6th INTERNATIONAL THERMAL SPRAYING
AND HARDFACING CONFERENCE

ITSHC 2022

PROGRESS, APPLICATIONS AND MODERN TECHNOLOGIES

BOOK OF ABSTRACTS

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Hardfacing Processes II

Poster Session

Purpose of the Conference

The aim of the conference is to present the latest researches and developments in the field of thermal spraying, as well as of hardfacing. We are looking for papers mainly dedicated to: new materials and technologies, properties of coatings and weld deposits, novel characterization methods as well as new industrial applications in different operating conditions. In addition, the problems concern training of specialists, quality and certification system at thermal spraying and hardfacing technologies will be discussed. The session dedicated to generative techniques (with particular emphasis on 3D printing) of metallic materials will be included since this year's edition.

Conference topics

- thermal spray processes: plasma spraying, High Velocity Oxigen/Air Fuel, cold spray,
- hardfacing processes: laser cladding, hardfacing,
- additive manufactiruing: 3D printing, Selective Laser Sintering, metal AM, Direct Metal Deposition and more…,
- allied processes: surface pretreatment, laser processing, heat treatment, …,
- new equipment for thermal spraying and hardfacing,
- development in materials for surface engineering,
- development in thermal spraying and hardfacing processes,
- quality and certification systems in thermal spraying.

Day I

PLENARY LECTURES

Thermal spraying using liquid feedstock

Lech Pawłowski
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The technologies of thermal spray coatings deposition using liquid feedstock are shortly described. The liquid feedstock, having initial form of suspension or solution generates at processing small, submicrometric or nanometric particles, which participate in coatings' formation. The characterization of suspension includes mainly solid phase granulometry and content as well as its stability, which describes the agglomeration of small solids. The solutions being frequently nitrates or acetates of metals dissolved in water or ethanol. The solutions require some additives to influence the chemical reactions occurring at high temperatures. The methods of liquids feeding to jets and flames are described as well as the phenomena leading to the formation of fine particles having desired chemical composition. Such fine particles are splashed on the substrate participating in coating's build up. The microstructure of liquid feedstock sprayed coatings' may include crystalline phase impossible to obtaining using rough powders feedstock. Moreover, careful process optimizing enables formation of columnar microstructure. These particularities result in many interesting application of the deposits in the fields of e.g. energy generation, thermal isolation at very high temperatures or biomaterials for medical implants. The examples of such applications are described and the perspectives of their use in industry are shown.

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Day I

PLENARY LECTURES

In pursuit of the next frontier in thermal sprayed tribological coatings

Shrikant Joshi

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Coatings primarily intended for tribological applications constitute a major fraction of the present-day thermal spray market. WC and Cr 3 C 2 based coatings, with Co/Co-Cr and NiCr as the respective metallic binders, have been the predominant materials of choice to meet a wide spectrum of industrial wear requirements. Despite the fact that they were developed a long time ago, the compositions of commercially available spray-grade WC and Cr 3 C 2 feedstocks have not undergone any significant change over the past several decades. Ever since the early 1990s when the high-velocity oxy-fuel (HVOF) process was demonstrated to yield properties comparable to corresponding detonation sprayed layers (extremely dense coatings with considerably reduced decarburization and high bond-strength), it too has come to represent the state-of-the-art spray process to deposit the above carbide coatings. Consequently, the thermally sprayed tribological coatings' canvas has seen little change for approximately the past three decades.

Notwithstanding the above, there is now a growing need to explore alternative hardmetal formulations for thermal spraying. The foremost driver is attributable to both W and Co being categorized ascritical raw materials, while use of Co also has additional health concerns associated with it. Moreover, as the operating environments become increasingly aggressive in search of higher productivity/efficiency and the demand for enhanced component longevity grows for reasons of sustainability, there is also an emergent need to surpass the current performance benchmarks. The talk will attempt to discuss the prospects of various facets of thermal spraying, spanning material chemistry, nature of feedstock, processing approaches and coating architecture, to contribute to our quest for the next frontier in tribological coatings.

