely, accessible to experiment. Such predictions must be verified against observations on a larger scale; they can then be combined with tractographic and other evidence into a micro-mechanistic model of the fracture process. Such models can provide a basis for understanding the role of microstructure and of the interaction between its components in fracture. A rational approach to the problem of improving the toughness of materials is emerging from such studies. Several other research groups are active in this field.

This study [12] describes the development of multilayer metal-dielectric graded index solar selective coatings in which the metallic volume fraction increases with depth, from top (air–film interface) to bottom (film–substrate interface). The work is based on computer simulation followed by validation through fabrication of the coatings and optical measurements. The influence of the choice of the number of layers present in a graded index composite selective absorber and results obtained for a new destructive interference bilayer (four-layer system) coating, designed using the computer model, were studied. The design and optimization of the composite coating was undertaken using a computer tool developed within this program of research employing Bruggeman and Maxwell–Garnett effective medium formalisms. The design tool enabled all key design parameters, with the exception of particle size and orientation, to be varied systematically to permit the sensitivity of the optical properties of the selective absorber coating to be studied. The model was validated with a supporting program of experimental research in which many different selective absorbers were prepared by co-sputtering of metal and dielectric materials.

4.CONCLUSION AND FUTURE WORK

In this paper we presented an introduction to the connection of microstructure and mechanical, and tribological properties of nanostructured nickel. We see the important role of different reinforcements in the tailoring of mechanical properties of composites. In the future could be considered new and still unfulfilled combinations of various reinforcing additives to the Ni matrix. Work can proceed with reinforcement of Ni with three phases at the same time as reinforcements. Possible extensions of this work may be investigation of:

- consideration of all possible substances as reinforcements in Ni matrix composite, comparing their parameters and selection of the most suitable for specific applications (aerospace and other applications);
- calculation of the structural characteristics of the data and planning an experiment to verify the validity of the calculations.

Theoretical calculations can significantly contribute to determine the optimal parameters for various combinations of reinforcement phases or possible and optimal composite coatings, to obtain the desired properties and design of the composite. As in [9], where are applied ANOVA and ANN modeling techniques to optimize the parameters of Al / SiC composites. The future studies, which focus on how nanostructured materials perform and how the microstructures affect their properties, will make the process of customizing these materials easier.

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TRIBOMETAMORPHISM OF DEFORMED ROCKS AND ORIGIN OF ECLOGITES IN THE RHODOPE MASSIF

Evgenia KOZHOUKHAROVA

Abstract. *The movements and frictions in the tectonic shear zones provoke deformations of minerals and rocks: cataclasis, mylonitization, lattice defects, decomposition or crystals till molecular and atomic level, exoemission of ions and electrons. The temperature, pressure and chemical activation of component increase considerable and they crystallize in new high termobaric rocks. Here is proposed an interpretation for the origin of eclogites in the Rhodope Massif on the base of tribometamorphism.*

Key words: *tribometamorphism, shear zones, deformation, eclogites, Rhodope massif*

1. INTRODUCTION

Deformation and metamorphism are closely interlinked, but although many authors have touched upon various aspects of the subject, there has never been a completely satisfactory understanding of the interrelationships at the mechanistic lever [3]. The petrologic literature abounds with descriptions of mineralogical changes observed in the deformed rocks, while the tectonic studies reflect mainly the effects of stress and strain. The effect of mechanical deformation of solids on the course of chemical reaction is studying of mechanochemistry (or tribochemistry) that has developed into an exact science in the last four decades. “The theoretical study of mechanochemistry is concerned with the elementary physical and chemical processes which take place during the straining of solids and which result in their mechanical activation” [17]. The results of experimental studies on the activation grinding of minerals have found their application in various scientific or practical aspects. They are applicable also for explanation of some geological processes and a lot of petrologic problems to find a better decision.

The Earth`s crust is in a state of eternal movement. Tectonic processes cause dislocations and different deformations of the rock layers like folding, thrusting, arising of shear zones, that result to destruction and disintegration of rocks. At the same time a crystallization or re-crystallization of the rock minerals is going on in different level of the crust. It is particularly more intensive in the zones of active deformation and friction where the minerals should be mechanically activated.

Usually the new mineral association from the shear zones points to a higher temperature and pressure of crystallization than that of the host rocks. The new high termobaric rocks appear to be “alien” between the country rocks and their genesis often is discussed. Similar rocks are eclogites.

The eclogites are rare basic and ultrabasic rocks in the metamorphic complexes. They have been considered as indicators for high temperature and pressure of metamorphic crystallization. The main ultra high pressure (UHP) mineral indicators are the polymorphs of silica and carbon - coesite and microdiamond, respectively. The debate over the petrogenesis of eclogites and their host rocks is still active. The two main hypotheses involved in interpreting the appearance of eclogites in crust sequences are: 1. eclogites like external bodies, forming from upper mantle materials and tectonically emplaced into thickened crust and 2. the eclogitization “in situ” into “the burial by subduction complex of crust rocks to previously unsuspected depths, presently on the order of 150-200 km, and by exhumation from such depths [5] have been raised again to the upper levels of the Earth`s crust. But at the same time “the UHP rocks raise a formidable geological problem: that of the mechanisms responsible for their burial and, more pressingly, for their exhumation from the relevant depths” [5]. Pilchin [15] also notes “Some authors show that if subduction is an obvious mechanism to take supracrustal rocks to mantle depths then processes of exhumation are more controversial”. Dawson and Carswell [6] commenting the origin of eclogites, confess somewhat disheartened “It is clear no

single simple model will satisfy the formation of the high temperature and ultra high pressure eclogites". It is importantly to note that the most of the models for eclogitization involved only the confining pressure as a factor which is directly related to depth and this is the way the idea for subduction mechanism was proposed. But this interpretation of eclogite origin is unacceptable in case what the geological evidences for subduction are missing what the geological situation in the Rhodope Massif is.

In the Rhodope Massif the eclogites appear like small lens-shaped bodies usually between the amphibolites [11] being a component of the Rhodopian ophiolite association. Some authors regarded them: as external bodies [10], another as an argument for existing of Alpine regional deep thrusts [4, 7] or as high-pressure products into buried by subduction crust-fragments [2]. In our opinion an eclogite-formation in shear zones of deformation, friction, and crystallization is corresponding better to the real geological setting and an interpretation on the base of tribo processes is more suitable.

The aim of this paper is to focus the attention on the zones of deformation and friction in the Earth`s crust which arise during tectonic movements provoking a high temperature and pressure metamorphic crystallization, and to propose another interpretation for eclogite genesis in the Rhodope Massif. Special attention is given to the deformation of metabasic and metaultrabasic rocks in shear zones, where the chemistry, texture and structure illustrate varying types of tribometamorphic products.

A new point of view for the genesis of high termobaric metamorphic rocks eclogites and garnet lherzolites in the Rhodope Massif is proposed, which is based on detailed geological field investigation, petrological studies as well on the experimental and theoretical achievements of tribology and tribochemistry. All presented arguments allow to conclude that the mentioned rocks are products of tribometamorphism in the share zones of friction in the Earth`s crust during the tectonical processes.

2. TYPES AND LOCATION OF THE SHEAR ZONES OF FRICTION

The shear zones are formed:

1. at the lithological contacts between the beds of rocks with different rheological properties like density, hardness, elasticit, plasticity. Usually they occupy flanks of anticlinals or synclinals where tensile stress is stronger;
2. at the base of the thrusts plates which are gliding on the another immovable plates of allochthone;
3. on the faults crossing the layers;

On micro level shear zones appear:

1. between micro layers of rocks mainly in the mica schists;
2. between the surface of rolling minerals during interlamination sliding. Some of minerals like feldspars disintegrate rapidly but others like garnets are stronger, more solid and resistant and they only rotate (Fig. 2);
3. internal translation of crystal lattice of quartz, graphite and calcite and others where the individual properties of the lattice are in favour of internal sliding.

Secondary surfaces of dislocation and friction into thrusts or minerals are formed due to splitting of rock or mineral substance. Usually the secondary surfaces are parallel to the main sliding zone. Transmission electron microscopy has provided some observations of inner extended dislocations in deformed garnet [16] where stacking fault ribbons have been imaged orientated to (211) glide planes. Brodie&Rutter [3] also announce microzones of dislocation in a deformed amphibole, outlining a euhedral subgrain structure.

3. TRIBOPROCESSES IN THE SHEAR ZONES OF FRICTION

Along shear zones the rock plates are moving and a friction is proceeding. As a result a process of disintegration occurs: cataclasis, brecciation, mylonitization and in deeper zones – metamorphic recrystallization of minerals.

The transformation of mechanical activated rocks and minerals is studied in detail experimentally in grinding mills and described in numerous original papers. Here only some monographs are mentioned of G. Heinicke [9]. E. G. Avvakumov [1], K. Tkachova [17], M. Hedba, & A. V. Chichinadze [8] where were presented the first generalizations of the results. It is known now that the successive steps for genesis of a new mineral phase in a zone of friction pass through clastic, elastic and plastic deformation of minerals, emergence of point and line lattice defects in the crystals till complete decomposition of minerals reaching to molecular and atomic level and exoemission of ions and electrons. In the same time a dehydration of minerals also is developed. Due of mechanical-chemical (or tribochemical) processes, the temperature, pressure and chemical activation of

components increase considerable. A specific feature of the triboprocesses is preservation of the increasing temperature and pressure only in the closed space of the tribozone and out of its boundaries they rapidly fall. The free energy of activation in the system is very high and it is the driving force for nucleation of the grinded mass and subsequent grain growth. The new mineral assemblages crystallized in high T/P conditions of the tribozone form the new metamorphic eclogite rock. It is heterofacial to the surrounding rocks which have been crystallized in relatively lower. T/P conditions. Chemical equilibrium of the reaction achieved in the space of tribozone is a local equilibrium towards host rocks.

Factors of important significance for the tribo-reactions are: velocity and duration of friction between the plates, resistance of material, degree of unevenness (ruggedness) of gliding surface, presence of solid hard rolling beds or minerals. The accumulated effect of tribo-processes may possibly provoke the realization of extremely high temperature and pressure only in the narrow closed space of the trybo zone.

A lot of experimental and theoretical investigations clarified the relation between the quantity of heat generated in the zones of friction and some factors as: weight, velocity and time of plate movement, roughness of surfaces, availability of rolling resistant fragments.

The dependence of the main factors after Heinicke [9] is represented by the formula:

$$Q = \mu F g v \quad [1]$$

Q – thermal energy; μ – coefficient of friction; F – mass; v – speed of moving plates or bodies.

On the other hand during processes of eclogitization, especially into serpentinites, the density of the rocks has been quite changed. For example, the transformation of serpentine –Mg-hydrosilicate with planar structure and voluminous lattice to garnet-lherzolite assemblage: olivine, rhombic - and monoclinal pyroxene, garnet, rutile, spinel and magnetite (anhydrous silicates and oxides with axial or isometric dense lattices) shows a significant negative volume effect estimated to about 16-22%.

Pilchin [15] represents the dependence between volume (V), pressure (P) and temperature (T) by the formula:

$$Pe = Po + \alpha/\beta(Te - To) - 1/\beta(\Delta V/Vo) \quad [2]$$

Pe – eclogite pressure; Po – lithostatic (confining) pressure;
α – coefficient of thermal expansion; β – coefficient of compression;
Te – eclogite temperature; To – background temperature;
ΔV=Ve–Vo; Ve – volume of eclogite mineral association; Vo – primary volume of substrate.

Therefore the value of Pe increases parallel to increasing the temperature and decreasing of volume of the system. During tectonic processes in the Earth`s crust, friction is often created between the layers and it is possible that for a short moment in some narrow shear zones the values of pressure and temperature to reach the P/T conditions necessary for eclogite crystallization. In this way the idea for the descent of a rock complex by subduction to the deep mantle zones and after that for its rising again to the upper zones by unreliable exhumation mechanism is not reasonable.

The question now is “Do evidences exist in the geology for the realization of high (ultrahigh) pressure/temperature in the levels of Earth`s crust satisfactory for eclogite crystallization?

4. A NATURAL EXAMPLE FROM RHODOPE MASSIF FOR HIGH PRESSURE CRYSTALLIZATION

In the present paper an instructive example for crystallization in zones of friction, producing eclogites (more precisely a kind of them - garnet lherzolites) is announced.

The garnet lherzolites in the Rhodope Massif are outcropped in the peripheral parts of a serpentinite bogy in the intensively folded Avren syncline, Eastern Rhodopes [12]. Thin (1-2 cm) parallel stripes consisting of garnet, orthopyroxene, clinopyroxene, olivine and spinel alternate with serpentinite bands The garnet-lherzolite zones are in conformity with the boundaries of the body, as well as with the general stratification and of the metamorphic schistosity of the country rocks. The stripes gradually disappear towards the central parts of the body At first the garnet disappears and further on –the pyroxene. The serpeninites have no traces of eclogitization inside the body and they are partially replaced only by talc, chlorite and tremolite-actinolite.

Usually the bands have a zonal structure. Their central parts are occupied by garnet, followed by strips consisting mainly of enstatite, diopside, olivine and spinel. A transitional zone of cryptocrystalline talc-chlorite aggregate is formed between the new eclogite minerals and the serpentinite. The myrmekite-like symplectites are built up of: i) diopside and spinel; ii) diopside, enstatite and spinel; iii) diopside, spinel and magnetite; iv) diopside and actinolite. They are very characteristic reaction products, giving evidence for a rapid re-crystallization. Similar layered

metaperidotites are also found in North Greece at Kimi village where micro diamonds have been established [14].

The Al-content in ortho-and clinopiroxenes from garnet-lherzolites is higher (enstatite 0.13-0.18, diopside 0.12-0.14 pfu) than that from garnet-free lherzolites (enstatite 0.05-0.07, diopside-0.03-0.08 pfu) which also indicates for increased pressure.

The temperature/pressure conditions (determined by thermo - barometric methods, based on chemical composition of minerals) in the garnet-lherzolite zones are T - 800^{o}C/P - 10-15 kbar and in garnet-free lherzolite zones are T - 560^{o}C/P – 11-12 kbar. At the same time the background regional metamorphism of the country rocks is typical medium pressure amphibolite facies T - 480-540^{o}C/P – 4-5 kbar]13]. These facts suggest a spatial anisotropy of the thermodynamic parameters into the serpentinite body and change of the temperature and pressure only within a very short range in the shear zones.

The reaction relationships between minerals show undoubtedly that serpentine in the thin zones was dehydrated and replaced by a new anhydrous and higher T/P mineral ensemble. More over, the transformation of the serpentine - a Mg hydro-silicate mineral with planar lattice structure, into oxide and anhydrous silicate or oxide minerals with axial and isometric structure had a significant negative volume effect - theoretically about 16-22% as was noted.

The structure of garnet-lherzolite zones corresponds to the Beilby tribozone.

5. GENESIS OF THE ECLOGITES AND GARNET-LHERZOLITES IN THE RHODOPE MASSIF

The eclogites (lato sensu) in the Rhodope Massif are not external bodies. They have been formed in the Earth1s crust in its own environment - amphibolites and serpentinites, which are elements of the Rhodopean Ophiolite Association which has steady stratigraphic and transgressive position. The sufficiently well preserved stratification of the rock complex as well as the lineal synmetamorphic fold structure are an evidence for its stability without any completely destruction (whatever would take place in a subduction zone). This fact excludes a descent of the metamorphic complex through some subduction zone to mantle depth or deep collision and an exhumation to the upper levels of the crust again as believed by some authors [4, 7, 14]. The eclogites developed into narrow interlaminar spaces like bands parallel to the metamorphic foliation. The background metamorphism (T – 480-540^{o}C, P – 4-5 kbar) and eclogite metamorphism (T – 560-800^{o}C/P – 10-15 kbar) demonstrate a distinct spatial anisotropy of T/P conditions specific for tribozones. The eclogite mineral association is heterofacial but synchronous to the country rocks. Often some of the minerals (omphazite) are decomposed and replaced by symplectites as a mark of rapid decrease of T/P condition after crystallization which is also specific for tribo zones. All these features suggest that eclogites developed in narrow spaces with local conditions corresponding to the tribo processes.

