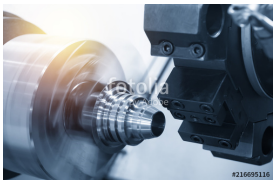
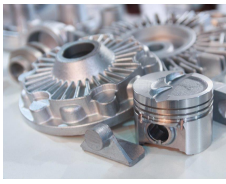

International Conference of Metals, Ceramics and Composites

25th–27th September 2019

Varna, Bulgaria

Conference Proceedings

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Polish Foundrymen's Association

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Dear Ladies and Gentlemen, Dear Colleagues and Friends,

Please let me evoke the memories of the spring of 2017, when in the course of my visit – as the Director of the Foundry Research Institute in Kraków – to the Technical University in Varna, and the meeting with TUV Rector, Professor Rosen Vasiliev, the Vice-Rector for International Cooperation, Professor Hristo Skulev, and with the Director of the Institute of Metal Science, Equipment and Technologies with Hydroaerodynamic Centre "Acad. Angel Balevski" of the Bulgarian Academy of Sciences in Sofia, Professor Ludmil Drenchev, the idea was born to organise a regular International Conference on Metals, Ceramics and Composites (IC MCC). Our concept was founded on the will to establish a new, international platform for the exchange of knowledge and experience for the purpose of effective application of results of research and development works in the field of new advanced materials and technologies under industrial conditions. As soon as several months following that momentous meeting, on the days of 13–17 September 2017, the first MCC Conference materialized under the motto "*Toward a successful transfer of materials science into industry*". The Conference was held in Varna, which is not only a delightful and charming holiday resort, but also an important symbol, so close to the hearts of the people of Bulgaria and Poland because of the tragic battle fought there in the ominous year of 1444 under the command of Władysław IV, the king of Poland, who died a hero's death there and was later granted the title of "Władysław of Varna – Warneńczyk" by the people of Bulgaria, who consider him their national hero. These were tragic times in the history of both our nations, with far-reaching historical and political consequences to the entire Europe. Hence, it is not by accident that the logo of the Conference is a stylised heart, with a depiction of mountains and vales, symbolising successes and failures, ups and downs, happy times and sad times…

It was the wish of the initiators of the Conference to have subsequent events held alternately in these two countries. However, the fate intervened, and this year the Conference will again be held in this beautiful, truly addictive Varna and many participants, I suppose, will find this fact a very pleasant surprise…

Please let me express my deepest gratitude to all who contributed to the organisation of this Conference in its new formula, to the members of the International Scientific Committee, and in particular, to His Magnificence, Vice-Rector of AGH University of Science and Technology, Professor Jerzy Lis, for assuming the position of Honorary Chairman, and to the Honorary Consul of Bulgaria in the Republic of Poland, Mr Janusz Zatoń, for providing patronage over our undertakings. Please let me also take this opportunity to thank the Metallurgy Commission of the Polish Academy of Sciences for their scientific patronage. I am also tremendously indebted to my Bulgarian friends, the co-organisers of the Conference, represented by Professor Ludmil Drenchev from IMSET BAN for their utmost commitment, cooperation and genuine Slavic hospitality which we enjoyed so much in the past and are still relishing today.

Please let me also address words of appreciation to the main organiser, the Main Board of the Polish Foundrymen's Association, represented by its President, Mr Tadeusz Franaszek as well as General Secretary, Dr. Katarzyna Liszka, and to all supporting organisations, especially to World Foundry Organization, Energy Industries of Ohio and Faculty of Foundry Engineering AGH University of Science and Technology.

Please let me wish all participants of the International Conference on Metals, Ceramics and Composites, representatives of Bulgaria, China, Germany, Poland, Sweden, Switzerland, the United Kingdom, and the United States brilliant presentations, creative and passionate discussions, wonderful impressions and unforgettable memories, as well as numerous new contacts and friendships of both professional and personal nature!

Professor Jerzy J. Sobczak, DHC
Faculty of Foundry Engineering
AGH University of Science and Technology in Kraków
Chairman of the Committee of Metallurgy of Polish Academy of Sciences
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2nd International Conference of Metals, Ceramics and Composites 25th–27th September 2019, Varna, Bulgaria

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CONFERENCE PROGRAMME

25th September 2019, Wednesday

12.00 – 14.00	Registration
12.30 – 14.30	**Lunch**
14.30 – 15.00	Opening ceremony
	SESSION I ***Foundry engineering and plastic deformation*** ***Chairpersons: Tomasz Babul/Beata Grabowska***
15.00 – 15.15	*Hybrid system for producing functional casting prototypes* **Pavel Ikonomov**, Western Michigan University, USA
15.15 – 15.30	*Application potential of carboxymethylcellulose (CMC) modified bentonite in the foundry industry* **Sylwia Cukrowicz**, AGH University of Science and Technology, Poland
15.30 – 15.45	*Isothermal and cyclic oxidation behaviour of alloys for high temperature applications* **Savko Malinov**, Queen's University of Belfast, United Kingdom
15.45 – 16.00	*Assessing ceramic resin coated sand for iron castings* **Sam Ramrattan**, Western Michigan University, USA
16.00 – 16.15	*A new method for limiting the fragmentation phenomenon in local reinforced composite castings* **Łukasz Szymański**, AGH University of Science and Technology, Poland
16.15 – 16.45	**Coffee break**
	SESSION II ***Foundry engineering and plastic deformation*** ***Chairpersons: Ludmil Drenchev/Deyan Veselinov***
16.45 – 17.00	*The analysis of microhardness variations in longitudinal sections of hydroformed axisymmetric components made from P265TR1 steel* **Tomasz Miłek**, Kielce University of Technology, Poland
17.00 – 17.15	*Thermal conductivity of "VARI–MORPH" (VM) cast iron with graphite of several forms* **Marcin Myszka**, AGH University of Science and Technology, Poland
17.15 – 17.30	*Melting of fine-grained aluminum scrap with salt flux* **Piotr Palimąka**, AGH University of Science and Technology, Poland
17.30 – 17.45	*Hybrid magnesium gasars – innovative ultralight porous materials* **Jerzy Józef Sobczak**, AGH University of Science and Technology, Poland
17.45 – 18.00	*New European initiative for novel ultralight materials with unique properties* **Jerzy Józef Sobczak**, AGH University of Science and Technology, Poland
18.00 – 18.15	*Effect of conditions of heating process on microstructure and corrosive resistance of titanium alloy used in implantology* **Jagoda Ryba**, AGH University of Science and Technology, Poland
19.00 – 22.00	**Dinner**

	26th September 2019, Thursday
7.30 – 9.00	Breakfast
	SESSION III ***Surface and coating technologies and powder metallurgy*** ***Chairpersons: Mihail Kolev/Dawid Myszka***
10.00 – 10.15	*Structural evolution in Al-Fe materials made by powder metallurgy route* **Magdalena Majchrowska**, AGH University of Science and Technology, Poland
10.15 – 10.30	*Electrochemical deposition of silver on aluminum alloys* **Vladimir Petkov**, Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre, BAS, Bulgaria
10.30 – 10.45	*Sintered structural alloy steels–processing, properties, microstructure* **Maciej Sułowski**, AGH University of Science and Technology, Poland
10.45 – 11.00	*Study of cobalt castings plated on Ti-6Al-4V* **Gieorgi Tomov**, Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre, BAS, Bulgaria
11.00 – 11.15	*Influence of the electrochemical anodizing parameters on the microstructure, microroughness and microhardness of anodized Ti-6Al-7Nb* **Deyan Veselinov**, Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre, BAS, Bulgaria
11.15 – 11.45	**Coffee break**
	SESSION IV ***Surface and coating technologies and powder metallurgy*** ***Chairpersons: Wojciech Polkowski / Maciej Sułowski***
11.45 – 12.00	*Influence of the type of substrate on structure and properties of aluminide NiAl coatings* **Ilona Nejman**, AGH University of Science and Technology, Poland
12.00 – 12.15	*High quality corrosion protection of sintered steel with chromium coating doped with diamond nanoparticles* **Radoslav Valov**, Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre, BAS, Bulgaria
12.15 – 12.30	*A mathematical model of magnetron sputter deposition* **Georgi Evt. Georgiev**, Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre, BAS, Bulgaria
12.30 – 12.45	*3D copper/graphene composite – production, properties, implementation* **Tomasz Babul**, ŁUKASIEWICZ Research Network – Institute of Precision Mechanics, Poland
13.00 – 14.00	**Lunch**
14.00 – 15.00	**POSTER SESSION**
15.00 – 17.00	Trip to Delphinarium
19.00 – 22.00	**Dinner**

	27th September 2019, Friday
7.30 – 9.00	Breakfast
	SESSION V ***Advanced materials characterization, additive manufacturing and heat treatment*** ***Chairpersons: Joanna Sobota/Justyna Kasińska***
10.00 – 10.15	*High temperature interaction of Si-rich alloys with graphite under thermocycling conditions* **Natalia Sobczak**, ŁUKASIEWICZ Research Network – Foundry Research Institute, Poland
10.15 – 10.30	*Structure and mechanical properties of ductile iron with different initial matrix after nanostructuralisation heat treatment* **Dawid Myszka**, Warsaw University of Technology, Poland
10.30 – 10.45	*AO translational research and development* **Boyko Gueorguiev**, AO Research Institute Davos, Switzerland
10.45 – 11.00	*Properties and microstructure of laser welded dissmilar joints of TP347-HFG and S235JR steels with additional material* **Hubert Danielewski,** Kielce University of Technology, Poland
11.00 – 11.30	**Coffee break**
	SESSION VI ***Advanced materials characterization, additive manufacturing and heat treatment*** ***Chairpersons: Hristo Skulev/Radoslav Valov***
11.30 – 11.45	*Mechanical and tribological characterization of open cell aluminum/ babbitt composites and their application to sliding bearings* **Mihail Kolev,** Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre, BAS, Bulgaria
11.45 – 12.00	*Development of tailor-made equipment for experimental preclinical surgeries using computer simulations and 3D printing* **Jan Barcik**, AO Research Institute Davos, Switzerland
12.00 – 12.15	*Modeling studies for the recycling of paladium from high entropy alloys, special purpose components and waste from different processes* **Boris Yanachkov**, Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre, BAS, Bulgaria
12.15 – 12.30	*Effect of hydrogen atmosphere on the mobility of 1/2[111] screw dislocation in BCC Fe* **Ivaylo Katzarov**, Institute of Metal Science, Equipment and Technologies with Hydroaerodynamics Centre, BAS, Bulgaria
13.00 – 14.30	**Lunch**
15.00 – 19.00	Excursion to Botanic Garden
19.30 – 22.00	**Dinner**

28th September 2019, Saturday	
7.30 – 9.30	Breakfast
until 12.00	Check-out

POSTER SESSION

Microstructure and properties of laser additive deposited of nickel base super alloy inconel 625
Hubert Danielewski, Kielce University of Technology, Poland

Microstructure of welds of galvanised steel sheets and cap electrodes at final stages of exploitation
Joanna Sobota, ŁUKASIEWICZ Research Network - Institute of Non-Ferrous Metals, Poland

Materials in foundry engineering: study of polylactide used as filament in 3D printing
Beata Grabowska, AGH University of Science and Technology, Poland

Fabrication and characteristics of copper-intermetallics composites
Marcin Kargul, Kielce University of Technology, Poland

A formation of multicomponent Mo-Si-B alloys via reactive interaction in Si-B/Mo system
Grzegorz Bruzda, ŁUKASIEWICZ Research Network – Foundry Research Institute, Poland

Structural and rheological characterisation of polacrylate-polysacharyde hydrogels for foundry application
Karolina Kaczmarska, AGH University of Science and Technology, Poland

Thermal regeneration of used moulding sand - conditions of implementation
Mariusz Łucarz, AGH University of Science and Technology, Poland

Effect of rare earth elements additions on critical temperatures of manganese cast steel for use at low temperatures
Justyna Kasińska, Kielce University of Technology, Poland

Knowledge-base as a part of Industry 4.0 in casting production
Paweł Malinowski, AGH University of Science and Technology, Poland

DSC study on recrystallization and precipitation in solution annealed and cold rolled Haynes 282 superalloy
Wojciech Polkowski, ŁUKASIEWICZ Research Network – Foundry Research Institute, Poland

Effect of hafnium alloying addition on wettability and reactivity between nickel and zircon sand mould
Rafał Nowak, ŁUKASIEWICZ Research Network – Foundry Research Institute, Poland

Processing and characterization of Fe-Cu-Ni sinters prepared by ball milling and hot pressing
Joanna Borowiecka-Jamrozek, Kielce University of Technology, Poland

Laser treatment of copper surface layer – computing simulation
Justyna Domagała-Dubiel, ŁUKASIEWICZ Research Network – Institute of Non-Ferrous Metals, Poland

Research on the impact of vibration machining of titanium alloys
Damian Bańkowski, Kielce University of Technology, Poland

Investigations of electro-discharge mechanical machining of manganese cast steels
Piotr Młynarczyk, Kielce University of Technology, Poland

Tribological performance of ionic liquids used as lubricants on steel with diamond-like carbon coating
Monika Madej, Kielce University of Technology, Poland

Influence of the processing conditions on the microstructure and properties of 3D printed components from titanium alloy
Savko Malinov, Queen's University Belfast, United Kingdom

High temperature interaction of molten Hayness©282© alloy with MgO and $MgAl_2O_4$ substrates
Robert M. Purgert, Energy Industries of Ohio, USA

Development of an innovative technology for the production of massive slag ladles with increased operation parameters (SLAG LADLE TECH) at the Krakodlew S.A. Foundry
Marcin Paszkiewicz, Krakodlew S.A., Poland

International Conference of Metals, Ceramics and Composites

25th September 2019

SESSION I

Foundry engineering and plastic deformation

International Conference of Metals, Ceramics and Composites
25th–27th September 2019, Warna, Bulgaria

HYBRID SYSTEM FOR PRODUCING FUNCTIONAL CASTING PROTOTYPES

Pavel Ikonomov*, Sam Ramrattan, Michael Konkel

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Key words: hybrid prototyping, machineable mold material, infrared light sintering, casting

A novel hybrid prototyping, utilizing both additive and subtractive manufacturing techniques for casted metallic parts, has been developed and implemented. It uses additive Infrared Light Sintering (IRS) of a Machineable Mold Material (MMM) and Computer Numerical Control (CNC) machining methods. The additive IRS deposit is used to build each layer, then the cavity is machined, over again this process is repeated until complete the mold cavity for a part. The hybrid approach is patternless and allows rapid mold development with complex geometry, high precision and superior surface finish.

1. Hybrid MMM/IRS Prototyping System

The hybrid MMM/IRS system utilizes a special machineable mold material (MMM) sand with CNC machine. Fig. 1 is used to explain the procedure. The MMM is delivered, leveled and light cured to a single layer in a flask (Fig 2). After each layer is cured a machining tool makes the necessary cuts before a new layer is placed on top of the previous one, producing a continous, complex cavity and providing high feature resolution. This process is repeated for each layer until the mold is complete. It is important to point out that the mold cavity and core is integral. The mold cavity can be accessed at each layer, allowing insert placement and smart coating technologies to chill, insulate or enhance the surface finish. Finally, the finished mold is delivered to a foundry for filling with the desired alloy.

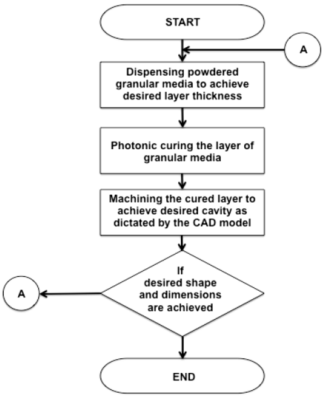

Fig. 1. Rapid Molding Sequence

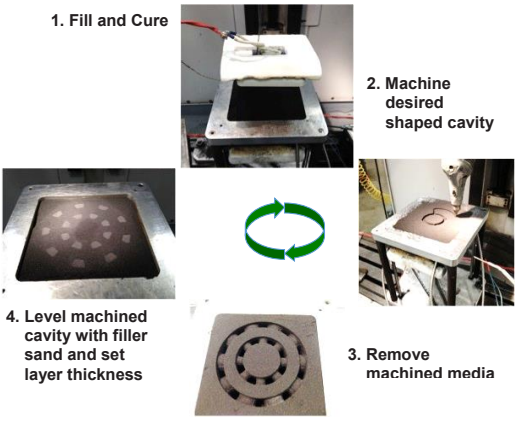

Fig. 2. Hybrid Additive/Substractive Process

2. Methodology

The MMM is a special thermosetting resin coated sand, to enhance the heat transfer between layers; when exposed to infrared light enabled the sintering and curing of up to 8-mm thick layers in 90 seconds. The ability to cure thicker layers can lead to much higher throughputs for the prototyping technique. The cured layer of sand is a machinable ceramic material that is not deleterious to the tool or machine components. An automated sand feed and leveling system is used. The Hybrid IRS/MMM prototyping system was built and tested (Fig. 2). The fast curing MMM was developed and tested to handel the casting of complex shapes from a variety of alloys.

3. Results and discussions

The researchers were able to design, produce and test the prototyping system. Successful trials with resulting castings are shown in Figs. 3 and 4. Process benefits of the hybrid MMM/IRS system are: high accuracy, high throughput, no need for hard tooling, complex geometry, low sand-to-metal ratio, minimal tool and machine wear.

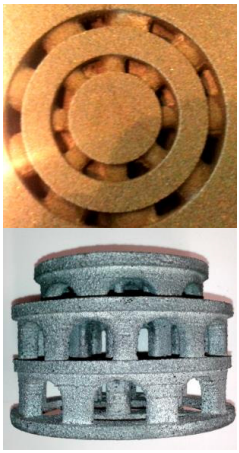

Fig. 3. Castle sample

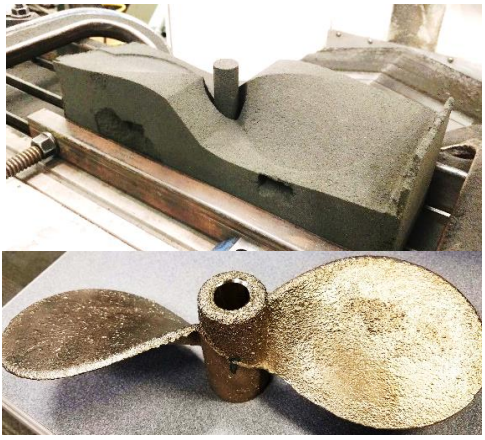

Fig. 4. Propeler sample

4. Conclusion

A technique/process for limited quantity functional prototypes from various casting alloys was developed and tested. Sand molds with a defined level of complexity including curvilinear shapes and surfaces was produced using the hybrid technique, involving additive and subtractive manufacturing. The MMM/IRS RP system will provide the industry with the ability to produce representative and functional casting prototypes utilizing equipment available at most machining and casting plants. This system will reduce the lead time, increase the quality, and produce complex shapes that were very challenging and cost prohibitive to produce with conventional 3D printing prototyping methods.

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APPLICATION POTENTIAL OF CARBOXYMETHYLCELLULOSE (CMC) MODIFIED BENTONITE IN THE FOUNDRY INDUSTRY

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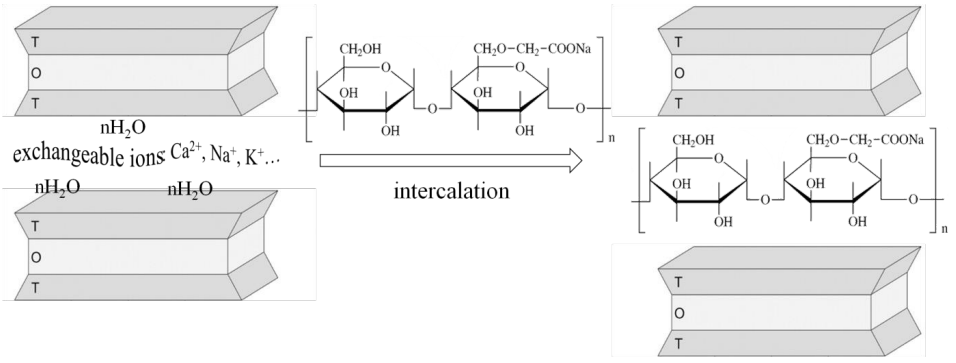
Key words: modification, bentonite, moulding sand, CMC, binder

The majority of the iron castings are made using the synthetic moulding sands (with bentonite) [1]. The quality of the bentonite-bonded sand mould is one of the crucial factors determining high quality of castings. In addition to the mineral matrix, bentonite binder and water, synthetic moulding sands must contain so-called lustrous coal carriers (coal dust, synthetic resins, etc.). These carbon additives, on the one hand, determining the surface quality of castings, on the other hand, are the source of harmful gases, which get into the atmosphere and remain in the waste moulding sands structure [2]. So far, only a few attempts have been made to develop effective and more ecological substitutes for commonly used in today's foundries carbon additives in moulding sands with bentonite.

The alternative solution can be a modification of the bentonite itself, and more specifically its main component - montmorillonite. The specific crystal structure and highly chemically reactive surface of this aluminosilicate give the possibility of a simple change/control of its properties by reaction with hydrated inorganic or organic cations [3]. Its reactions with organic compounds, which causing an increase in the distance between the platelets via embed or adsorb of long carbon chains on the surface of montmorillonite layers in the interlayer spaces are particularly interesting (Fig. 1) [3-5]. This process, called intercalation, depends on such factors as the cation exchange capacity (CEC), humidity, temperature, concentration and intercalate structure.



Rys. 1. Intercalation scheme for CMC in the montmorillonite

The effectiveness of the intercalation is usually measured as an extension of the basic distances by X-ray analysis, and the thermal stability assessed by comparing the effect of the organic compound on the montmorillonite using thermogravimetric analysis.
The observed trend of replacing the moulding sands constituents, which are the source of harmful substances released during the pouring liquid metal into the sand mould with biodegradable materials, inspired the authors to use them in the montmorillonite modification (intercalation) processes. The subject literature indicates that polymers from the polysaccharide group, in particular starch and its derivatives, were one of the most commonly used biopolymers as binders or additivies to moulding sands in recent times [6,7]. Studies with cellulose and its derivatives were much less frequent. Nevertheless, cellulose is a particularly interesting material in the aspect of montmorillonite modification, as it is a widely used carbon fibers precursor (carbonization of cellulose fibers occurs at 1000-1500 ° C [8]). As a result, it may be a potential source of the desired carbon structure, i.e. lustrous carbon. Its disadvantage, however, is the insolubility in water and organic solvents. For this reason, cellulose undergoes various modifications. The most practical applications among cellulose derivatives are cellulose ethers, in particular carboxymethylcellulose (CMC) [9]. It is a non-toxic compound that is soluble in both cold and warm water. It also has binding properties. Therefore, carboxymethylcellulose is a promising material in the context of modifying the montmorillonite selected properties useful from the synthetic moulding sand technology point of view, as well as surface quality of castings.

Acknowledgements
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ISOTHERMAL AND CYCLIC OXIDATION BEHAVIOUR OF ALLOYS FOR HIGH TEMPERATURE APPLICATIONS

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Key words: stainless steel, isothermal oxidation, cyclic oxidation modelling, SEM

In a wide variety of applications, metals and alloys that can maintain their desirable mechanical properties in a high temperature environment are essential. Research has been ongoing in this area for many years and there is constant industrial demand for alloys that provide high levels of oxidation resistance in a range of environments.

A review of the current literature in this area was carried out focusing on high temperature isothermal and cyclic oxidation of stainless steels and some selected chromia and alumina forming superalloys. The current practices used in high temperature oxidation testing were closely considered along with post exposure characterization techniques used to evaluate the type and structure of the oxide layers formed on the alloy samples. This study of the literature highlighted particular areas where it was felt that more work was needed to clarify alloy oxidation behaviour, in particular was the lack of application specific representative testing. It was found that there was a lot of research carried out in varying environments where isothermal high temperature oxidation was concerned, however, when cyclic oxidation high temperature was investigated it seemed that there was significantly less variation in the testing environments covered by the literature. This was especially surprising when specific applications of the alloys were mentioned by researchers, yet the testing that they carried out was not in an environment that would closely represent the working environment of that application, therefore prompting the questioning of the usefulness of the results to that industrial process.

To address the key areas of interest in the literature a comparison would be made between representative tests and tests carried out in a more simplistic static air environment. It was hoped that the results from this would highlight the importance of testing alloys for a specific application in a way that matches as closely as possible the conditions that the alloy would experience in service.

It was decided that samples should be exposed to a number of 8h cycles in static air at 950°C, and to air at 950°C with a flow velocity of approx. 3.5 m/s. In order to carry out this work a test rig was designed that would house a minimum of 20 samples at one time inside a chamber furnace with controllable temperature and controllable flow velocity across the samples surfaces. Using the test rig a relatively short term data set was produced indicating significant differences in alloy performance in both environments and from this data set using the COSP,

predictions for long term cyclic oxidation behaviour could be made for alloys which showed promising oxidation resistance during the short term testing, Fig. 1. These predictions of long term behaviour in a flowing air environment using the COSP have not been carried out elsewhere in the literature and provide substantial novelty and usefulness to this work. The alloys chosen for this study were austenitic stainless steel grades 304, 316 and 310 along with the Ni-based superalloy Inconel 625 and the Fe-based superalloy Kanthal APMT, 304 and 316 stainless steel are the most commonly used stainless steels in elevated temperature environments, while the other three were chosen because of their know ability to provide significant resistance to high temperature oxidation along with resistance to creep.