Keywords: *thermal spray, hard coatings, wear, HVAF, suspension, hybrid*

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PLASMA SPRAYING

How to identify degradation of a three-cathode cascaded plasma spray torch

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The TriplexPro™-210 plasma spray torch (Oerlikon Metco) is a three-cathode plasma spray torch. It became a kind of workhorse for the wide range of tasks handled at the Jülich Thermal Spray Center (JTSC). Compared to conventional single-cathode torches, the cascaded design of the nozzle suggests low fluctuations of the arc and thus high stability. But once in a while, degradation sets in also with such a torch, impairing the reproducibility and reliability of the process. It is therefore important to detect this in time and not only when inspecting the sprayed layers.

In this work, standard samples of YSZ thermal barrier coatings were sprayed regularly over a period of more than one year. Operational data and feedstock characteristics were collected and correlated with the area-specific mass deposition. It turned out that the measured substrate surface temperature showed a significant correlation.

Searching for the reasons for the temperature variations, several process parameters could be excluded as they are monitored by calibrated sensors and their time course is recorded by the control unit. But besides, there are other parameters which can have a significant impact like the robot alignment or the cooling conditions. However, the purposeful experimental variation of such variables resulted in only lower variability in the substrate temperature, significantly smaller than observed over the year. It was concluded that torch degradation was the reason. Thus, the substrate surface temperature can be used as a reliable indicator for the reproducibility of the spray process.

Keywords: *plasma spraying, cascaded plasma torch, three-cathode plasma torch, degradation, substrate surface temperature*

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PLASMA SPRAYING

High-enthalpy spraying of hybrid biocompatible coatings

Tomas Tesar[1], Radek Musalek[1], Jan Cizek[1], Jan Medricky[1], Frantisek Lukac[1], Jonas Dudik[2]

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Hybrid plasma spraying is an innovative thermal spray deposition process combining the more conventional spraying of dry coarse powders and the more recent spraying of liquid feedstocks (e.g., suspensions and/or solutions). By virtue of simultaneous feeding of both feedstocks, this process aims to augment the conventional coatings with additional functionality provided by the finelystructured material delivered from the liquids.

This contribution presents the initial results on deposition of hybrid coatings composed of TiO_2 deposited from the coarse powder and hydroxyapatite (HAp) deposited from the suspension designed for biomedical applications. The coatings' microstructure was characterized using scanning electron microscopy, elemental and phase composition were characterized using energy-dispersive X-ray spectroscopy and X-ray diffraction spectroscopy, respectively, and mechanical properties were evaluated using the hardness measurement.

The coatings displayed homogeneous dispersion of the HAp splats in the TiO_2 matrix and no unmelted material was found in the coatings. The phase composition evaluation revealed partial transformation of the originally fully crystalline HAp feedstock to the amorphous phase and also substoichiometric oxygen content in the TiO_2, both resulting from the nonequilibrium thermal conditions experienced during the plasma spray deposition.

Keywords: *hybrid coatings, biocompatible coatings, plasma spraying, WSP-H*

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PLASMA SPRAYING

Influence of air plasma spraying process parameters on the Thermal Barrier Coating deposited with micro- and nanopowders

Tadeusz Kubaszek, Marek Góral, Paweł Pędrak

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This study investigates the optimal conditions to deposit a thermal barrier coating (TBC) using micro- and nanopowders in the air plasma spraying (APS) process. The aim of this work is to determine the influence of the APS process parameters on the thickness and porosity of the yttria-stabilized zirconia (YSZ) coatings deposited with a single-electrode plasma gun. The properties of melted particles, such as temperature and velocity, were determined by the DPV eVolution diagnostic system to decrease the number of experimental processes. The current and flow rate of the plasma gas mixture, especially H_2, have the greatest impact on the properties of the deposited coatings. Hence, these parameters were changed in this research. The Metco 6700 YSZ oxide micropowder has already been used in the plasma spray physical vapour deposition process (PS-PVD). However, the results of this study suggest the possibility of its deposition in the APS process. It was found that the particles of this powder move in the plasma stream at high speed (>380 m/s) and are characterized by high temperature ranging from about 2700 to 2900°C. The temperature of the particles depends on the current, while their velocity depends on the hydrogen flow rate. The highest thickness of the ceramic coating was obtained with 6 NLPM of H_2 flow and 800 A current. Difficulties with the feeding of the powder particles at higher H_2 flow were also observed. The results also showed that in the APS process, it is possible to deposit a nanopowder, Metco 6609, which is normally used mixed with ethanol in suspension plasma spraying (SPS). In the research, this powder was fed using a carrier gas. The coatings were around 40 μm and have high porosity. The lowest porosity of the ceramic layer (16%) was obtained in a spraying process at the current – 600 A and the hydrogen flow rate of 12 NLPM. In the coatings, there were also visible unmelted spherical particles.