Metamorphic complexes in the Rhodope Massif are a product of termodynamic processes, causing simultaneous deformation and recrystallization, particularity more intensive in numerous zones of movement and friction. The friction provoked elastic, plastic and brittle deformation of minerals, followed by different degree of disintegration of the crystals and impacts of movement bits, the temperature, pressure, chemical potential of the components increased and a new eclogite mineral association appeared. “In narrow (a few cm) fault zones where the stress, strain rate, and displacement are large, temperatures may rise by as much as 1000^{o}C, where frictional melting and pseudotachylite may occur” [18]. Similar conclusions are made by another authors “The high concentration of energy into narrow space more over with high velocity of friction is possible for a brief moment to get to temperature “explosion” and during a second or microsecond the temperature to increase till 1000^{o}C [8].

6. CONCLUSION

The main features of eclogites/garnet-lherzolites in the Rhodope Massif are:

-Constancy of stratigraphic position connected to Ophiolitic Association (amphibolites and serpentinites),

-Distribution in intense folded rock complex;

-Development in thin bands alternating with unaltered serpentine bands only near to contact of the body;

-Metamorphic (not relict magmatic) origin;

-Different high T/P facies of eclogites in comparison with medium T/P background facies of country rocks;

-Lack of real evidence for subduction and later exhumation of rock complex;

prove that eclogites in the Rhodope Massif are not external bodies, but developed “in situ” in narrow zones with local high T/Pconditions of crystallization. The most satisfactory interpretation for their origin are the tribo principles, according to which the friction processes in thin zones provoke a uneven arising of high temperature and pressure. The roughness of surfaces, availability of rolling resistant rock or mineral fragments and sudden rapid tectonic movements favorable tribo-processes.

The eclogites are the most known high pressure basic/ultrabasic metamorphic products. Similar to that are also some finegrained garnet-zoisite-rutile mineralisations marking secondary surfaces of friction in Alpine epidermal thrust built of nonmetamorphosed sedimentary rocks.

Recrystallizations of rocks in narrow zones caused of tribo processes represented a specific kind of termodynamic metamorphism which may be named tribometamorphism.

We can assert now that evidences for the realization of high (ultrahigh) pressure and temperature conditions in the levels of Earth`s crust satisfactory for eclogite crystallization exzist.

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CONTACT APPROACH WHEN EXAMINING THE RELATIONSHIP BETWEEN THE COLORS AND THE CORPORATE DESIGN.

Genoveva VLADIMIROVA

Abstract: *The publication looks at the relationship between colors and their impact on consumers in corporate design. Proved the need for a high level of knowledge of his physical and mental - emotional impact on people with its behavioral habits. Were presents the main colorist approach to developing corporate identity, corresponding to the quality of the offered components of the product network. Were describe the basic color combinations according to sectors which use, made primary, secondary and tertiary communication with potential user group. Were make a individual features of the primary colors with their impact on conscious and even subconscious level.*
Key Words:*. colors, contact approach, corporate design, impact on consumers.*

КОНТАКТЕН ПОДХОД ПРИ ИЗСЛЕДВАНЕ НА ВРЪЗКИТЕ МЕЖДУ ЦВЕТОВЕТЕ И КОРПОРАТИВНИЯ ДИЗАЙН

Геновева ВЛАДИМИРОВА

Резюме: *В публикацията се разглежда връзката между цветовете и тяхното въздействие върху потребителите в корпоративния дизайн. Доказва се необходимостта от познание на високо ниво за неговото физическо и психо – емоционално влияние върху човека с неговите поведенчески навици. Представят се основните колористични подходи при разработване на корпоративна идентичност, съответстваща на качеството на предлаганите елементи от продуктовата мрежа. Описват се базови цветови комбинации в съответствие с отраслите, в които се използват, осъществявайки първичната, вторичната и третичната комуникация с потенциалната група потребители. Прави се индивидуална характеристика на основните цветове с тяхното въздействие на съзнателно, а дори и на подсъзнателно ниво.*
Ключови думи: *цветове, цветово въздействие, корпоративен дизайн, въздействие върху потребителите.*

I. ВЪВЕДЕНИЕ

Ако цветовете не съществуваха нямаше да я има носещата свежест дъга и красотата на благоуханната червена роза, нямаше да се радваме на чистото синьо небе и на цъфналите дръвчета през пролетта, нямаше да има прекрасни лица с теменужени очи. Нашият свят щеше да бъде еднообразен и сив. Благодарение на цветовете ние възприемаме околната среда като жива част от нашата природа.

Цветът е навсякъде около нас, той е този, който ни привлича вниманието, насочва ни, прави ни спокойни или напрегнати, развеселява ни и ни стимулира.

Доказано е, че цветът оказва физическо и прихо – емоционално въздействие върху хората. Например върху кръвното налягане и пулса – то се понижава от синьото и зеленото и се повишава от жълтото и червеното. Цветовете от топлата гама въздействат на централната нервна система и създават усещане на възбуда на възприятията и желание за консумация.

II. ИЗЛОЖЕНИЕ

Независимо дали е малка фирма или огромна корпорация, влиянието на цвета върху потребителите е един от най-значимите фактори в изграждането на т.нар. брандиране или налагане на фирмена идентичност. Има много компании, които години наред спазват конкретна цветова гама, наложена с времето и следва определени традиции. Има и такива, които използват сложен и не често срещан колористичен подход, но го налагат като свой разпознавателен знак за клиентите си.

Разработването на т.нар. ***бранд бук*** (книга с цветови, формени, типографски и др. закономерности) е сложен процес, който изисква отлични познания по психология, символика и физика на цветовете, както и познаване на потенциалната група клиенти. Доказано е, че съществуват възрастови, полови, социални, регионални, етнически и др. предпочитания при избор на цветови гами и комбинации. Тъй като изработването на фирмен стил зависи от предпочитанията на клиентите, те също имат определени очаквания и предположения по отношение на компанията. Например: ако компанията е насочена към продукти за малки деца – тя трябва да избере ярки наситени цветове или тяхната пастелна вариация.

Много от тези компании за всъщност физически места – като търговци на дребно, ресторанти, където клиентите могат да закупят определени стоки или използват определени услуги. В такъв случай собствениците трябва да установят цветове, които са вече познати на клиентите от използвани извън „магазините" такива в рекламни кампании и обозначения, печатни медии и уеб сайтове.

Цветовете са от решаващо значение за изграждане на имиджа на компанията. Когато се изгражда уеб сайт, цветовете трябва да бъдат вече познати за клиентите, за да чувстват те като „у дома си". Също така цветовете и логото трябва да бъдат разпознаваеми на подсъзнателно ниво и да се свързват именно с тази компания, а не да предизвикват колебание и учудване.

В корпоративните среди най-често използваните цветове за два: син и червен. Наскоро проведено проучване показа, че синьото е цветът, който избират най-влиятелните компании в света. Някои от тях са Facebook, Twitter, Dell, IBM, Nokia и още стотици компании, чието лого е синьо на цвят, както и Fujitsu, Canon, Toshiba, YouTube, BBC, CNN и други, чиито фирмен стил е в червено. През годините дори и да има леки корекции – основните цветове винаги се запазват за да изглеждат компаниите познати.

Този факт се обяснява с теорията за трикомпонентното цветно зрение на хората (потребителите, клиентите). Това е т.нар. принцип на трикомпонентността и според теорията, се свърза с наличието на 3 вида рецептори, които реагират съответно на син, зелен и червен цвят. Тази хипотеза на Йънг се потвърждава от съвременните изследвания, които доказват съществуването на 3 вида колбички в ретината на окото, които имат различна крива на спектрална чувствителност и реагират на различна дължина на вълната. Колбичките са наречени сини, зелени и червени и ако съотношението между тяхното възбуждане е същото, както при смесването на трите цвята, може да се получи всеки друг цвят. Например едновременното възбуждане на зелени и червени колбички води до усещането за жълт цвят, а на трите заедно – за бяло. Черен цвят се получава при пълното отсъствие на възбуда.

Синият цвят създава предпоставка за дълбок размисъл над живота и истината. Синият цвят символизира постоянство, упоритост, настойчивост, преданост, сериозност, строгост. Хората, които го предпочитат, се стремят към ред и систематизация, те винаги имат своя гледна точка, предани са на делото си. Синьото на подсъзнателно ниво отдалечава оцветените в него предмети и дава усещане за хлад, намалява пулса на сърцето, както и кръвното налягане. Същевременно въздейства като стабилен и сериозен цвят, делови, дава усещане за тишина, чистота и прозрачност на отношенията. Затова и се използва предимно от компании, свързани със строга йерархия, строги делови отношения, компанни, разработващи нови комуникационни продукти, черна и бяла техника и типичен „банков" цвят – повечето от банките го предпочитат именно него.

Червеният цвят олицетворява могъществото, силата, волята за победа. Хората, които харесват червеното, винаги постигат онова, което искат, винаги са в движение, винаги са извор на енергия. Обичат да бъдат първи, но невинаги могат да бъдат – това зависи от разрушителните им качества. Той действа по обратен начин на синия – дава усещане за приближаване на предметите, за топлина, увеличава пулса и кръвното налягане, поради което се създава т.нар. шум в ушите. Той е агресивен, но и рязко привлича вниманието към себе си, не може да остане незабелязан. Въздейства на централната нервна система и създава желание за консумация и усещане за глад – било на храни или услуги. Предпочита се от компании, които се занимават с търговия, в хранително – вкусовата промишленост, най-много в

сферата на заведенията за бързо хранене, в сферата на услугите и др. Предвид значението му, логотата на Happy или Flirt явно са добри примери за привличане на вниманието.

Зеленият цвят се получава от сливането на синия и жълтия – те взаимно се допълват. В зеленото е заложена потенциална енергия. Зеленото отразява отношението на човека към самия себе си. Този цвят символизира процъфтяването и новите начинания. Зеленото е цветът на природата и свободата. Той отпуска и предразполага към почивка. Не е агресивен и поради това се използва предимно от организации за опазване на околната среда или от компании, които произвеждат еко и био продукти. Бледозеленият фон и белите букви, характерни за новото лого на Globul, не са съвсем подходяща асоциация, съгласно описанията на цветовете по-горе, тъй като това са прекалено успокояващи и стерилни цветове. За компания, която обещава, че *"Най-доброто предстои"*, биха били по-удачни нюанси в жълто или оранжево.

Черният цвят е предпочитан от хора със силна воля, упорити и дисциплинирани. Може да са твърде непреклонни и независими. Той винаги скрива в себи си онова, което носи, загадъчен и мистичен. Предизвикващ любопитство, привличащ и плашещ, винаги призовава човека да освободи своята същност. В корпоративните среди е често срещан, тъй като говори за стабилност, сигурност и наличие на добри доходи. Използва се главно при избор на работно облекло за професии, които не са свързани с артистизъм. В логото на Vivatel ясно изпъква черния цвят. Това е отличен фон, но както става ясно по-горе, този цвят внушава сериозност, класически стил. В същото време всички рекламни инициативи на Vivatel са насочени към младите хора, към тинейджърите, които са всичко друго, но не и сериозни и класически.

Белият цвят характеризира съвършенството и завършеността, демонстрира абсолютното и окончателно решение, пълната свобода на възможностите и премахване на препятствията. В корпоративните среди е символ на чистота и желание за размах и простор на възприятията. Неслучайно този цвят се предпочита за униформи на професионалисти с физически чисти занимания. Използва се често в дизайна на компании, занимаващи се с ефирни бижута, мебели и други декоративни предмети.

Жълтият цвят олицетворява ума и вниманието, той е най-гъвкавият, прониква навсякъде, помага да се преодолеят трудностите, подобрява концентрацията и мисленето.

Жълтият и оранжевият цвят са предпочитани от свободните професии, защото говорят за артистичност от използващия го. Те са ярки и привличат вниманието, но не носят агресията на червеното. Жълтият цвят се използва и когато трябва да се стимулитат умствените процеси и паметта. Предпочитани са от хранително – вкусовата промишленост, тъй като създават желание за консумация у потребителите., стимулирайки производството на хормона на глада.

Лилавият цвят е на царствеността, загатва за лукс, богатство, изисканост. Също така е женствен, романтичен. Заради това, че е рядко срещан в природата, може да изглежда изкуствен. Хората, които го предпочитат, са тайнствени и желаят да получат духовно просвещение. Свързва се с коронната чакра, чрез която може да се получава енергия от Космоса. Той е комбинацията от червено и синьо и носи отчасти характеристиките и на двата цвята. Привлича вниманието, но е тежък и властен, без агресията на червеното. Предпочита се от компании, които са дълго време на пазара, смятат се за коректив и имат самочувствието на изградена вече йерархия.

Комбинацията от лилаво и златисто говори за лукс, величие и власт и се предпочита за скъпи, луксозни стоки или такива, които искат да създадат такова впечатление.

Златистото и сребристото говорят за скъпи услуги и продукти, но докато сребристото е чисто и невинно, златистото е символ за откровено богатство и великолепие.

Цветовете осъществяват както първичната, така и вторичната и третичната (по – дълбоката) комуникация с предвидените потребители. Заедно с балансирани правилно подбрани формени категории те „разказват" на потенциалните клиенти за стоките и услугите, които компанните производители предоставят.

Цветовете контролират вниманието, добавят акценти в съдържанието на представения материал, открояват приликите и разликите, предизвикват индивидуална емоционална реакция у възприемащия материала. Доказано е, че 80% от предпочитанията на потребителите се ръководят от цветовете на фирмения стил или опаковките. Затова основните закономерности трябва да се спазват, умело съчетани с индивидуалните потребности на различните групи потребители.

III. ЗАКЛЮЧЕНИЕ

Всички тези знания могат да се прилагат за лечение на хората, за създаване на уютен дом, съответстващ на характера им, както и за сериозни и стабилни бизнес отношения. Знаейки как въздейства всеки един от тях, цветовете могат да бъдат добър съветник и помощник в търсенето и изграждането на по - щастлив и хармоничен живот.

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CONTACT APPROACH WHEN EXAMINING THE RELATIONSHIP BETWEEN THE COLORS AND THE FOOD PRODUCTS

Genoveva VLADIMIROVA

Abstract: *The publication is considered the natural link between the colors with their physical characteristics, their presence in the natural products and the impacts on people - their consumer. Through this "contact approach" of study of tribological interactions were describes the relationship between the pigments in food products and their healing properties. In the publication were mentioned also some alternative treatments of healing, which are in connection with the colors and their possessions centers in the human body through the exchange of fine and high energies.*

Key Words:. *colors, contact approach, tri-identity, color effects, chakras, colorful foods.*

КОНТАКТЕН ПОДХОД ПРИ ИЗСЛЕДВАНЕ НА ВРЪЗКИТЕ МЕЖДУ ЦВЕТОВЕТЕ И ХРАНИТЕЛНИТЕ ПРОДУКТИ

Геновева ВЛАДИМИРОВА

Резюме: *В публикацията се разглежда естествената връзка между цветовете с техните физически характеристики, присъствието им в натуралните природни продукти и въздействието им върху човека – техния консуматор. Чрез конкретния „контактен подход” на изследване на трибологичните взаимодействия се описва връзката между пигмента в хранителните продукти и техните лечебни свойства. В публикацията се споменават някои алтернативни методи на лечение, свързани с цветовете и прилежащите им центрове в човешкото тяло посредством обмен на фини и високочестотни енергии.*

Ключови думи: *цветове, контактен подход, триединство, цветово въздействие, чакри, цветни храни..*

I. ВЪВЕДЕНИЕ

Цветът е едно от божествените проявления на природата с неговите възможности за въздействие на физическо и психо – емоционално ниво. Цветът насочва, стимулира и вдъхновява.

Познавайки възможностите му, той би ни помогнал да опознаем света вътре и около нас, би ни дал възможност да открием източника на своята жизнена сила.

Всеки цвят „вибрира” със собствена честота, която се предава и на обагрените в него тела.

Той може да зарежда, но и да отнема енергия, може да концентрира и отпуска, да въздейства на физическите възприятия за малко, голямо, ниско и високо, а дори и да променя нюанса на намиращия се в съседство цвят и да лекува.

II. ИЗЛОЖЕНИЕ

Лечението с цветове има своите корени в далечното минало. Още египтяните почитали слънцето като източник на енергия и изцеление и приемали, че емоциите са свързани с цветовете. В древен Вавилон и древен Рим са се правели слънчеви бани. Персите също практикували лечение със светлина и цвят.

По-късно гръцкият лекар Гален търсел връзката между цвета и промените във физическото тяло на човека. Авицена също отдавал роля на цветовете в своите изследвания и търсения.