Prior to this a isothermal investigation of selected stainless steels was carried out across a range of high temperatures, close to the maximum suggested limits of the alloys, over a range of time periods. This was carried out to investigate the limits of the stainless steel alloys and to provide information on the breakdown of the alloys protective qualities. Three different alloys were tested and compared across a range of temperatures. The results of this investigation were used to show that certain alloys may not be acceptable for long term high temperature operation and that further study of more advanced alloys was required.

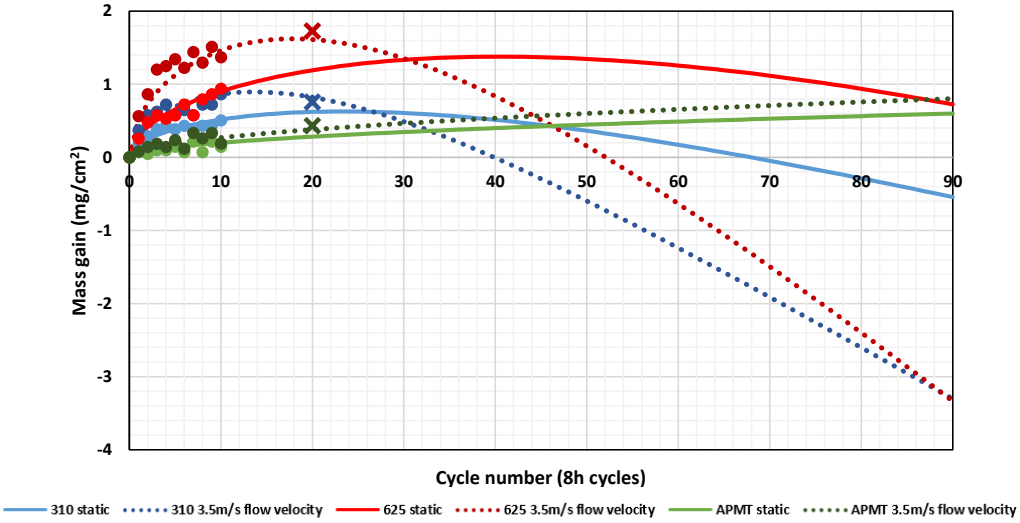

Fig. 1 - Long term predictions of alloy performance in static and flowing air environments

Conclusions

Deviations from parabolic oxidation in stainless steels tested isothermally were observed at temperatures of 1050°C and above. This was found to be due to vaporization and subsequent depletion of Cr in the base alloy.

The introduction of a flow velocity across sample surfaces in a cyclic oxidation testing environment increased the rate of mass loss from sample surfaces for a number of alloys. The process of Cr vaporization was found to be increased due to the introduction of this flow velocity.

The COSP modelling software gave indications of the significant impact of increased mass loss over longer testing preiods and showed that within certain environments alloy performance may be unacceptable.

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ASSESSING CERAMIC RESIN COATED SAND FOR IRON CASTINGS

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Key words: ceramic sand, disc-shaped specimen, hot-box shell, thermal distortion

There is a lack of information available on shell resin coated sand (RCS) produced with ceramics. This paper relates the physical, mechanical, and thermo-mechanical properties of disc-shaped shell core specimens made from either silica or ceramic sands and gravity filled. Specimens were laboratory tested (according to newly adopted American Foundry Society (AFS) Standards) and evaluate in aluminum and iron casting trials, included density, abrasion, thermal distortion, hot permeability, impact and retained strength.

1. Introduction & objective

Increasingly foundries are considering alternative molding materials such as synthetic ceramic granular media. Engineers must distinguish difference between silica and ceramic RCS cores and molds that are cured for casting in aluminum and iron foundries [1-3]. The objective was to determine the physical, mechanical, and thermal cured properties and characteristics for gravity fill silica and ceramic RCS at aluminum and cast iron temperatures.

2. Methodology

Preparation and testing of specimens: The shell RCS samples for silica (S) and ceramic (C) sands were prepared to two binder levels (1% & 3%). The RCS samples were gravity poured into a disc-shaped cavity of an electronically heated core box (aluminum die tool) manually, then cured at 232°C for 3 minutes. The shell RCS disc-shaped - 50 mm in diameter by 8 mm thick and were identified as $S_{1\%}$, $S_{3\%}$, $C_{1\%}$ and $C_{3\%}$. The tests runs for fifteen specimens: 1) specimen weight, 2) hot permeability, 3) abrasion, 4) impact and 5) TDT [1-3].
Casting trial: Specimens were compared using an experimental doughnut-shaped model (Fig. 1). Molds were manually poured with a gray cast iron (Grade 30) alloy, average pouring time ~12 sec., temperature at pour ladle - 1430 ± 3°C; delivered through a pouring sleeve fitted with a ceramic foam filter, and poured to a 10 cm head-height.

3. Results and discussion

Mechanical and physical properties: Table 1 shows the test of the shell disc-shaped samples.
Thermal distortion testing (TDT): TDT and change in mass results is presented according to shell RCS (Table 2) showed significant differences. The thermal distortion curves (TDC) are provided and compared for all systems in Fig. 2 (l) & (r). The thermo-mechanical changes brought forth are in the forms of TDC, cracks, and percent change in mass on the surface. For all silica shell RCS specimens tested, the hot surface/specimen interface showed brown to to black discolorations due to binder degradation. Cracks were macroscopically evident in both the $S_{1\%}$ and $S_{3\%}$ specimens (Table 2). The crack propagations on the silica RCS systems were detected as inflection points at ~10 seconds on the radial TDC (Fig. 2 (r)).

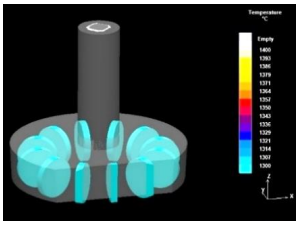

Fig. 1. Doughnut-shaped model with specimens

Table 1. Properties of the RCS Specimens

	$S_{1\%}$	$S_{3\%}$	$C_{1\%}$	$C_{3\%}$
Specimen Weight (g)	0.21	0.17	0.38	0.22
Specimen Bulk Density (g/cm^3)	1.47	1.58	1.83	1.75
Impact Strength (J)	0.09	0.07	0.03	0.08
Retained Strength (J)	0.08	0.07	0.03	0.08
Abrasion Loss (%)	0.78	0.22	1.45	0.10
Hot Permeability Index #	205	200	180	189

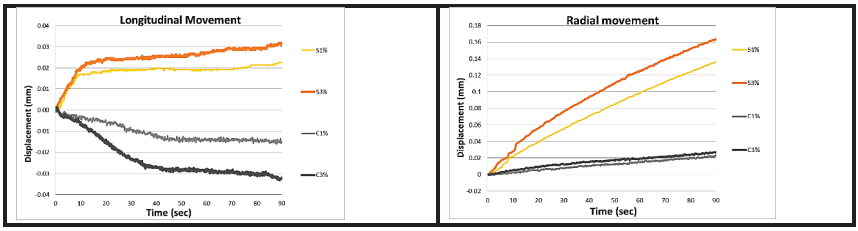

Fig2. Longitudinal (l) and Radial (r) TDC for Shell RCS specimens

In addition, sand losses were evident at the hot surface/specimen interface where binder bridges pyrolyzed and sand grains broke loose; this was most apparent in the $S_{1\%}$ and $S_{3\%}$ specimens (Table 2).

Table 2. Thermo-mechanical properties of Specimens and Observations at Specimen/Iron Interface after Casting Trial

Specimens	As-Cast Interfs: 10 cm head 1430°C	3D macro images at 12X	1000ºC TDT @ 2.5 N for 90 sec. Distortion (mm*sec)			Observation at Elevated Temp.		Observations within the same casting / Ra µm
			D_L	D_R	T_D	%Mass Change	Cracks & Fract.	
			Longit.	Radial	Total			
$S_{1\%}$			1.64	6.75	8.39	1.60	Present	Large penetration/70
$S_{3\%}$			2.22	8.65	10.87	1.25	Present	Slight penetration/68
$C_{1\%}$			0.96	1.03	1.99	0.71	None	Surface relat. clean/ 13
$C_{3\%}$			2.05	1.39	3.44	0.25	None	Surface relat. clean/ 12

4. Conclusions

Sand cores and molds, desirable for casting in gray cast iron, can be produced with ceramic shell RCS technology to a measurable quality Table (2). The ceramic shell RCS systems were thermo-mechanically superior to the silica shell RCS systems and this was reinforced with the iron casting trial.

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A NEW METHOD FOR LIMITING THE FRAGMENTATION PHENOMENON IN LOCAL REINFORCED COMPOSITE CASTINGS

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Key words: *in situ* iron composites, TiC, SHS, wear resistance, fragmentation

The statistical data show that about 80% of machine and device failures are caused by wear on those surfaces that rub against each other or due to so called hydrogen degradation [1]. Abrasive wear is a costly and serious problem in mining and mineral processing [2]. Ferrous alloys with high hardness and wear resistance constitute the most popular materials used in the production of machine parts. Martensitic, austenitic, and chromium cast steels may be included in the first group. The second group represents the selected types of cast iron such as martensitic and chromium white cast iron [3]. Due to the still-growing working parameters of crushing elements, their properties are insufficient. As a consequence, a necessity appears to design materials that offer an attractive combination of price and industrial output.

Iron matrix composites reinforced with ceramic particles are characterized by their good mechanical properties and high wear resistance [4]. Among the most popular ceramic phases used as reinforcements are TiC, WC, VC, TiN, Al_2O_3 and ZrO_2 [5]. As a reinforcing phase, titanium carbide is characterized by increased hardness (from 3000 to 3200 HV), a high melting temperature (3067°C), thermodynamic stability, and relatively good wettability by Fe-based alloys. Over the last several years, researchers have attempted to produce several composite materials reinforced by TiC [6].

One of the most popular methods for obtaining composite layers in locally reinforced castings is based on the initiation of an *in situ* synthesis reaction of the ceramic phase by self-propagating high-temperature synthesis (SHS) in a molten metal.

Many publications contain descriptions of the experimental process of fabricating composite zones. Most of these are based on the same technological process. In the first process,

the authors prepared green compacts that contain substrates of a ceramic phase (TiC) that is located in a mold cavity. In the next part, the high temperature of the liquid alloy initiates a synthesis reaction during the metallurgical process and in this way, particles of reinforcing phase are created *in situ* in Fe-based castings. The obtained materials were analyzed in view of their structural homogeneity, mechanical properties and wear resistance [7].

The reaction of TiC synthesis is highly exothermic, with an enthalpy of -187 kJ/mol [8,9]. Intensive energy production in the form of the generated heat results in the local increase in the temperature of the liquid metal, significantly intensifying the phenomenon of infiltration within the local composite reinforcements. Thus, the TiC particles are being separated by the molten matrix alloy; due to their lower density, the particles move within the casting and this phenomenon was called "composite zone fragmentation". One of the newest methods for limiting the fragmentation of composite zones or layers is the introduction of a moderator addition. The moderator is to be defined as a mixture of metallic powders with non-metals that can influence the structure of the composite zones and layers as a result of the crystallization processes [10].

The results of experimental study allowed to develop a new method for manufacturing of cast iron components locally reinforced with in situ formed TiC particles by creating a metal matrix composite zone using the TiC synthesis reaction.

Acknowledgments

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SESSION II

Foundry engineering and plastic deformation

THE ANALYSIS OF MICROHARDNESS VARIATIONS IN LONGITUDINAL SECTIONS OF HYDROFORMED AXISYMMETRIC COMPONENTS MADE FROM P265TR1 STEEL

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Key words: Hydroforming, microhardness, axisymmetric components, P265TR1 steel

Abstract

The paper presents experimental results that concern hydroforming process axisymmetric components made from P265TR1 steel. The specimens used in investigations were segments of tubes having the outer diameter D = 22 mm and wall thickness s_0 = 1 mm whose relative wall thickness was s_0 / D = 0.045. The research on hydroforming of axisymmetric components was conducted at a stand which included ZD100 testing machine (1 MN force) equipped special tool with hydraulic feeding system. The machine was modified by LABORTECH firm (Czech Republic) and it is compliant with metrological requirements for Class 1. Computer stand with Test&Motion software to measure forces and displacements was used. Axisymmetric components were hydroformed at upsetting ratios $\Delta l / l_0$ = 0.07 and 0.09 (where Δl – the punch displacement, l_0 – the initial length of tube). Changes in force and liquid pressure for hydroformed axisymmetric components made from P265TR1 steel are presented in Fig. 1. Examples of the axisymmetric components obtained in experiment are shown in Fig. 2.

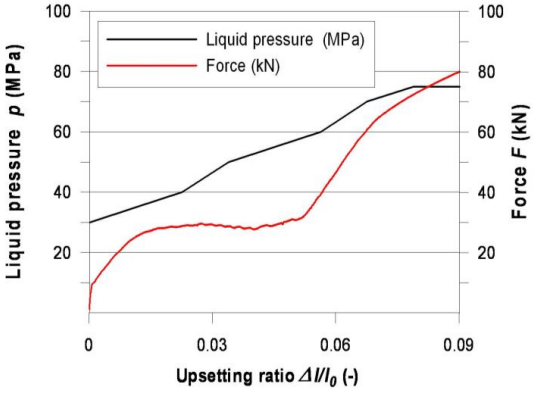

Fig. 1 Changes in force and liquid pressure for hydroformed axisymmetric components made from P265TR1 steel at different upsetting ratios $\Delta l / l_0$ = 0.07 and 0.09

Fig. 2 Examples of the axisymmetric components

The paper gives the comparison of the microhardness distributions in different zones of longitudinal sections of axisymmetric components. The measurements of microhardness were taken with a MATSUZAWA MMT-X3 Vickers hardness tester at load of 100 g, the measuring accuracy of which was compliant with ASTM E-384. Fig. 3 presents the spacing of measurement zones for microhardness measurements. Fig. 4 shows exemplary identations in longitudinal sections of hydroformed axisymmetric components made from P265TR1 steel after a Vickers hardness test.

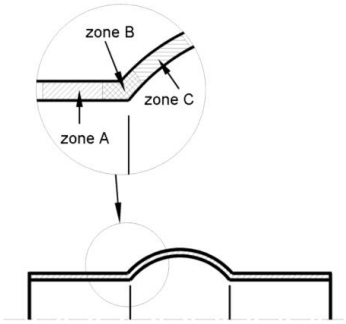

Fig. 3 Spacing of measurement zones for microhardness measurements in longitudinal sections of hydroformed axisymmetric components made from steel tubes at relative ratio $s_0/D=0.045$

Fig. 4 Identations for microhardness measurements in different zones of longitudinal sections of hydroformed axisymmetric components made from P265TR1 steel

The results obtained on the basis of arithmetic values of measurements in different zones of longitudinal sections of hydroformed components are presented in Fig. 5 in the form of graph.

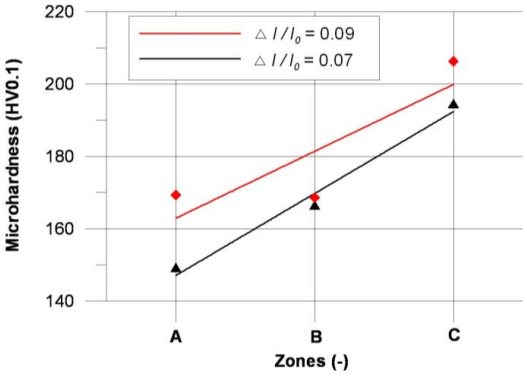

Fig. 5 The microhardness distributions in different zones of longitudinal sections of hydroformed axisymmetric components made from P265TR1 steel at upsetting ratios $\Delta l / l_0$ = 0.07 and 0.09

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THERMAL CONDUCTIVITY OF"VARI – MORPH" (VM) CAST IRON WITH GRAPHIT OF SEVERAL FORMS

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Key words: cast iron, compact graphite, thermal conductivity

Abstract: The paper presents the results of research on the influence of graphite precipitates on the thermal conductivity of cast iron. As a result of a series of casts, cast iron was obtained, in which in the next samples the form of graphite changes from the flake form, through mixed (vermicular+flake), vermicular, vermicular+nodular, to the nodular itself. The graphite form is described as a weighted average of individual forms of graphite. Using the ImageJ program, the value of the so-called graphite shape factor f_K was obtained, whose value varies in the range f_K=0.32 - 0.90. Parallel to the evaluation of the structure and form of the graphite, the thermal conductivity λ was determined using a fixed heat flow method. Conductivity tests were carried out on the original apparatus built at the AGH for testing the conductivity of foundry alloys. The research covered ferritic cast iron with many graphite forms, called by the authors "Vari - Morph" cast iron (VM). The dependence between the graphite form f_K and the thermal conductivity λ has been determined in the form: $\lambda=f(f_K)$, which is characterized by a high correlation coefficient.

Introduction: Cast iron with a mixed graphite forms, with controlled fractions of individual shapes, which proposed name is VM cast iron, can become an interesting material for castings of a special requirements. Cast irons with graphite F+V will be characterised by a good thermal conductivity and better plasticity and strength than grey cast iron. It was previously shown [1÷6], that such cast iron is characterised also by a high heat fatigue resistance higher than vermicular cast iron.

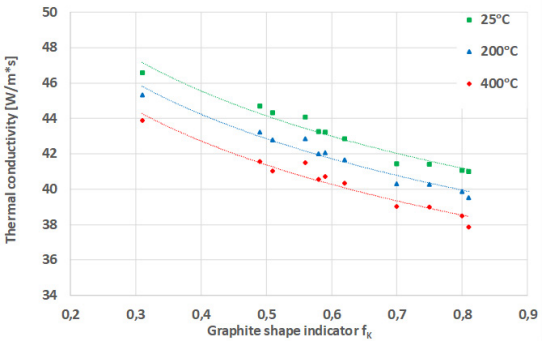
Materials and methods: The group of cast iron grades, which chemical composition oscillated near the eutectic value, was subjected to investigations (C=3.3÷3.6%, Si =2.6÷2.95%, Mn < 0.1; P < 0.02%; S < 0.01%; Mg =0.005÷0.030%).

Determination of the graphite shape indicator (f_K): Microscopic images were subjected to the stereological analysis by means of the program Image J for pictures analysing [7].

Results of own investigations: One of the features, which will be controlled is the thermal conductivity of cast iron. Investigations of the samples group obtained in successive melts were carried out on the prototyped research set-up, shown in Fig. 1a. The thermal conductivity was determined under conditions of a stable heat flow in cylindrical samples of diameter ø 20 mm and length 80 mm. The conductivity was determined within the temperature range T=25÷500°C. The obtained results are presented in figure 1b. It is generally known that the

change of the graphite form from flake ($f \leq 0.31$) to spheroidal ($f > 0.82$) leads to decreasing of the thermal conductivity. The quantitative dependence, in which the graphite shape is described by the mean value of indicator „f_K", is determined in the hereby paper.

a



b

Fig. 1. Research set-up for testing the thermal conductivity of materials: metals and alloys (a) and dependence between the graphite shape indicator and thermal conductivity

4. Conclusions

Investigations performed in this study allowed to determine empirically dependencies existing between the graphite shape indicator and thermal conductivity, $\lambda=f(f_K)$. The computer aided methodology of determining the shape indicator was developed, with using the ImageJ program. This is a new method especially suitable in quantitative determinations of this indicator of cast iron grades having different graphite forms. This method is based on the concept of calculating the mean weighted value of the shape indicator and all visible separation on the microstructure are included in the calculation, regardless of their size and shape.

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MELTING OF FINE-GRAINED ALUMINIUM SCRAP WITH SALT FLUX

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Key words: aluminium recycling, turning scrap, salt flux

1. Introduction

Due to its high chemical activity, during melting in the atmosphere of air, aluminium is easily oxidized. Particularly difficult is the recycling process in which parts with the high degree of surface area (foils, sheets, chips) are melted. In such cases, to reduce metal oxidation and increase the yield of the melting process, the particulate material should be introduced either directly into the liquid metal by means of suitable pumps or it should be loaded into the melting furnace in the form of compacted packages. The use of salt flux protects the metal against oxidation and facilitates the coalescence of fine drops. This article discusses the results obtained during melting of compacted, fine aluminium chips under the layer of salt flux.

2. Experiments

Tests were carried out on chips in sizes of less than 1 mm. Since the chips were characterized by a very high degree of surface area, direct remelting would lead to their rapid oxidation. Therefore, before melting, the chips were pressed into cylindrical compacts. The compacting pressure was 170 ÷ 720 MPa. Each of the obtained compacts was remelted in an alumina crucible under the salt flux containing 30 wt% KCl - 70 wt% NaCl with the addition of 5 wt% KF. The temperature of melting was 750ºC and the time was 30 minutes. After removal of samples from the furnace, they were cast in a steel crucible and then the products of melting were separated. The obtained metal was weighed and analyzed for the chemical composition on a WDXRF analyzer. The appearance of samples before and after melting is shown in Figure 1.

Fig. 1. The appearance of aluminium chips before compacting (a), after compacting b), after melting (c)

3. Results

To ensure precise metal separation and determination of the melting and coalescence efficiency, the salts were dissolved in hot water. Next, the non-coagulated fraction and the metal which underwent coalescence were weighed. The melt yield *n* was calculated from equation (1), while the degree of coalescence *c* was determined from equation (2).

$$n_{\%} = \frac{m_{fr(n)}+m_{fr(c)}}{m_t} \times 100 \quad (1)$$

where: $m_{fr(n)}$ - mass of non-coagulated metal [g], $m_{fr(c)}$ - mass of coagulated metal [g], m_t - mass of the sample before melting [g].

$$c_{\%} = \frac{m_{fr(c)}}{m_{fr(n)}+m_{fr(c)}} \times 100 \quad (2)$$

where: $m_{fr(n)}$ - mass of non-coagulated metal [g], $m_{fr(c)}$ - mass of coagulated metal [g].

Figure 2a shows the relationship between compacting pressure and density of the obtained compacts, while in Figure 2b the melt yield and the degree of coalescence are plotted as a function of the compacting pressure. Table 1 gives the average chemical composition of the metal.

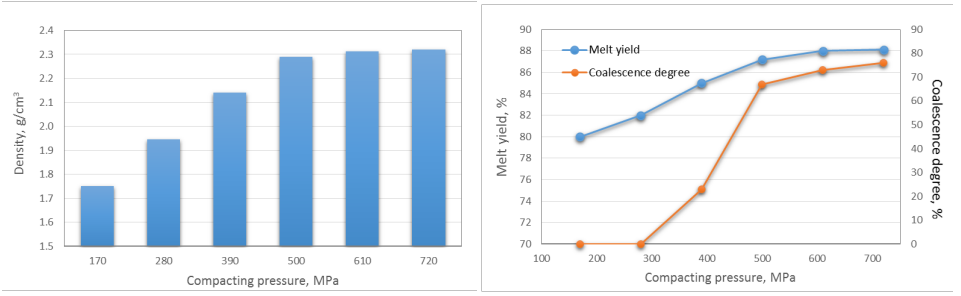

Fig. 2. Effect of compacting pressure on the density of compacts (a) and on the melt yield and coalescence degree (b)

Table 1. Chemical composition of the metal averaged from six melts

Si	Cu	Ni	Fe	Mg	Ti	Mn	Zn	Na	Al
19.05 ±0.82	1.25 ±0.02	0.85 ±0.05	0.06 ±0.01	0.87 ±0.02	0.21 ±0.01	0.22 ±0.02	0.20 ±0.02	0.2 ±0.04	REST

4. Conclusions

Fine-grained aluminium waste poses a challenge for the recycling process. It requires high degree of compaction (use of considerable forces during pressing) and large amounts of salt flux to obtain a good coalescence of the metal and a correspondingly high yield. Additionally, the presence of dusty fraction demands special care to be taken in all technological operations. The post-melting metal analysis indicates that the mechanical treatment resulting in the tested waste has been carried out on AlSi18CuNiMg alloy. After a small correction of the composition, this material can be a valuable commercial product applicable, among others, in the manufacture of pistons for internal combustion engines.

Acknowledgments

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HYBRID MAGNESIUM GASARS – INNOVATIVE ULTRALIGHT POROUS MATERIALS

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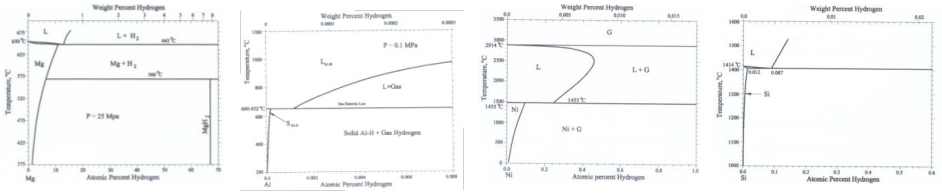
Key words: ultralight materials, high-porosity media, magnesium gasars, hybrid gasars, pressure–thermal management, non-destructive analysis, computed tomography, mathematical modeling, computer simulation

As a result of the nature of gas pores creation on the front of metal solidification, functionally metal-gas graded materials with high, usually directionally oriented porosity, are named either "gasars" (as effect of thermodynamic gas-eutectic transformation) [1] or "lotus-like structures" (as effect of physical gas evacuation from liquid metal being solidified) [2].Hydrogen is mainly considered as an effective porosity creating agent, although there are reports on the attempts to use other gases or its mixtures, including active and inert ones such as oxygen, nitrogen, helium and argon [3]. The recognition of gasars as a result of the thermodynamic reaction is justified from the experimental confirmation of the occurrence of gas-eutectic transformations in many gas containing systems, as those ones with hydrogen, shown in Fig. 1.



a b c d

Fig. 1. Examples of metal-hydrogen phase diagrams: a) Mg-H (under 25 MPa external pressure); b) Al-H, c) Ni-H, d) Si-H (d) (under atmospheric pressure) [4-7]

The presentation is focused on critical review of literature data and experimental results on the synthesis of magnesium-based gasars using the original authors' set-up, procedures and optimized methodology [8]. Special attention is paid to mathematical modeling and computer simulation implemented in order to clarify and understand the phenomenon of porosity nucleation and growth from hydrogen saturated melts. The results of computer simulation are

compared with experimental data from the literature and own trials as well as with non-destructive analysis by X-ray computed tomography for the complex evaluation of the structure of magnesium gasar ingots produced (Fig. 2).