Keywords: *thermal barrier coatings (TBC), air plasma spraying (APS), yttria-stabilized zirconia (YSZ), nanopowders*

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PLASMA SPRAYING

2D time-dependent modeling of YSZ molten particles impinging on a microtextured substrate during plasma spraying

Tomasz Kiełczawa, Paweł Sokołowski

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In this work, the trajectory of the YSZ droplets is numerically investigated in the boundary layer of the microtextured substrate. This opens the possibility of predicting the coating material behavior in the closest proximity of the substrate and understanding the build-up mechanism of columnar coatings.

The analysis considered three different locations over the microtextured substrate: 3.125, 6.25 and 9.375 mm from the plasma jet centerline. 2D microscale computational domains were located in the substrate boundary layer and discretized with 40 000 uniform tetragonal finite elements. Additionally, pre-selected substrate topography was introduced to the boundary conditions, including heat transfer phenomena and the interaction between YSZ droplets and the microtextured substrate.

It appeared that the substrate topography affects the TBC build-up mechanism and the resulting columnar structure due to the shadowing effect of the surface asperities. This phenomenon plays a major role in the columnar coatings build-up mechanism based on the analysis of the concentration of landed droplets on the microtextured substate. However, the intensity of the shadowing effect depends on the distance from the plasma jet centerline. It was observed that due to different inclination angles the shadowing effect is reduced for droplets deposited close to the center of the plasma jet compared to droplets reaching the substrate in the outer regions.

Keywords: *Thermal Barrier Coatings, build-up mechanism, substrate topography, microtexturing*

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Day I

LASER CLADDING AND HARDFACING

Gradation of surface properties of high-manganese steel X120Mn12 coating systems by turning and diamond smoothing

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Austenitic high manganese steels offer very good wear resistance under impact and shock loading due to their high work hardening capacity. Powder metallurgical synthesis and processing offers opportunities in the field of surface protection applications. In the present study, the work hardening behavior of thermal sprayed and laser clad coatings of X120Mn12 is investigated by mechanical finishing. Starting from the polished state, a significant increase in surface hardness is possible by turning, which can be further increased by diamond smoothing. The wear resistance is also positively influenced by the processing steps. Due to in situ hardening, the polished surfaces exhibit good wear resistance as well. The results confirm the great potential for powder metallurgy products in surface protection applications.

Keywords: *ASTM A128; EN 1.3401; manganese steel; austenitic high manganese steel*

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LASER CLADDING AND HARDFACING

Microstructure and sliding wear behaviour of *in-situ* TiC-reinforced Fe-based composite surface layers synthesized on the ductile cast iron by laser surface alloying

Damian Janicki

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In situ TiC-reinforced composite surface layers (TRLs) were synthesized on a ductile cast iron substrate via laser surface alloying process with different chemical compositions of Ti-based alloying material (pure Ti powder as well as Ti/Cr and Ti/Mo powder mixtures). The resulting differences in the composition of the melt in the molten pool affected the fraction, morphology, and mechanical properties of TiC precipitates, as well as the phase composition of the matrix material. Comparative dry sliding wear tests between the as-received ductile cast iron, TRLs, and also laser surface melted layers have been performed following the ASTM G 99 standard test method under different contact pressures. The TRLs exhibited significantly higher wear resistance than the others, which was found to be load-independent. Furthermore, it was found that increasing TiC fraction decreased both wear rates and friction coefficient. The friction coefficient of TRLs was also affected by normal contact pressure. The formation of the transfer layer, being composed of an oxidized counterface material (AISI 52100 steel) and the TRL's matrix as well as fine TiC particles, was observed during testing all types of TRLs. The hardness of the matrix material had the significant effect on a cracking intensity of TiC precipitates and their removal from the worn surface.

Keywords: *in situ composite, titanium carbide, laser surface alloying, ductile cast iron, dry sliding, transfer layer*

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Usage of CMT process in Power Industry – cladding applications in production

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Presentation “Usage of CMT process in Power Industry – cladding applications in production” will show advantages of using “Cold Metal Transfer – CMT” process in cladding applications, with focus on cladding with nickel alloys. CMT is a process that puts minimal heat input in to the welded material, this allows to create cladding with superb quality and extremely low dilution with parent material. Beside that, there will be presented Fronius solutions that allows to clad pipes and membrane walls.