През 19 век Е. Бабит публикува книгата „Принципи на светлината и цвета" със свидетелства за цветолечение, които за своето време са революция в медицината. Използвал е уред наречен хромолеща в различни цветове. Тя се е пълнела с вода и се е използвала за филтриране на съответния цвят върху болната част от тялото. След излагане на слънчева светлина водата се зареждала с елементи от светлината според цвета на стъклото. Съгласно вселенския закон за подобието (Подобното привлича подобно), филтрираните през жълт цвят лъчи привличат фосфора, натрия, желязото, въглерода и др. Червените лъчи зареждат водата с желязо, цинк, стронций и др. Според автора по този начин се създават положителни и отрицателни потоци на енергия в тялото, които му въздействат и лекуват болното място.

В днешно време има много публикувани данни за въздействието на цветовете върху развитието на различни заболявания.

Общо стимулиращото ЧЕРВЕНО се препоръчва при:

- инертност, физическо изтощение; нарушено кръвообращение - за повишаване на кръвното налягане и ускоряване на пулса; страхове, тревоги; настинки, треска; недохранване, анемия, слабеене; слаба менструация.

Укрепващо едновременно физическото тяло и способностите за концентрация, ОРАНЖЕВОТО повишава положителните емоции и създава чувство на радост от живота. То се препоръчва при:

- умствена и душевна отпадналост; заболявания на белите дробове - бронхит, астма; емоционално напрежение; мускулни спазми и схващания; болни бъбреци; хемороиди.

ЖЪЛТОТО излъчва високочестотна оптимистична енергия, която влияе на нервната система и стимулира умствените способности. То се препоръчва при:

- депресия, забавена умствена дейност; стомашни неразположения, лошо храносмилане; запек, чревни оплаквания; отслабен слух; кожни заболявания; страдания на черния дроб.

Енергията на ЗЕЛЕНОТО е естествено ободряващо средство, защото едновременно отпуска тялото, нормализирайки кръвообращението и го освежава. То се препоръчва при:

- високо кръвно налягане, язва; главоболие; безсъние; нервно разстройство, раздразнителност; мускулно напрежение.

СИНЬОТО – енергия на надеждата и ведростта – оказва успокояващ ефект върху нервната система и мисловната дейност. То се препоръчва при:

- възпаления на очите и ушите; възпалено гърло, ларингит, спаднал глас; инфекциозни болести; гадене, диария, гастрит; силна менструация; ожулване на кожата, порязване, изгаряне, ужилване, сърбеж.

„Интуитивните" качества на ИНДИГОТО предоставят енергия, която освобождава съзнанието от страхове, тревоги и ненужни задръжки. То се препоръчва като:

- анестезия и болкоуспокояващо средство и при: заболявания на очите, ушите, носа и гърлото; пневмония; висока температура; кожни болести; умствена свръхвъзбудимост, мании.

ВИОЛЕТОВАТА енергия е естествен антиоксидант, успокоява нервите и устремява ума и духа към възвишени цели. Препоръчва се при:

- невралгия, ишиас; пърхут и други болести по окосмената част на главата; заболявания на бъбреците и пикочния мехур; ревматизъм; невроза, душевни разстройства; безсъние.

Широко използван днес метод за алтернативно лечение е този, който се основава на познаване и въздействие върху основните чакри на човека, всяка от които е свързана с определен цвят.

Представата за чакрите - енергийните центрове на човека, е дошла от Изток, а самият превод на думата означава „колело". Чакрите преобразуват енергиите на Вселената и ги интегрират в нашето физическо тяло. Естествено те не са разположени в плътното физическо тяло, а във финото енергийно поле и въпреки това имат свои проекции и върху физическото тяло. Най-често се използват две техни проекции-отпред на тялото и по гръбнака, където местоположението им съвпада със специфични нервни центрове на гръбначния мозък.

Всяка чакра „вибрира" в честоти, близки до тези на цветните лъчи, получени при опита на Исак Нютон, които са част от видимата светлина. Те са подредени както следва: коренна чакра (червена), коремна (оранжева), слънчев сплит (жълта), сърдечна (зелена), гърлена (синя), третото око (индигова) и коронна чакра (виолетова). Алтернативната медицина поддържа вярата, че тъй като всяка чакра е свързана и с определени анатомични области, при въздействие с определени цветове може да се лекува конкретен огран, разположен в близост до съответния център. Затова при увреждане на тези енергийни центрове се разболяват и определени органи.

Друг метод на лекуване на физиката и психиката е т.н цветно дишане – при него се взима предмет с цвят, характерен за съответната чакра и е необходимо човек да се взира продължително време в него, докато нищо друго не остане в съзнанието му. Той се съсредоточава върху дишането си и мислено изхвърля всички отрови от организма си. Така последователно, докато се премине през всички цветове и съответстващите им чакри.

Цветът играе важна роля и при подбирането на храната. Необходимо е да се съставя определено меню така, че да се поглъщат цветове, съответстващи на липсващите енергии в тялото. Човек е това, което яде. Храната е предназначена да даде енергия на тялото му. При храносмилането функциите на храносмилателните органи трансформират храната в енергия. Но когато се подбира храната, често не се намира време за нужния рационален подход към нея. Вкусът или внушението за него става приоритет, вместо енергйното съдържание и полезността за огранизма.

Трите основни групи цветни храни са зелени /съдържат хлорофил/, червени и оранжеви /съдържат каротиноиди/ и сини/ съдържат антоцианидини/.

Как тези цветове влияят върху здравето на човека и има ли закономерности, които е важно да се спазват?

Белите на цвят продукти като мляко, извара, сирене и др. млечни продукти, ориз, чесън, карфиол успокояват, премахват раздразнителността и извеждат от организма токсините.;

Сините като грозде, сливи, патладжани съдържат биологично активни вещества - антоцианини, които защитават кръвоносните съдове и зрението.

Зелените хранителни продукти като маруля, броколи, зелен грах, свежа салата, спанак подхранват мозъка, повишават активността, премахват напрежението. Хлорофилът, съдържащ се в зеленчуците и плодовете със зелен цвят, стимулира изработването на еритроцити (червени кръвни клетки) в кръвта и активизира имунната система.

Червените на цвят като цвекло, чушки, домати, ягоди стимулират обменните процеси, подобряват кръвообращението и повишават работоспособността. Но ако се употребяват в големи количества, те могат да предизвикат превъзбуждане и проблеми със заспиването.

Оранжевите - праскови, кайсии, тиква, мандарини, моркови спомагат за възстановяването на нервните клетки и обновяването на мускулните тъкани, повишават сексуалността, подобряват настроението, помагат в борбата с умората и апатията, успокояват главоболието.

Жълтите продукти като лимони, ананаси, ябълки, банани, царевица, кашкавал, яйчен жълтък стимулират храносмилането, подобряват апетита, снабдяват с енергия.

Кафявите хранителни продукти - сладък картоф, звездовиден анасон, стафиди, какао, елда, чай, мушмули, кестени, ленено семе, кафяви гъби, орехи, леща, фурми контролират щитовидната жлеза, влияят върху умствените и физическите способности. Продуктите от кафявата гама помагат при болести на очите, ушите, носа и кожата.

Цветът на храните влияе на настроението, здравето и самочувствието. Това показват резултатите от специален експеримент на европейски учени.

По време на изследването, нормалният за човешкото око цвят на храната, чрез специално осветление придобива други оттенъци, неприсъщи за естествения цвят на храните. Например, зелен грах по цвят прилича на хайвер, месото е сиво на цвят, млякото - лилаво, а яйцата са оцветени в ярко червено. Повечето от поканените не могли да се докоснат до приготвените храни, а тези, които са се решили, са почувствали ужасно неразположение.

Цветовата информация влияе не само на решението да се опита от храната, но и на удоволствието, което ще се изпита от нея. Затова с основание може да се каже, че в този случай зрението и вкусът са в синестезия (от гръцки syn, „заедно“ и aishesis, „усещане“- означава смесено възприятие. Това е състояние, при което възприятията се свързват едни с други. Едно сетивно възприятие или идейна представа предизвиква в съзнанието същевременно друга представа, от сетиво, което не е било стимулирано) - едното възприятие предизвиква другото.

В хранителното меню присъстват много зеленолистни, червени плодове и зеленчуци, опечено до кафяво месо, бели зърнени и млечни продукти. Но какво да може да се каже за цветове като синьото? Като че ли не предизвиква голямо слюноотделяне в устата. Най-много да се опитат шепа боровинки в планината, но само след уверението, че не е нещо отровно. По всичко личи, че що се отнася до храната, това не е цвят, който вдъхновява майката природа. С малки изключения сините и черните храни са или развалени (мухлясали) или изначално токсични, например плодовете на беладоната. Затова при вида на така обагрен продукт човешкият инстинкт не реагира с желание за опитване, а напротив – подава сигнал за опасност.

Днес хранителната индустрия разполага с всевъзможни синтетични оцветители и в магазина могат да се открият продукти с най-различни цветове. Но въпреки, че са необичайни и забавни, те не се радват на особен успех. Видът им просто не предизвиква „вкусни” асоциации и потребителите ги подминават. Но както едни цветове потискат апетита, други го разпалват.

Чрез невроните зрителната информация директно влияе на производството на хормоните**,** които регулират глада. Така предупредителните цветове като синьо, сиво и индиго стимулират хипоталамуса да произвежда **лептин**, които потиска апетита, докато оранжевото, червеното и жълтото водят до засилена секреция на **грелин** – **хормонът на глада**.

Този факт е не само любопитен, но и много полезен, човек има желание да регулира теглото си. Не е нужно да се търсят храни с необичаен цвят, а просто да се трансформира зоната за хранене в „неапетитна" гама – например синьо-сиви стени, прибори, покривка или светлина. Добре е да се избягват заведенията за бързо хранене, защото там най-вероятно ще се дебалансира хранителният режим заради преобладаващите в интериора, опаковките и храните жълт и червен цвят – най-опасните за диетата.

Обратното – ако има желание за сплотяване на семейството около трапезата и да се изпита наслада от приготвените ястия е необходимо да се предпочетат топли цветове за кухнята. Всеки човек ще опита от зеленчуците, ако са сервирани в червена или оранжева чиния. Освен влиянието върху апетита, тези цветове имат мощно въздействие върху целия организъм – учестяват сърцебиенето, повишават кръвното налягане и така създават атмосфера на уют и близост.

Храните с определени цветове могат и да „помагат" според различните сезони:

Оранжевият цвят говори за наличието на бетакаротини, които осигуряват хидролипидния слой на кожата. Той пък от своя страна слага край на прекомерното потене в летните горещини. Така че вместо дезодоранти срещу прекалено изпотяване, хората трябва да наблягат на оранжеви храни, като праскови, кайсии, моркови, пъпеши.

Червеният цвят в доматите и дините, богати на ликопен, има антиоксидантен ефект и помага на кожата да се защитава по-добре от щетите, които й нанася лятното слънце.

Лилавият цвят в храните говори за наличието на антоцианини - субстанции, които предпазват кръвоносните съдове и подобряват микро-кръвообращението.

Следователно храни**,** които са лилави на цвят, като синьото грозде, черниците, боровинките и патладжаните са най-благоприятни през летните месеци срещу подуването на краката - неудобство, което тормози много хора през лятото.

III. ЗАКЛЮЧЕНИЕ

На първично ниво цветовете въздействат физически върху човека чрез тяхната визуализация, посредством органа на зрението. Благодарение на разликите в дължината на вълната окото ги възприема различни като тон, нюанс и контраст. На по-дълбоко ниво се включва психо – емоционалното колористично въздействие върху човека, което може да хармонизира или дебалансира в зависимост от начина, силата и познанието при използването на цветовете. На трето ниво се появява енергийно – вибрационният ефект на въздействие, който оказва голямо влияние върху финитe полета на човека и дълбоката му връзка с цялата природа.

Както в древността, така и до днес цветът остава съкровена част от нашето съществуване, с помощта на който можем да открием и преодолеем дисхармонията както в нас, така и в света около нас.

Ако се доверим на интуицията си и се опитаме да разберем вълшебствата на цвета, той ще ни обогати с безкрайното познание, срито в него. Богатство, завещано ни от майката – природа.

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3D SIMULATION OF STRESS-STRAIN STATE OF T-JOINT WELDING PROCESSS BY CAD/CAE SOFTWARE SYSWELD

Rayna DIMITROVA, Alexander NEDELCHEV

Abstract: *The deformation process during the welding of T-joint is analyzed by CAD/CAE software SysWeld under Visual Environment using 3D simulation. The aim of simulation is visualization of a temperature field and a stress-strain state distribution as results of welding under typical technological parameters of MAG processing which could be used for education.*

Key Words: *CAD/CAE simulation of welding processing, stress-strain state*

3D СИМУЛИРАНЕ И МОДЕЛИРАНЕ РАЗПРЕДЕЛЕНИЕТО НА НАПРЕГНАТО-ДЕФОРМАЦИОННОТО СЪСТОЯНИЕ ПРИ ЗАВАРЯВАНЕ НА Т-ОБРАЗНО СЪЕДИНЕНИЕ В СРЕДАТА НА CAD/CAE ПРОДУКТ SYSWELD

Райна ДИМИТРОВА, Александър НЕДЕЛЧЕВ

Резюме: *Заваръчният процес на Т-образно съединение с двустранен заваръчен шев е анализиран чрез 3D симулация, проведена с CAD/CAE пакет за компютърна симулация SysWeld с използване на Visual Environment. Целта на симулирането е визуализирането разпределението на температурните полета и напрегнато-деформационното състояние, в резултат от МАГ заваръчен процес, което да бъде използвано за обучение*.

Ключови думи*: CAD/CAE симулационно моделиране на заваръчен процес, напрегнато-деформационно състояние*

1. *ВЪВЕДЕНИЕ*

Процесите на заваряване с разтопяване са свързани с едновременно протичане на термични и деформационни процеси, свързани с нагряване, разтопяване, кристализация и охлаждане на разтопения и основния метал, които са развити на различен етап в различните точки от и около заваръчния шев. В зависимост от вида на материала и температурата тази нееднородност води до формиране на няколко зони с различна структура [1]. При нисковъглеродна стомана могат да се разграничат следните зони [2]: - в заваръчния шев - над 1500^{O}C; зона на частично стопяване (сплавяване) – около 1500^{O}C; - в зоната на прегряване или уедряване на зърното – над 1200^{O}C; - зона на фазови аустенит–феритни превръщания с финозърнеста структура - над 800^{O}C; - зона с частична прекристализация - над 600^{O}C; - зона без фазова прекристализация – под 600^{O}C.

Неравномерността на тези процеси и невъзможността от осигуряване на цялостно отвръщане непосредствено след заваряването, води до поява на остатъчни знакопроменливи напрежения по протежение и напречно на заваръчния шев [2], [3]. Съществен ефект от количествените параметри и разпределението на тези напрежения, който влияе силно върху качеството на завареното съединение е възникването на пластични деформации.

SysWeld 7.0 е продукт на **ESI Group**, който предлага на производителите на заварени конструкции надеждно решение за симулации и оптимизация на технологичния процес при заваряване и термична обработка. С помощта на виртуалните прототипи и симулация на заваръчните процеси, има възможност да се предвиди резултата от топлинния ефект при заваръчните процеси, което позволява ефективно управление на резултатните напрежения и деформации, от които завеси качеството на заварените съединения и остатъчните напрежения.

Целта на симулирането е визуализирането на разпределението на температурните полета, неравномерността на деформациите и напреженията, в резултат от заваряването на Т-образно съединение при зададени конкретни технологични параметри на МАГ заваръчен процес.