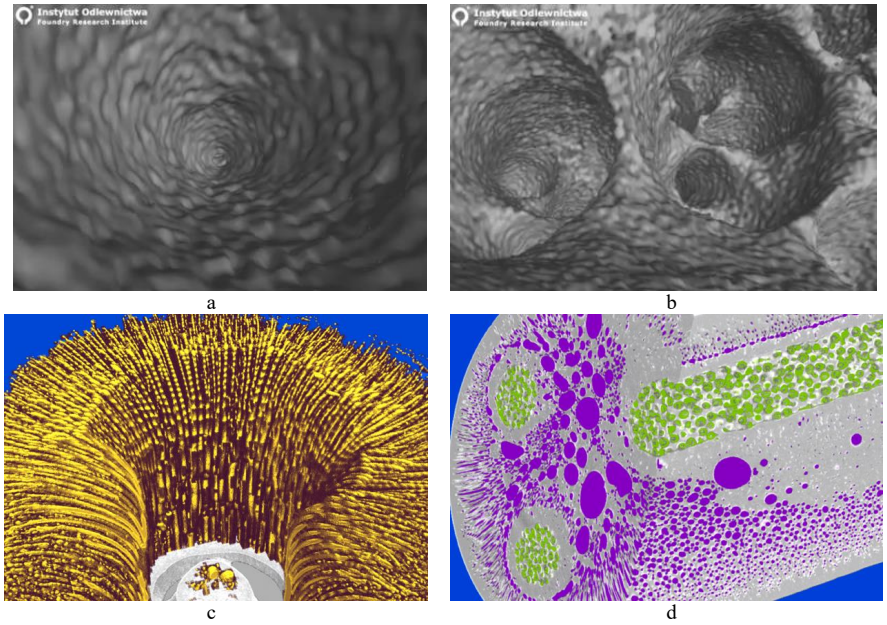


Fig.2. The structure of internal pores in conventional Mg gasars (a,b), distribution of porous capillars in hybrid Mg gasar ingot (c) and hybrid Mg gasar ingot locally reinforced with Mg-matrix composite rods containing B_4C microspheres of diameter 1 mm (d). The Mg gasars of average 25 vol.% porosity was produced with Ar-35%H_2 mixture of 1 MPa (snapshots come from CT scans) (based on data from [8])

Computer-assistant development of gasar process has evidenced that application of combined thermal-pressure management approach for both making a hydrogen saturated melt in Ar-H_2 mixture (35-50 vol.%) and its subsequent solidification allows the synthesis of hybrid Mg gasars with a controlled ordered, directional, arranged and functional porous structure. The combination of properties of such novel ultralight Mg-based materials (e.g. compressive strength, thermal conductivity, electrical conductivity) are at least comparable or even better than those of conventional gasars, depending on the process variables used.

Acknowledgments
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NEW EUROPEAN INITIATIVE FOR NOVEL ULTRALIGHT MATERIALS WITH UNIQUE PROPERTIES

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Key words: ultralight-porosity media, aerogels, COST Action, international cooperation

Aerogels represent a relatively new class of advanced ultralight materials comprised of a microporous solid in which the dispersed phase is a gas [1]. The main constituent of aerogels is air (up to 99.8%) due to a unique structure of porous solid network composed of air pockets thus resulting in extraordinary properties of these synthetic nanostructured materials, particularly extremely low density and low thermal conductivity.

The aim of this presentation is to familiarize the participants of ICMCC[2] with the activities of a new European initiative dedicated to aerogels and organized in the frame of the EU Framework Programme Horizon 2020 under COST Action 18125 "*Advanced Engineering and Research of AeroGels for Environment and Life Sciences*" (Action Chair - Dr Carlos A. Garcia Gonzales from Universidad de Santiago de Compostella, Spain. Start of Action - 30/04/2019. End of Action – 29/04/2023) [2].

As other COST Actions, this one represents a network focused on **CO**operation in **S**cience and **T**echnology by complementing national research funds. During the *kick-off* meeting in Brussels, April 30, 2019, 36 countries have confirmed their participation in AERoGELS: Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Montenegro, The Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom as well as one cooperative member – Israel.

The long-term scope of COST Action 18125 is to develop an aerogel technology able to improve the welfare of European people and to move towards cleaner and smarter production in Europe. Therefore, in this Action, the use of aerogels will be specifically explored in the context of environmental and life sciences applications by joining the knowledge and efforts of the most renowned experts on cutting-edge aerogel technology, on advanced characterization of materials as well as on biomedical and environmental research (Fig. 1).

This Action sets a forum to disseminate knowledge to society and to train European young researchers on research, innovation and entrepreneurial skills *via* technical schools, publications and STSM exchanges.
The main research objectives for this Action are as follows [2]:

1. To establish clusters to define the specific cutting-edge bioactive aerogels to be developed.
2. To establish clusters to define the specific aerogel features to be developed for environmental applications.
3. To explore routes for aerogel processing, and analytical tools for characterization and performance.
4. To evaluate aerogel processing approaches to turn advanced materials development from lab scale into commercial products.
5. To set the basis of a common knowledge on aerogels regarding toxicity, risk safety assessment, health and environmental impact and regulatory issues.

For this COST Action, the capacity building objectives are:

1. To identify the opportunities of aerogel technology in biomedical and environmental applications.
2. To set up a community on aerogel technology in a lifelong basis beyond the Action timeframe.
3. To join together research efforts, trans-disciplinary expertise on nanostructured materials and facilities to reach the main aim of the Action.
4. To train ECIs for skills development to become the next-generation scientific and technological leaders.
5. To promote, disseminate and share knowledge on aerogel technology.

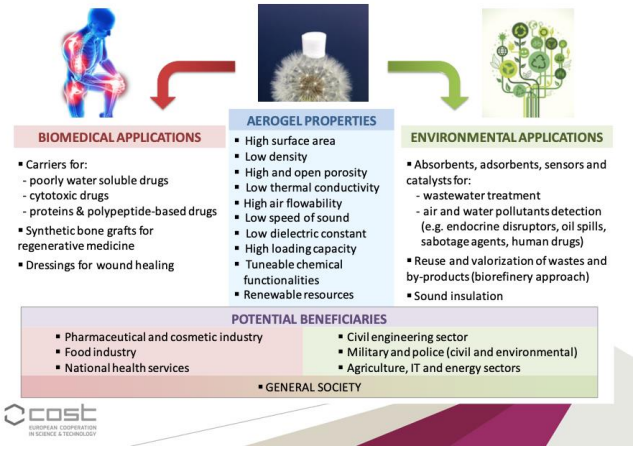

Fig. 1. Overview of CA18125 COST ACTION [3]

Acknowledgment
Support from the project 2018/31/B/ST8/01172 financed by the National Science Centre of Poland is greatly appreciated.

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International Conference of Metals, Ceramics and Composites

26th September 2019

SESSION III

Surface and coating technologies and powder metallurgy

International Conference of Metals, Ceramics and Composites
25th–27th September 2019, Warna, Bulgaria

STRUCTURAL EVOLUTION IN Al-Fe MATERIALS MADE BY POWDER METALLURGY ROUTE

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Key words: phase evaluation, powder metallurgy, Al-Fe materials

In recent years, iron aluminides have gained widespread interest due to their attractive technical and physical properties. This is due to the possibility of using them in high temperature conditions. A small addition of aluminium to iron provide to get the availability of resistance to corrosion, increase conductivity and decrease weight of the produced material. Additionally, potential application is growing, due to low material price and production costs. Increasingly, attention is focused on Al-Fe materials as a potential substitute for steel [1, 2].
In order to obtain a material that will combine the properties of aluminium and iron as well as some profitable intermetallic phases from the Al-Fe system, it is necessary to mix both of metals. Some good solution is to use powder materials and sintering methods to obtain appearance of promising intermetallic phases. The use of powder metallurgy method can produce materials at lower temperatures than the melting point of iron or the desired intermetallic Fe-Al phase [1, 3].

Methodology

As a starting material the mixture of aluminum and iron powder was used. Aluminum powder has average particle size 25μm and irregular shape which was obtained in a commercial atomization process. Iron particles has average particle size under 100μm and irregular shape with sponge-like microstructure and large surface area what is characteristic for the method production (Höganäs). The Al-Fe mixture of powders was placed in a sleeve and cold compacted at room temperature in a uniaxial press under 400 MPa. Sintering of all the green compacts was carried out using a ceramic furnace in a vacuum at 600 °C for 6 hours.
The microstructure of the prepared composites was examined by both optical model OLYMPUS GX microscope and scanning electron microscope (SEM, model: HITACHI S-3400N). The elemental analysis of the specimens was performed using an energy dispersive spectroscopy (EDS) microanalyses equipped on scanning electron microscope (SEM). X-ray diffraction (XRD) analysis was carried out on a diffractometer model Burcker Discover D8 Advance with Ni filtered and Cu target, Kα radiation. Hardness was measured using Vickers indentation technique with a load of 1 kg for a dwelling time of 10 s and an average of five readings was reported (SHIMADZU HMV-2T E).

Results and discussion

Observations performed under SEM microscopy revealed (Fig. 1) that the sintered material contain three areas: white - which is the iron phase (tab. 1 pt.1), grey dark areas - Al phase (tab. 1 pt.2), and light grey which is newly-formed phase. The EDX analysis revealed (tab. 1, pt. 3)

the ~72%at aluminium and ~28%at of iron what is corresponded to the phase Fe_2Al_5 which has the highest cohesion energy among the phases of the Al-Fe system and its formation is most likely under these conditions. The X-ray diffraction (XRD) analysis confirms that in sintered material occur: areas rich in aluminium and iron phase as well as Fe_2Al_5 phase was defined. In all of produced material black spots was observed and defined as porosity.

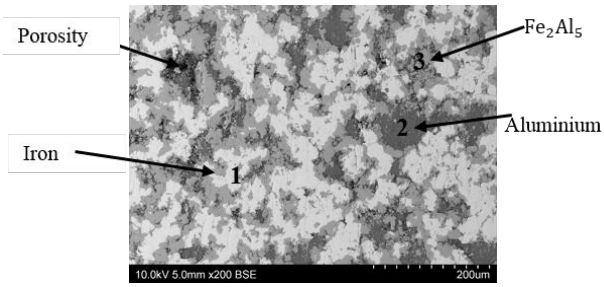

Fig. 1. Microstructure of sintere Al-Fe material (SEM)

Table 1. Results of EDX analysis of point shot for Fig. 1

point	Al [%at.]	Fe [%at.]
1	0.00	100.00
2	99.42	0.58
3	72.60	27.40

Conclusions

Regardless of the initial ratio of the proportion of Al-Fe powders, an intermetallic phase was formed at the interface between sintered aluminium and iron powders. Based on the analysis of the X-ray diffractogram and the EDS / SEM test, it was determined that the newly formed phase is Fe2Al5. The highest porosity after sintering process occur for sample of 41%Fe59%Al, in which the highest amount of Fe_2Al_5 phase was generated. The characteristic micro-cracking on the contact between Al and Fe_2Al_5 phase, swelling of the sample and increase in porosity is related to the Kirkendall diffusion effect, known in the literature.

Acknowledgments

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ELECTROCHEMICAL DEPOSITION OF SILVER ON ALUMINUM ALLOYS

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Key words: silver plating, aluminum alloys, diamond nanoparticles, SEM

Silver plating is mainly used in jewelery, optics, electronics and electrical engineering. It can be done in several ways: chemical, electrochemical, contact, etc. The most common way of silver plating is the electrochemical using cyanide and non-cyanide electrolytes. The aim of the study is to obtain electrochemically deposited silver layer with high density, adhesion and electric conductivity on aluminum alloys substrate. It is to be directly plated without intermediate layer.

A complex electrolyte without potassium cyanide is used in the present study for economic and environmental reasons. It is based on a compilation of existing electrolytes with the following composition:

Silver nitrate ($AgNO_3$) - 25-30 g/l calculated as Ag

Potassium hexacyanoferrate (II) trihydrate - $K_4Fe(CN)_6.3H_2O$ - 50-80 g/l

Potassium rodanide (KSCN) - 120-150 g/l

Potassium carbonate (K_2CO_3) - 25-30 g/l

The coated specimens (substrates) are from Al alloy with 10 % Si.

The parameters of the electrochemical process and the thickness of the layer were determined. Temperature of the electrolyte (T) – 18–23°C; duration of the process (t) – 25-35 min.; current density (I) - 0.3-0.5 A/dm^2; thickness of the coating (l) - 14-23 µm depending on the duration.

Thanks to the diamond nanoparticles in the working electrolytic a bigger thickness of the silver layer of 20-25 µm has been achieved after a special chemical treatment (etching) of the aluminum substrate surface.

A possible mechanism of the chemical and the electrochemical processes taking place during the silver plating is the following:

1. $AgNO_3 \leftrightarrow Ag^+ + NO_3^-$ (1)
2. $K_4Fe(CN)_6 \leftrightarrow 4K^+ + [Fe(CN)_6]^{4-}$ (2)
3. $[Fe(CN)_6]^{4-} \leftrightarrow Fe^{2+} + 6CN^-$ (3)
4. $Ag^+ + CN^- \leftrightarrow AgCN$ (4)
5. $AgCN \leftrightarrow Ag^+ + CN^-$ (5)
6. $KCNS \leftrightarrow K^+ + CNS^-$ (6)
7. $Ag^+ + CNS^- \leftrightarrow AgCNS$ (7)
8. $AgCNS \leftrightarrow Ag^+ + CNS^-$ (8)
9. $Ag^+ + e^- \leftrightarrow Ag^0$ (9)

The scanning electron microscope "JCXA 733" and "Zeiss EVO-10" with X-ray micro-analyzer "BRUKER" were used to characterize the silver layer. Figures 1 and 2 show a SEM image of the silver layer on substrate of aluminum alloy with 10 % Si. The substrate surface was etched and the concentration of the diamond nanoparticles (ND) in the electrolyte was 12 g/l. Special software "analySIS" with a hardware key was used and an average thickness of the 23.02 μm of the silver layer was measured (Fig. 7).

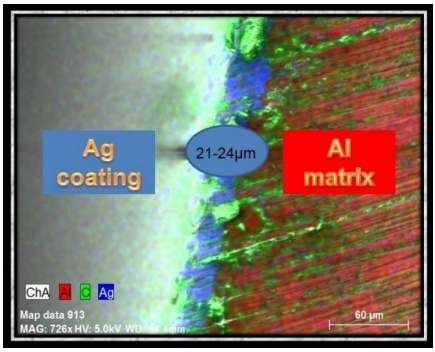

Fig. 1. SEM image of silver layer with ND on Al + 10 % Si, red -aluminum, green - carbon, blue - silver

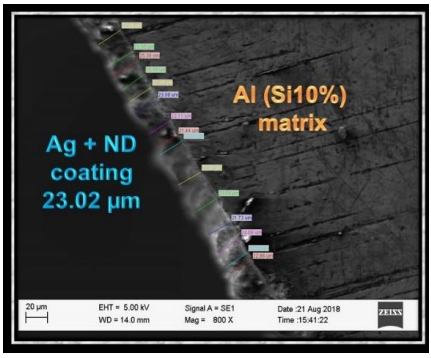

Fig. 2. Determination of the average thickness of the silver layer with ND on Al + 10 % Si

Conclusions

1. Electrolyte composition and electrochemical parameters were determined in order to produce Ag coatings on Al alloy substrate. The coating is with good adhesion, density and thickness of 14-23 μm.
2. The probable mechanism of obtaining a silver coating on aluminum alloy by the use of potassium hexacyanoferrate in the electrolyte was determined.
3. A special chemical treatment (etching) of the aluminum alloy surface was used, which allows direct electrodeposition of silver without an intermediate layer of Ni or Cu.
4. The use of diamond nanoparticles in the electrolyte increases the thickness of the silver layer with 60 % compared to the silver layer deposited from electrolyte without ND.

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SINTERED STRUCTURAL ALLOY STEELS – PROCESSING, PROPERTIES, MICROSTRUCTURE

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Key words: sintered steels, sintering atmosphere, mechanical properties, microstructure

Till to now the majority of sintered structural alloy steels contained Ni, an extreme cancerogenic element (category 3). European Council Directives [1], strongly advise against using this metal, especially in a very dispersed form. In the investigated steels, Cr, Mo and Mn were used as a substitution for nickel. During the whole research, the route of sintering PM steels in semi-closed container, the microatmosphere effect, was employed. This technique, developed and theoretically described – mainly in case of simple manganese steels [2], makes possible use of non-explosive and not toxic inert atmospheres in the furnace chamber.

During carrying out the work, the following sintering atmospheres were used: hydrogen, mixture of hydrogen and nitrogen with different N_2/H_2 ratios and pure nitrogen, described in [2-9]. Sintering temperature was varied from 1120 up to 1250°C because the analysis of Ellingham-Richardson diagram [10] shows that an atmosphere with extremely low dew point does not ensure, during sintering at 1150°C, protection of Cr and Mn from oxidation. It means that thin film oxides are created in the structure, rapidly decreasing the strength of sintered part. Metal oxide will thermally dissociate during sintering in an atmosphere with a given partial oxygen pressure at a given temperature. To decrease the cost production, an attempt was made to sinter Mn-Cr-Mo steels in air [11], what was novum.

Following mechanical tests of investigated steels it can be concluded that Mn, Mn-Cr and Mn-Cr-Mo steels can be successfully sintered in N_2-rich atmospheres [12,13], only if semi-closed containers can be used. The positive results with ferromanganese and carbon, added in the form of graphite [14] on the structure and mechanical properties were observed.

During metallographic investigation of sintered steels an attempt was made to discover the relationship between processing variables and the structure of PM Mn-Cr-Mo steels. The investigations showed that these sintered steels were characterized by high structural inhomogeneity. The structural constituents were ferrite, pearlite, upper and acicular bainite, austenite and martensite, and the influence of the structural microconstituents depended on the chemical composition of sintered steels and their processing parameters [15].

The aim of this investigations was to demonstrate that sintering of Mn-Cr-Mo steels can be carried out in old furnaces using the effect of local microatmosphere, obtained when the

compacts are in a semi-closed container [2] , because of the gettering effect of manganese vapour and reduction of oxides by carbon monoxide, hydrogen and active carbon.

Acknowledgments
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STUDY OF THE COBALT COATINGS PLATED ON Ti-6Al-4V

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Key words: technological parameters, brush-plating, micro-density, micro-hardness, thin-film coatings

1. Introduction

Use of titanium and its alloys in machine-building industry is limited due to their poor tribological properties [1-8].

One of the possible methods for improving the mechanical properties of titanium and its alloys is the method of selective brush plating[3,7,9,10].

This paper presents preliminary results of study on plating cobalt coatings, using SIFCO ASC technology, on Ti-6Al-4V titanium alloy. The influence of technological parameters – current density, voltage and type of electrode cover material on the microstructure, element distribution, micro-roughness and microhardness is investigated.

2. Experimental details

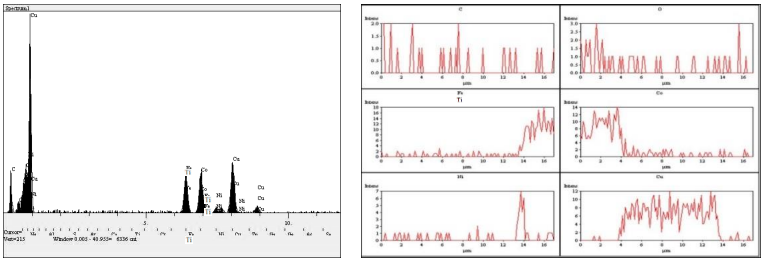
Samples of Ti-6Al-4V with dimensions 10x10x1 mm are degreased and brush-plated with cobalt coating at various voltage, current density with different electrode cover material.

Element distribution (EDS, Joel, JSM 6060-LU), microroughness(Mitutoyo Surftest SJ-301) and microhardness (Vickers aparatus HVS-1000) analysis were performed.

3. Results and discussion

The selective brush plating was leaded in the following steps: Electrical cleaning→Rinse →Activation→Plating with Ni→Rinse→Plating with Cu→Rinse→Plating with Co. After the coating, samples are rinsed with deionized water.

Figure 1 shows the EDS maps depth distribution of the elements formed after selective brush plating of Co.



a. b.

Fig.1. EDS dispersion analysis of deposited layers on titanium alloy Ti-6Al-4V (a); Mean analysis of the cobalt coating elements deposited on the titanium alloy Ti-6Al-4V (b)

Mainly Co, Cu and homogeneously dispersed in small amounts O were detected in plated Co film (Fig. 1). The main elements of the coating Co and Cu content, decreased regularly from outer to inner layers of the coating and very thin Ni layer was detected from the boundary titanium matrix. The Ti comes from the substrate surface (Fig. 1.b.).
The study shows that the process parameters are directly related to the resulting mechanical properties of selectively plated cobalt coatings on the titanium alloy Ti-6Al-4V samples. The measured maximum microhardness of the cobalt coating is 666±5 HV0.025 (Fig.2).

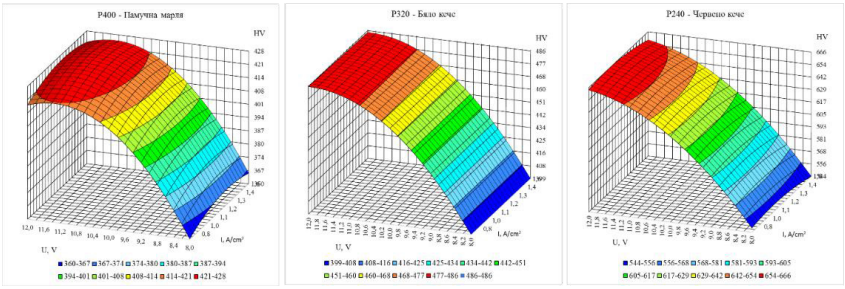


Fig.2. Influence of the plating voltage, current density and anode cover material over the surface microhardness (HV)

4. Conclusions

The elemental analysis (EDS) indicates the presence of nickel, copper and 4 μm cobalt layers as calculated in advance. The layer elemental concentration is identical and the layers does not blend regardless the variation of process parameters due to low temperature nature of the process.
The roughness of electrode cover material, current density and voltage have influenced the micro-roughness and microhardness of the applied cobalt coatings.

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INFLUENCE OF THE ELECTROCHEMICAL ANODIZING PARAMETERS ON THE MICROSTRUCTURE, MICROROUGHNESS AND MICROHARDNESS OF ANODIZED Ti-6Al-7Nb

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Key words: anodizing, surface oxidation, electrochemical, titanium alloy, Ti-6Al-7Nb

1. Introduction

Electrochemical anodizing is a common surface modification method for Ti and its alloys. [1-8] The process can be performed under potentiostatic or galvanostatic mode in numerous electrolytes. [9-12] This process allows the oxide layer to obtain various properties by controlling the electrochemical parameters. [13-15]

This paper presents preliminary results of the study on anodizing titanium alloy Ti-6Al-7Nb. The influence of the anodizing process parameters - voltage, anodizing time and distance between electrodes on the microstructure, elemental distribution, microroughness and microhardness is investigated in particular.

2. Experimental details

Ti-6Al-7Nb cylinders with dimensions 12 mm x 4 mm are mechanically processed by grinding, chemically degreased, deoxidized and electrochemically anodized in 1M sulphuric acid at various voltage, time and electrode distance.

Microstructure (Hitachi S-4700 SEM), elemental distribution (EDS, Joel, JSM 6060-LU), microroughness (Marsurf PS10) and microhardness (Vickers aparatus HVS-1000 at load of 0,01 kg) analisys were performed.

3. Results and discussion

The study shows that the process parameters are directly related to the resulting microstructure and mechanical properties of the newly formed oxide layers on the anodized titanium alloy Ti-6Al-7Nb. (Fig. 1)

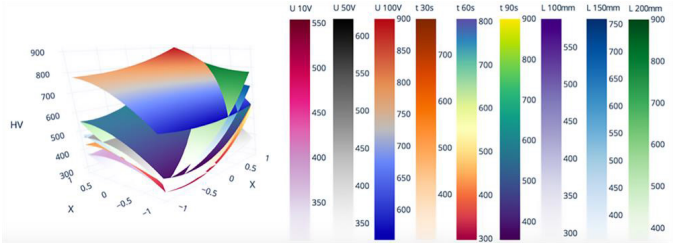

Fig. 1. Influence of the anodizing voltage (U), time (t) and electrode distance (L) on the surface microhardness (HV)

4. Conclusions

The formed microstructure in the electrochemical anodization process is more saturated and compact with the increase of the voltage from 10V to 100V. Micro cracks are observed, which are most likely to occur due to internal tension during the oxide layer growth.

The elemental analysis (EDS) indicates the presence of titanium and oxygen, which form an oxide layer with dimensions up to 200 nm. The concentration of alpha and beta alloying elements in the alloy decreases near the surface. The oxygen content is reduced in depth and the presence of aluminum and niobium increases. This effect is explained with the higher activity of titanium to oxygen.