Keywords: cladding, CMT, power plant, membrane wall

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Coaxial Laser Wire Deposition of AISI 316L steel – research on influence of processing parameters

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Laser cladding technology is a well-established process, commonly used for deposition of improved-property coatings, repair of machine parts and additive manufacturing. Currently, in terms of application of laser cladding, the method based on powder deposition is much more common, as the use of an adapted nozzle allows the coaxial and direction-independent feeding of additional material into the weld pool. However, laser cladding with powder also has some significant drawbacks, e.g. limited powder feeding and melting efficiency, lower productivity and the resulting dust that poses a health risk to operators.

The solution to these limitations is the use of additional material in the form of wire. To maintain the ability to coaxially feed the wire to the laser beam interaction point, a specialized cladding head is necessary. In mentioned system the laser beam, while being passed through the optical system, is divided into three separate beams that are focused on the substrate on the working point of the head.

In this study, the COAXwire cladding head was integrated into the robot station and laser cladding process was carried out in order to determine the influence of the processing parameters on the deposition results. The parameters of the cladding system were identified, including the measurement of laser beam caustic. The experimental trials were carried out using AISI 316L wire deposited on S420MC substrate. The effect of the processing parameters on the geometry of the clad was determined with particular emphasis on the wire feeding.

Keywords: *laser cladding with wire, steel AISI 316L, processing parameters, COAXwire*

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Day I

COLD SPRAYING

Mechanical properties of Cu-Ti composites prepared by cold spray

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The presented study addressed the mechanical properties of cold sprayed (CS) composite deposits prepared from constituents of similar stiffness. As case study materials, Cu and Ti at different mutual weight ratios from 0–100 wt. % were sprayed together, with HCP Ti featuring low density and diffusivity sprayed and heavier FCC Cu featuring high thermal diffusivity. Stress-strain, fracture toughness and fatigue crack growth rate (FCGR) at stress ratio $R \sim -1$ were all characterized using unified miniature specimen methodology. It was shown that the stress-strain behavior and fracture toughness are defined by the ductile copper component up to 60 wt. % Ti concentration. At higher Ti concentrations, the continuous load-carrying structure of Ti is formed and the composite properties approach those of pure CS Ti. FCGR at low load in trans-particular regime was similar for all Ti concentrations. As opposed to this, at higher loads, the regime changed to inter-particular and the corresponding FCGR differed among the different various Cu- Ti deposits. Interestingly, Cu-Cu cracks in the pure Cu deposit grew significantly faster than the cracks containing Cu-Ti interfaces, the slowest FCGR was observed for the Ti-Ti cracks in the pure Ti deposit. The results obtained in our study provide a valuable insight into the properties and failure mechanisms of two-phase composites for the rarely studied case when the effect of elastic modulus is nearly eliminated.

Keywords: *cold spray, Cu-Ti composite, stress-strain, fracture toughness, fatigue crack growth rate*

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COLD SPRAYING

Forming behaviour of Al/Ti material compounds produced by cold gas spraying

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Cold gas spraying has great potential for additive manufacturing, especially of oxidation-sensitive metals, because the material is not melted and significantly higher deposition rates can be achieved than with conventional additive manufacturing processes such as selective laser melting or direct metal deposition. Titanium is regarded as a particularly high-performance engineering material due to its combination of properties, including good corrosion resistance, biocompatibility and high strength at comparatively low density. However, due to its high price, it appears reasonable for many applications to use material compounds in which titanium is only used on the surface of the workpiece, while less expensive materials such as aluminum are used for the remaining volume. In the present work, cold gas sprayed pure titanium coatings were deposited on Al substrates and then formed to a defined 3-dimensional final contour by die forging. Different porosities and coating thicknesses were selectively set in order to evaluate their influence on the coating adhesion in and the surface quality after the forming process. Preconsolidation of the coatings and increased forming temperatures proved to be promising strategies.

Keywords: *cold spray, titanium, forming, die forging*

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COLD SPRAYING

Aerosol cold spraying of 8YSZ thermal barrier coating on various shapes of nose cone for re-entry vehicles

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The novel aerosol cold spraying system joining low-pressure cold spraying and aerosol deposition was used for the deposition of 8YSZ thermal barrier coating on two different shapes of nose cone demonstrators for re-entry vehicles.