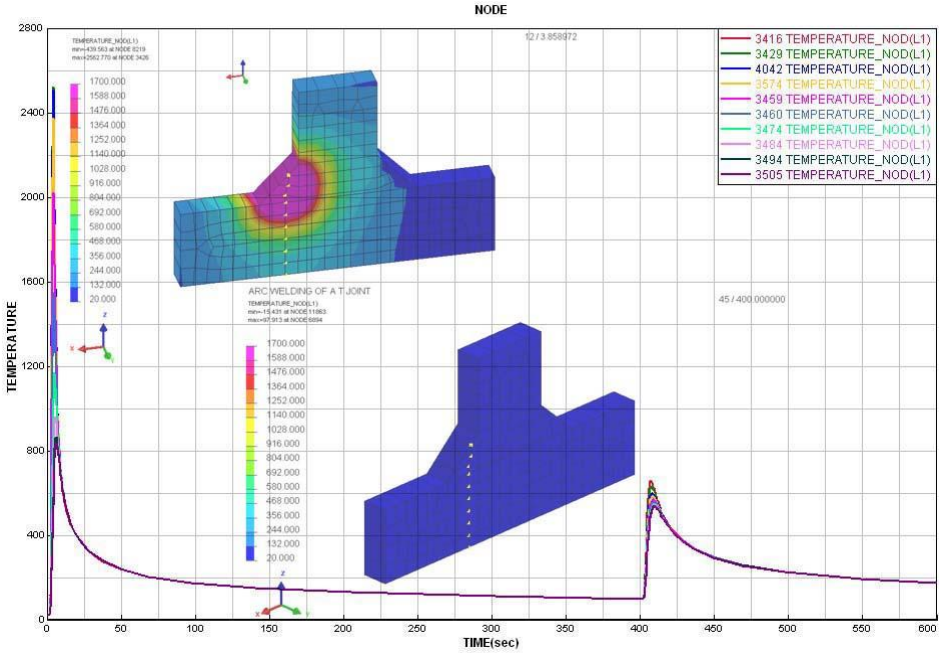
2. ЗАДАВАНЕ НА ТЕХНОЛОГИЧНИТЕ ПАРАМЕТРИ

Дефинирането на процеса на заваряване във Visual Weld от програмния продукт SysWeld се определя от набор от входни параметри, както следва: - геометрия и омрежване – избор на основни детайли и заваръчен шев за Т-образно съединение, от пример към продукта; - материал - конструкционна стомана S355J2G3, от базата данни към продукта. В съответствие със стандарт EN10025-2:2004 конструкционната стомана S355J2G3 е с граница на провлачване 355 MPa и якост на опън 490 - 630 MPa при стайна температура.

Зададените технологични параметри, характерни за МАГ заваръчен процес, са: скорост на заваряване $V_З$ = 9 mm/sec, $q_Л$ = 566 J/mm (определена е за заваръчен ток I = 260 A, напрежение на дъгата U = 28 V и ефективен коефициент на полезно действие η = 0.7), температура на околната среда 20^0C, очаквана дължина на заваръчната вана 14 mm, очаквана широчина на шева 7 mm и очаквана дълбочина на провара 4 mm. Предвидено е изпълнението на двустранно заварено Т–образно съединение с дебелина на заваряваните планки 6 mm и катет на шевовете 3 mm. Заваряването на вторият шев започва 400 секунди след първия.

3. 3D СИМУЛАЦИЯ НА ТЕМПЕРАТУРНОТО ПОЛЕ ПРИ Т-ОБРАЗНО СЪЕДИНЕНИЕ

Пресмятането на задачата с продукта SysWeld 7.0, отнема около 3 часа, като постпроцесингът на пресметнатите резултати дава комбинации от температури, напрежения и деформации за всички възли от предварителното омрежване във Visual Mesh.



Фиг. 3.1. Разпределение на температурата по време и възли в напречно сечение

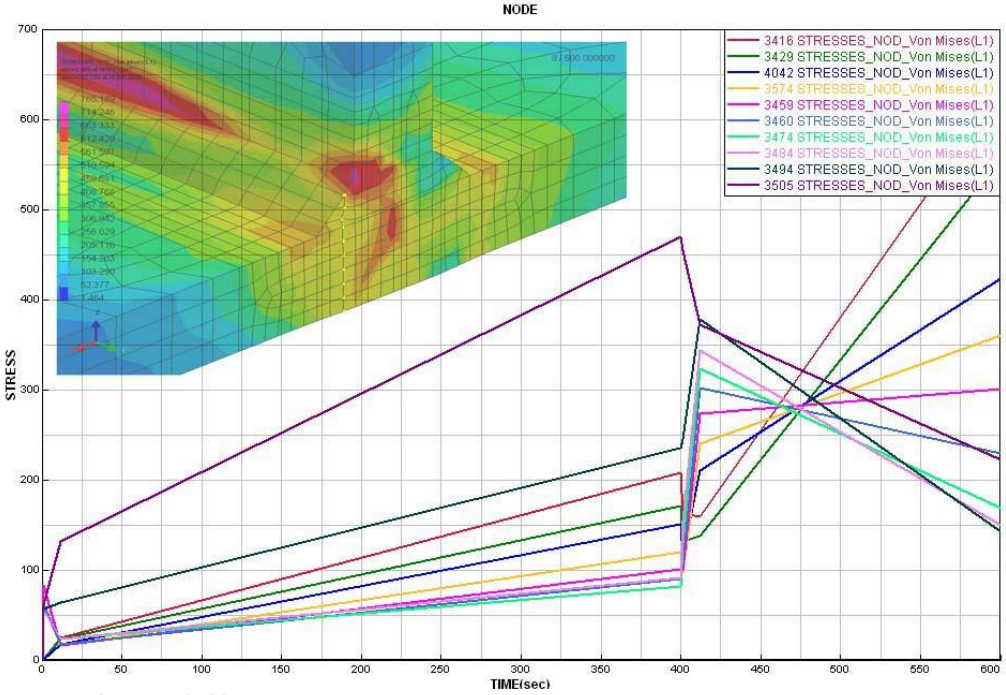
Представени са изолиниите на температурното поле в обозначените с бели точки възли от напречното сечение в 12 секунда при преминаването (полагането) на първия шев (фиг. 3.1 горе в ляво) и непосредствено преди преминаването (полагането) на втория шев в 400 секунда (фиг. 3.1 долу), заедно с изменението им по време на процеса по възли в избрания разрез.

4. 3D СИМУЛАЦИЯ НА НАПРЕГНАТОТО СЪСТОЯНИЕ

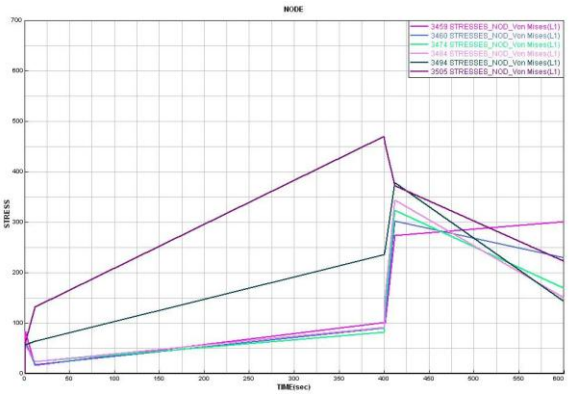
Напрегнатото състояние в дадена точка се описва от комбинацията нормални и тангенциални напрежения в три взаимно перпендикулярни площадки, които представляват компоненти на тензора на напреженията (девиатор и сферичен тензор). Тензорът на напреженията може да бъде представен като комбинация от вектори - три нормални и шест (симетрични по двойки) тангенциални напрежения от произволно избрана координатна система или само като главни напрежения по три главни оси [4]. Тензорът, като числена стойност, може да бъде представен и от обобщаващ параметър на тези векторни величини – например, втория инвариант на тензора на напреженията, дефиниращ интензивността на тангенциалните напрежения [4].

Програмният продукт има възможности за визуализация на шестте независими векторни параметъра, именно: - три нормални напрежения XX, YY и ZZ по трите представени оси (на фигури 4.2.2 – 4.2.4); и – три тангенциални напрежения в перпендикулярни на тези оси площадки XZ, XY и YZ. Продуктът има възможност да представи и и обобщени напрежения, напр. интензивност на тангенциалните напрежения (фиг. 4.2.1).

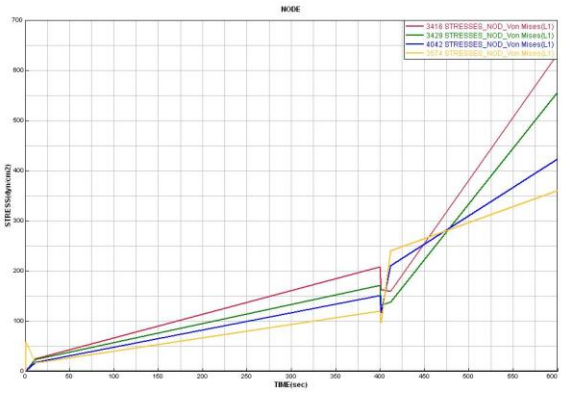
Изменението на интензивността на тангенциалните напрежения във времето до 600 секунда в напречно (перпендикулярно) на шева сечение в обозначените с бяло точки е дадено на фиг. 4.1.



Фиг. 4.1. Интензивност на тангенциалните напрежения, MPa



Фиг. 4.1.1 Интензивност на напреженията в основния метал

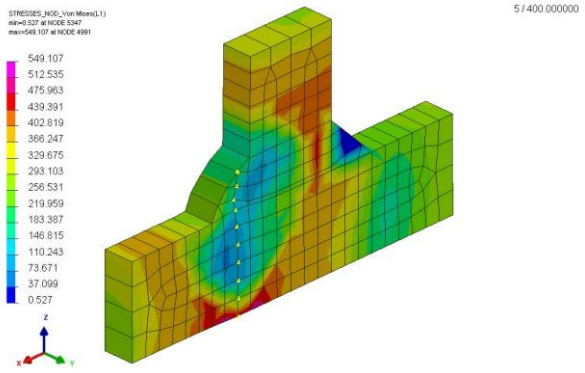


Фиг. 4.1.2 Интензивност на напреженията в заваръчния шев

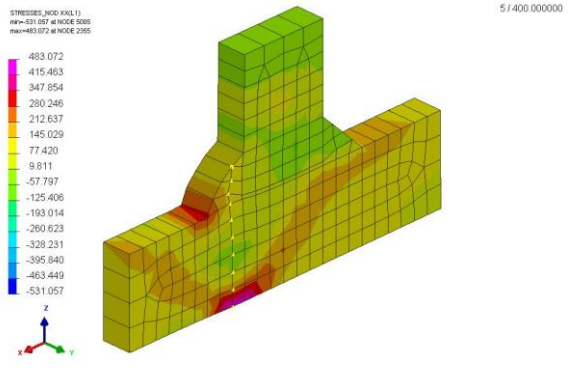
Представени са изолиниите на интензивността на напреженията в цялото напречно сечение до 600 секунда (фиг. 4.1 горе в ляво), заедно с изменението им по време на процеса по възли за избрания разрез. Представено е разпределението на интензивността на тангенциалните напрежения поотделно за основния метал (фиг. 4.1.1) и заваръчния шев (фиг. 4.1.2), за целия цикъл при МАГ заваряване (до 600 секунди при двустранен Т-образен шев) и съответно охлаждане на съединението. Остатъчните напрежения са дадени, като стойности в края на диаграмата в 600 секунда (фиг. 4.1).

Първоначално стойностите на интензивността на тангенциалните напрежения нарастват до 400 секунда. Ефектът от преминаването на втория заваръчен шев е свързан с протичане на рекристализацинни процеси и съответно - намаляване на интензивността на напреженията. Остатъчните напрежения отново нарастват след преминаване на втория шев и са с максимални стойности в 600 секунда (след повторното охлаждане на завареното съединение- фиг. 4.1.2).

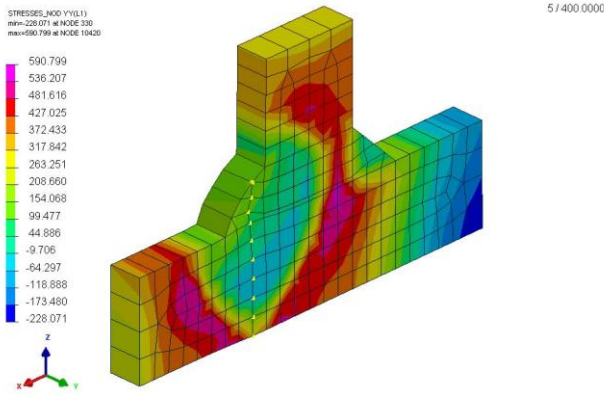
Представено са изолиниите на интензивността на тангенциалните напрежения (фиг. 4.2.1), и нормалните напрежения по осите в цялото напречно на шева сечение (фиг. 4.2.2 – 4.2.4) в 400 секунда, заедно с обозначените възли от мрежата за избрания разрез (фиг. 4.2.1).



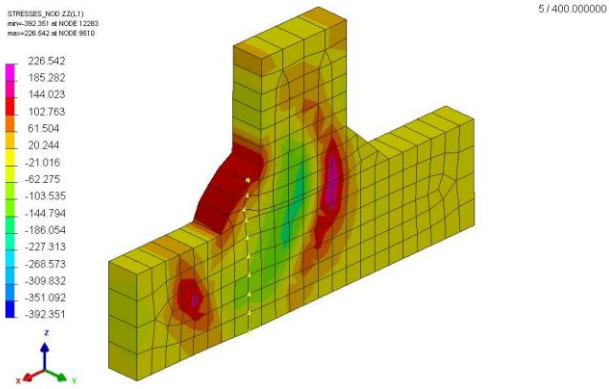
Фиг. 4.2.1 Разпределение интензивност на тангенциалните напрежения (Мизес)



Фиг. 4.2.2 Разпределение нормални напрежения по оста X (напречно на шева)



Фиг. 4.2.3 Разпределение нормални напрежения по оста Y (надлъжно на шева)



Фиг. 4.2.4 Разпределение нормални напрежения по оста Z (напречно на шева)

Максимално достигнатите стойности на интензивността на напреженията (по критерия на Мизес) при завареното Т-образно съединение (МАГ процес) с двустранно нанасяне на шева са около 765 MPa (фиг. 4.1).

Достигнатите стойности на интензивността на тангенциалните напрежения от първия шев, в напречния разрез в 400 секунда (преди втория шев), е около 550 MPa (фиг. 4.2.1), с нормални напрежения по съответните оси разпределени, както следва: - по ос X (напречно на шева) фиг. 4.2.2 – от около +485 MPa (опън) до около -520 MPa (натиск); - по ос Y (надлъжно на шева) фиг. 4.2.3 – от около +590 MPa (опън) до около -230 MPa (натиск); - по ос Z (напречно на шева) фиг. 4.2.4 – от около +230 MPa (опън) до около -390 MPa (натиск).

От представеното разпределение на напреженията в 400 секунда (фиг. 4.21 – 4.2.4) и сравняването им със съответното разпределението на температурата в 400 секунда (фиг. 3.1) е видно, че в заваръчния шев (зоните с температури над 1 500^{O}C), около линията на сплавяване и в зоната на прегряване (с температури над 1 200^{O}C) преобладават опънови напрежения с ниска интензивност. В зоната на термично влияние с фазови превръщания (зоната на перлит-аустенитно превръщане с температури над 800^{O}C) преобладават натискови нормални напрежения. В основния метал се наблюдават две противоположни зони - в нагряваните части (зоната с максимална температура между 250^{O}C и 600^{O}C) преобладават опънови нормални напрежения с висока интензивност на тангенциалните напрежения, които в отдалечените ненагрявани части (зоните с максимално нагряване под 150^{O}C) постепенно намаляват интензивността си и стават нулеви.

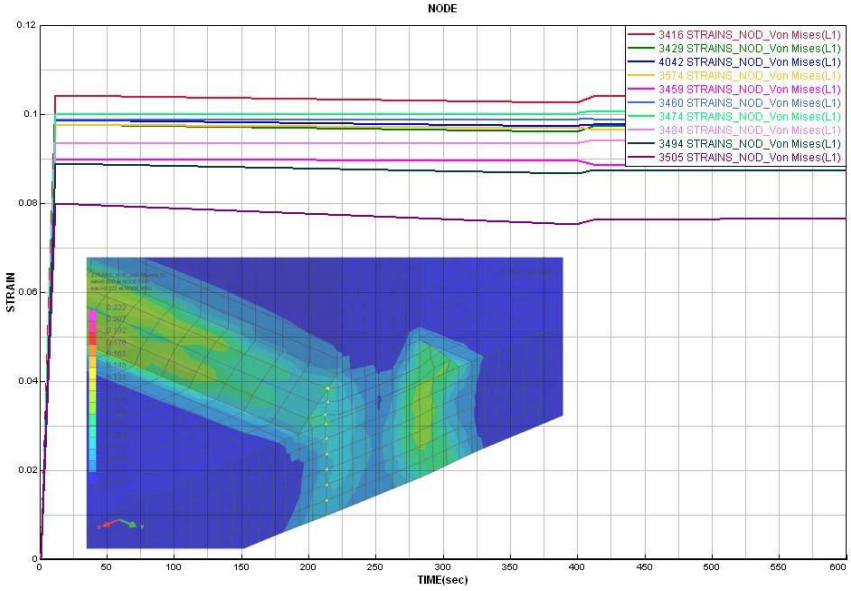
Полученото при симулирането разпределение на напреженията в избраното напречно сечение, представено в 400 секунда, съответства на известните данни за разпределение на напреженията в ъглово съединение [5].