Data arrays have been created to observe the variations of Ra, Rz and HV when changing the values of the technological parameters from -1 to +1. The influence of separate technological parameters on the surface roughness and microhardness is established.

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International Conference of Metals, Ceramics and Composites

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SESSION IV

Surface and coating technologies and powder metallurgy

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INFLUENCE OF THE TYPE OF SUBSTRATE ON STRUCTURE AND PROPERTIES OF ALUMINIDE NiAl COATINGS

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Keywords: coatings, CVD, NiAl aluminide

Surface engineering plays an important role in the design of coatings and protective layers. This is due to the fact that properties of structural materials shaped by heat treatment or by selected phase and chemical composition do not show significant improvement [1]. Continuous use of machines and devices requires constant maintenance and modernization. During processes, technical tools are exposed to various factors that make their service life shorter. This leads to the replacement of individual components or entire devices [2]. The process of wear is caused by numerous factors, including mechanical, thermal, chemical, electrochemical, microbiological and electrical factors, or radiation. The use of modern processes in the field of surface engineering allows modification of the surface layers of products, improving in this way their operational properties [1]. To increase the corrosion resistance of alloys used in the aerospace, machine or tool industry, various types of protective coatings are applied. When the main purpose is higher heat resistance, reduced thermal conductivity or satisfactory structural stability, aluminide coatings (NiAl) are deposited [3,4]. They are used on a large scale, among others, to protect blades exposed to contact with high temperature [5].
The use of various substrates such as nickel alloys, steels or cast irons is expected to help in verification of the influence that substrate may have on the structure, properties and quality of NiAl aluminide coatings formed as a result of the chemical vapour deposition process.

1. Investigated method

Studies concerned nickel alloys, steels and cast irons subjected to the process of aluminizing. The aluminizing treatment was carried out by the Chemical Vapour Deposition (CVD) method using a BPXPRO3252 device from IonBond available at the Aerospace Research Laboratory of the Rzeszów University of Technology. The conditions of the aluminizing process were developed, and technological conditions of the device operation as well as their influence on the mechanical properties of alloys selected for testing were taken into account. The aluminizing temperature of 1040°C and a constant time of 6h were adopted.
The structure was examined on previously prepared metallographic specimens using an OLYMPUS GX5 optical microscope and a HITACHI S-3400N scanning microscope equipped with an EDS system.

2. Results

The SEM cross-section NiAl coatings is presented in figure1. Clearly visible is a hybrid structure, which included an outer NiAl aluminide layer, a diffusion zone and a substrate (Fig. 1 a, b).

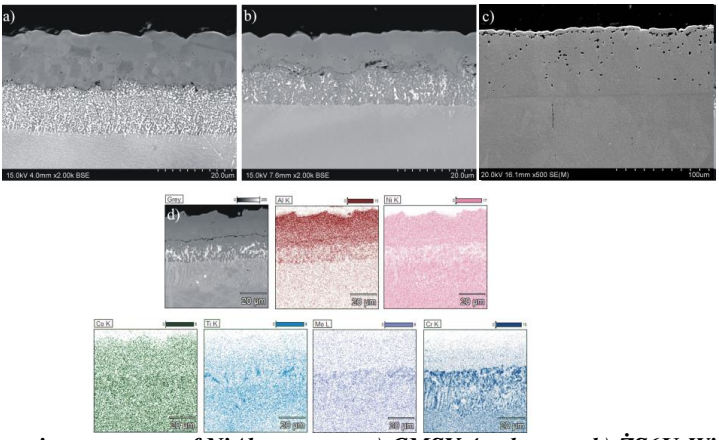

Fig. 1. The microstructure of NiAl coatomgs a) CMSX 4 substrate, b) ŻS6U-Wi substrate, c) 316 l steel substrate, d) Chemical analysis

The use of steel as a substrate has revealed a structurally different type of NiAl aluminide coating in which no intermediate layer was present (fig. c). The results of the studies have demonstrated that in each case the external NiAl aluminide coating was compact and strongly adhering to the substrate surface. The structure of the layer is typical for the low-active aluminization process and results from the core diffusion of nickel to the layer. The structural analysis of individual coatings showed differences in the width of the NiAl aluminide layer, most likely due to the type of the substrate material used. Attempts to deposit the layer of NiAl coatings on various substrates is possible.

Carrying out tests of hardness, Scratch test, will allow us to assess their applicability in other industries.

Acknowledgments

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HIGH QUALITY CORROSION PROTECTION OF SINTERED STEEL WITH CHROMIUM COATING DOPED WITH DIAMOND NANOPARTICLES

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Key words: chromium coating, diamond nanoparticles, corrosion resistance, sintered steels

The aim of the study is to determine the corrosion behavior of sintered steel samples with electrochemically deposited chromium coating modified with diamond nanoparticles.
The parameters of the electrolytic process were equal for all investigated samples. It was found in previous studies that chromium yield, respectively, the thickness of the layer significantly increases with the increase in the concentration of the diamond nanoparticles in the electrolyte [1]. For this reason the electrolysis of the samples was performed from electrolyte with 10, 25 and 40 g/l diamond nanoparticle concentration (C_{ND}). The resulting chromium coatings were 30 - 50 µm thick. The effect of the diamond nanoparticles concentration in the electrolyte on the corrosion rate of the tested specimens was investigated (Table 1).

Table 1. The corrosion rate versus C_{ND}

C_{ND}, g/l	10	25	40
Corrosion rate, g/m^{2}h	0.042	0.019	0.021

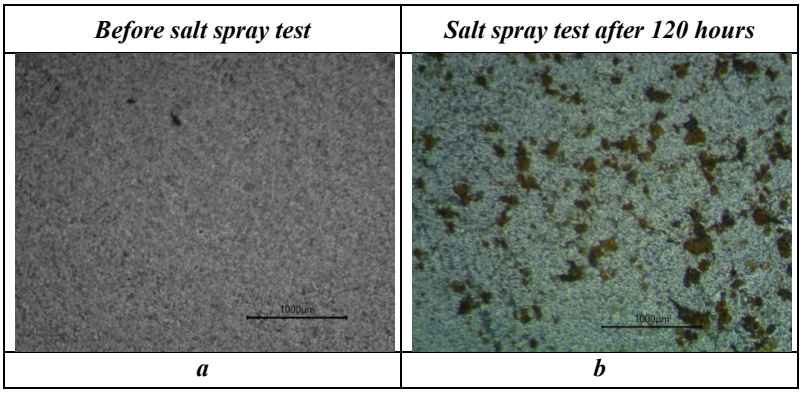


Fig. 1. Surface image of sample prepared from C_{ND} = 10 g/l

Corrosion rate = 0.042 g/m²h, Rp = 1, A = 25<A≤50 %

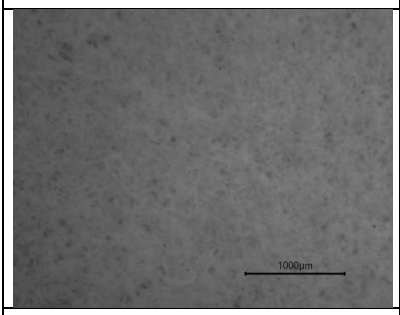
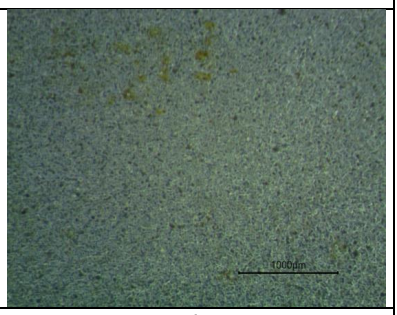
Before salt spray test	*Salt spray test after 120 hours*
	
a	*b*

Fig. 2. Surface image of sample prepared from C_{ND} = 25 g/l, Corrosion rate = 0.042 g/m²h, Rp = 2, A = 0.25<A≤0.50 %

The corrosive behavior of coated specimens was investigated by accelerated testing - a salt spray test (5 % NaCl solution) at 35°C according to EN ISO 9227 for 120 hours [2]. The corrosion rate [g/m²h] is calculated by the change in mass before and after the test. The corrosion rate is reduced twice when the C_{ND} is increase from 10 g/l (Fig. 1) to 25 (Fig. 2) and 40 g/l respectively (Table 1).
An assessment of the protective capability of the coating (Rp) according to EN ISO 10289 [3] was made. Rp is estimated by the area of the defects (A, %). As with the corrosion rate the best protective capability has the coating obtained from an electrolyte with C_{ND} of more than 25 g/l (Fig. 1, 2).

Conclusions

1. A new product, consisting of a chromium and diamond nanoparticles coating, applied on sintered steel materials is obtained. The resulting coating is smooth and tightly bonded to the substrate.
2. The influence of the concentration of diamond nanoparticles in the electrolyte on the corrosion process was studied and it was found that the corrosion rate decreased twice at C_{ND} above 25 g/l.
3. Composite chromium coating with diamond nanoparticles gives new possibilities for application of sintered steel products.

Acknowledgments
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A MATHEMATICAL MODEL OF MAGNETRON SPUTTER DEPOSITION

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Key words: mathematical modelling, magnetron, sputter deposition, optimization

In this work, the thickness distribution of thin films deposited by the magnetron sputtering technique are studied with the means of mathematical modelling. A mathematical model describing the process of atomic or molecular sputtering followed by deposition process in a RF/DC magnetron equipment is proposed. A principal scheme of the magnetron device is shown on Fig.1. In a vacuum chamber filled with noble gas (most often argon) a target (metal, ceramic or semiconductor) and a substrate are arranged opposite each other. Above the target an appropriate electromagnetic field is created which ionizes the atoms of the argon and directs them to bombard the target material. Upon collision of energetic ions on the target, atoms or molecules are ejected from the cathode target and are deposited onto the anode substrate. The proposed mathematical model describes this process and obtains the distribution of the thickness of the formed layer on the substrate. It has enough comprehensiveness to describe the sputtering of metals, insulating materials or semiconductors. It assumes arbitrary function of the distribution of the intensity of bombing ions like this presented on Fig.2. It can be set both analytically and discretely in case it is obtained with experimental measurements.

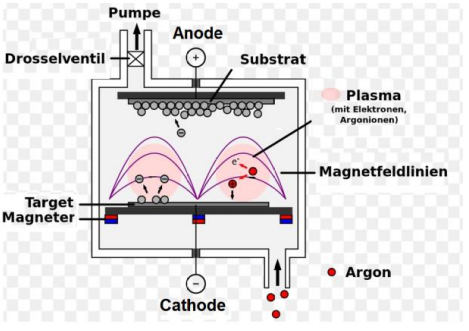

Fig.1. A principal scheme of magnetron device

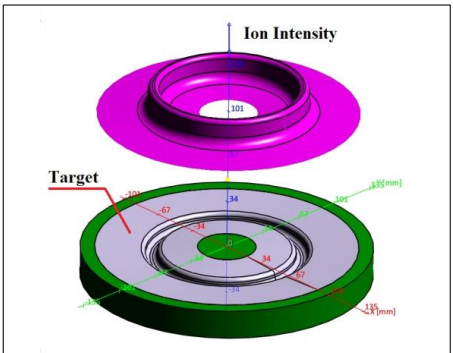

Fig.2. Distribution of ion intensity

The distribution of the intensity of the particles reaching the substrate (Fig. 3) is also assumed to be arbitrary. An algorithm has been developed to solve the equations of the model, which is implemented in the form of a computer program. With the help of this program model solutions have been received and presented by different configurations and parameters of the magnetron system. An optimal solution has also been found, where the non-homogeneity of the coating is minimal – Fig.4.

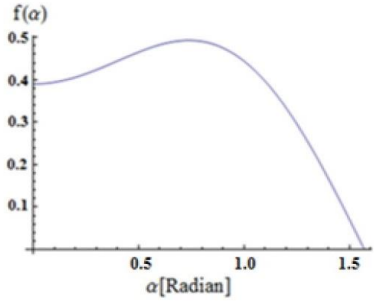

Fig.3. Distribution of sputter deposition.

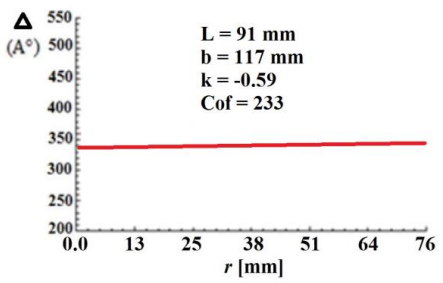

Fig.4. Solution with a homogeneous film.

Acknowledgments

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3D COPPER/GRAPHENE COMPOSITE - PRODUCTION, PROPERTIES, IMPLEMENTATION

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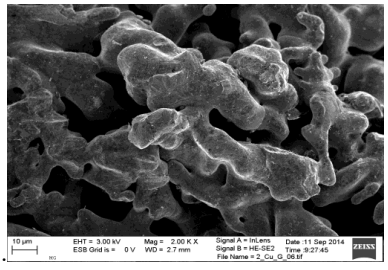
Keywords: copper powder, coating, graphene, composite, properties

1. Introduction

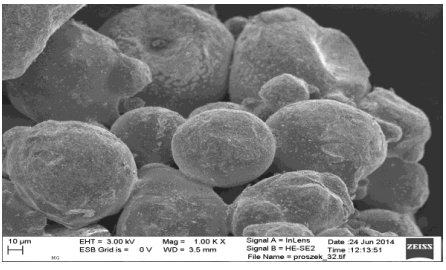
Graphene in recent years has generated great interest as a new material with many potential applications. Graphene layers are promising for applications in the production of transistors, transparent electrodes and organic electronics. Due to the unique properties of graphene, graphene-metal composites are opening a new class of construction materials.
So far, it has been possible to carry out an increase in graphene on metals such as SiC, Ni, Ag, Ni and Cu. Of these metals, copper seems to be the most promising due to, inter alia, the low price of the base material. To date, sheets and flakes have been the most common form of graphene.

2. Production of Graphene 3D^{IMP}

Researches on the production of composites with graphene as a dispersed phase are carried out at the Institute of Precision Mechanics (IMP). The Institute produces Graphene 3D^{IMP} – composite material, where graphene covers powders of copper. Graphene 3D^{IMP} can be produced in thermo-chemical processes, in which the Institute has many years of experience.
In the production of Graphene 3D^{IMP} fluidization processes are used. Thermo-chemical processes are carried out on the stand for fluidization, which was produced by the IMP. Gas flow provides fluidization in the working chamber, the process is assisted by the introduction of vibrations. The process of nucleation and growth of carbon structures on the surface of the copper occurs through interaction of gases containing hydrocarbon, which surrounds the particles of powder..
Fig.1 shows different types of graphene-covered copper powder, while Fig. 2a shows graphene separated from copper powder as a result of its etching and the structure of graphene obtained on Cu powder.

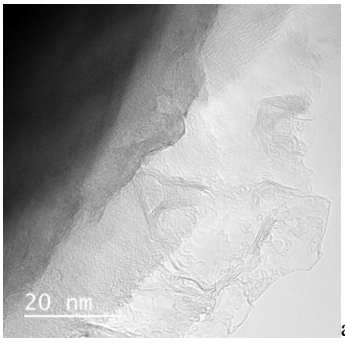


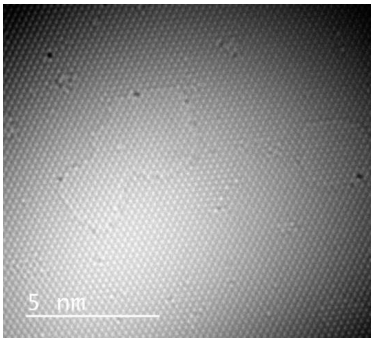
a)



b)

Fig.1. Dendritic (a) and spherical (b) copper powder particles after graphene processing



a)


b)

Fig. 2. Surface of copper powder with visible decohesion of the graphene coating (a), structure of the graphene coating (b)

In the work carried out at the Institute, copper powder coated with graphene in an amount up to 100g was obtained in one process. This means that the surface of copper powder (depending on its granulation) coated with Graphene is about 1.0-1.5m^2. The resulting powder can be used immediately after the process. It is also possible to iron it into fittings of any shape and size. The powder Cu/graphene composite can be successfully sprayed on various types of metal substrates such as iron, aluminum, copper, nickel and other alloys, but also on SiC and Al_2O_3 substrates.

3. Properties of copper/graphene composite

Three-dimensional composites with spatially distributed graphene around compressed powder grains are characterized by high performance properties such as electrical conductivity. Selected electrical properties (resistance) of the copper-graphene composite are given in Fig. 3.

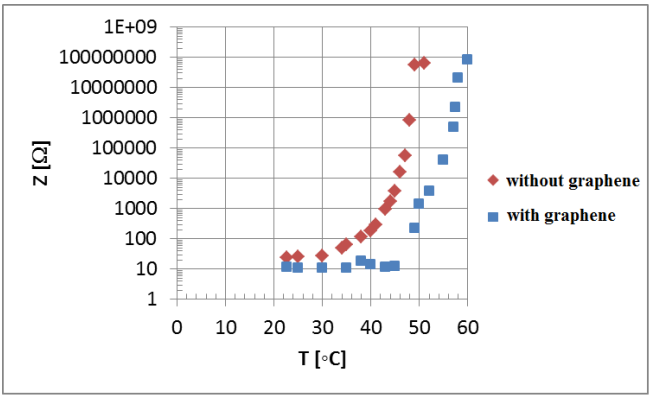


Fig. 3. Comparison of the impedance temperature relationship (Z) for an epoxide copper sample with graphene and without graphene

Such composites can be very widely used in the production of contacts, wires and winding wires for: 1) electrical contacts with increased thermal and electrical conductivity (use in power contactors); 2) high quality coils (applications in loudspeakers, transformers, machines electrical - including automotive industry); 3) transmission cables (power grids, transmission grids - better conductivity, lower transmission losses, better transmission quality); 4) heat exchangers for the energy sector - increased efficiency; 5) heat sinks for cooling electronic systems - increased efficiency.

International Conference of Metals, Ceramics and Composites

27th September 2019

SESSION V

Advanced materials characterization, additive manufacturing and heat treatment

International Conference of Metals, Ceramics and Composites
25th–27th September 2019, Warna, Bulgaria

HIGH TEMPERATURE INTERACTION BETWEEN Si-RICH ALLOYS AND GRAPHITE UNDER THERMOCYCLING CONDITIONS

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Key words: high temperature interaction, Si-alloys, graphite, LHTES, PCM

1. Introduction

Recently, Si-based alloys have been pointed out as novel ultra-high temperature phase change materials (PCMs) for electric thermal energy storage due to high latent heat released upon solidification of these alloys, as an advantage allowing to potentially extract very high energy density and conversion efficiency potentials [1]. However, due to high operating temperature coupled with cyclic PCM melting/solidification conditions of such latent heat thermal energy storage (LHTES) devices a proper selection of a refractory material for PCM container presents a key technological challenge [2-4]. Despite high reactivity between liquid Si and carbon, graphite is widely used as crucible material in silicon melting processes because reactively formed interfacial SiC layer may play a role of self-crucible, if the type of graphite is selected appropriately to working circumstances.

This paper discusses high temperature behavior of selected Si-rich alloys in contact with graphite under thermocycling that mimics real operating conditions of LHTES devices.

2. Materials and methods

The following materials were used in this study: 1) silicon-rich alloys of near eutectic composition containing 3.25 wt% B (Si-B alloy) or 26 wt% Si and 9 wt% B (Fe-Si-B alloy), selected as PCM candidates in previous studies of AMADEUS project [2-4]; 2) two grades of polycrystalline graphite (either dense graphite or that containing about 18% porosity).

Long-term reliability experiments of PCM containers were performed in high temperature device described in details in [5]. The containers having a geometry adopted from the prototype device were cut from graphite blocks, next filled with alloys and subjected to thermocycling testing (12 or 20 cycles of melting/solidification steps, for Si-B and Fe-Si-B alloy, respectively, Fig. 1). In order to ensure non-oxidizing atmosphere, the experimental chamber was prepared before starting long-term tests using ultra-high vacuum or ultra-high purity gas approaches. The real-time behavior of the graphite containers and the alloys was recorded by high-speed CCD camera. After tests, the containers were non-destructively inspected by X-ray computed tomography technique (GE Phoenix Nanotom, 100 kV) and finally, by observation of cross-sectioned crucibles with solidified alloys under light microscope (Carl Zeiss Axio Observer ZM10).

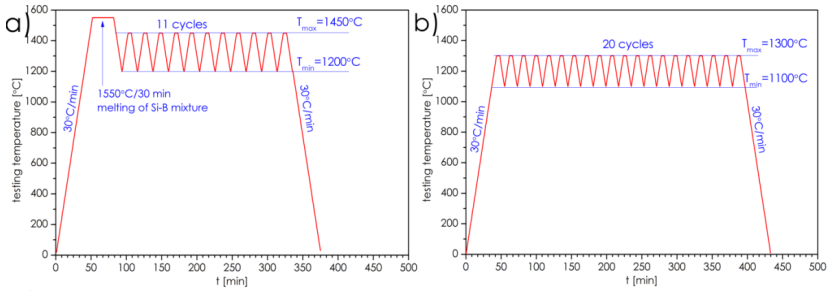

Fig. 1. Temperature profiles used for thermocycling tests: a) Si-3.2B; b) Fe-26Si-9B

3. Results and conclusions

Under testing conditions used in this study, there is a good wettability accompanied with a high reactivity between both alloys and graphite containers. The inert atmosphere facilitates a thermal destabilization of native surface oxide layers on the alloys and thus it allows for a direct contact of molten metal with the graphite body. Two grades of graphite containers demonstrated different results but in both cases, leading to intolerable "leakage" of the alloy and severe mass losses:

1) *A porous graphite* – during the first cycle, molten Si-B alloy rapidly wets, spreads and infiltrates through and over the container walls. The continuous SiC+B_4C layer produced at the residual Si-B alloy/graphite interface did not protect the container against the formation of through-thickness SiC stringers. As a consequence of reactive infiltration, the alloy completely covered internal and external walls of the container.
2) *A dense graphite* – after three cycles of melting/solidification of the Fe-Si-B alloy, the pre-existed native oxide skin on the alloy was completely destabilized and the alloy wets and spreads over the container walls. Consequently, the alloy "climbed" above the container's walls and it was removed outside the container. A low porosity and small pores diameter combined with the *in-situ* formed SiC interfacial product layer effectively suppressed a penetration of molten metal inside container's walls.

In the view of above described behavior, using graphite as the material for the PCM vessel working under ultra-high vacuum conditions is not recommended.

Acknowledgments

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STRUCTURE AND MECHANICAL PROPERTIES OF DUCTILE IRON WITH DIFFERENT INITIAL MATRIX AFTER NANOSTRUCTURISATION HEAT TREATMENT

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Key words: austempered ductile iron, microstructure analysis, nanostructurization

Austempered ductile iron (ADI) is a construction material widely used for machine parts and equipment in the agricultural industry, rail, automotive and mining. ADI microstructure is composed of spheroidal precipitates of graphite in the ferritic-austenitic matrix, so called ausferrite [1]. Recently, it has been shown that the use of properly designed austempering heat treatment allows to produce a nanocrystalline ausferritic microstructure, consisting of nanometric bainitic ferrite plates separated by a nanometric layers of residual austenite [2, 3]. This long-time, low temperature austempering can be considered as a nanostructurisation heat treatment.

The aim of the study was to analyze the influence of the initial microstructure of ductile iron on the final microstructure and mechanical properties of ductile iron after nanostructurisation heat treatment. In order to achieve this goal samples with perlitic-ferritic and ausferritic microstructures were subjected to austempering heat treatment in the range of bainitic transformation, for time needed to complete bainitic transformation (nanostructurisation heat treatment). The nanostructurisation heat treatment led to produce in both kinds of samples the same type of microstructure (fig. 1a-1d) consisting of nanoausferrite – very thin (about 120 nm thickness) bainitic ferrite laths separated by the nanometric (about 50 nm thickness) layers of the residual austenite. Blocky austenite was also observed. The microstructure of ferritic-perlitic ductile iron after nanostructurisation contains higher fraction of ferrite laths with the thickness below 100 nm and is more homogenous in terms of morphology. It has been shown, the amount of the residual austenite was similar – about 22 %, regardless of the initial state of the ductile iron. Both kinds of samples were subjected to mechanical tests such as hardness, impact strength and tensile strength. The samples exhibited comparable mechanical properties regardless on the initial structure of the ductile iron (tab. 1) – it can be concluded that the initial microstructure slightly influences final microstructure afeter nanostructurisation but not mechanical properties. The obtained results were also compare to the results after conventional austempering heat treatment of ferritic-perlitic ductile iron, which lead to produce typical ausferritic microstructure (fig. 1e-1f), composed of submicron bainitic ferrite laths, with high (about 41 %) amount of residual austenite in form of relatively thick layers and large blocks. It has been shown, that nanostructurisation heat treatment significantly

increases hardness and tensile strength of ductile iron but decreases it's ductility (tab. 1), which is related to the amount and form of residual austenite.