5. 3D СИМУЛАЦИЯ НА ДЕФОРМАЦИОННОТО СЪСТОЯНИЕ

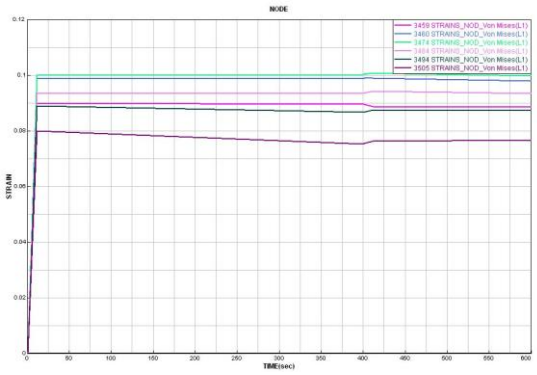
Деформационното състояние в дадена точка се описва от комбинацията линейни и ъглови деформации в три взаимно перпендикулярни площадки, които представляват компоненти от тензора на деформациите (девиатор и сферичен тензор). Тензорът на деформациите може да бъде представен като комбинация от вектори - три нормални и шест (симетрични по двойки) тангенциални напрежения или само като главни напрежения [4] по три главни оси. Той може да бъде представен и като обобщени величини, например, втория инвариант на тензора на деформациите, от който се дефинира интензивността на ъгловите деформации [4].

Програмният продукт SysWeld има възможности за визуализация на шестте независими векторни параметъра, а именно: - три линейни деформации XX, YY и ZZ по трите представени оси (фиг. 5.2.2 – 5.2.4); и – три ъглови деформации в перпендикулярни на тези оси площадки XZ, XY и YZ. Продуктът има възможност да представи и обобщени величини, напр. втория инвариант на тензора на деформациите, дефиниращ интензивността на ъгловите деформации [фиг. 5.2.1).

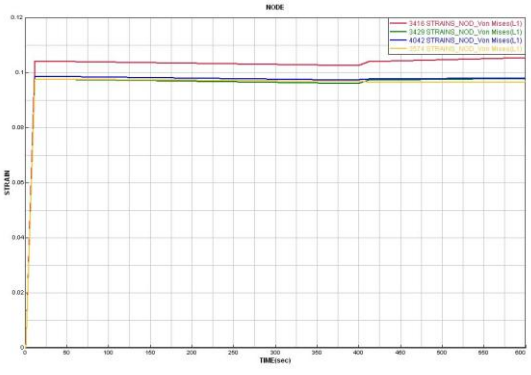
Предвиденото захващане на определени части от завареното съединение ограничава преместванията на листовия метал (основно по оста Y) и променя съществено връзката между напрегнатото и деформационното състояние, като влияе силно и върху остатъчните деформации. Разпределението на интензивността на ъгловите деформации във времето до 600 секунда в напречно на шева сечение е дадено на фиг. 5.1.



Фиг. 5.1. Интензивност на ъгловите деформации



Фиг. 5.1.1 Интензивност на деформациите в основния метал

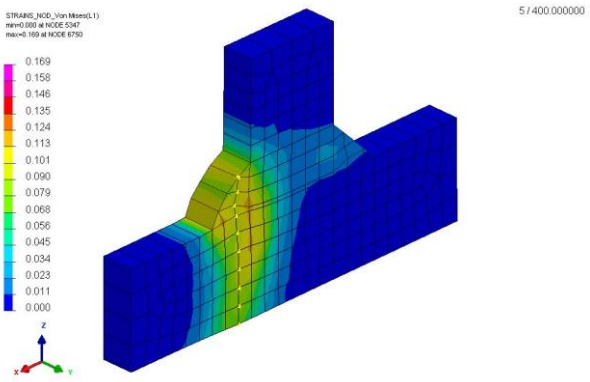


Фиг. 5.1.2 Интензивност на деформациите в заваръчния шев

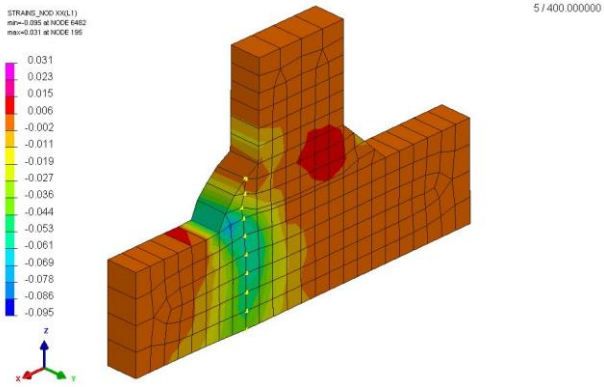
Представено е разпределението на интензивността на ъгловите деформации в напречно сечение до 600 секунда (фиг. 5.1 долу), заедно с изменението им по време на процеса по възлите обозначени в бяло за избрания разрез. Представено е разпределението на интензивността на деформациите поотделно за основния метал (фиг. 5.1.1), и заваръчния шев (фиг. 5.1.2) за целия цикъл при МАГ заваряване (до 600 секунди при двустранен Т-образен шев

и охлаждане на съединението). Вижда се, че те не се променят съществено след повторното нагряване, като например, незначително нарастват след преминаването на втория шев от противоположната страна в 400 секунда и запазват големината си до 600 секунда (фиг. 5.1).

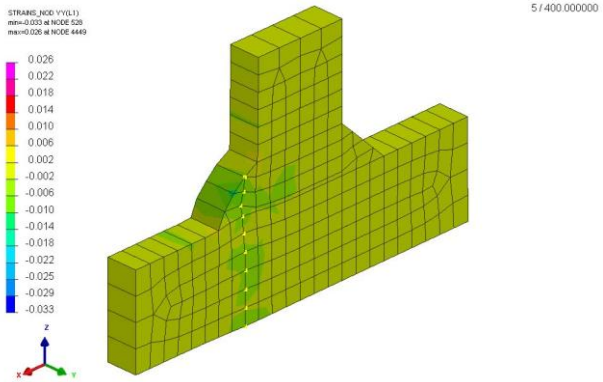
Разпределение на интензивността на ъгловите деформации и линейните деформации по осите в перпендикулярно на шева сечение, след преминаване на първия шев и охлаждане до стайна температура, е дадено на фиг. 5.21 – фиг. 5.2.4.



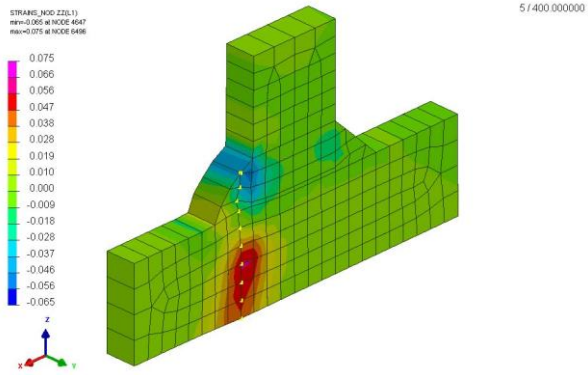
Фиг. 5.2.1 Разпределение интензивност на ъгловите деформации (Мизес)



Фиг. 5.2.2 Разпределение линейни деформации по оста X (напречно на шева)



Фиг. 5.2.3 Разпределение линейни деформации по оста Y (надлъжно на шева)



Фиг. 5.2.4 Разпределение линейни деформации по оста Z (напречно на шева)

Максимално достигнатите стойности на интензивността на ъгловите деформации при двустранно завареното Т-образно съединение от нисковъглеродна стомана S355J2G3 (МАГ процес) са около 0.22 (фиг. 5.1).

В корена на заваръчния шев не са регистрирани опънови линейни деформации и по трите оси. Максимално достигнатите стойности на линейните деформации по съответните оси в избраното напречно сечение при първия шев (400 секунда) са разпределени, както следва: - по ос X (напречно на шева) фиг. 5.2.2 – от около +0.031 (опън) до около -0.095 (натиск); - по ос Y (надлъжно на шева) фиг. 5.2.3 – минимални и почти еднородни, поради предвиденото ограничаващо захващане; - по ос Z (напречно на шева) фиг. 5.2.4 – от около +0.075 (опън) до около -0.065 (натиск).

6. РЕЗУЛТАТИ И ИЗВОДИ

Проведената 3D компютърна симулация на заваряването на Т-образно съединение при МАГ процес с програмния CAD/CAE пакет SysWeld може да бъде използвана за обучение, тъй като цялостно визуализира разпределението на температурните полета и напрегнато-деформационното състояние в обема на завареното съединение.

В резултат от заваряването Т-образно съединение от нисковъглеродна стомана S355J2G3 в напречно на шева сечение възникват знакопроменливи напрежения, съвпадащи с температурното зониране при заваряване. В заваръчния шев и около линията на сплавяване преобладават опънови нормални напрежения с ниска интензивност на тангенциалните напрежения, а в зоната на термично влияние преобладават натискови нормални напрежения. В

основния метал се наблюдават две противоположни зони - в нагряваните части преобладават опънови нормални напрежения с висока интензивност на тангенциалните напрежения, които в отдалечените ненагрявани части намаляват интензивността си и стават нулеви.

Стойностите на интензивността на деформациите при завареното Т-образно съединение от нисковъглеродна стомана S355J2G3 (при зададените конкретни технологични параметри на МАГ заваръчен процес) са около 0.22, като в корена на заваръчния шев не са регистрирани опънови линейни деформации.

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COMPARATIVE ANALYSIS BETWEEN SPHEROIDIZATION EVALUATIONS STANDARDS OF 12CRMOV STEEL USED IN POWER PLANT

Anton MIHAYLOV

Abstract: *In this paper are compared the requirements about the metal state of 12Cr1MoV steel as shipped and mostly are compared spheroidization evaluation standards CTO 1723082.27.100.005-2008 and DL/T 773-2001 in operation control. Determined is the ability to compare the results on both standards.*

Key Words: *heat-resistant steel, 12Cr1MoV, spheroidization evaluation, microstructure*

СРАВНИТЕЛЕН АНАЛИЗ МЕЖДУ ИЗИСКВАНИЯТА НА СТАНДАРТИ ЗА ОЦЕНКА НА СТЕПЕНТА НА СФЕРОИДИЗАЦИЯ КАРБИДНАТА ФАЗА НА СТОМАНА 12Х1МФ ИЗПОЛЗВАНА В ТОПЛОЕЛЕКТРИЧЕСКИ ЦЕНТРАЛИ

Антон МИХАЙЛОВ

Резюме: *В настоящата работа са съпоставени изисквания за състоянието на метала на тръби от стомана 12Х1МФ в състояние на доставка и най-вече са сравнени стандартите СТО 1723082.27.100.005-2008 и DL/T 773-2001 за оценка на степента на сфероидизация на карбидната фаза при периодичен контрол. Определена е възможността за съпоставяне на резултати по двете норми.*

Ключови думи: *топлоустойчива стомана, 12Х1МФ, степен на сфероидизация, микроструктура*

1.Въведение

Стомана 12Х1МФ е широко използвана в топлоелектрическите централи главно във вид на тръби за паропроводи и паропрегреватели с работна температура рядко надвишаваща 540°C парата и 580°C на стената на тръбата [1,2,11]. Марката създадена в бившият Съветски съюз като легирана (Cr-Mo-V) топлоустойчива стомана, доказала качествата си с времето, се използва понастоящем в Русия, в бившите Съветски републики, както и в страни от източна Европа, близкият изток, Индия, Китай и др.

В европейските стандарти (EN) стомана 12Х1МФ няма аналог - близки по химически състав са тръби от стомана 14MoV6-3 и 13CrMo4-5 по EN 10216-2 [10] (БДС EN 10216-2), регламентиращ условията на доставка на безшевни тръби за съдове под налягане от нелегирана и легирана стомана с гарантирани свойства при повишени температури.

В процеса на експлоатация структурата и свойствата на метала деградират, което изисква стриктен контрол метала и определяне на ресурс, осигуряващ безопасната работа на съоръженията.

Целта на настоящата работа е да се съпоставят основните изискванията за стомана 12Х1МФ между съществуващите нормативни документи за входящ контрол и контрол за състоянието на метала по време на експлоатация на елементи от съоръжения в ТЕЦ и най-вече по отношение на степента на сфероидизация на карбидната фаза – основен параметър при определянето на остатъчния ресурс, характеризиращ достатъчно обективно достигнатото микроструктурното състояние.

2.Сравнителен анализ на изискванията при входящ контрол

Изискванията към тръбите във вид на доставка и необходимия входящ контрол са регламентирани в руските технически условия ТУ 14-3Р-55 [3] и украинските ТУ 14-3-460-2009 [2], които са идентични и китайският стандарт GB 5310-2008 [5].

Химически състав

Химическият състав на стомана 12Х1МФ и в двата документа е еднакъв с изключение на съдържанието на фосфор и сяра. По ТУ 14-3-460-2009 количеството и на фосфора и на сярата е не повече от 0,025 масови %, докато по GB 5310-2008 P≤0,025%,а S≤0,010%. ТУ 14-3-460-2009 регламентира и марка 12Х1МФ-ПВ, за която фосфора и сярата не превишават 0,015%.
И в двете норми се допускат регламентирани отклонения в състава на тръбите (готовото изделие) от състава на металургичната (течната) проба. Може да се каже, че в зависимост от вида и количеството на химичните елементи интервалите на присъствието им в готовото изделие се разширяват.

Термична обработка

Термичната обработка в двете норми е нормализация и отвръщане. Температурните интервали за термична обработка зависят от дебелината на стената на изделието и металургичния процес и не се различават съществено. При дебелина на стената над 15 mm е необходимо интензифициране на охлаждането при нормализацията. За тръби с дебелина на стената ≤30 mm GB 5310-2008 предписва нормализация при температура 980-1020°C и отгряване в рамките на 1-3 часа при 720-760°C.

Механични показатели

Обхващат се показатели определяни при нормални и повишени (работни) температури. Нормирани са показателите $R_{p0,2}$, R_m, A и Z от изпитване на опън при нормална температура и абсорбираната енергия K от изпитване на ударно триточково огъване (Charpy test) за надлъжни и напречни образци. Минималната стойност на границата на провлачване $R_{p0,2}$ за стомана 12Х1МФ по GB 5310-2008 е с 20 MPa (7%) по-ниска от тази за стомана 12Х1МФ по ТУ 14-3-460-2009. Интервалът за якостта на опън R_m за 12Х1МФ по GB 5310-2008 е по-тесен от този по ТУ 14-3-460-2009, тъй като минималната му стойност е по-висока с 29 MPa (6%). За изпитване на ударно триточково огъване по ТУ 14-3-460-2009 се използва образец с U-образен надрез, докато по GB 5310-2008 образеца е с V-образен надрез, което трябва да се има в предвид при съпоставяне на резултатите.

Технологични изпитвания

Технологично изпитване на сплескване на отрязък от тръба е предвидено в изискванията и на двата сравнявани документа. Разстоянието между плочите H след сбиване се определя по един и същи начин и зависи от номиналния диаметър D и дебелината на стената на тръбата S. В зависимост от вътрешният диаметър на тръбата може да се изисква още изпитване на разширение и изпитване на опън на пръстени от тръби.

Състояние на метала във вид на доставка.

По отношение на състоянието на метала на тръбите в състояние на доставка техническите условия ТУ 14-3-460-2009 и стандарта GB 5310-2008 определят изисквания за замърсеността на метала с неметални включвания, размер (бал) на зърната и микроструктурно състояние. При оценката на замърсеността с неметални включвания и размера на зърната се препраща към съответните национални стандарти. Съществена е разликата при определянето на микроструктурното състояние – докато в GB 5310-2008 е написано, че структура на стомана 12Х1МФ трябва да е ферит+отвърнат бейнит или ферит+перлит, то в руските технически условия се използва еталонна деветобална скала конкретно за 12Х1МФ. Микроструктурата се „приема", ако съдържа не по-малко от 15% отвърнат бейнит и перлит, т.е. се оценява като съответстваща на бал от 1 до 5, и се „бракува" при съдържание под 15 % или прегряване при отвръщане над A_{C1}– бал 6-9. Освен това в ТУ 14-3-460-2009 заляга оценка на ивичност при наличието ѝ в микроструктурата на 12Х1МФ, подкрепена със съответните скали.
От направения анализ при съпоставката на изискванията при входящ контрол на метала на стомана 12Х1МФ може да се обобщи, че изискванията и по двата нормативни документа се различават несъществено. При провеждането на изпитванията трябва да се има в предвид спецификата в изисквания към препращаните национални и международни стандарти, да се спазва проследимостта, както и да се съобразява възможността за сравнение на резултатите

при оценка на съответствието. Преимущество по отношение на оценката на микроструктурата има ТУ 14-3-460-2009, поради по-ясно дефинирани критерии и наличието на скали, което я улеснява и прави по-обективна.
Трябва да се отбележи съществуването на значителна разлика между разглежданите два нормативни документа и EN 10216-2:2007. Тя произтича от факта, че европейският стандарт не третира микроструктурата и не предявява изисквания към нея.