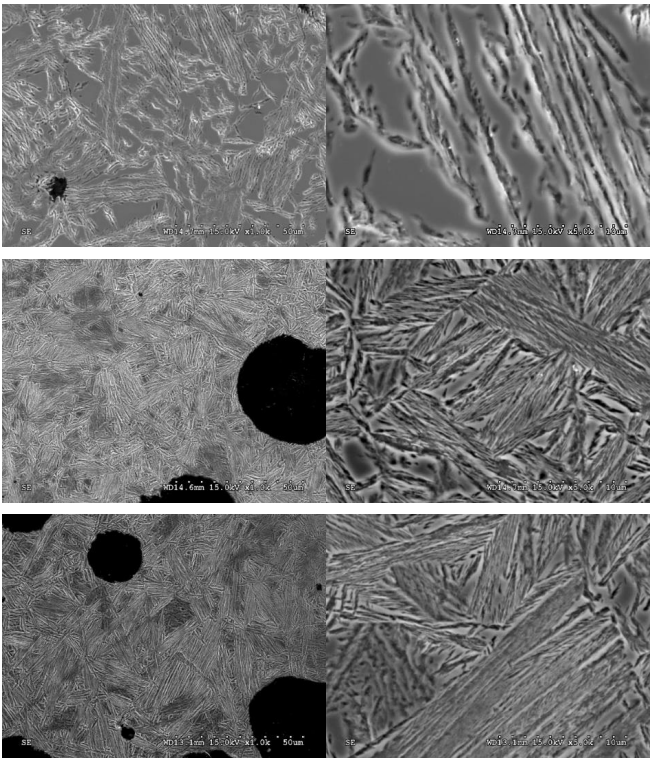

Fig. 1. The microstructure of perlitic-ferritic ductile iron after conventional austempering heat treatment (a), (b), perlitic-ferritic ductile iron after nanostructurisation (c), (d) and ADI after nanostructurisation (e), (f)

Table 1. The mechanical properties of the ductile iron after various heat treatments

	Ferritic-perlitic ductile iron after conventional austempering	Ferritic-perlitic ductile iron after nanostructurisation	Austempered ductile iron after nanostructurisation
HB	266 ± 12	349 ± 38	331 ± 45
$R_{0.2}$ [MPa]	683 ± 7	1030 ± 28	1054 ± 22
R_m [MPa]	1033 ± 28	1220 ± 30	1296 ± 2
A_5 [%]	11 ± 0.3	4.3 ± 2.9	4.9 ± 0.2
KVC [J/cm^2]	13.3 ± 1.15	9 ± 0	8.3 ± 1.15

Acknowledgments
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AO TRANSLATIONAL RESEARCH AND DEVELOPMENT

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Key words: translational, research, development, preclinical, AO

1. Background

In line with the AO mission promoting excellence in patient care and outcomes in trauma and musculoskeletal disorders, high-quality preclinical translational research and innovative development are advanced through collaboration between the Foundation's units.

2. Methods

The activities of AO Research Institute Davos – the Foundation's world-wide recognized hub for multidisciplinary research and development – are structured in 3 programs within the fields of musculoskeletal regeneration, biomedical development and preclinical services.

3. Results

The main achievements result from:

- Development, inspection and analysis of new concepts, approaches, technologies and novel implant systems to solve clinical problems (Fig. 1);
- Optimization of stem cell isolation and stable differentiation into bone, disc and cartilage;
- Development of tailored biomaterials and surface modifications to regulate cell behaviour and cell-material interactions;
- Development of patient specific implants using 3D printing technology (Fig. 2);
- Investigation of bone defect regeneration by applying tissue engineering approaches;
- Development of appropriate preclinical in-vivo and in-vitro models;
- Integration of powerful numerical methods and comprehensive tools for virtual simulations – along with development of experimental protocols – to investigate biomechanical behavior of bone-implant constructs for surgical applications (Fig. 3);
- Development and implementation of advanced methods and procedures for analysis of medical image data;
- Investigation of mechanisms and implications of intervertebral disc degeneration and development of long-term functional biological treatments;
- Development of improved diagnostic tests to provide rapid, accurate and safe diagnosis of infection and patient prognosis.

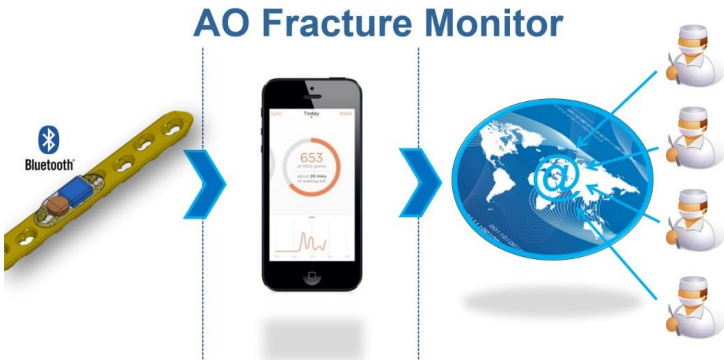

Fig. 1. The AO Fracture Monitor system for monitoring of bone fracture healing progression

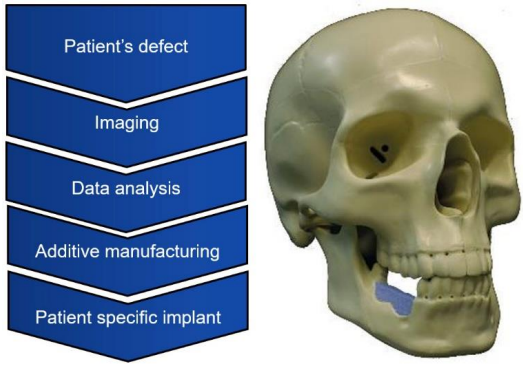

Fig. 2. Workflow for additive manufacturing of patient specific implants based on bioceramics and polymers

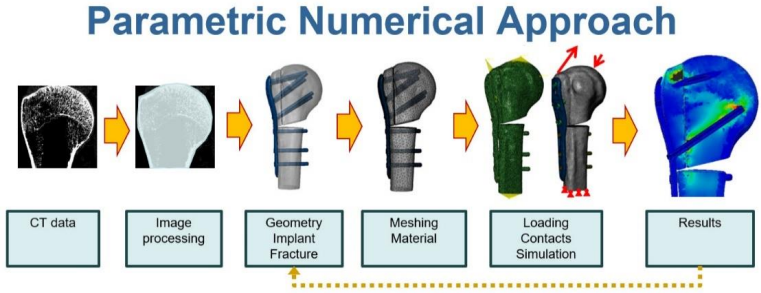

Fig. 3. Workflow for parametric virtual biomechanical testing by means of FE analysis of bone-implant constructs

4. Conclusion

The AO preclinical translational research and development are interdisciplinary, meant to solve existing clinical problems, and focused towards clinical solutions and applications.

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PROPERTIES AND MICROSTRUCTURE OF LASER WELDED DISSIMILAR JOINTS OF TP347-HFG AND S235JR STEELS WITH ADDITIONAL MATERIAL

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Key words: laser welding, dissimilar joints, TP347-HFG and S235JR steels, additional material, metallographic structure

1. Introduction.

Paper presents results of laser welding of dissimilar joints. Flange pipe joints of austenitic TP347-HFG and low carbon S235JR steels were performed. Possibility of laser girth welding of dissimilar joints were presented. Laser welding is method of joining using concentrated photons beam as a heat sources for metal melting process. Welding of dissimilar materials are complex phenomena, differences in thermo physical material properties, melting points and crystallization affect in difficulties in joining process. Chemical composition of chromium and nickel base austenitic steel with carbon amount of 0.07% comparing to low carbon steel without chromium neither the nickel and with 0.17% of carbon are significantly different. Amount of carbon and chromium have great effect on steel phase change and crystallization process which affect on material hardenability and strength characteristic. In conventional GMA welding methods solidification process of different metals is controlled by use of an additional material with chemical composition for creating buffer zone. The main advantages of laser welding over other methods is process without an additional material, nevertheless some application may require its usage[1,2]. High power density obtained in laser welding affect on ionization of vapor metal and create keyhole effect. Ablation pressure affect on liquid metal flow and provides high mixture volume. Laser welding with additional material combines advantages of both methods. To carry out weld with proper strength characteristic without welding defects selecting filler wire with adequate chemical composition are required[3].

2. Numerical simulation results

Laser welding parameters could be estimated using numerical simulation. Volumetric heat sources simulating keyhole effect, material library for used steels and additional material allow to estimate weld dimension and phase transformation results[4].

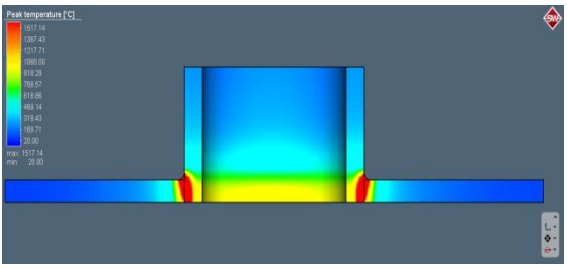

Fig. 1. Results of numerical simulation of laser welding flange pipe joints

Based on process parameters estimated in numerical simulation, experimental welding of flange pipe joints was performed.

3. Macrostructures of laser welded dissimilar joints

Welding process affect on metallographic structure, filler wire used in laser welding process create buffer zone improving joint characteristic. Using SimufactWelding software numerical simulation for estimating phase transformation results were performed. Material structure, hardness, temperature isotherm of joints material were estimated.

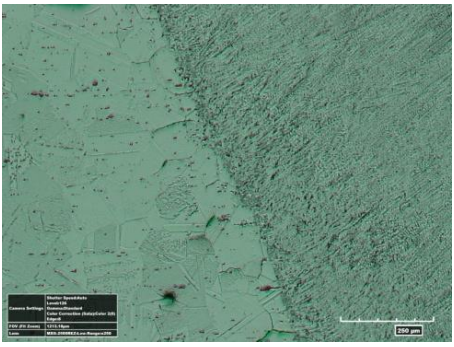

Fig. 2. Metallographic structure of HAZ and weld inobtained joint

Acknowledgments

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International Conference of Metals, Ceramics and Composites

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SESSION VI

Advanced materials characterization, additive manufacturing and heat treatment

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MECHANICAL AND TRIBOLOGICAL CHARACTERIZATION OF OPEN CELL ALUMINUM / BABBITT COMPOSITES AND THEIR APPLICATION TO SLIDING BEARINGS

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Keywords: composite materials, tribological properties, mechanical properties, sliding bearing

Development of strong light-weight metal matrix materials can be realized by employing lighter alloys, such as aluminum alloys [1, 2], magnesium alloys [3], nickel alloys [4] and zinc alloys [5]. Other way to obtain stronger and lighter metallic materials is to apply new and improved technologies. The most often used technique is replication method [5, 6] in which leachable preform (space holder) with or without reinforcing phase is infiltrated by liquid metal. Afterwards the preform is removed and the remaining skeleton represents an open-cell porous material. That process is an effective way for production of high porous metal materials with an open-cell structure. For its outstanding high specific strength, light weight, good heat transfer capability and high corrosion resistance the high porosity open cell aluminum based materials are extremely desired for various structural and functional applications in the modern industry. The aluminum and nickel based alloys are the most commercially available materials for liquid metal infiltration process [5]. For application in friction assemblies the most widespread bearing alloys are based on tin and lead [7-10].

The aim of the present study is the development and characterization of high porosity open cell aluminium (AlSi10Mg) and babbitt B83 (Fe/Al/Cu/As/Pb/Zn/Sb/Bi/Sn) based alloys with reinforcing phase for application in sliding bearing. The composites are obtained by replication method applying salt (NaCl) as space holder with average size of particles 500-1000μm. The salt (NaCl) is one of the most applied space holder methods for obtaining different metallic open-cells materials because of its advantages like relatively high melting temperature, low cost, free of toxicity and fast dissolution in water [11−15]. The reinforcing phase is Al_2O_3 particles with average size of 10-30μm. For the study we've examined three types of specimen, one is a nominally non-porous matrix from babbitt B83 alloy, the other two are reinforced with Al_2O_3 composite materials which differ by its infiltrated alloys (aluminium and babbitt). The microstructure of the obtained materials is observed. Mechanical and tribological properties such as mass wear, linear wear, friction force and coefficient of friction are determined and compared for the three types of test specimen. The obtained by replication method high-porous composite materials are intended to be used for manufacturing of sliding bearings (Fig 1).

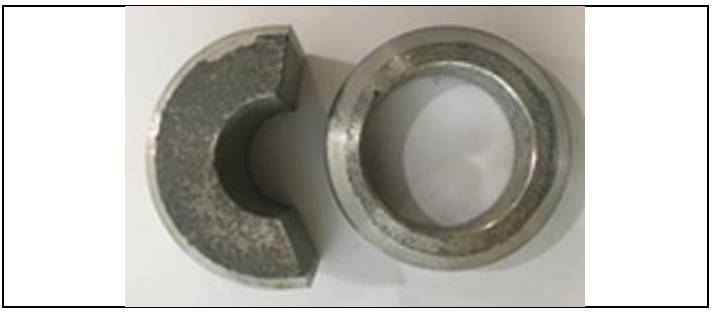

Fig. 1. Sliding bearing obtained by babbitt alloy infiltrated into porous aluminum skeleton

Conclusions

Mechanical and tribological characteristics are determined and compared for three test specimens. Due to the obtained data from the tests we conclude that all specimens can be used in dry sliding conditions.

Coefficient of friction, linear and mass wear in respect to sliding distance/time indicate that the reinforced composite infiltrated with babbitt alloy have shown the finest performance under the test conditions due to its infiltrated alloying elements and reinforcing phase. The nominally non-porous babbitt matrix has shown better test values for linear wear and coefficient of friction than the reinforced composite with infiltrated aluminum alloy.

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25th–27th September 2019, Warna, Bulgaria

DEVELOPMENT OF TAILOR-MADE EQUIPMENT FOR EXPERIMENTAL PRECLINICAL SURGERIES USING COMPUTER SIMULATIONS AND 3D PRINTING

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Key words: experimental surgery, pre-operative planning, virtual surgery, surgical guide, 3D printing

1. Introduction

Experimental preclinical surgeries require high repeatability of applied procedures, especially for precise creation of experimental bone fracture models and implant positioning to monitor healing progression. The required precision is usually achieved by application of cutting guides and drilling jigs. In most of the experimental surgeries they need to be individually designed and manufactured to reflect the specificity of each particular experiment. Often, the ultimate instrument design differs considerably from its original variant. Development of tailor-made surgical tools is therefore a time-consuming and expensive process, however, necessary to achieve precision and repeatability required during *in vivo* preclinical experiments.

2. Goal

The aim of this study was to establish a framework for development and production of tailor-made tools for experimental preclinical surgeries that will reduce the amount of invested time and financial efforts.

3. Materials and methods

The framework was set and tested during the implantation procedure of an active external fixator described by Tufekci et al [1] and modified to measure forces acting in the experimental bone fracture gap. The used fracture model required placement of Schanz Screws at pre-defined distances from each other and creation of an experimental osteotomy in relation to them.
An iterative workflow was established to define the cost- and time-efficient framework for development and production of the necessary surgical tools (Fig. 1). The workflow starts with definition of the requirements for functionalities of the equipment, followed by creation of virtual models of the instruments and bones involved in the surgical procedure. Following, a computer tomography scan of a Swiss White Alpine sheep was created (SOMATOM Emotion

6, Siemens Healthcare GmbH, Germany) and a 3D geometry of the right sheep tibia was reconstructed (Amira, Thermo Fisher Scientific, USA).

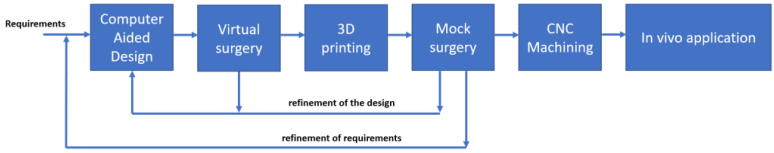

Fig. 1. The framework workflow

Further, CAD prototype models of a cutting guide and a drilling jig were created and validated via 3D simulation of the surgical procedure using the reconstructed 3D model of the bone (SolidWorks, Dassault Systèmes, France, Fig. 2a). Subsequently, prototypes were manufactured by means of 3D printing (Ultimaker B.V., Netherlands). Functionality and usability of the 3D-printed instruments were tested during 3 mock surgeries on cadaveric sheep limbs (Fig. 2b, c). In order to enhance the surgical procedure, 2 refinement loops were executed to improve the mechanical design of the tools. Having tested the prototypes during the mock surgeries, the tailor-made instruments were manufactured from stainless steel (1.4301) and utilized in preclinical surgeries on Swiss White Alpine sheep after approval of the local ethics committee (Fig. 2d).

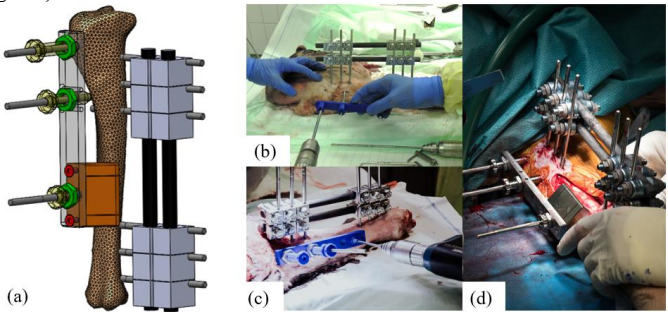

Fig. 2 (a) Cutting guide validated by means of computer simulation; (b) Cadaveric surgery to test the initial cutting guide prototype; (c) Cadaveric surgery applying refined design of the cutting guide prototype; (d) Application of the stainless-steel cutting guide during preclinical surgery

4. Results and conclusions

No complications related to the tailor-made surgical equipment were observed during the preclinical surgeries. Utilizing computer simulations and 3D printing enabled iterative testing of all prototype tools with prompt implementation of design changes. We set and tested a framework for development and production of tailor-made tools for experimental preclinical surgeries that decrease the invested time and reduce financial efforts.

Acknowledgments

This study was supported by the AO Foundation via the AOTRAUMA Network (Grant No.: AR2016_06).

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MODELING STUDIES FOR THE RECYCLING OF PALADIUM FROM HIGH ENTROPY ALLOYS, SPECIAL PURPOSE COMPONENTS AND WASTE FROM DIFFERENT PROCESSES

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Key words: palladium, precious metals, recovery, multi-component high entropy alloys

Modern technologies in their intensive development use a significant amount of precious metals. For various reasons, palladium is one of the most frequently used. This metal is an indispensable component in electronics, catalysts, hydrogen filters, component in alloys with special application and others. All this, coupled with its high cost, makes the issue of regenerating extremely up-to-date. In the present work a model system of Cu-Pd is studied (in the form of palladium target). The proposed technological scheme and conditions improve the purity and degree of Pd extraction compared to the ones known.

In the present work different parameters of the process were investigated:

- Influence of pH during precipitation on the purity and recovery rate of palladium
- Influence of the precipitation velocity on the quality of intermediate product.
- Influence of the reducing conditions on the size and monodispersity of product

The monodispersed particles thus obtained can be seen in (Fig. 1). An EDX analysis of the resulting particles was carried out (Fig. 2).The achieved recovery rate of the procedure was 99.9%, with purity of the metal palladium being 99.97%. The technology was tested for two real systems by regenerating palladium from multi-component high entropy alloys such as $Pd_{43}Ni_{10}Cu_{27}Si_{20}$ and PdNiSiSb. The results obtained after research on the real systems confirm the advantages of the method. It is envisaged that the technological scheme will serve as a basis for regeneration of Pd from other alloys containing it.

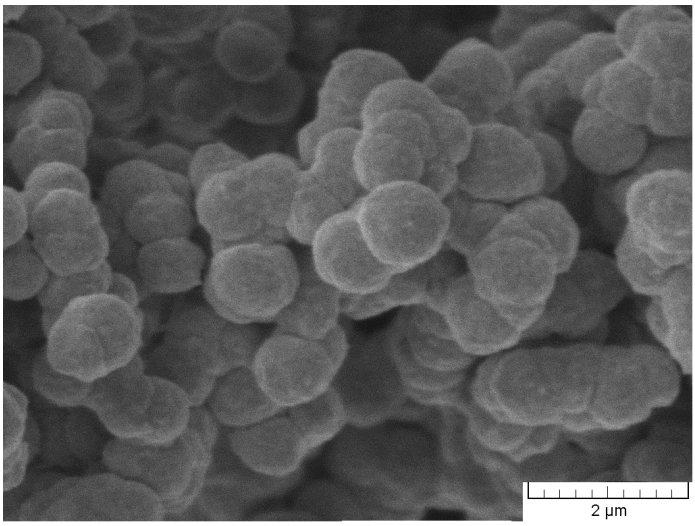
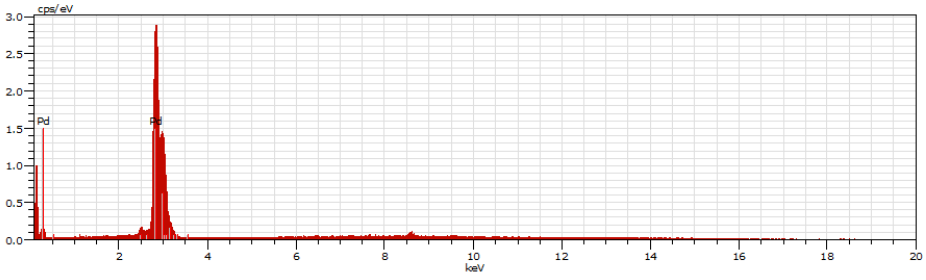


Fig. 1. SEM image of monodispersed palladium particles



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El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error [%]
Pd	46	L-series	193.22	100.00	100.00	6.2
		Total:	193.22	100.00	100.00	

Fig. 2. EDX analysis results of palladium particles

Conclusions

The palladium regeneration method is effective for separating the target metal from other metals in high concentrations. The final product is a high purity, monodispersed palladium powder of a certain size which has a value not only as bulk metallic palladium. The proposed methods are applicable to many different alloys and economically profitable because they use widely available, low-cost reagents.

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EFFECT OF HYDROGEN ATMOSPHERE ON THE MOBILITY OF 1/2[111] SCREW DISLOCATION IN BCC FE

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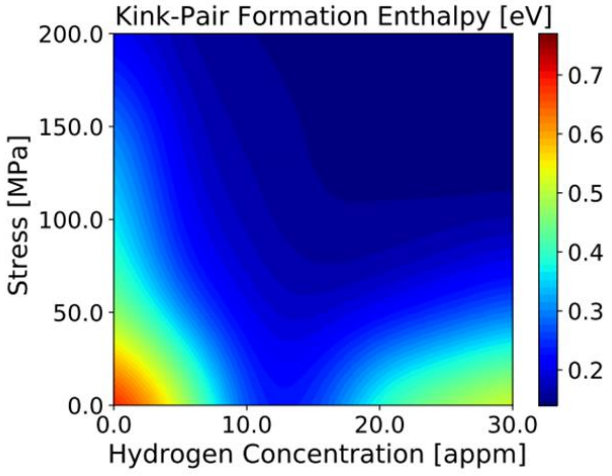
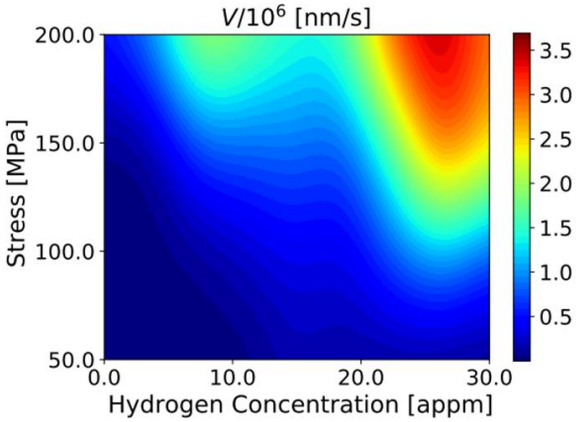
Key words: h embrittlement, help mechanism, dislocations

The purpose of this study is exploring the reasons for the experimentally observed dislocation mobility in bcc Fe in presence of hydrogen. The present work aims at exploring the effect of hydrogen atoms trapped in the core of 1/2[111] screw dislocation on its mobility through simulation of the specific mechanisms of motion of an individual dislocation. In order to overcome the limitation of molecular dynamics simulations we employ kinetic Monte-Carlo (kMC) model of 1/2[111] screw dislocation to describe the dynamics of a dislocation segment with a realistic length over long time scales [1]. The key idea of kMC approach is to treat dislocation motion as a stochastic sequence of discrete rare events (kink-pair formation and migration) whose mechanisms and rates are computed within the framework of transition state theory. In present work we determine the kink-pair formation enthalpy in presence of H in the core of a screw dislocation at different stresses and H concentrations in the bulk, taking into account H occupancy, migration and rearrangement in the dislocation core throughout kink-pair formation process.



Since the non-planar core of these dislocations spreads symetrically on three cross-slip (110) planes [2,3], the kMC model allows nucleation of kink pairs on either of the (110) planes by

which screw dislocations change their glide directions. The dislocations can generate jogs and debris (prismatic loops) during their movement as a result of colision and recombination of kinks moving on different planes. Here we make explicit simulations of 1/2[111] screw dislocation propagation and determine the velocity of dislocations in iron as functions of stress and hydrogen concentration.



The dislocation mobility predicted by the kMC simulations qualitatively agrees with the experimentally observed dislocation mobility in bcc Fe at different H concentrations [4]. The results from the simulations show that the ability of screw dislocations to move out of the primary slip plane together with the kink-pair formation rate dependence on the concentration and rearrangement of H atoms in the dislocation core are key factors for understanding screw dislocation mobility in Fe in presence of H. At low H concentrations the probability for formation of KP in the secondary (110) glide planes is low, dislocation moves predominantly in the primary glide plane and its velocity increases with increase of H concentration. The low KP formation enthalpy for all RSS in the interval 10-15 appm leads to formation of pinning points and gradual reduction of the average speed of the dislocation. At higher hydrogen concentrations, KP formation energy at low stresses increases and probability for pinning decreases, which together with the low KP formation enthalpy at higher RSS reults in reduced pinning and high dislocation velocity. At H concentrations above 25 appm hydrogen trapping effect becomes dominant mechanism leading to reduction of kinks mobility and dislocation velocity.

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EFFECT OF CONDITIONS OF HEATING PROCESS ON MICROSTRUCTURE AND CORROSIVE RESISTANCE OF TITANIUM ALLOY USED IN IMPLANTOLOGY

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Key words:Ti-6Al-4V alloy, corrosion resistance, heat treatment, microstructure

Titanium alloys from all metallic biomaterials are currently one of the most popular and best materials for various types of implants. One of the most commonly used titanium alloys in implantology is the Ti-6Al-4V alloy. It has good mechanical properties, and very good corrosion resistance and biocompatibility. In comparison to austenitic steels and cobalt alloys, the Ti-6Al-4V alloy has the lowest specific gravity and Young's modulus, which is closer to the Young's modulus of human bone [1,3]. Very good biotolerance and biocompatibility of the titanium alloy in the environment of the human body causes the occurrence of osseointegration (bone tissue adhesion with the titanium surface of the implant without the need to use so-called cement fasteners) [2]. Titanium alloys used in implantology contain aluminum and vanadium, elements that make their corrosion products toxic to the patient. However, this is not a common phenomenon, because titanium and its alloys are very well protected against corrosion thanks to the passivation process, consisting in spontaneous formation of airtight, stable oxide layer of TiO_2 on their surface (in contact with air). This layer protects against passing dangerous elements into the human body [3-5].

The Ti-6Al-4V alloy microstructure is very important because the number, shape and size of grains affect the mechanical and chemical properties of this alloy [6]. The microstructure of these alloys consists of a mixture of solid α solution and a solid β solution. In order to stabilize the α-phase, it is usually introduced into an aluminum alloy, which not only strengthens the α-phase and increases the strength of the alloy, but also improves the thermal stability of the β-phase [7]. The β phase can be fixed thanks to the introduction of eutectoid or isomorphic elements to alloys [8]. The strength and corrosion properties of the alloy α + β are dependent on the morphology and volume fraction of the respective phases [7, 8].

The occurrence of phase transformations in the Ti-6Al-4V alloy allows to carry out the following methods of heat treatment, such as quenching, tempering, supersaturation and aging [8]. It should be noted, however, that the effect of heat treatment in titanium alloys is not as pronounced as in iron alloys. Heat treatment of the Ti-6Al-4V alloy is one of the methods that allow you to change their microstructure. Such changes sometimes reduce the amount of pathogenic aluminum or other elements released into body fluids during corrosion [8, 10]. Heat treatment of titanium alloys covers all processes occurring during heating and cooling, which cause phase changes, segregation of alloy components, etc. process [9]. The aim of the

conducted research was to examine the influence of selected areas of the heat treatment process on corrosion resistance and Ti-6Al-4V alloy microstructure used in implantology.

The research was conducted in the environment of simulated physiological solutions: artificial saliva solution and Hank's solution. The Ti-6Al-4V alloy was heat treated under specific conditions (temperature between 900°C and 1000°C for 2 hours and then water quench), then the changes in the microstructure and its corrosion resistance were tested in the above-mentioned solutions.

Based on the results obtained, it was found that:
a) There are still two phases of α + β in the test alloy after the heat treatment, however their percentage composition has changed.
b) After the heat treatment of Ti-6Al-4V alloy the β phase was enriched in vanadium.
c) The presence of a large amount of vanadium in the passive layer accelerates its anodic dissolution.
d) Heat treatment modifies the microstructure of titanium alloys, but the corrosion resistance of titanium alloys after heat treatment is dominated by the corrosive environment.
e) The passive layer formed on the surface of the Ti-6Al-4V alloy has better corrosion resistance in the artificial saliva solution than the layer formed on the Ti-6Al-4V alloy after heat treatment tested under the same conditions. However, in the Hank solution, the corrosion resistance of both alloys is very similar.

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POSTER SESSION

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MICROSTRUCTURE AND PROPERTIES OF LASER ADDITIVE DEPOSITED OF NICKEL BASE SUPER ALLOY INCONEL 625

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Key words: Laser additive manufacturing, Inconel 625 powder, prototyping, metallographic structure

1. Introduction

Article presents results of laser padding welding of metal powder Inconel 625. Laser metal deposition is modern manufacturing process for low scale production series. High alloy materials such as Inconel 625 nickel based super alloy are hard to machining. Plastic working of high alloy material such as milling are difficult. Additive manufacturing using laser beam for selective deposition of metallic powder combine with finishing process can be used as alternative technology. Laser melting of metallic powder are fully controllable process, high energy density of focused photons beam combine with coaxial powder delivery system allow to selective deposit molten metallic powder [1] (Fig. 1).

Fig. 1. Laser material deposition of Inconel 625 metallic powder

Due to high energy density quick melting and crystallization process affect on metallographic structure of manufactured spatial element. Thermo physical material properties change during deposition process, absorbed heat energy affect on beam absorption and crystallization rate. Metallographic structure change over padding welding pass, liquid metal of additive and base material mixing, chemical composition of obtained overlay weld may vary over metallic powder. In laser additive manufacturing relevant is that chemical composition of additive material should be same as base material, alloying elements could affect on crystallization process decreasing mechanical properties and caused padding welding defects[2].

2. Mechanical properties of additive manufactured sample

Nickel base Inconel 625 is low carbon and iron super alloy, with nominal hardness of approximately 250HV. To verified properties of deposited material Vickers hardness test (HV10) in cross section was performed. Test exhibit decrees of hardness, average value in measured point was 220HV10. Thermal cycles of manufacturing process caused thermal accumulation and may results annealing in upper layers. Migration of alloying elements from base material was avoided by using same substructure material - Inconel 625 sheet plate.

3. Macrostructures and distribution of chemical composition

Differences in hardness over base material are insignificantly and may caused by re-interfusion. Structure of base material is dendritic, in upper layers of deposited material structure are dendritic-polyhedral. Chemical composition in cross section are uniform [3].

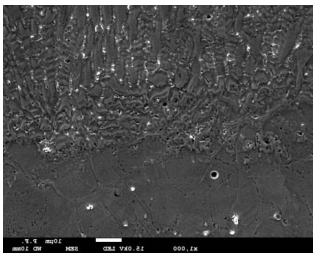

Fig. 2. Structure of material in fusion zone of padding welding Inconel 625

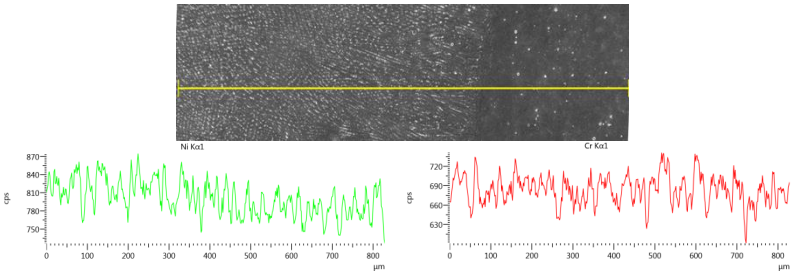

Fig. 3. Marker line and chemical distribution of Cr and Ni in fusion zone

Acknowledgments

The presented research results are the effect of the project entitled: „Multiscale analysis of physical and chemical processes during rapid prototyping using concentrated energy sources in view of formation of microstructure and mechanical properties" no. of the contract UMO-2016/23/B/ST8/00754 financed by the National Science Center, Poland.

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MICROSTRUCTURE OF WELDS OF GALVANISED STEEL SHEETS AND CAP ELECTRODES AT FINAL STAGES OF EXPLOITATION

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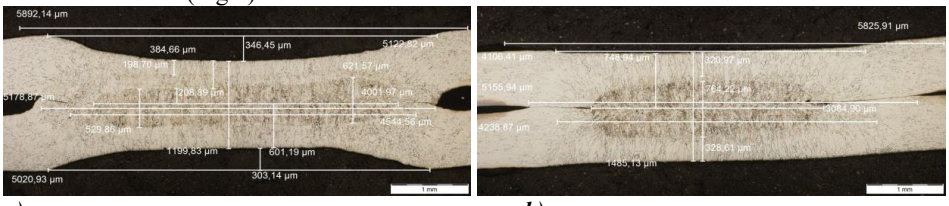
Key words: welding cap, welding process, microstructure, copper alloys

The paper presents the general characteristics of copper alloys with high mechanical properties, high levels of electrical and thermal conductivity and stability under varying conditions of current, heat and power load, intended for welding electrodes [1-3]. The most important elements influencing the operational durability of cap electrodes used for welding galvanized bodywork steel sheets are discussed [4-6]. Selected results of examination of microstructure changes after 100 and 2500 welds of joined galvanized steel sheets and microstructure of the cap electrodes made of CuCrZr alloy after the end of exploitation were presented.

As a result of high temperature, electrode pressure, erosion, material aging and its local plastic deformation during the sheet welding process, irreversible wear of the electrodes at the work surface occurs. During resistance welding of galvanized sheets additional degradation of the functional properties of electrode occurs as a result of diffusion of zinc into its working area and the loss of the operating properties of the electrode. This results in a decrease in electrical properties of the electrode and an increase in the contact resistance and lowering of the melting temperature of the thin layer of brass by about 200°C in relation to the base material of the electrode. Investigations of microstructure of welds and microstructure of cap electrodes after finishing using them showed that during the welding process of galvanized steel car body sheets a gradual 'flattening' of weld cross-section and a change in weld 'core' dimensions occur (Fig.1).



a) ***b)***

Fig. 1. Microstructure of a sample with visible core of the weld and selected measurements of distance after a) 100 welds and b) 2500 welds (metallographic specimen polished and etched)

Apart from copper, in the micro-areas on the working surface of the cap electrode, significant concentrations of zinc, iron, chrome, zircon and other oxides in some areas were observed. Additionally, inclusions of iron, pitting, and thermal etching of grain boundaries occurred on the working surface of the cap electrodes (Fig.2). A surface layer of brass, about 40 micrometres thick, was observed on the longitudinal sections of the cap electrode (Fig.3).

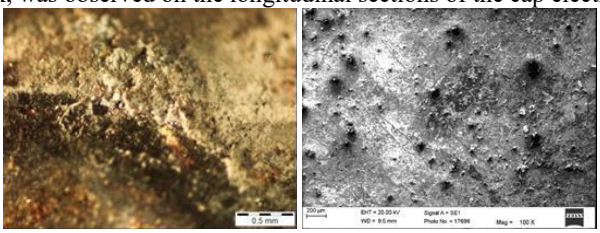


Fig. 2. Macrostructure and microstructure of the working surface of the CuCrZr alloy cap electrode and the average chemical composition of the surface (EDS) in % of the mass. Cu = 28,35; Zn = 44,83; Fe = 13,42; Cr = 0,44; O = 12,34

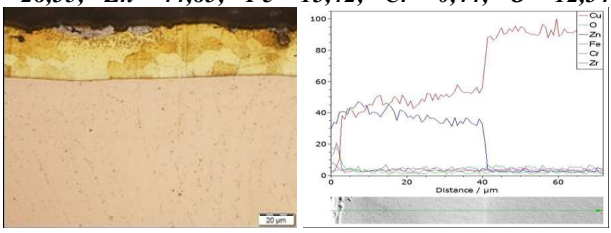


Fig. 3. Microstructure of the cross-section of the working part of the electrode and changes of the concentration of the examined elements from the working surface into the electrode

On the basis of the obtained results, further research is planned on copper alloys with appropriate alloy additives of low concentrations favouring the limitation of zinc diffusion to the copper electrode warp.

Acknowledgments

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MATERIALS IN FOUNDRY ENGINEERING: STUDY OF POLYLACTIDE USED AS FILAMENT IN 3D PRINTING

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Key words: foundry materials, polylactide, 3D printing technology, thermal degradation

The literature review in terms of structure, properties and applications of polymers, including those commonly used in the 3D printing technology was undertaken. The most widely known 3D printing technologies have also been characterized [1-5]. The research part included the structural and thermal analysis of polylactide (PLA), which is an example of the extensively used polymer in the developing 3D technology. Special attention was paid to the comparision of structure and thermal stability of two different polylactide samples (from various producers: PLA1 – INK3.DE and PLA2 – VAKIND. The PLA-based samples were parts of polymers rolls of circular cross-section measuring 1.75 mm in diameter). The research involved such analytical methods as infrared spectroscopy (FTIR) and diffuse reflectance infrared spectroscopy (DRIFT, Fig 1).

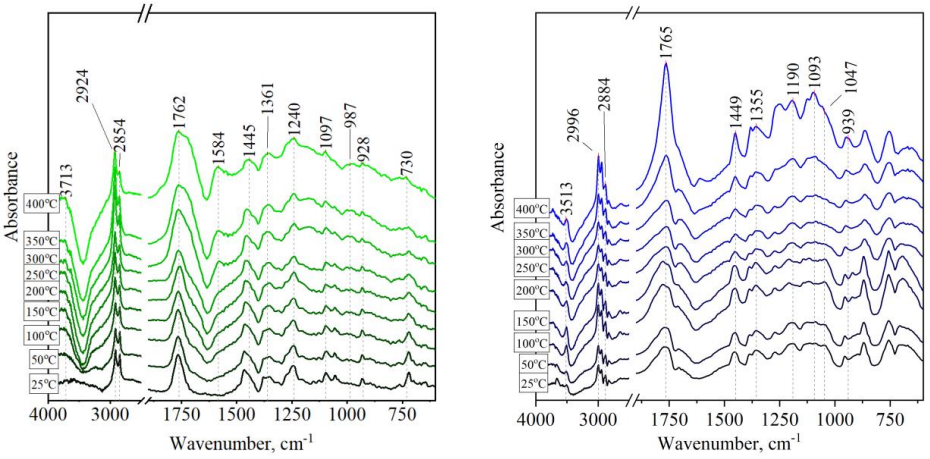

Fig. 1. Spectra IR of a) PLA1 and b) PLA2 done method DRIFT

In addition, thermal studies were carried out by thermoanalysis techniques (TG-DTG-DSC, Fig. 2). Based on the physicochemical tests, a comparison between the structure of the two considered PLA samples (FTIR method) was made. Determination of the temperature range

in which changes related to PLA thermodestruction occur was a result of performed thermoanalytical research (DRIFT, TG-DTG-DSC).
The obtained knowledge from the thermal degradation, will make it possible to conduct further research in the area of the technology of forming a new polymer-composite systems likely to use of 3D printing.

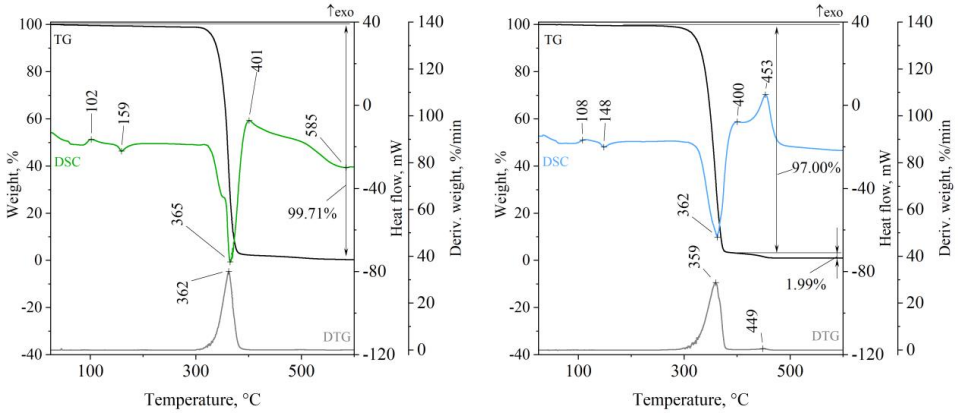

Fig. 2 TG-DTG-DSC curves of : a) PLA1, b) PLA2 in an oxidizing atmosphere

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FABRICATION AND CHARACTERISTICS OF COPPER- INTERMETALLICS COMPOSITES

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Key words: powder metallurgy, composite, intermetallics, copper, titanium

1. Introduction

This paper presents the results of research on the production of a sintered Cu-intermetallic composites fabricated by powder metallurgy. The starting materials for obtaining the composites were commercial powders: Cu and Ti. Ti particles were introduced into a copper matrix in the amount of 5% by weight. Finished powders mixtures were subjected to single pressing with a hydraulic press at a compaction pressure of 620 MPa and then subjected to sintering process at 860 °C in an atmosphere of dissociated ammonia. The sintering time was 2,5 hours. The addition of titanium to copper caused the formation of different intermetallic layers around titanium particles. The titanium content of the intermetallics decreased from the center of the particle to the copper matrix. The sintered compacts were subjected to the following tests: hardness, measurement of density, electrical conductivity and abrasion resistance. Observations of the microstructure on metallographic specimens made from the sintered samples were also performed using a scanning electron microscope (SEM). The hardness and wear resistance of materials increased in comparison with a sample made of pure copper whereas density and electrical conductivity decreased.

2. Materials

The materials used in the experiment to fabricate the composites were commercial powders. Copper powder with an average particle size of less than 63 μm was used as the matrix while titanium, with an average particle size of less than 1 mm was used as the reinforcement. The shapes and arrangements of the powder particles used in the experiments are shown in Fig 1.

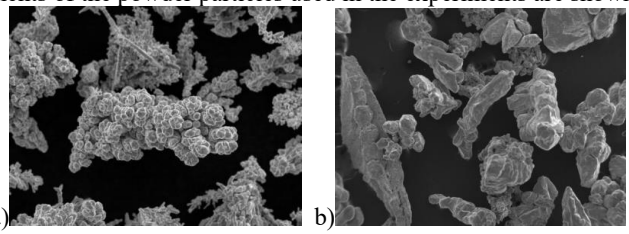

Fig. 1. Images of a tested powders: a) copper powder, b) titanium powder

3. Results

Some of the representative microstructures of sintered Cu–Ti alloys obtained using an optical microscope are shown in Fig. 2, where multiple layers of different intermetallic phases can be seen around titanium particles inside sintered specimens.

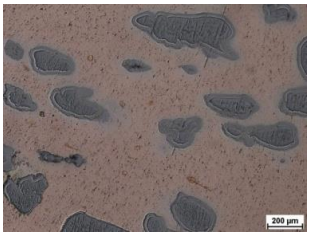

Fig. 2. Microstructures of the sintered compacts observed with a SEM obtained for Cu+5% of titanium

SEM with an EDS attachment was used to understand the chemical compositions of different phases in the microstructures of specimens. As expected, the amount of Ti was found to be higher at the center of the particle and decreased dramatically at the interface between the particle and matrix, as shown in EDS line scan analysis in Fig. 3.

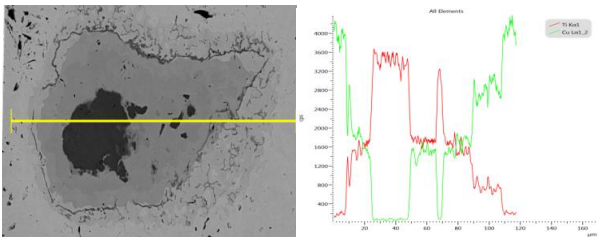

Fig. 3. EDS line scan analyses of phases around a Ti particle

4. Conclusion

The addition of pure titanium powders to the copper matrix causes the formation of different intermetallic layers around these particles. EDS analyses show that titanium particles were converted to intermetallic phases because of copper diffusion towards the center of the particle. The increase in the hardness caused by intermetallic phases also results in a higher wear resistance. The morphology of formed intermetallic phases can affect the wear properties of the materials.

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SYNTHESIS OF MULTICOMPONENT Mo-Si-B ALLOYS VIA LIQUID-ASSISTED REACTIVE INTERACTION APPROACH

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Key words: Mo-Si-B alloys, sessile drop method, liquid assisted processing, reactively formed compounds, interfaces

1. Introduction

Intermetallic based alloys from Mo-Si system (molybdenum silicides) have gather a lot of attention from many industry branches such as automotive, aviation or metallurgy. Molybdenum silicides are classified as ultra-high temperature materials and are under continuous development in order to substantially increase working range of high temperature devices and to provide them a new level of durability beyond that coming from actually applied heat resistant materials. The $MoSi_2$-based silicides exhibit excellent resistance to oxidation up to 1650°C, a good corrosion resistance at high temperature in different environments and a thermodynamic compatibility with many ceramic reinforcements [1]. Beside of high temperature structural applications, $MoSi_2$ and other refractory metals silicides (in particular $TiSi_2$ and WSi_2) have already found wide usage as in integrated circuit technology (as ohmic contacts, gate and interconnectors) because of the high electrical conductivity and the ability to form good connections to silicon [2]. Furthermore, alloying with boron (i.e. using of Mo-Si-B ternary alloys) provides further significant improvements in terms of oxidation resistance and creep behavior. Actually reported fabrication routines for Mo-Si-B alloys are characterized by either (i) a high complexity and multistep nature [3] or involve using chemical compounds having a high toxicity as the activators of the process [4].
In this work, we propose a novel technological approach (*borosiliconizing*) for a fabrication of multiphase Mo-Si-B alloys by using a direct reactive interaction of the molten Si-B alloy with polycrystalline Mo in a one-step process, under pressure-less conditions, at temperatures below 1400 °C and without using any chemical substances as activators.

2. Materials and methods

The materials investigated were polycrystalline molybdenum (99.95 %) plate having a thickness of 6 mm (Wolften, Poland) and binary eutectic silicon-boron alloy (Si-3.2B wt%). The eutectic composition was chosen due to corresponding low melting point (1385 °C). The Si-3.2B alloy was produced from polycrystalline pure materials (Si: 99.999%; B: 99.9% — provided by Onyxmet, Poland) by using electric arc melting under protective argon atmosphere (Buehler Arc Melter MAM-1, Germany). The main experiment was performed by

using an experimental complex dedicated for examining high temperature capillarity phenomena described in details elsewhere [5]. The test was carried out by a sessile drop method coupled with a contact heating procedure, i.e., the Si-3.2B alloy was placed on polished Mo substrate (Fig. 1a) and then the couple was subjected to the heating/cooling experiment following temperature profile and test scheme given in Fig. 1b.

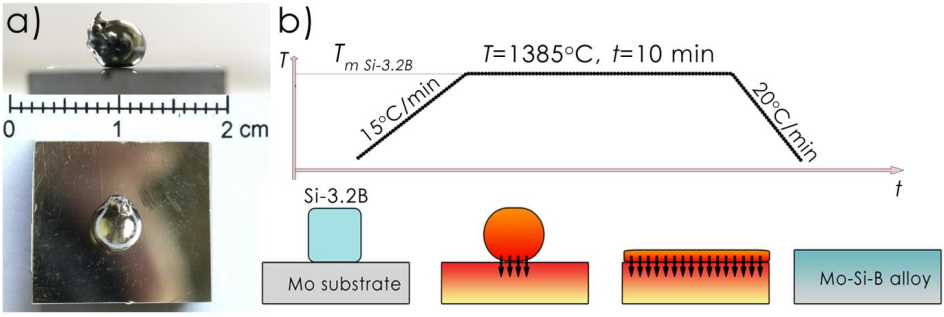

Fig. 1. a) A macroview of the Si-3.2B/Mo sessile drop couple before the experiment; b) temperature profile and a schematic drawing of the applied sessile drop experiment [6]

3. Results and conclusions

The main purpose of the experiment described in the present work was to examine interfacial phenomena (wetting, spreading and reactivity) taking place between molten Si-3.2B alloy and polycrystalline Mo. The in-situ observed high temperature behavior of the couple, as well as the results of structural characterization showed that the interaction between molten Si-3.2B alloy and Mo substrate is dominated by chemical reactions leading to the transformation of initial Si-3.2B/Mo couple to a new one of layered structure $MoSi_2/MoSi_2(+Mo_5Si_3)/MoSi_2/Mo_5SiB_2/MoB/Mo$. However, a visible porosity was formed in the $MoSi_2(+Mo_5Si_3)$ layer indicating a need for further development of the process.

Acknowledgments

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STRUCTURAL AND RHEOLOGICAL CHARACTERIZATION OF POLACRYLATE-POLYSACHARYDE HYDROGELS FOR FOUNDRY APPLICATION

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Key words: material engineering, hydrogel, polymer, poly(acrylic acid), native starch,

1. Introduction

Hydrogels are considered as a group of polymeric materials whose hydrophilic structure enables to retain large amounts of water in three-dimensional networks. Today, hydrogels continue to fascinate material scientists and researchers, and great progress has been made in their formulations and applications. The wide range of components, their miscibility and origin mean that hydrogel materials are used in many industrial and environmental areas [1].

Hydrogels based on both natural and synthetic components are of interest. The latter, together with technological progress, have gradually dominated the market due to higher water absorption and long service life. The most popular synthetic base polymers of hydrogels include acrylic polymers, whose monomers of primary importance are acrylic acid, methacrylic acid, acrylamide and their derivatives. Among natural polymers, polysaccharides and their modified forms are mentioned as components of hydrogels. In the case of this group of polymers, the type of biological raw material from which they are obtained may have a significant influence on their properties [2, 3].