3.Изисквания при експлоатационен (периодичен) контрол

В процеса на експлоатация контрола на състоянието на метала, нормите и изискванията се определят в отрасловият руски стандарт СТО 1723082.27.100.005-2008 [1] и китайският стандарт DL/T 773-2001[4].
На изрязани контролни образци се извършва:

- Визуален контрол и измерване на външния и вътрешен диаметър и дебелина на стената;
- Изучаване на строежа и деформационната способност окисния слой;
- Изследване на състоянието на микроструктурата и степента на повреждане на метала;
- Определяне на еквивалентната температура по фактическото състояние на метала и окисния слой.
- Определяне на продължителната якост, при необходимост.

В условията на продължителна експлоатация при висока температура и налягане в стомана 12Х1МФ успоредно протичат процеси на сфероидизация на карбидната фаза и преход на легиращите елементи обезпечаващи топлоустойчивостта – молибден, ванадий, а също и хром от твърдия разтвор в карбиди. Промените настъпващи в състава и морфологията на карбидите, в твърдият разтвор, микроповреждането на метала (образуване на пори и пукнати в резултат на пълзене), обуславят - заедно с корозионното действие на средата – промяна на свойствата в посока деградиране.
Степента на сфероидизация на карбидната фаза е важен параметър, с който се определя еквивалентната температура на експлоатация и времето до разрушаване по кривите за продължителна якост за съответното микроструктурно състояние при определянето на остатъчния ресурс, а също така е критерии за достигнато гранично състояние.
Оценката на степента на сфероидизация се извършва по описание на структурното състояние и по еталонни скали, поместени в нормативните документи за експлоатационен контрол на метала.

4.Скали за оценка на степента на сфероидизация на карбидната фаза

Оценката на степента на сфероидизация (бал) на карбидната фаза за въглеродни и нисколегирани стомани е регламентирана в руския СТО 1723082.27.100.005-2008 и китайският стандарт DL/T 773-2001, отнасящ се специално за стомана 12Х1МФ.

Метод на оценяване.

И по двата технически документа оценяването се извършва чрез сравняване на реалните изображения на изследваните микроструктури с еталонните изображения от стандартизираните скали, като се избира изображението от скалата, съответстващо на изследваното или доближаващо се най-много до него. Сравнението трябва да се извършва при увеличение отговарящо на еталонните изображения. Този начин на оценяване е известен като традиционен или класически.
Стандарта DL/T 773-2001 допуска, когато балът не съответства достатъчно на еталонните изображения, да се определя междинен бал – напр. 2,5.

Подготовка на микрошлиф

Посочено е механично полиране и проявяване с широко използвания реактив за въглеродни и нисколегирани стомани – 2 до 5% разтвор на азотна киселина в етилов алкохол (Нитал). За постигане на необходимото качество на металографска обработка СТО 1723082.27.100.005-2008 регламентира няколкократно (от 3 до 5 пъти) механично полиране и проявяване. DL/T 773-2001 допуска химично или електрохимично полиране, както и извършване на оценката от снет металографски отпечатък (реплика).

Скали за оценка

Скалата за оценка на морфологията на карбидите по DL/T 773-2001 е петобална и описанието на микроструктурата за различните балове е дадено в табл. 1. Стандарта съдържа еталонни

изображения, отнасящи се конкретно за стомана 12Х1МФ, за всеки бал при две увеличения - 200х и 700х.

Таблица 1. Степени на сфероидизация по DL/T 773-2001

Бал (ниво)	Описание на микроструктурата
1 - *отсъсвие на свероидизация*	Перлитът (бейнитът) формира обособени, плътни зони не изцяло с пластинчат характер
2 - *лека степен на сфероидизация*	Перлитът (бейнитът) започва да се сфероидизира, но остава достатъчно плътен и в същите граници.
3 - *средна степен на сфероидизация*	Перлитът (бейнитът) е сфероидизиран, но все още остава в първоначалните граници.
4 - *пълна сфероидизация*	Голямата част от карбидната фаза е разположена по границите на феритните зърна; малка част от перлита (бейнита) все още личи.
5 - *сериозна сфероидизация*	Перлитът (бейнитът) е напълно изчезнал; карбидните частици са разположени по границите на феритните зърна; наблюдават се двойни граници.

По СТО 1723082.27.100.005-2008 скалата е шестобална и еталонните изображенията, показани в приложението на документа, са при увеличение 1000х и се използват при оценката на сфероидизация на карбидната фаза за перлитни стомани въобще. Описанието на микроструктурното състояние, отговарящо на всеки бал е направено в табл. 2, където P е време-температурен параметър и се определя по формула (1) чрез температурата T [K°] и продължителност на експлоатация τ [h].

$$P = T \cdot \left(\lg \tau - 2\lg T + 24.88\right) \cdot 10^3 \quad (1)$$

Параметъра P отразява изменението на структурата и е критерий за разграничаване на баловете, но на практика за реалните образци не може да се определи, защото температурата на метала зависи от множество конструктивни и експлоатационни фактори – тип на съоръжението, работни параметри на флуида, отклонения от стационарен режим, преходни режими, брой пускания и спирания и т.н. По-скоро се постъпва обратното – по бала на карбидната фаза се определя еквивалентната температура $T_{екв}$, - постоянна температура, предизвикваща еквивалентно въздействие върху структурата и свойствата на метала на променливата температура в процеса на експлоатация за еднакъв период.

Таблица 2. Степени на сфероидизация по СТО 1723082.27.100.005-2008

Бал	Описание на микроструктурата	P	Структурни изменения	
			перлит	ферит
1	*Ферит и перлит*. Перлита има пластинчат строеж	< 19.6	плътна структура	незначително отделяне на карбиди
2	*Неголяма степен на сфероидизация*. Цементита има предимно зърнеста форма и при неголямо увеличение изглежда точковиден	19.6 – 19.75	плътна структура	интензивно отделяне на карбиди
3	*По-голяма отколкото бал 2*. Разграничаване на перлита и малко количество структурно-свободен сферичен цементит, разположен по границите на ферита.	19.75 – 20.0	начален етап на сфероиди-зация	интензивно отделяне на карбиди
4	*Значителна сфероидизация*. Границите на перлитните зърна са размити; значително количество структурно свободен сферичен цементит, разположен по границите на феритните зърна.	20.0 – 20.25	етап на сфероиди-зация	начало на коагулацията на карбидите
5	*Значителна сфероидизация*. Липсват границите на перлитните зърна; увеличаване на размерите на цементитните частици, разположени по периферията на зърната.	20.25 – 20.5	интензивна коагулация на карбидите	интензивна коагулация на карбидите

Бал	Описание на микроструктурата	P	Структурни изменения	
			перлит	ферит
6	*Пълна сфероидизация*. Типично уедряване на цементитните частици, разположени по границите на феритните зърна.	20.5 – 20.75	Ферито-карбидна смес	

При качествен анализ на микроструктурата, какъвто е сфероидизацията на карбидната фаза, оценката трябва да се извършва при едновременно използване на описанието на структурата за различните балове и еталонните изображения. Наличието на ясно описани състоянията на структурата и еталонни изображения за всеки вид изследвана марка, са предпоставки за по-голяма достоверност (точност) на резултата. Все пак, традиционният начин на изпитване е в много голяма степен субективен и зависи от знанията и опита на този, който я извършва. Експертната оценка обуславя най-голяма обективност.

За повишаване на достоверността на оценката и намаляване на субективността при качествен анализ на металографски изображения могат да се използват съвременни, софтуерно базирани адаптивни методи, математически алгоритми за обработка на морфологични параметри или комбинация от тях [6,7]. Възможно е дори оценката да се извършва дистанционно, в реално време, чрез отдалечено базиран софтуер за анализ на подаваните изображения [8].

При анализа на сравняваните технически норми се установява, че описанието на микроструктурата за различните балове е по-пълно при СТО, но пък скалата по DL/T е конкретно за стомана 12Х1МФ. Трябва да се отбележи факта, че в руския РД 34.17.452-98 [9] съществува шестобална скала с изображения за стомана 12Х1МФ, но стандарта е отменен именно от СТО 1723082.27.100.005-2008.

5.Възможност за съпоставяне на резултати определени по двете скали

Въз основа на показаните в табл. 1 и табл. 2 описания на структурата, като се има в предвид, че се изхожда от едно и също начално и крайно състояние може да се определи сходството между двете скали, показано в табл. 3.

Направен е опит за съпоставяне на балове чрез специализиран софтуер за определяне на бала [6], основаващ се на адаптивни методи. За тази цел на входа на невронна мрежа, обучена за оценка по петобалната скала се подават металографски експертно оценени изображения на стомана 12Х1МФ с различна степен на сфероидизация. Същите изображения са оценени експертно и подложени на разпознаване от адаптивната системата, обучена по шестобалната скала. Резултатите от проведеният експеримент (табл. 4) зависят от правилното обучение на адаптивната система, експертната оценка и качеството на металографската подготовка на образците.

Таблица 3. Съпоставка на скалите за степен на сфероидизация

Бал по скалата от СТО 1723082.27.100.005-2008					
1	2	3	4	5	6
1	2		3	4	5
Бал по скалата на DL/T 773-2001					

Таблица 4. Резултати от оценката на изображения на по двете скали

№	Бал по DL/T 773		Бал по СТО 1723082.27.100.005-2008	
	експертна	адаптивна	Експертна	Адаптивна
1	1	2	2	1
2	1	1	1	1
3	2	2	2	3
4	2	2	3	2
5	3	3	4	3
6	3	3	4	4
7	4	4	5	5
8	4	4	5	6
9	5	5	6	5
10	5	5	6	6

Бал 2 по СТО 1723082.27.100.005-2008 частично се припокрива с балове 1 и 2 по DL/T 773-2001, който допуска зърнест характер на перлита за бал 1 и степен на сфероидизация за бал 2, отговаряща на бал 3 по руския СТО. Балове 3, 4 и 5 по DL/T 773-2001 съответстват почти напълно на балове 4, 5 и 6 по СТО 1723082.27.100.005-2008.

6.Изводи

По отношение на изисквания при входящ контрол, касаещи състоянието на метала на стомана 12Х1МФ, ТУ 14-3-460-2009 поставят по-голям брой и по-строги критерии. Това позволява да се контролира термичната обработка и да не допускат до експлоатация, например, тръби с неправилно проведено отвръщане или със силно изразена ивичност.

По отношение на скалите за определяне на степента на сфероидизация на карбидната фаза не може категорично да се даде предпочитание на петобалната скала по DL/T 773-2001 или на шестобалната по СТО 1723082.27.100.005-2008. Описанието на структурното състояние е по-пълно по СТО 1723082.27.100.005-2008, но DL/T 773-2001 предлага еталонни изображения за стомана 12Х1МФ, което значително улеснява съпоставянето при оценката на реалните структури. По-големият брой балове по СТО 1723082.27.100.005-2008 не води автоматично до по-прецизен резултат, тъй като достоверността му има субективен характер.

Конвертирането на резултати от една скала в друга, дава възможност да се използват предимствата на всяка една от тях. Това води до по-прецизно определяне на бала на сфероидизация. Така може с балът определен по DL/T 773-2001, след привеждане, да се използват номограмите от СТО 1723082.27.100.005-2008 за определяне на $T_{екв}$ и времето до разрушаване, в които той участва.

Несъответствието в скалите е при началните степени на сфероидизация, когато метала притежава по-голямата част от проектния и реалния си ресурс. При напреднал стадий на сфероидизация, когато метала се доближава до граничното си състояние има сходство между баловете, отместено с единица.

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INVESTIGATION OF THE STATE OF THE METAL AND THE CAUSES FOR DESTRUCTION OF DAMAGED PIPES OF STEAM HEATERS

Anton MIHAYLOV, Bojana TABAKOVA

Abstract: *In this paper are being examined two cases of damaged seamless tube in operation – super-heater of steel 12Cr1MoV from power plant and steam generator of steel P265GH from waste heat boiler. Mechanical and non-destructive tests were carried out to compare with the requirements for incoming and in-operation control of the metal. Causes for fracture are established and recommendations are made to reduce the risk of emergency.*

Key Words: *pressure vessels, seamless steel tubes, P265GH, 12Cr1MoV, microstructure, fracture*

ОБСЛЕДВАНЕ НА МЕТАЛА И ПРИЧИНИТЕ ЗА РАЗРУШАВАНЕ НА АВАРИРАЛИ ТРЪБИ ОТ КОТЛИ НА ПАРОГЕНЕРАТОРИ

Антон Михайлов, Божана Табакова

Резюме: *В настоящата работа са разгледани два случая на разрушени безшевни тръби от котли по време на експлоатация – паропрегревател от стомана 12Х1МФ на ТЕЦ и парогенератор от Р265GH на котел утилизатор. Проведени са механични и неразрушаващи изпитвания за съпоставяне с изискванията при входящ и експлоатационен контрол. Установени са причините за разрушаване и са направени препоръки за намаляване на риска от аварии.*

Ключови думи: *съдове под налягане, безшевни тръби, Р265GH, 12Х1МФ, микроструктура, разрушаване*

1.Въведение

Съоръженията от котлите работят продължително време при висока температура, налягане и агресивна обкръжаваща среда, предизвикваща корозия и много често ерозия на метала или отлагане на продукти на горенето. Параметрите на експлоатация често излизат извън рамките на стационарните и преходните режими, като в много случаи отклоненията са по-големи при преходните (спиране-пускане) условия. Тези отклонения трудно могат да се предвидят и водят до разминаване с определените проектен и остатъчен ресурс на съоръженията и в крайна сметка до настъпване на аварийни ситуации - разрушаване. Минималните изисквания при проектиране, осигуряващи безопасната и безаварийна експлоатация на съоръженията под налягане е Директива 97/23/ЕС [1], въведена у нас чрез наредба [2]. При входящ контрол трябва да се удовлетворяват изискванията на продуктовите стандарти за технически условия в състояние на доставка [3,4], а при експлоатация нормите за контрол на състоянието на метала [5].

Обект на изследване на настоящата работа са тръбен образец от ширмов паропрегревател от котел на ТЕЦ с номинални размери Ø32/5 от стомана 12Х1МФ [3].и тръбен образец от котел утилизатор с номинални размери Ø32/4 от стомана Р265GH [4], разрушени по време на експлоатация.

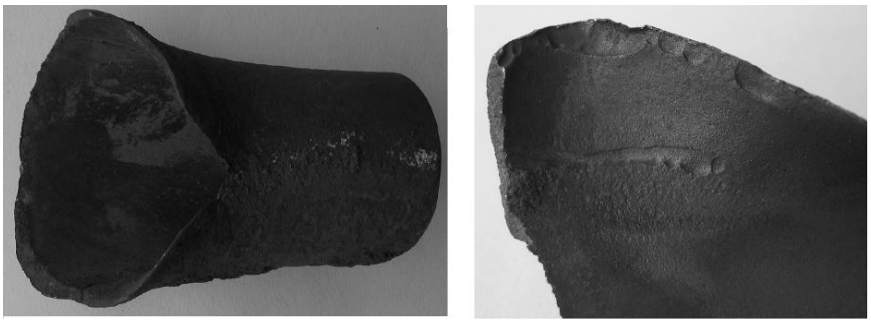
Определени са параметри от механични изпитвания, дебелометрия, микроструктурен анализ и химанализ за съпоставяне с изискванията при входящ и експлоатационен контрол, както и корозионно състояние по външна и вътрешна повърхност, визуален оглед и фрактография на ломовете.

Целта на обследването е да се определи фактическото състояние на метала на образците и възможните причини, довели до разрушаване, както и да се дадат препоръки за предотвратяването на такива аварии.