2. Material and methods

In this paper a comparative analysis of polyacrylate hydrogels with addition of gelatinized native starch of various botanical origin. Combination of synthetic and natural polymers consists of poly(acrylic acid) (35% aqueous solution; *PA*, BASF) and starch gel (5% aqueous solution) in proportion 1:3.5 in part of weight) was carried out. The following polysaccharides were selected as components of polyacrylate hydrogels: native (natural) potato starch (S_P, Trzemeszno S.A., Poland) and native tapioca starch (S_M, Kreyenhop & Kluge Gmbh, Thailand). The analysis of the collected results was aimed at the evaluation of the influence of biological origin of starch on:

- the structure (FTIR; Digilab Excalibur FTS 3000 Mx) in initaial and crosslinked form
- thermal sensitivity (ATR-FTIR; Digilab Excalibur FTS 3000 Mx) in the temperature range up to 200°C
- and dynamic viscosity (RHEOTEST-2) of hydrogel based on acrylic polymer at 10°C, 25°C, 50°C.

3. Results

Figures 1 and 2 show selected results of structural and rheological tests

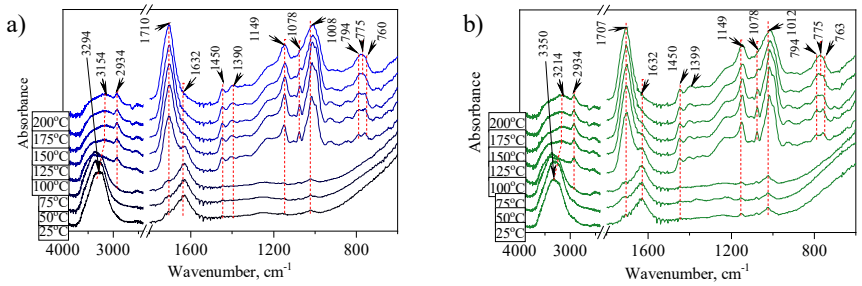

Fig. 1. ATR spectra in the temperature range from 25-200°C: a) hydrogel PA+S_M; b) hydrogel PA+S_T

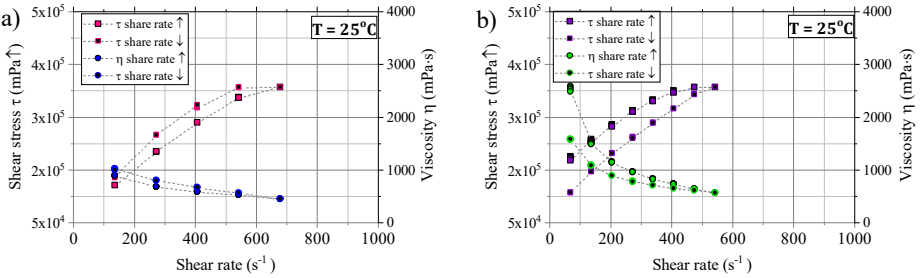

Fig. 2. Flow and viscosity curves for hydrogel samples at 25°C: a) hydrogel PA+S_M; b) hydrogel PA+S_T

4. Conclusions

On the basis of the research carried out, it was found that:

- the chemical structure of the prepared polyacrylate hydrogels, regardless of the biological source of natural starch used, is similar;
- in both cases the structural changes occurring in the conditions of increasing temperature were carried out according to a similar scheme;
- however, the biological origin of starch has a significant influence on the rheological properties of the prepared polyacrylate hydrogel;
- it is possible to form a layered object from both hydrogels

The properties of the tested samples indicate the potential for application of polyacrylate hydrogels with gelatinized native starch, both potato and manioc starch, and after optimizing their consistency they could be taken into account e.g. in 3D thermosetting printing technology.

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THERMAL REGENERATION OF USED MOULDING SAND - CONDITIONS OF IMPLEMENTATION

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Key words: thermal regeneration, used molding sands, organic binders, thermal analysis

1. Introduction

Thermal regeneration is widely perceived as a process in which certain thermal conditions have to be created in order to burn organic compounds (resin). Commonly used construction solutions in regeneration devices consume significant amounts of energy, making the thermal regeneration process too expensive. There is also no method for selecting the regeneration temperature, nor instructions how to determine the specific temperature value to be provided in the thermal regenerator, so that it efficiently runs the process of cleaning the grain matrix from the resin used in the given molding sand. Use of wide range of resins with different properties in the foundry generates a problem that is extremely important because of the use of an unjustified high temperature range of regeneration for a specific binder or too long time of the regeneration proces that leads to increases in the cost of the process, making the thermal regeneration treatment uneconomical. Lack of solutions the issue of too large outlays of the process is one of the factors that limits the widespread use of this method, with undeniable advantages in terms of the quality of the obtained grain matrix, in relation to other regeneration methods used for molding sands with organic binders.

2. Conditions of thermal regeneration process

The limitation of excessive costs of thermal regeneration can be realized in two aspects: the construction of a thermal regenerator and the selection of the required regeneration temperature [1]. Based on the research [1, 2] and the analysis of the nature of phenomena that occur during thermal regeneration the potential changes in the construction of the thermal regenerator can be made in the division of the combustion chamber. It can be devided into independent sections in which individual thermal regeneration sequences will be performed separately. Figure 1a shows a typical solution for the thermal regenerator chamber, and Figure 1b shows the design of the thermal regenerator chamber after modification. Limiting the size of the combustion chamber is a way of generating energy savings in the process.

The second important factor of regeneration is the selection of the correct regeneration temperature, individual for each organic binder. The method for determining the required regeneration temperature for an examplary binder is shown in Figure 2. On the basis of thermal analysis carried out under aerobic and anaerobic conditions, it is possible to determine the temperature that guarantees effective burning of the binder without heating the regenerator chamber to too high temperature.

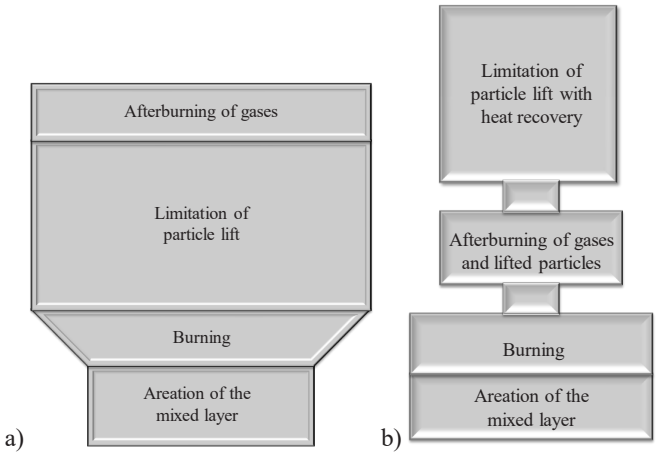

Fig. 1. Scheme of proper regeneration carried out in the thermal regenerator chamber: a) typical solution, b) modified system

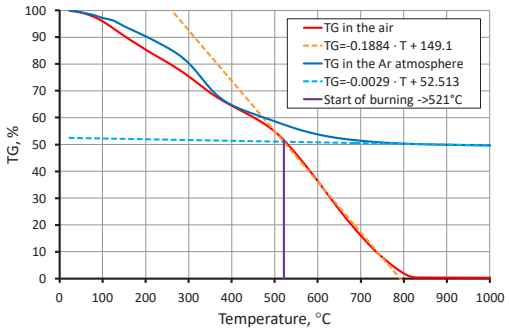

Fig. 2. Selection of the required regeneration temperature on the basis of thermal analysis of an exemplary organic binder

3. Summary

The developed model of selecting the required temperature for thermal regeneration of used molding sands with organic binders, created on the basis of thermal analysis in aerobic and anaerobic conditions, is one of the conditions which guarantees effective stripping of the grain matrix from the organic binder residue. The research has been realized in a built-in laboratory bench in which the various stages of broadly defined specific regeneration processes were separated and confirmed the creation of conditions for effective disintegration of the organic binder (its combustion) with the least possible energy inputs that are directly related to the selected regeneration temperature and duration of the treatment.

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EFFECT OF RARE EARTH ELEMENTS ADDITIONS ON CRITICAL TEMPERATURES OF MANGANESE CAST STEEL FOR USE AT LOW-TEMPERATURES

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Key words: manganese cast steel, microstructure

The present paper discusses the effects of rare earth elements (REE) addition on phase transformation temperatures in G20Mn5 manganese cast steel intended for use under low temperatures. The rare earth elements were incorporated into the liquid metal as mischmetal composed of 49.8% Ce, 21.8% La, 17.1% Nd, 5.5% Pr and 5.35% REEs. The test ingots were subjected to quenching at 940°C. Dilatometric characterization was performed with a L78 R.I.T.A. (Linseis) dilatometer. The specimens were heated at the rate of 0.08°C/s up to the temperature of 1200°C to determine critical temperature. For testing the kinetics of transformations of supercooled austenite specimens were heated at the rate 5°C/s up to 940°C, then cooled at different rates. Dilatometric curves were plotted for each heating and cooling variant. Time-temperature-transformation diagram were developed. Critical temperatures were determined for non-modified and modified (with REE addition) cast steel.

1. Introduction

Low alloy castings are widely used due to their properties and low manufacturing costs. An important advantage is that their properties such as impact strength or weldability can be increased by controlling the carbon content or introducing micro-additives [1-3]. Manganese steels are used, among others, for the production of wear-resistant elements (railway, clutch bodies) or plates for the installation of larger structures or devices working under increased pressure (valve bodies) and in offshore structures [4].

2. Material and experiment

Manganese steel was smelted in an induction furnace with a capacity of 300 kg. Steel scrap, Fe -Mn and Fe -Mn and Fe - Si were used as furnace feed. Granulated aluminium was used for deoxidization, while a mischmetal was used for the modification. The melts were subjected to heat treatment including quenching (920°C/water) and tempering (720°C/air).

Dilatometric tests were performed with a L78 R.I.T.A. dilatometer. The prepared specimens (Ø=3 mm, h=10 mm) were subjected to induction heating. For critical temperature investigations, the specimens were heated at the rate of 0.08°C/s to 1200°C and at at 5°C/s up to the austenitization temperature of 940°C for the study of kinetic transformations of supercooled austenite. After annealing at 940°C for 20 minutes different rates of cooling were applied.

3. Test results

Figure 1 shows representative heating curves for determining critical temperatures, and selected photos of the specimens after cooling at the rate of 1°C/s from 1200°C. Modification of the tested cast steel with mischmetal promotes the formation of Widmanstätten ferrite. In addition to dark perlite areas and few equiaxed ferrite grains, this cast steel is characterised by the presence of ferrite with characteristic elongated grains. The critical temperature results were used to determine the optimum austenitization temperature of 940°C.

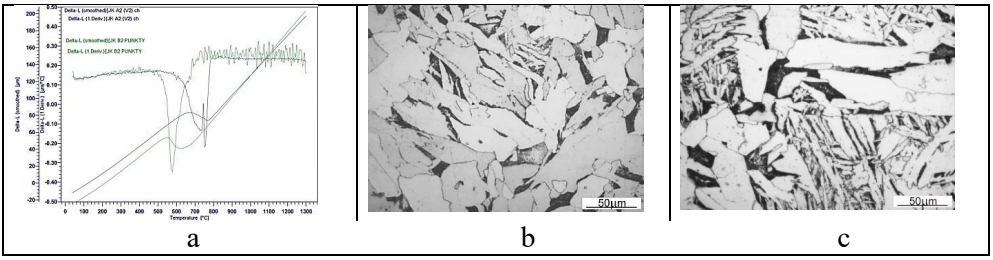

Fig. 1 Results of critical temperature tests a) dilatometric curves of the tested steels heated at a rate of 0.08°C/s with corresponding differential curves, b and c) photos of the specimen microstructure after cooling down from 1200°C for unmodified steels and after modification, respectively

4. Conclusions

Small differences in critical temperatures were found for the melt under investigation. Small changes in the temperature ranges of individual phase transformations are also visible, which result in minor microstructural changes in the tested steels.

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KNOWLEDGEBASE AS A PART OF INDUSTRY 4.0 IN CASTING PRODUCTION

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Key words: database, knowledgebase, industry 4.0, sharing data,

INTRODUCTION

Knowledgebase is one of the most important IT systems in casting production. This is a collection of data, technologists experience which build case study of each single project.

Industry 4.0 is a set of different technologies which create an ecosystem of databases, informatic systems, machines, robots, sophisticated algorithms, Internet of Things systems, Artificial Intelligence algorithms, Data Processing systems, Supervisory Control And Data Acquisitions, Additive Manufacturing systems, etc.

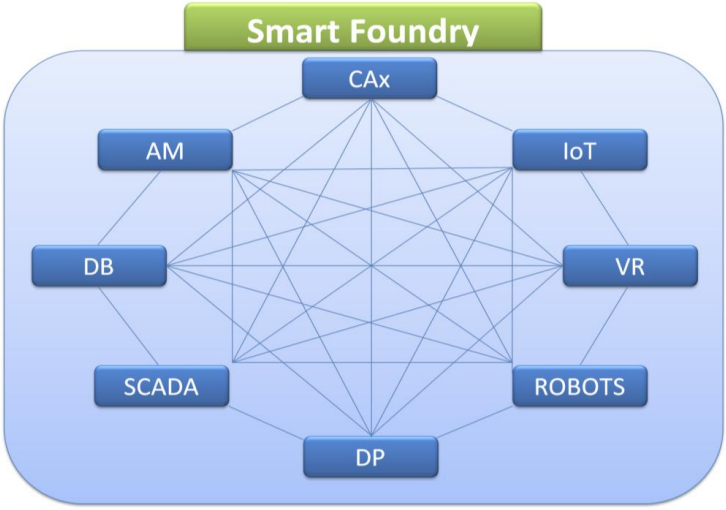

Fig 1. Ecosystem of industry 4.0

SimulationDB 2.0 as an example of knowledgebase.

SimulationDB 2.0 is a system for gathering simulation results in a database. It stores different types of data including:

- pictures,
- set of parameters,

- animations,
- charts,
- analysis.

It is dedicated knowledgebase system for storing, archiving and analysing simulation data in casting production process.

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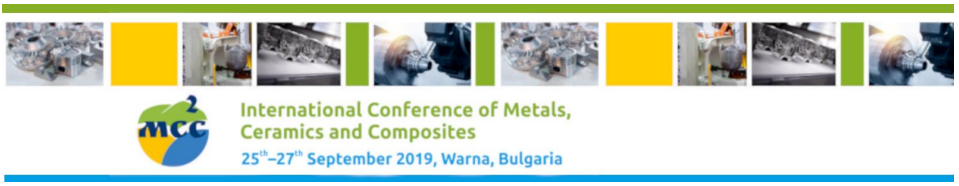

DSC STUDY ON RECRYSTALLIZATION AND PRECIPITATION IN SOLUTION ANNEALED AND COLD ROLLED HAYNES® 282® SUPERALLOY

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Key words: nickel superalloys; differential scanning calorimetry; recrystallization; cold rolling;

1. Introduction

Haynes® 282® wrought nickel-based superalloy has been recently developed to surpass working temperature limits of Inconel 718 and Waspaloy in gas turbine engines [1]. Presently, the improved creep strength of Haynes® 282® combined with excellent heat resistance and weldability, make it also one of the main materials under consideration for using in advanced ultra-supercritical power plants [2]. Relatively lower gamma-prime content in Haynes® 282® alloy ensures its very good room temperature formability. The alloy is provided in the form of flat products in solid-solution annealed (SSA) state in which it is ready to be formed by cold-working. In order to put the alloy into a high-strength condition, a two-step aging heat treatment is applied after a cold forming processing. Therefore, a structural evolution during post-deformation heat treatment of Haynes® 282® components is complex in nature, since it involves a number of endo- and exothermic effects, associated with a dissolution of primary and a precipitation of secondary particles (γ'-Ni_3(Al,Ti), MC, $M_{23}C_6$ and M_6C), as well as to recrystallization related phenomena.
Previous works reported by Joseph *et al*. [3], Haas *et al.* [4] or Polkowska *et al.* [5] have mostly focused on a possibility of a further improvement of mechanical properties of Haynes® 282® alloy via tailoring parameters of the aging steps. On the other hand, as far as we know there has been little discussion on the effect of cold-working prior the heat treatment on structural changes upon annealing of the solutionized Haynes® 282® alloy. Therefore, this paper explores a course of two "competitive" phenomena i.e. (i) a softening due to releasing of stored energy of deformation and (ii) the age-hardening due to precipitation of secondary phases, is examined. Thus, the aim of present work is to explore a heat affected structural evolution in Haynes® 282® alloy through experimental research involving differential scanning calorimetry (DSC) and microstructure characterization.

2. Materials and methods

The commercial Haynes® 282® alloy in the form of 0.062" (1.6 mm) sheet was provided by Haynes International (Kokomo, Indiana, USA) company in the SSA condition.

The cold rolling (CR) process was carried out in several consecutive passes, without any intermediate anneals. In order to examine the effect of cold-working degree on the annealing behavior, three different values of thickness reduction were applied - 30, 60 and 90 %.
The TA Q1000 differential scanning calorimeter was used to record heat flow effects upon DSC experiments on SSAed and CRed samples. Each experiment contained two consecutive DSC runs between 20 and 1200°C at constant heating/cooling rate of 10°C·min^{-1} in purified argon gas atmosphere. Thermal effects associated with releasing of stored energy of deformation were measured during the first run. After reaching the final temperature, a sample was cooled down to room temperature and then heated again to 1200°C.

3. Results

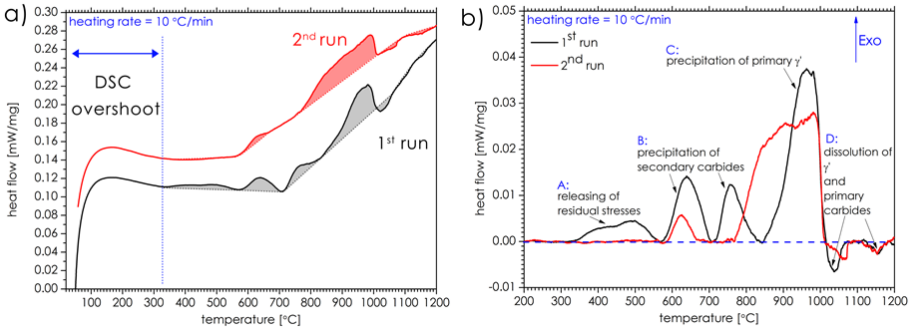

Fig. 1. An exemplary DSC curves recorded for Haynes® 282® alloy in the as-received SSA condition during two consecutive runs up to 1200°C at 10°C/min (a). Reduced DSC curves with a proposed interpretation of thermal effects (b)

Acknowledgments
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EFFECT OF HAFNIUM ALLOYING ADDITION ON WETTABILITY AND REACTIVITY BETWEEN NICKEL AND ZIRCON SAND MOULD

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Key words: wettability, sessile drop method, interfaces, nickel superalloys

Introduction

The development of materials technology of nickel superalloys has been building a background for a progress in automotive, aviation and energy industries starting from early 1930s [1]. In fact, at this moment superalloys represent up to 70% of the weight of new gas-turbine engines [2]. Moreover, superalloys are key players in the global efforts devoted to the development of new highly efficient power generators, e.g. clean coal-fired ultra-supercritical steam plants [3]. Regarding a crucial practical importance of cast nickel superalloy components, a special attention must be paid to ensure their high metallurgical quality (i.e. a lack of porosity or non-metallic inclusions), that in turn strongly affects the component's reliability under operating conditions.

The main purpose of the INSURFCAST project is to find new solutions for investment casting processes of complex-shaped superalloy blades through understanding of high temperature solid-liquid interaction phenomena occurring at the alloy/mould interface. The innovation objective of the Project is to reduce expensive operations of castings' finishing and blades' rejections or failure. In this work, we present the results of sessile drop experiments aimed to investigate the interaction between model hafnium containing nickel alloy and zircon sand mould. Hafnium is an important alloying element that provides a second-phase strengthening (through the formation of Chinese script MC carbides) as well as it retards grain boundary sliding through a modification of the γ' morphology [4].

1. Materials and methods

The materials investigated were: Ni-20.1Hf alloy (wt%), pure nickel 99.999% (as reference) and $ZrSiO_4$ substrates. The alloy was produced by CNR-ICMATE from pure metals (Ni:

99.999%; Hf: 99.9%) by electric arc melting under argon. The substrates were cut off from commercial ceramic mould produced from zircon sand by Specodlew company.
High temperature tests were performed in an experimental complex described in details elsewhere [5]. The tests were carried out by the sessile drop method coupled with a contact heating procedure, i.e., a piece of a metal was placed on the ceramic substrate and then the couple was subjected to the heating/cooling experiments under the high vacuum (10^{-6} mbar) up to 800°C and next under the argon protective atmosphere, including: heating to 1500°C at 15°C/min holding for 15 minutes and then cooling down to room temperature at 20°C/min. During high temperature tests, the drop/substrate images were recorded by using a high speed CCD camera and used for computing a change of contact angle *vs* time (the wetting kinetics). After the tests, the solidified sessile drop couples were subjected to structural characterization be means of SEM/EDS analysis.

2. Results and conclusions

The results (Fig. 1) show that both investigated couples demonstrate a non-wetting behavior under conditions applied in this study, i.e. for both of them, the contact angle values were significantly higher than 90°. Moreover, the contact angle value of Hf-containing alloy is about 20° higher than that of pure Ni while the Ni-20.1Hf drop was spontaneously detached from the substrate upon cooling down from 1500°C. These observations suggest that the addition of Hf to Ni-base alloy may decrease an adhesion of the alloy to the examined ceramic. Although, a deeper insight into interfacial phenomena in the Ni-20.1Hf/$ZrSiO_4$ system is still needed, our first indication is that this behavior could be related with reactively formed hafnium oxide precipitates at the metal/ceramic interface.

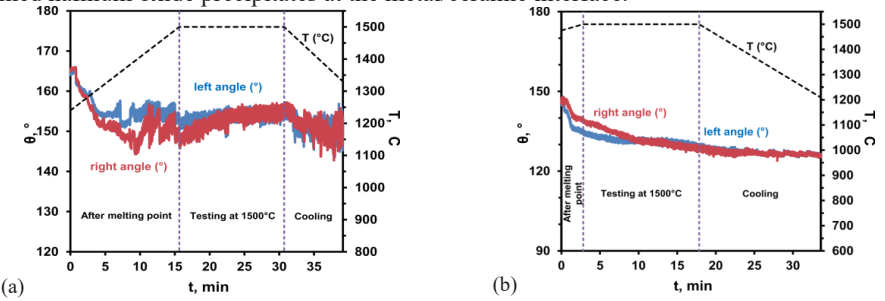

Fig. 1. Wetting kinetics recorded for Ni-20.1Hf/$ZrSiO_4$ (a) and Ni//$ZrSiO_4$ couples (b) upon sessile drop experiments in Ar (heating to and at 1500°C for 15 min)

Acknowledgments

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PROCESSING AND CHARACTERIZATION OF FE-CU-NI SINTERS PREPARED BY BALL MILLING AND HOT PRESSING

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Key words: matrix, diamond, sinters, hot pressing, diamond tools

Nowadays, diamond blades and wires are commonly used for cutting natural stone, concrete and ceramics. The cutting tool consists of synthetic diamond crystals embedded in a metallic matrix by various PM fabrication routes [1-4]. A typical fabrication process, commonly used in the manufacture of diamond impregnated sawblade segments, utilises Powder Metallurgy (PM) technology whereby a mixture of diamond grit and bonding powders, predominantly metallic, is consolidated to form a cutting tool. While cutting, the protruding diamonds pass over the machined material, wearing away its mineral constituents, which, in turn, abrade the matrix, to expose fresh crystals that take over the cutting action from mechanically degraded or dislodged diamonds.

Cobalt has long been the most valued matrix material used for professional tools, due to its excellent diamond retention characteristics and sinterability of commercial Co powders. As the price of cobalt is highly unstable and increasingly contributes to the overall tool cost, the recent industrial trend is toward replacement of cobalt-containing matrices with other, preferably iron alloys produced by PM, by various routes.

Despite the high and growing price of cobalt and its harmful effects on health, it is still used in manufacturing professional tools, although the recent trend is towards a broader application of inexpensive, premixed and ball milled powders [5-8].

The main objective of the present work was to determine the effect of powder composition on microstructure and properties of iron-base materials used as matrices in diamond impregnated tools. The Fe-Cu-Ni premixed and after milling for 30, 60, 120 hours powders were used for the experiments. The influence of manufacturing process parameters on microstructure and mechanical properties of produced sinters was investigated. Sintering was done by hot-pressing technique in graphite mould.

The powders were consolidated to a virtually pore-free condition during 3 minutes hold at 35MPa and 900°C. Investigations of the obtained sinters included: density, hardness, static tensile test and X-ray diffraction (XRD) analysis. Observations were also made of microstructure and fracture surfaces of broken samples using an electronic scanning electron microscope (SEM).

The obtained test results indicate that the produced sinters have a similar to theoretical density, good plasticity with relatively high hardness and yield strength, but sinters premixed characterized by a coarse-grained microstructure.

For this reason, in order to be able to be the matrix material of sintered metallic-diamond segments intended for the production of circular saw blades for cutting natural stone, the next stage of the research will be to thoroughly tribology test the sintered after ball milling.

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LASER TREATMENT OF COPPER SURFACE LAYER – COMPUTING SIMULATION

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Key words: copper, laser treatment, temperature, melt pool, finite element

In many cases the use of copper is limited by the unsatisfactory properties of the surface layer, i.e. low hardness and wear resistance. Therefore, in surface engineering, various techniques are used to increase the durability of products by reducing their wear. Laser surface layer treatment may be a better alternative to other techniques used in surface engineering of shaping the surface layer of copper based alloys intended for elements in which high conductivity is required combined with high functional properties.
Laser alloying of the copper surface layer was performed using a HPDL Rofin DL 020 high power diode laser. During the laser machining processes, the material layer is melted. In the area of the melt pool there are, among others convection movements, evaporation of material, heat exchange with the sample material, heat exchange with the surrounding gas (air), radiation and heat exchange with the material on which the sample is mounted. The melting process diagram which takes into account selected phenomena is shown in Fig. 1.

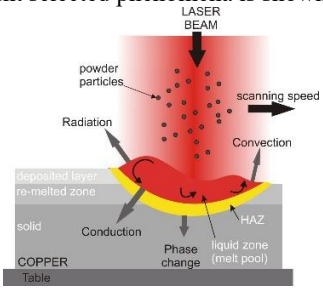

Fig. 1. The laser treatment process diagram taking into account the most important phenomena appearing in the melt pool area [1, 2]

The paper presents the results of investigations of copper microstructure after laser treatment. Non-contact thermographic inspection of Cu samples subjected to laser surface treatment was performed. A numerical model of the surface laser copper alloying process was developed for the analysis of temperature changes based on the finite element method (FEM). The boundary and initial conditions of this stage of the analysis were specified on the basis of thermographic images (Figure 1). The role of the developed FEM model was to identify the temperature occurring in the area of the liquid metal pool on the basis of thermographic measurements

possible, i.e. outside the area of the pool. Based on the determined emissivity within the pool of Cu samples, it was found that the temperature prevailing in the pool is outside the measurement range of the thermal imaging camera. The lack of such data causes difficulties in identifying the correct operating parameters of the modelled laser as a heat flux. The temperature values calculated using FEM were compared with the results of thermographic tests.

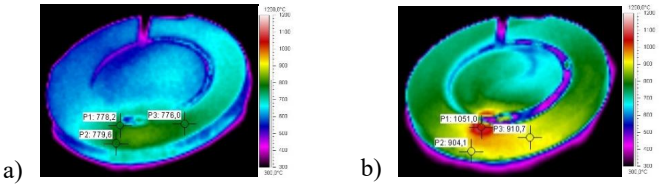

Fig. 2. Registered thermal image of the sample surface after 1/30 s since the end of laser treatment: a) Cu sample, melting, b) Cu sample after alloying with Ni powder; laser power: 2.0 kW, 0.15 m / min

Fig. 3. Example of colour maps of the temperature distribution: a) during alloying, b) during cooling process

The developed model uses typical simplifications known from the literature on computer simulation of laser metal processing methods [2, 3]. The developed model takes into account the complex processes occurring during alloying, which affect the assumed boundary and initial conditions determined by experimental measurements. Despite the simplifications, the analysis reflects qualitatively the nature of temperature changes during the process and allows us to estimate the shape of the liquid metal pool. The model can be considered sufficient.

Acknowledgments

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RESEARCH ON THE IMPACT OF VIBRATORY MACHINING OF TITANIUM ALLOYS

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Key words: titanium alloy, vibratory machining, mass finishing, surface roughness, micro-hardness

This article proposes these of vibratory machining to Ti-6Al-4V titanium alloy as finishing treatment. Titanium alloy was used in the aerospace industry, military, metallurgical, automotive and medical processes, extreme sports and other. The three-level, three-dimensional (Box-Behnken) experiment examined the influence of machining time, the type of mass finishing media used and the initial state of the surface layer on the mass loss, geometric structure of the surface, micro hardness and the optimal process parameters were determined. Considerations were given the surfaces after milling, after cutting with a band saw and after the sanding process. The experiment used three types of mass finishing media: polyester, porcelain and metal. The form profiles before and after vibratory machining were determined with a Taylor Hobson PGI 1200 contact profiler.

1. Introduction

Titanium is a light metal, much lighter than iron- density 4507 kg / m³. Application found in the aerospace (jet engines), military, metallurgical, automotive, medical (prosthesis), extreme sports and other industries [1]. The most common form of failure is mechanical damage as a result of high cyclic loads caused by vibrations [2]. Titanium alloy has low hardness, low wear resistance and poor fatigue properties. It should be emphasized that titanium is difficult to machine. In order to improve the suitability of materials from titanium alloys in industrial applications, it must be subjected to surface and finishing treatment. Research was conducted to improve the fatigue properties of the titanium alloy through reinforcing treatment. Zhecheva investigated the modification of titanium by nitriding [3, 4].

The authors proposed a finishing treatment in the form of vibratory machining [5-8] with three types of machining media (polyester, porcelain and steel media).

2. Conditions and methodology of research

The aim of the research was to show quantitative relations between vibratory machining parameters and effects. The tests included determining the effect of conditions on the speed of machining and surface roughness. The tests were carried out using a Rollwach SMD-R25 container smoothing machine using different machining media, at 50% tumbler filling. A treatment fluid FE-L120-B32/R was used for treating chemistry. The vibration frequency of the container was set at 2500Hz. The experiment consisted of using cuboid samples of 15x17x9 mm made of Ti-6Al-4V titanium alloy. On the sample, the selected surfaces were machined with a given technique in order to obtain different output areas. The selection of input factors

was based on the analysis of the preliminary results of the research and the criterion of their easy selection [5-8]. The input factors and ranges of their variability are presented in Table 1.

Table 1. Conditions of research

	Input quantity	Variable range			Units
1	machining time	20	40	60	min
2	media	polyester	porcelain	steel	-
3	surface	after milling	after cutting	after sanding	

3. Conclusions

The vibratory machining allows effective smoothing of the surface from titanium alloys. The smallest surface roughness can be observed when using typical polishing shapes, ie porcelain and steel media. Porcelain media dedicated to polishing processes allow to reduce the roughness of the surface along with the duration of the treatment. The longer the time is the greater the observed effects. The use of steel balls due to the nature and type of interactions occurring results in even smaller surface roughness by burnishing protruding tops, and consequently reducing the highest surface elevations. The use of polyester profiles containing abrasive grains in their volume results in the most rough surface compared to other media, and thus the largest mass losses of processed titanium alloy samples. The largest increases in hardness are observed with the use of metal media and 60 minutes of processing time.

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INVESTIGATIONS OF ELECTRO-DISCHARGE MECHANICAL MACHINING OF MANGANESE CAST STEELS

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Key words: EDM, BEDMM, flexible electrode, cast steel, machining efficiency, roughness

The paper presents the results of the hybrid electro-discharge mechanical machining with the application of a rotary disk brush as a working electrode. The discussed method enables not only an effective machining with a material removal rate of up to 300 mm3/min but also finishing (with the obtained roughness of Ra < 0.5μm) of the surfaces of complex-shaped alloys with poor machinability. The analysis of the factors involved in the machining process indicates that its efficiency is determined by electrodischarge. The use of flexible working electrodes makes it possible to apply simple technological instrumentation and results in the simplicity of the process automation. The presented experimental research results define the effect of the process input parameters on the performance and roughness of machined surfaces obtained for manganese cast steel.

1. Introduction

One of the problems connected with the machining of castings made of alloy cast steels is the significant wear of abrasive or cutting tools. These problems become particularly important during surface machining associated with the removal of the casting epidermis, remnants of the removed gating system, defects in shape such as dislocations, flashes, swells, casting surface defects such as folds, scars, pits, burn-ons, as well as cleaning welds [1-4]. These faults often cause the uneven distribution of machining allowance. Another reason for the conditions of the machining allowance removal being significantly difficult is the hardening of the austenitic cast steels due to cold workor surface improved parts [5-8]. These difficulties increase in the case of castings with complex macrogeometry as well as thin-walled or medium and large-sized castings. The conducted industrial study provided the basis for the selection of a material with particularly poor mechanical machinability – Hadfield L120G13T cast steel.

The authors predict that the use of flexible electrodes with a discrete structure (brush electrodes) in the electrical discharge machiningwill result in the generation of periodic electrical microdischarges at low values of the supply voltage (5-25V) and non-fullcontact between the working electrode and the workpiece.

2. Conditions and Methodology of Research

The aim of the study was to obtain quantitative relationships between the parameters of brush electro discharge mechanical machining (BEDMM) machining and its effects. The study included determining the impact of the conditions on the machining rate and roughness of the surface. The tests were performed using a working liquid in the form of aqueous solution of

sodium silicate (water glass) $Na_2SiO_3nH_2O$ with a specific density of 1.15 g/cm^3 and the initial temperature of T_{el} = 293 K. The experiment involved using 35x30x10 mm cuboid samples made of L120G13T wear-resistant manganese cast steel, quenched from 1340 K with cooling in water. The input factors selection was based on the analysis of preliminary study results and on the criterion of controlling them easily. Input factors and the ranges of their variability are presented in Table 1.

Table 1. Ranges of input factor variability

	Input quantity	Symbol	Variability range		Units
			x_{kmin}	x_{kmax}	
1	supply voltage	U	8.00	16.00	V
2	disk rotational velocity	v_0	0.40	7.10	m/s
3	feed rate	v_f	12.00	36.00	mm/min
4	wire deflection value	Δ	0.40	1.20	mm

3. Conclusions

The effect of the machining voltage and the federate on the material removal rate for manganese cast steel (Hadfield L120G13T), show that the effectiveness of the material removal rate increases with an increase in the discharge energy. At a small voltage the plasma channel is very narrow and therefore the removal rate is low. In the case of a high voltage the removal rate is higher because of an increase in the discharge energy.

Technological research of the manganese cast steel demonstrates that the machining efficiency at U = 24 V, v_0 = 7.1 m/s, v_f = 36 mm/min, Δ = 1.2 mm is about 300 mm^3/min.

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TRIBOLOGICAL PERFORMANCE OF IONIC LIQUIDS USED AS LUBRICANTS ON STEEL WITH DIAMOND-LIKE CARBON COATING

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Key words: diamond-like carbon, coating, ionic liquid, friction, wear

Thin-layered materials with good tribological properties and wear resistance are increasingly desirable because of their great potential to improve the surface properties of the substrate. The aim of this study was to determine the effect of ionic liquids on the properties of diamond-like carbon (DLC) coatings deposited on 100Cr6 steel using the plasma-assisted chemical vapour deposition (PACVD) method. The surface topography of the DLC coatings was examined by atomic force microscopy (AFM) and by scanning electron microscopy (SEM). A nano-indentation tester was employed to determine the nanohardness of the DLC coatings. The tribological tests were performed with a pin-on-disc tribometer under dry friction conditions as well as under lubricated friction conditions using PAO8 synthetic oil or two ionic liquids: IL1, trihexyl(tetradecyl)phosphonium bis(trifluoromethylsulfonyl) amide and IL2, 1-butyl-3-methylimidazolium tetrafluoroborate.

1. Introduction

Science and technology are constantly in need of new materials with enhanced properties. Steel parts with DLC coatings have greater wear resistance and lower coefficients of friction than uncoated components, which make them widely applicable across all sectors, especially in the tool, automobile, food and medical industries [1, 2)]. Because of their remarkable mechanical and tribological properties as well as high surface smoothness, high chemical inertness and biocompatibility, DLC-coated parts are excellent for tribological applications in special environments [3]. Recent research has focused on the performance of ionic liquids (ILs) a type of lubricant with excellent properties and environmental friendliness. Ionic liquids are becoming widely used in the field of tribology due to their remarkable lubricating and anti-wear properties compared to traditional lubricating oils [4].

2. Materials and results

Single-layer a-C:H-type diamond-like carbon, DLC, coatings were deposited on a 100Cr6 steel disk substrate using the plasma-assisted chemical vapour deposition (PACVD) method.
The images of the surface topography in Fig. 1a) indicate that the DLC coating was very smooth; the small scratches observed were probably created during the grinding and polishing of the substrate required for coating deposition. Fig. 1b) shows an image of the surface morphology of the DLC coating, while Fig. 1c) provides cross-sectional views of the coating with information on the coating thickness (3.21 μm). The nanohardness tests were carried out

at a maximum load of 100 mN using a diamond Berkovich indenter tip. The indentation curves were analysed following the Oliver-Pharr procedure. The tribological properties of the DLC coatings were studied using a ball-on-disc type T-01M tribometer. The results was from testing under dry friction (TDF), with synthetic oil (PAO-8) and with the two ionic liquids.

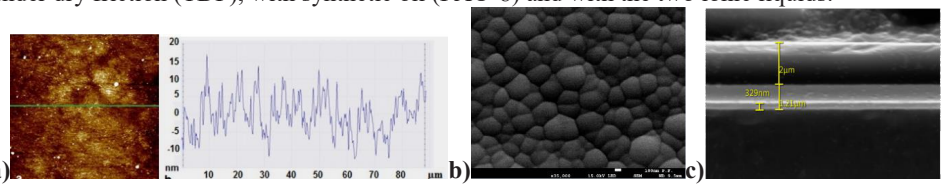

Fig. 1. Analysis of the DLC coating: a) AFM 2D view of the surface topography and surface profile; b) SEM view; c) SEM cross-sectional view

Table 1. Mechanical properties of the DLC coatings

Parameter	Hardness indentation H_{IT}, GPa	Vickers hardness indentation, HV	Young's modulus E^*, GPa	Rigidity S, mN/ µm
Value	25.88	2396	209.77	427
Standard deviation	1.88	174.34	10.40	28

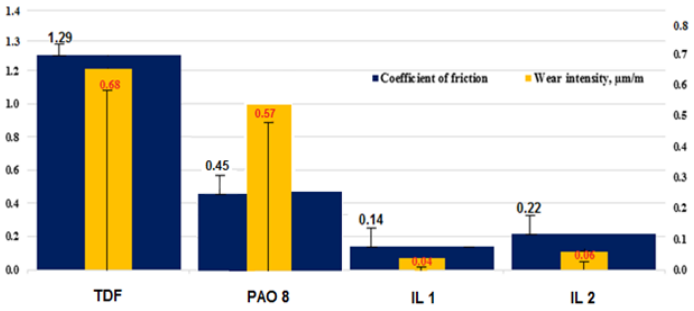

Fig. 2. Coefficient of friction versus wear intensity obtained for the two lubricants using a T-01M tribotester

3. Conclusions

The surface topography tests showed very high smoothness of the DLC coating deposited on the 100Cr6 steel disks. The thickness of the coating was 3.21 µm. From the nanohardness test it was evident that the elasticity of the DLC coatings was high. The hardness of the DLC-coated 100Cr6 steel was 25.88 GPa. The tribological data showed that elements coated with DLC had better tribological properties than uncoated elements both under dry friction and also when lubricated with ionic liquids. The tribological data indicate that a boundary film formed on elements coated with DLC in the presence of the ionic liquid.

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WETTABILITY OF GRAPHENE-COATED SILICON CARBIDE SUBSTRATES BY LIQUIDE TIN

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Key words: liquid Sn, graphene, high temperature, wetting kinetics, interfaces

1. Introduction

The paper concerns pioneer research on the behavior of liquid Sn in contact with graphene (G_n) coated substrates along with a specific effect of graphene production technique on the interaction in the Sn/G_n/substrate system. This information is of practical importance for potential applications of graphene that may improve and even replace our existing technologies and could revolutionize the technology of the future.

The goal of this study is to deepen the knowledge of *graphene wetting transparency* phenomenon [1] and its effect on the stability, reactivity and shaping of interface structure in the metal/G_n/substrate systems as well as the effect of this phenomenon on the nucleation of secondary 2D structures.

2. Materials and methods

The following materials were used: 1) Sn (99.95%); 2) SiC single crystal substrate (SiC^{sc}) commercially coated with graphene (Institute of Electronic Materials Technology, Poland) [2]; 3) SiC^{sc} with graphene layer *in situ* deposited in vacuum chamber directly before wettability test by heating the substrate (1250ºC,30 min) in vacuum (10^{-5} mbar) [3].

Real-time melting, wetting, spreading and solidification behavior of Sn/G_n/SiC^{sc} couples were examined at 700ºC for 15 min in vacuum by the sessile drop method combined with capillary purification procedure in experimental facility described in [4,5]. This procedure allows non-contact heating and *in situ* removal of native oxide film from a metal drop directly in vacuum chamber. During wettability tests, the drop images were recorded using high resolution digital camera with a rate of 100 frames per second. The collected drop/substrate images were used for calculation of contact angle values using the ASTRA software [6,7].

The structure and chemistry of solidified couples were examined using: a) scanning electron microscopy (SEM) coupled with energy dispersive X-ray analysis (EDS), b) versatile automated laser raman spectrometer (LRS).

3. Results and conclusions

The results (Fig. 1) show that under conditions of this study, liquid Sn drop deposited on the G_n/SiC^{sc} substrates at 700°C does not wet both G_n-coated substrates (θ >90°). Moreover, the graphene production technique does not affect the contact angle value since it is similar to that on G_n-free SiC^{sc} [3], as an experimental evidence of *graphene wetting transparency* effect. The mechanism of interaction accompanied with structural changes taking place in examined couples will be discussed in details.

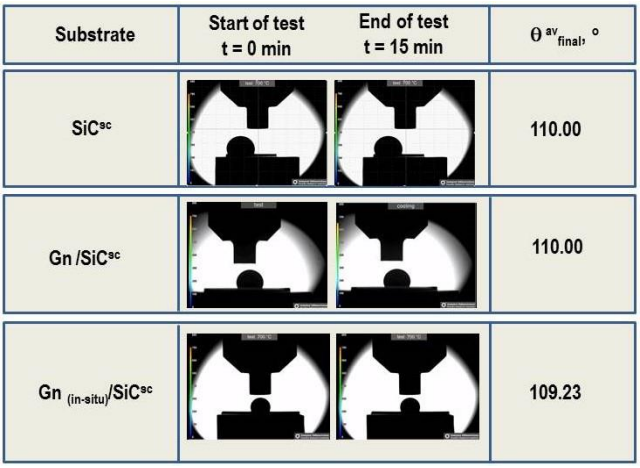

Fig. 1. The most representative moments of wettability tests: data for SiC^{sc} and $G_{n(in\ situ)}/SiC^{sc}$ substrates are from [3]

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HIGH TEMPERATURE INTERACTION OF MOLTEN HAYNES®282® ALLOY WITH MgO AND $MgAl_2O_4$ SUBSTRATES

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Key words: wettability, sessile drop method, interfaces, nickel superalloys, Hayness©282©

1. Introduction

Haynes®282® alloy has been developed by Haynes International Inc. as a new, gamma-prime strengthened superalloy for high temperature structural applications, especially those in aero and land-based gas turbine engines [1]. It was initially designed as wrought alloy but actually, Haynes®282® is under consideration also for casting applications including ultrasupercritical components in a new generation power plants [2,3]. Therefore, information on high temperature interaction of molten Haynes®282® alloy in contact with different refractory ceramics is of practical importance in order to produce defect-free casting components. Following literature data (e.g. [4,5]), MgO-rich oxide inclusions represent the main casting defects of many superalloy castings. This paper is focused on investigation of melting, wetting and reactivity of Haynes®282® alloy in contact with two oxides commonly used in foundry practice, i.e. magnesia (MgO) and magnesium aluminide spinel ($MgAl_2O_4$) that represents binary oxide of $MgO\text{-}Al_2O_3$ system (Fig. 1a).

2. Materials and methods

Commercial wrought Haynes®282® alloy containing 10Co, 20Cr, 8.5Mo, 1.5Al, 2.1Ti, 1.5Fe, 0.3Mn, 0.15Si, 0.06C and 0.005B (wt%) was received from Haynes International Inc., USA [1]. MgO and $MgAl_2O_4$ were used in the form of single crystalline substrates those surface roughness was about 1 nm. Comparative studies were also performed on polycrystalline alumina Al_2O_3(pc) and magnesia MgO (pc) substrates.

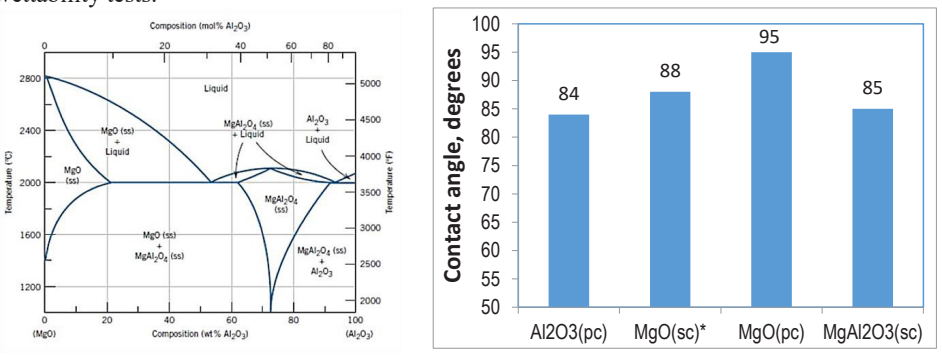
For wettability tests, a sessile drop method [6] coupled with contact heating procedure was applied at a temperature of 1500°C under protective atmosphere for 15 min using experimental facility described elsewhere [7]. Specially developed procedure for *in situ* opening of the metal/ceramic interfaces at the testing temperature directly during wettability tests was used by pushing a metal drop to another position on a substrate.

After wettability tests, the solidified metal/substrate couples were examined by scanning electron microscopy coupled with energy-dispersive X-ray spectroscopy analysis followed by scanning probe microscopy characterization.

3. Results and conclusions

The results obtained show that after melting Haynes®282® alloy, its drop wets both single crystalline MgO(sc) and $MgAl_2O_4$(sc) substrates (in both cases, the contact angle is below 90°, Fig. 1b). Thus wetting phenomenon might be one of the reasons responsible for the presence of MgO and $MgAl_2O_4$ inclusions in final casting components. Moreover, in the case of MgO(sc) substrate, the drop is not stable on the substrate, showing "dancing drop" effect that is typical for the formation of gaseous products at the drop/substrate interface.

These results will be compared with those obtained on polycrystalline substrates of MgO-Al_2O_3 systems and discussed in terms of interfacial chemical reactions taking place during wettability tests.



a) *b)*

Fig. 1 a) Al_2O_3-MgO phase diagram; b) experimental values of contact angles recorded for selected Haynes®282®/ceramic couples at 1500°C in argon

Acknowledgments

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DEVELOPMENT OF AN INNOVATIVE TECHNOLOGY FOR THE PRODUCTION OF MASSIVE SLAG LADLES WITH INCREASED OPERATION PARAMETERS (SLAG LADLE TECH) AT THE KRAKODLEW S.A. FOUNDRY

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Key words: cast iron, cast steel, foundry, large castings, massive slag ladles

This paper is a current summary of the work carried out under the SLAG LADLE TECH project at foundry Krakodlew S.A., which is being implemented until 2021. Krakodlew S.A. realize a project in the area of massive slag ladles with a mass of up to 30 Mg. As part of this project, the following research tasks have now been carried out:

1. Research on the optimal batch bearing and smelting conditions were developed, chemical composition of casting alloys with micro-additives for slag ladle castings was developed.
2. Research on a method of refining liquid metal with secondary metallurgy was developed
3. Research on the method of refining liquid metal with secondary metallurgy.
4. Research on molding sand and cores were developed for the production of foundry molds
5. Research on the technology of the mold for restoring slag vats from high and medium temperature iron-carbon alloy (cast steel and cast iron) was developed and verified.
6. Research on computer analysis of the crystallization and cooling process of slag ladle castings using mold technology as well as cast steel and cast iron
7. Research on improving the heat treatment of slag ladles from high and medium temperature casting alloy

The aim of the project is to give properties to the alloys from which massive castings of slag ladles are to be made, which can be described like thermo-mechanical properties that are concept of heat fatigue resistance.

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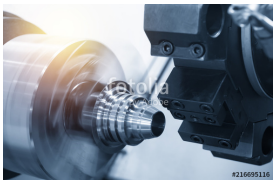
POLISH FOUNDRYMEN'S ASSOCIATION (STOP)

The Polish Foundrymen's Association (STOP) is an independent scientific, technical and managerial organization associating individual members on a voluntary basis, in particular engineers, students and members supporting members whose activities are related to foundry, and in particular cooperating with it universities, research institutes, design offices, commercial sector, services and production units operating on its behalf. The association was officially registered and established on September 7th, 1936. The first goals of the Association were to maintain professional communication between founders to develop and spread technical knowledge in the field by organizing lectures, courses, conventions, providing technical advice and promoting the foundry industry in its own magazine „Foundry Review", which faithfully accompanied the Associations activities since 1939. As in the past, to this day it is a source of foundry information and is the only official foundry industry magazine in Poland.

For over eighty years of its activity, the Association actively participated in the promotion of Polish foundry industry on the international arena. Poland as one of ten countries in 1926 formed the industry Committee of Technical Foundry Associations – CIATF. From the beginning of its existence the Association was an active member of this organization and currently belongs to the most esteemed. STOP also undertakes a number of activities and is earnestly involved in the Central European agreement of MEGI foundry associations, which is currently the World Foudry Organization – WFO commission. The Association is also a member of the Federation of Scientific and Main Technical Association – NOT and the co-organizer of the Foundry Chamber of Commerce. Thanks to domestic and foreign cooperation, it enables the exchange of scientific and technical ideas as well as the consolidation of people and enterprises from the foundry industry.

Currently, the Association operates in Poland through 16 branches and over 56 interest groups established in foundries, schools, offices and other enterprises. STOP organizes conferences, symposia and specialist foundry training. The Association is also involved in economic, innovative, advisory and expert activities.

www.stowarzyszenie-stop.pl



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