2. Резултати от изследването на тръбен образец от котел утилизатор

2.1.Визуален оглед и фрактография

Изследваният тръбен образец представлява разрушена тръба от котел утилизатор (работно налягане p=25 atm) с номинални размери ∅ 38/4 mm (фиг. 1).
По вътрешната повърхност на образците е установено наличието на надлъжни дефекти във вид на улеи с променлива ширина от 1÷3 mm и дълбочина до 0,5 mm, които имат най-вероятно производствен характер. В мястото на тези дефекти се наблюдава локално изтъняване на стената до 2,4 mm, а максимално измерената дебелина на стената е 3,4 mm.
От лома на тръбните образци се установява наличие на надлъжна пукнатина, възникнала в дефект от вида описан по-горе и разпространила се впоследствие в напречна (фиг.1б) до пълното разрушаване на тръбата на две части.

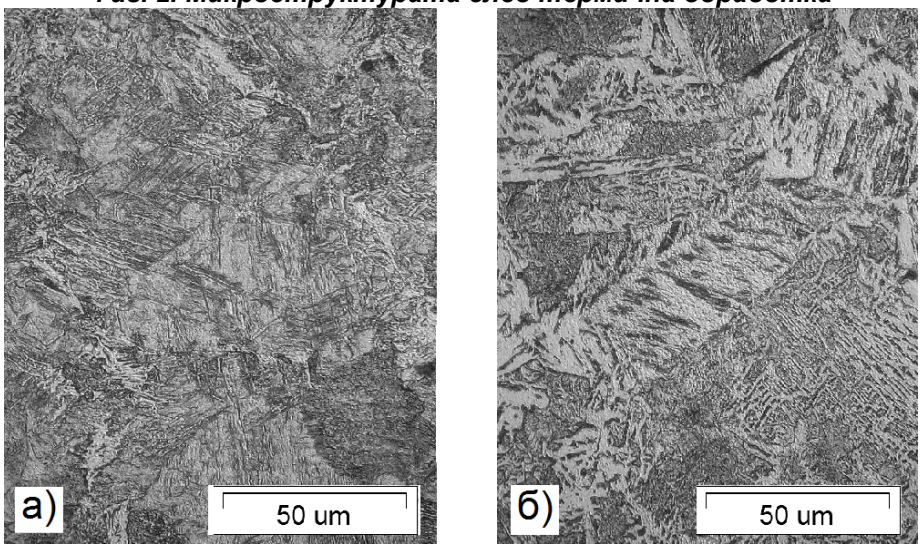


Фиг. 1. Микроструктурата след термична обработка

2.2. Микроструктура в напречно сечение

В напречно сечение е подготвен шлиф, проявен с 3 %-ен р-р на HNO_3 к-на в етилов алкохол и наблюдаван под увеличение на металографски микроскоп Neophot-2.
Микроструктурата на тръбните образци е неравновесна, състояща се от мартензит и бейнит (фиг.2а) от страната на надлъжната част на пукнатината и се променя

Фиг. 2. Микроструктурата след термична обработка



до бейнитна от видманщетанов тип от противоположната страна на надлъжната част на пукнатината (фиг.2б).

2.3.Резултати от изпитването на твърдост

Извършено е изпитване на твърдост по метода на Бринел съгласно БДС EN ISO 6506-1:2006 [6] на твърдомер Zwick.

Табл. 1. Твърдост по Бринел

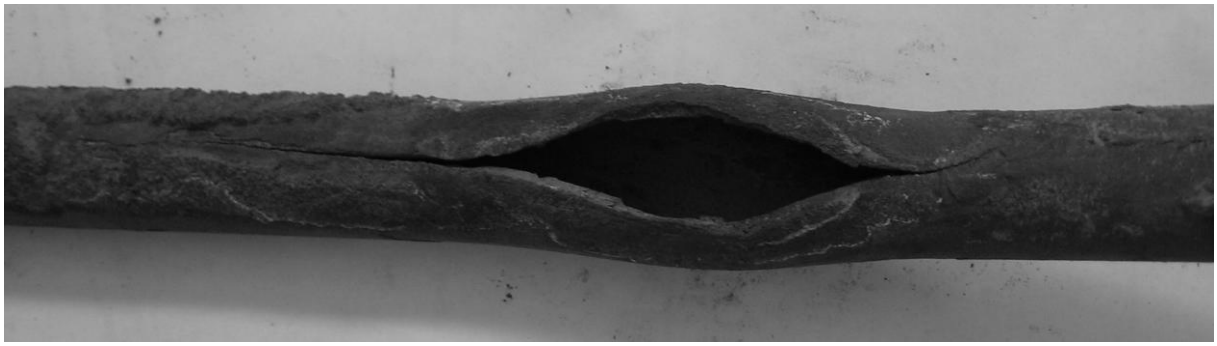
Твърдост по Бринел HBW от страната на надлъжната част на пукнатината	366, 365, 358
Твърдост по Бринел HBW от противоположната страна на надлъжната част на пукнатината	163, 157, 173

Получената твърдост може да се сравни с изискваната за тръбопроводи от стомана 20 и 18К [5], работещи при температура до 450°С от 120÷180 HBW. Твърдостта от страната на надлъжната част на пукнатината превишава двойно горната допустима граница.

3.Резултати от изследването на тръбен образец от ширмов паропрегревател от котел на ТЕЦ

3.1.Визуален оглед и фрактография

Обекта на изследване е разрушена тръба от ширмов паропрегревател, работила в продължение на 158000 часа при температура 544°С и налягане 14,4 MPa на флуида. Тръбата е изкривена в резултат на разрушаването (фиг.3). Пукнатината е в изтънената страна на тръбата, с дължина 200 mm и разтворена 22 mm в най-раздутата част. Лома на пукнатината е силно кородирал.
Измерена е минимална дебелина на стената на тръбата в срезовете 3,9 mm, което е отклонение от номиналната дебелина с 22% при допустими по техническите условия [3] ±10%.



Фиг. 3. Микроструктурата във вид на доставка

3.2.Изпитване на опън, твърдост и сплескване

В съответствие с изискванията на БДС EN ISO 6893-1 [7]е проведено изпитване на опън на надлъжни образци във вид на ленти при нормална и работна температура и е измерена е твърдост по Бринел съгласно БДС EN ISO 6506-1:2006. Резултатите заедно с изискванията по техническите условия ТУ 14-4-460-2009 са поместени в таблица 2.
Изпитването при температура 595°С е с цел определяне на реалният коефициент на сигурност след изчисляване на еквивалентните напрежения, при приемане че температурата на тръбата по време на експлоатация достига стойност с 50°С по-висока от тази на флуида. Максималните еквивалентни напрежения 156 MPa са определени по метода на крайните елементи с помощта на софтуерния продукт ANSYS като модела е с действителните дебелини на стената и е използван критерият на von Mises.

Табл. 2. Резултати от механични изпитвания

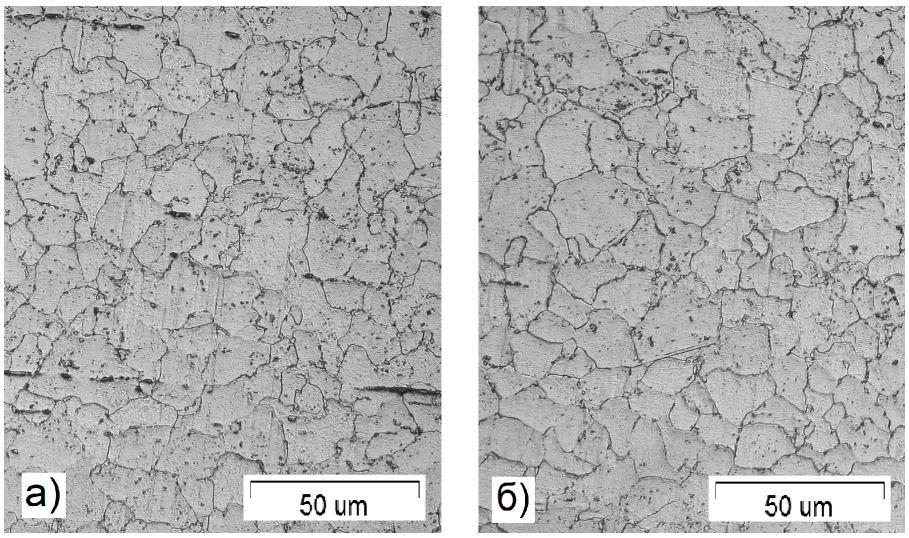
	Темп. t [°C]	$R_{e0,2}$ [Mpa]	R_m [Mpa]	A [%]	Z [%]	HBW
Изследван образец от 12Х1МФ	20	283	454	21	59	127
	545	204	328	22	62	-
	595	195	319	21,5	63	-
Изисквания за 12Х1МФ по ТУ 14-4-460-2009	20	274	441-637	19	50	-
	500	186	294	-	-	-

Измерената твърдост от 127 HBW е по-ниска при сравнение с изискваната за тръбопроводи от стомана 12Х1МФ [5], работещи при температура над 450°С от 130÷190 HBW.
Технологичното изпитване на сплескване е проведено съгласно БДС EN ISO 8492:2005 [8] върху образци, представляващи отрез от тръбата с дължина 33 mm (1,5 пъти номиналния вътрешен диаметър на тръбата). Височината на сплескване H=22,9 mm е определена от БДС EN 10216-2 и ТУ 14-3-460-2009. До разстояние Н между сплескващите плочи, не се наблюдават пукнати в образците, което удовлетворява изискването на техническите условия, но се наблюдават пукнатини в зоните на максимално огъване на стената при пълно сплескване.

3.3.Корозионно състояние и микроструктура

По външната повърхност има наличие на оксиден слой с дебелина до 0,25 mm, разпокъсан на места, както и на продукти от изгарянето на твърдото гориво - налепи. Наблюдава се равномерен оксиден слой с дебелина 0,35 mm по вътрешната повърхност. Наличие на групи корозионни язви по вътрешната повърхност с дълбочина до 0,2 mm

Микроструктурният анализ е проведен върху образци проявени чрез трикратно полиране и проявяване в 3 %-ен р-р Нитал, по цялата дебелина на стената в напречно (фиг.3а) и в надлъжно сечение (фиг.3б).



Фиг. 4. Микроструктурата в надлъжно и напречно сечение

Микроструктурата е феритно-карбидна и отговаря на пълна степен на сфероидизация на карбидната фаза. Напълно липсват перлитни зърна, а карбидите са разположени предимно по границите на феритните зърна. Сфероидизацията оценена по шестобалната скалата на СТО 1723082.27.100.005-2008 е бал 6, а по петобалната скалата на DL/T 773-2001 [9] е бал 5. Еквивалентна температура на експлоатация определена от номограми [3] чрез структурното състояние е 580°С, а чрез дълбочината на корозия - 570°С. Според СТО 1723082.27.100.005-2008 метала на тръбите от перлитна стомана е достигнал гранично състояние, тъй като не се допуска бал 6 по скалата за сфероидизация.

4.Анализ на получените резултати. Изводи

4.1.Тръба от котел утилизатор

Резултатите от изпитването на разрушена тръба от котел утилизатор от стомана Р265GH, както от измерената твърдост, така и от металографския анализ показват неравновесно структурно състояние на метала, коренно различаващо се от състоянието изисквано при доставка, отговарящо на нормализация. Получаването на закалъчни структури в условията на работа е възможно при значително отклонение от стационарните режими, предизвикващо прегряване стоманата (в аустенитната област) следвано от бързо (рязко) охлаждане. Много често такива условия може да се създават при преходните режими, поради неправилно спиране и пускане на съоръженията.

Наличието на описаните дефекти по вътрешната повърхност са недопустими [3] и са изиграли своята роля за разрушаването. Възникването на пукнатината е именно в такъв дефект в най-окрехкостения участък на тръбата (фиг.1б).

Наличието на подчертано неравновесна структура по цялото сечение е причина за разпространение на пукнатината и в напречно направление и разрушаване на тръбата на две части за разлика от другия разглеждан случай при ширмовия паропрегревател.

4.2.Тръба от ширмов паропреглевател

Определената еквивалентна температура на експлоатация на метала показва, че не е имало съществени отклонения от стационарните режими. Съоръжението е работило 158000 часа, което е значително над проектният ресурс от 100000 часа, а по СТО 1723082.27.100.005-2008 още след 50000 се изисква стриктно следене на състоянието на метала и определяне по методика на остатъчен ресурс. Степента на сфероидизация на карбидната фаза и дебелината

на оксидния слой отговарят на достигнато гранично състояние, при което тръбите нямат повече ресурс и трябва да се извадят от употреба и заменят. Сфероидизацията на перлита е свързана с понижаване на якостта на стоманата, като в същото време коагулиращите карбиди се разполагат предимно по границите на феритните зърна.

По резултатите от изпитването на опън и дебелометрията с помощта на софтуерния продукт ANSYS е изчислен реален коефициент на сигурност 1,25, който е значително по-нисък от минимално допустимия при проектиране - 2. Върху състоянието на метала влияние оказва още и броя на преходните режими, което не може да бъде отчетено в случая. Якостните характеристики попадат на долната граница или под нея на изискваните стойности.

Причината са разрушаване на тръбата от ширмов паропрегревател е понижената носеща способност на сечението поради протичането на процеси водещи до разякчаване на метала и изтъняване на стената от корозия с образуване на корозионни язви. Металът запазва достатъчна пластичност, поради което тръбата се огъва и раздува значително в зоната на пукнатината, но не се разрушава на две части.

5.Изводи

И в двата разглеждани случая на аварирали тръби от котли е достигнато гранично състояние в резултат на експлоатация. Причините довели до това състояние са различни – при тръбата от стомана Р265GH са получени закалъчни структури при екстремни условия на работа, докато при стомана 12Х1МФ структурата е деградирала в резултат на продължителна експлоатация при висока температура и налягане.

За по-пълно оценяване на съответствието често се използват технически нормативи (международни, национални и отраслови стандарти) неуказани в основния документ, поради което е необходимо внимателна преценка на възможността за съпоставяне и даване на заключения.

За намаляване на риска от възникване на такива аварии се препоръчва предприемане на следните мерки:

- Стриктно спазване на параметрите на стационарните и преходни режими
- Коректно водене на дневници за стойностите на работните параметри, възникване на непредвидени ситуации, броя и условията на преходните режими, извършвани ремонти, обозначаване на проблемните и по-тежко натоварени участъци от съоръженията.
- Провеждане на периодичен контрол съгласно действащите нормативни уредби
- Обследване състоянието на метала и определяне на нов остатъчен ресурс на тежко натоварените елементи на съоръженията работещи при температура над 450°С при всеки планов и авариен ремонт, въпреки наличието на преди това определен ресурс, поради спецификата на условията на работа на котлите.

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IMPORTANCE OF THE MICROSTRUCTURE OF SEAMLESS STEEL TUBES P235GH IN DELIVERY CONDITION AND THE CONFORMITY ASSESSMENT ACCORDING TO EN 10216-2

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Abstract: *In this paper are examines seamless steel pipes P235GH in delivery condition to check the conformity with the requirements of EN 10216-2:2003 A2:2008. Metallography was carried out before and after heat treatment. Results of microstructural analysis and hardness are compared. Differences have been found between the samples examined and the prescribed heat treatment according to EN 10216-2 for steel P235GH.*
Key Words*:* pressure vessels, seamless steel tubes, P235GH, microstructure, heat treatment, delivery condition

ЗНАЧЕНИЕ НА МИКРОСТРУКТУРАТА НА БЕЗШЕВНИ СТОМАНЕНИ ТРЪБИ МАРКА P235GH В СЪСТОЯНИЕ НА ДОСТАВКА ПРИ ОЦЕНКА НА СЪОТВЕТСТВИЕТО ПО EN10216-2

Божана ТАБАКОВА, Антон МИХАЙЛОВ

Резюме: *В настоящата работа са изследвани стоманени безшевни тръби от стомана P235PH в състояние на доставка за установяване на съответствието им с изискванията на EN 10216-2:2003+A2:2008. Проведена е металография преди и след термична обработка. Съпоставени са резултатите от микроструктурния анализ и твърдостта и са констатирани отклонения неотговарящи на предписаната по стандарта термична обработка.*

Ключови думи: *съдове под налягане, безшевни тръби, марка P235GH, микроструктура, термична обработка, условия на доставка*

1.Въведение

Безшевни тръби от стомана P235GH се използват за съоръжения под налягане, работещи при температура до 450°C. Изискванията към тръбите са регламентирани в европейският стандарт EN 10216-2:2002+A2:2007, на който идентичен е БДС EN 10216-2:2003+A2:2008 [1].
В настоящата работа са изследвани тръбни образци от стомана P235GH по EN 10216-2, във вид на доставка, с външни диаметри Ø60, Ø76, Ø89, Ø219 и Ø273 mm и дебелини на стените от 4 до 6,3 mm. Проведени са стандартизирани изпитвания заложени в продуктовия стандарт, както и допълнително металографско изследване. Анализирани са особености, наблюдавани в структурата в изследваните образци. Проведена е термична обработка с цел де се установи влиянието на охлаждането от температурата на аустенитизация върху формирането на структурата и механичните свойства във връзка с оценката на съответствие по EN 10216-2.
Според EN 10020 [2] стомана P235GH се класифицира като нелегирана стомана. Стомана P235GH отговаря по химически състав и свойства на стомана 12К по БДС 6609:1973 [3], който БДС EN 10216-2 отменя и заменя. Разликата има по отношение на съдържанието на манган – за стомана 12К е определена долна граница от 0,6%, докато такава за P235GH липсва. Според обхвата и нивото на провеждания контрол БДС EN 10216-2 определя изисквания към тръбите в две категории – ТС1 и ТС2. И двете категориите включват задължителни изпитвания - анализ на течният метал, механични изпитвания при нормална температура (опън и ударно огъване), технологични изпитвания, визуален контрол и определяне на размерите - и допълнителни (по избор) – химически анализ на продукта, изпитване на опън при повишени температури, ударно огъване при отрицателна температура. Категория ТС2 включва неразрушаващ контрол за откриване на надлъжни несъвършенства (задължителен), напречни и ламинарни несъвършенства (допълнителен).

2.Резултати от химически анализ и механични изпитвания на изследваните образци във вид на доставка

За съпоставка с изискванията на БДС EN 10216-2 са изготвени образци и са проведени:

- Химически анализ – анализа е проведен на спектрометър Spektroport F. Резултатите и изискванията за стомана P235GH са представени в таблица 1, като интервали за различните елементи са разширени с допуските за отклонение на готовото изделие;
- Изпитване на опън и твърдост при нормална температура – резултатите от изпитване на петкратни надлъжни образци и твърдост по Викерс в напречно сечение са показани в таблица 2 заедно с нормите. Изпитванията са проведени на универсална изпитвателна машина Instron 1195 и твърдомер Zwick с товар 10 kg.

Табл. 1. Съдържание на химични елементи, тегл. %

Образец	C	Si	Mn	P	S	Cr	Al	Cu	Ti	Ni
P235GH	**≤ 0,18**	**≤ 0,40**	**≤ 1,30**	**max 0,030**	**max 0,025**	**≤ 0,35**	**≥ 0,020**	**≤ 0,35**	**max 0,050**	**≤ 0,35**
Ø60	0,098	0,245	0,420	0,016	0,012	0,051	0,021	0,122	0,001	0,24
Ø76	0,195	0,281	0,621	0,034	0,035	0,110	0,020	0,104	0,002	0,22
Ø89	0,110	0,221	0,441	0,018	0,011	0,076	0,022	0,207	0,001	0,28
Ø219	0,089	0,310	0,364	0,015	0,010	0,010	0,055	0,014	0,001	0,30
Ø273	0,150	0,166	0,494	0,020	0,011	0,048	0,046	0,052	0,001	0,25

Табл. 2. Механични показатели

Образец	R_{eH}, MPa	$R_{p0,2}$, MPa	R_m, MPa	A, %	HV
P235GH	**min 235 MPa**		**360-500 MPa**	**min 25**	**-**
Ø60	359	-	427	29,8	132
Ø76	-	395	513	26,0	145
Ø89	385	-	438	31,8	137
Ø219	383	-	445	26,5	138
Ø273	-	388	490	30,6	142

Химическият анализ и механичните показатели от изпитването на опън показват съответствие с БДС EN 10216-2 за марка P235GH за всички изследвани образци с изключение на Ø76, който трябва да бъде определен като марка P265GH поради въглеродното съдържание от 0,195% и якостта на опън R_m над 500MPa**.** Въглеродното съдържание за всички образци варира в интервала 0,089-0,195%, а количеството на Mn е значително под максимално допустимото от 1,3%.

3.Микроструктурен анализ на образците във вид на доставка

БДС EN 10216-2 не предвижда контролиране на структурното състояние на метала както за нелегираните, така и за легираните марки. Презумпцията очевидно е, че щом металът на изделието отговаря на задължителния (ТС1) и допълнителния контрол (ТС2), изискващ се по стандарта, то и структурата следва да е подходяща и не е необходимо да се контролира.

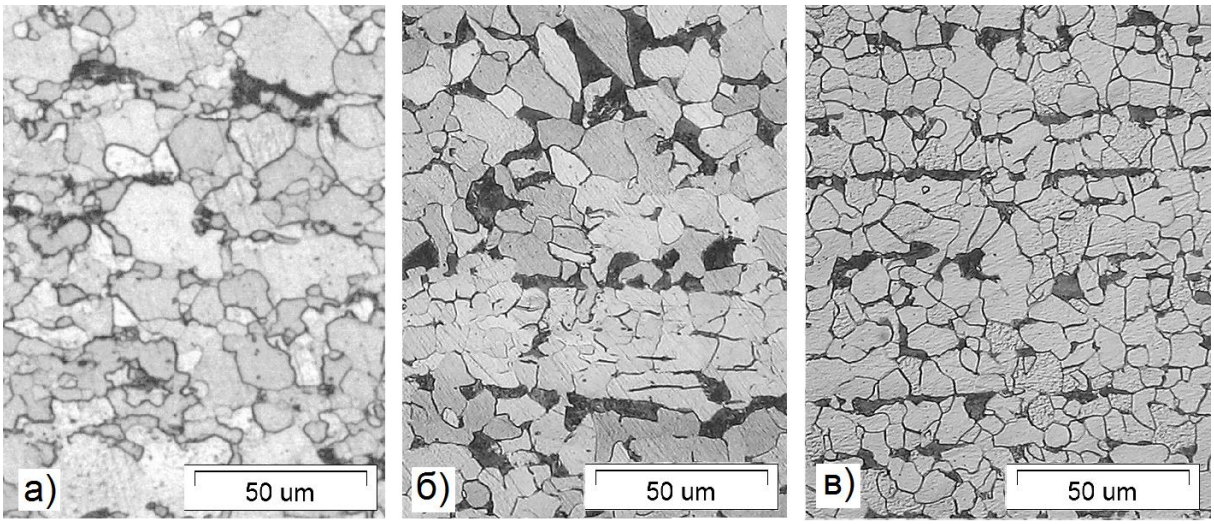
За трите марки нелегирани стомани (P195GH, P235GH и P265GH) БДС EN 10216-2 определя условия за термична обработка – тръбите трябва да са нормализирани (охлаждани на въздух от температура 880-940°C) или нормализиращо валцовани. Според БДС EN 10052 [6] нормализацията включва аустенитизация на стоманата и следващо охлаждане на въздух. Това означава, че за стомана P235GH структурното състояние трябва да е достатъчно близко до равновесното – ферит и малко количество перлит.

Приготвени са микрошлифове чрез механично полиране и няколко кратно полиране и проявяване с 3 %-ен р-р на HNO_3 к-на в етилов алкохол до постигане на необходимото металографско качество. Проявените шлифове са наблюдавани при увеличение 500х на оптичен металографски микроскоп Neophot-2. Структурата на всички изследвани образци е феритно-перлитна, но се забелязват различни особености описани в таблица 3 и подкрепени с изображения на фиг. 1 и фиг. 2.

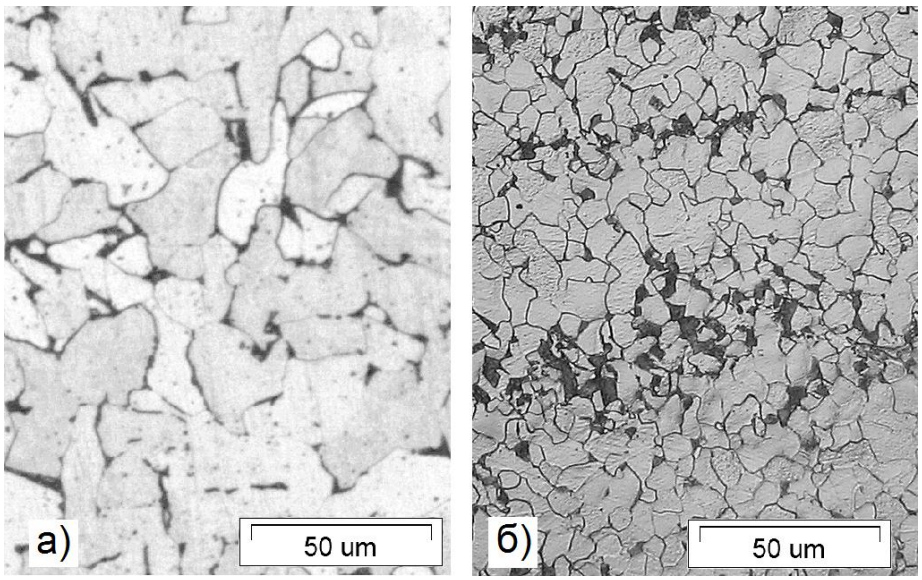
Табл. 3. Описание на микроструктурата

Обр.	**С-ние на перлит, %**	**Особености на структурата**	**Изобра-жение**
Ø60	5	Уедряване на феритни зърна от външната повърхност до средната част от дебелината на образеца	Фиг. 1а
Ø76	12	Силно изразена феритна ивица по средата на стената на тръбата	Фиг. 1б
Ø89	8	Ивичност по цялата дебелина на образеца, увеличаваща се в посока на вътрешната повърхност.	Фиг. 1в
Ø219	4	В по-голямата си част перлитът е разположен като тънки прослойки по границите на феритните зърна	Фиг. 2а
Ø273	10,5	В близост до външната и вътрешната повърхност се наблюдават зони, нехомогенни по отношение на съдържанието на перлит и ивици с направление, отличаващо се от надлъжното.	Фиг. 2б

В национални норми като украинските технически условия ТУ 14-3-460-2009 [4] и китайският стандарт GB 5310-2008, микроструктурата на безшевните тръби от нелегирани и легирани стомани за съдове под налягане е обект на обстоен контрол, включващ металографско определяне на големината зърната, ивичност и видманщетенов характер. Това дава възможност да се отчетат и оценят по-голямата част от особеностите посочените в табл. 3.



Фиг. 1. Микроструктурата във вид на доставка на тръбите



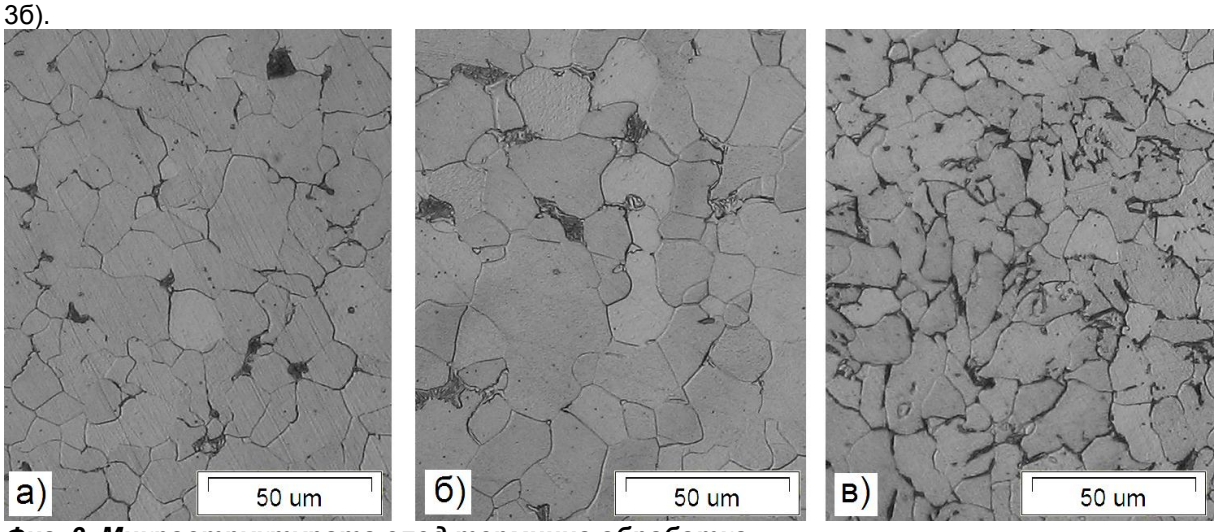
Фиг. 2. Микроструктурата във вид на доставка

4.Микроструктура след проведена термична обработка

С цел да се определи влиянието на охлаждането от температура на аустенитизация върху формирането на микроструктурата е проведена термична обработка на изследваните образци. Образци са нагрявани при температура 900°C, след което са охлаждани в масло, на въздух и с пещта. Проявените микроструктури за образец Ø219 след охлаждане на въздух, с пещта и в масло са показани съответно на на фиг. 3а, 3б и 3в.

Типична структура на нисковъглеродна стомана след бавно охлаждане се наблюдава на фиг.3а, където перлитът е формиран преобладаващо във вид на зърна, личи пластинчатия характер на фазите.

В структурата на образеца, охлаждан с пещта поради бавното охлаждане перлитът е груб с добре различаващи се пластинки. Както е известно [7], при фазовото превръщане между A_{c3} и A_{c1} въглерода се изтласква към периферията на аустенитните зърна и често образува евтектоид, които представлява ферит, сливащ се с преди това образувания и цементит по границите на зърната – различимите на металографското изображение двойни граници (фиг. 3б).



Фиг. 3. Микроструктурата след термична обработка

За образеца охлаждан в масло е характерно образуването на перлит по-често във вид на плослойки с различни дебелини по границите на зърната и рядко като обособени зърна. При ускорено охлаждане поради затруднена дифузията се потиска образуването на ферит и той остава до известна преситен с въглерод [7]. От друга страна се образува квазиевтектоид с по-дисперни фази, с концентрация на въглерод по-малка и количество по-голямо от равновесния евтектоид. Зачатъци на Видманщетенов характер на структурата.

От получените след термичната обработка структури на образци Ø219, тази при охлаждането в масло (фиг. 3в) е най-близка до фиг. 2а, което означава че в състояние на доставка е формирана при значително по-интензивно охлаждане от това на въздух.
Твърдостта на образците Ø219 охладени на въздух, с пещта и в масло е съответно 129HV, 112HV и 139HV, което също показва ускорено охлаждане на изделието при получаването му.

5.Изводи

Металографското изследването по напречното сечение и в направление на дебелина на стената, показва нееднородност в структурата за повечето изследвани образци, изразяващо се в ивичност, уедрени феритни зърна, различно разположение и морфология на перлита. Това означава, че има нееднакви условия на охлаждане не само между различните тръби от дадена партида, но и в рамките на една и съща тръба. В повечето случаи охлаждането е по-бързо от това, отговарящо на нормализация. Причините за това могат да бъдат различни:

- особености в технологията на обработването при получаването на изделието – особено това важи, когато не се прави отделна термична обработка, а има нормализиращо валцоване;
- начин на подреждане на тръбите, нееднакви условия на нагряване (прегряване или недогряване) в пещта и следващо охлаждане (най-често ускорено).

На практика често се реализира термична обработка, при която се получава структура различаваща се от нормализираната, но тя се приема за правилна тъй като определяните по стандарта показатели отговарят на критериите. Заложените изпитвания не могат да установят описаните особености в структурата. EN 10216 обхваща, освен нелегираните, и легираните марки топлоустойчиви стомани, но за тях също не предвижда никакъв контрол на микроструктурата, при положение че други норми [4,5] постановяват значително изследване.

Липсата на изисквания за контрол на структурата може да бъде избегната чрез допълнителното им заявяване пред производителя по критерии заимствани от други норми. Разбира се, това ще доведе до оскъпяване на продукта, но ще гарантира по-добрата му работоспособност и надеждност по време на експлоатация.

Различното микроструктурното състояние може да оказва съществено влияние върху работоспособността на тръбите в условията на продължителна експлоатация – кратковременните и продължителни механични показатели при високи температури, корозионната устойчивост, възможността за технологично обработване (огъване, заваряване) и др.

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