The demonstrators with a diameter of 75 mm were manufactured from 3YSZ-10vol.%MWCNTs powder mixture by spark plasma sintering at 1350°C at 60 MPa for 20 min. Due to the oxidation of carbon nanotubes which occurred during the tests of the sintered samples conducted in the arc-heated facility L2K in collaboration with DLR Cologne, as a result of the partnership between the LightCoce and RETALT project consortia, a protective thermal barrier coating on the external surfaces of the demonstrators of nose cones needs to be deposited.

The deposition of thermal barrier coatings from 8YSZ powder was carried out using the aerosol cold spraying device designed and manufactured at the Łukasiewicz Research Network – Poznań Institute of Technology. In the process, the powder was mixed with a helium carrier gas in the aerosol chamber and then the powder-gas suspension was delivered to the nozzle and deposited on the convex substrate. As a result, a dense coating structure was obtained. To enhance the adhesion and strength of the coating, post-processing heat treatment was conducted using pressureless sintering at 1000°C for 2 h in an argon atmosphere.

Acknowledgments: This research is part of a project that has received funding from the European Union Horizon 2020 research and innovation programme under grant agreement No. 814632.

Keywords: *8YSZ, thermal barrier coatings, aerosol cold spraying, nose cones*

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COLD SPRAYING

Low pressure cold sprayed TiO_2 suspension coatings for visible-light photocatalytic applications

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This work discusses the spraying of TiO_2 suspensions using one of the most cost-efficient thermal spraying technique - low pressure cold spray method without vacuum or special shielding gases. The main purpose of coatings preparation is to form photo-catalyticaly active coatings to be activated by visible light for water purification. The presentation will start with comparison of the self-synthesized solid (powders) and liquid (suspensions) feedstocks with commercially available ones to discuss the benefits and drawbacks of spraying them. Afterwards, the samples of spraying suspensions with different spraying parameters, various feedstock powders as well as examples of heat treatment following the spraying process will be presented and discussed with regards to the selected properties, such as morphology, roughness, or crystal structure of obtained TiO_2 coatings. This study shows that possibility of low pressure cold--spraying of visible-active TiO_2 coatings may be efficient and competitive solution for large-scale photocatalytic coatings production, which is worth of further research.

Keywords: *low pressure cold spray, TiO_2, suspension spraying*

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ADDITIVE MANUFACTURING

Properties and applications of titanium coatings in additive manufacturing

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New low-cost manufacturing technologies are the base for further development for many branches of industry. Titanium with high strength to weight ratio and excellent corrosion resistance in many media including seawater is an irreplaceable material for many applications in aerospace. Currently used technologies for manufacturing titanium components which involve casting, forging, extrusion and machining are expensive and labor-consuming. Moreover, production process of many parts leads to significant losses of material that can reach up to 60%. Therefore, direct producing titanium is crucial in aviation industry. Additive manufacturing technology allows to manufacture parts of machines based on layer by layer deposition. This process allows to produce components with complex shapes and additionally significantly lower time and cost. Recently, cold spraying has joined to the group of applied additive technologies as selective laser sintering (SLS) or direct metal deposition (DMD).

Cold gas spraying technology was developed in the mid-1980s by a team of prof. A. Papyrin at the Institute of Theoretical and Applied Mechanics in Novosibirsk. In the first years, research focused mainly on metal coatings in the area of surface modification. The obtained results allowed for the introduction of this method to the industry and subsequent research on ceramic reinforced metal matrix composites. In recent years, cold spraying has continued to be used in additive manufacturing. Advantages of this method compared to fusion-based additive manufacturing technologies include a wide range of materials, short production time, no dimensional limitations for machine parts and the possibility of their regeneration also without disassembly.

The objective of presented studies is to analyze microstructure and mechanical properties of cold sprayed titanium structure for application in additive manufacturing.

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ADDITIVE MANUFACTURING

Wire Arc Additive Manufacturing as an effective method of fabrication of 316L steel structures

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Research was conducted on the additive manufacturing (AM) of 316L austenitic steel elements by the multi-layer wire arc additive manufacturing (WAAM) method. The applied heat source (CMT method) in the form of an electric arc in the multilayer deposition process causes that a significant amount of heat is introduced into the produced structure, modifying its structure and changing the conditions of bead deposition. This is especially important in the case of stainless steels, for which too high temperature can significantly reduce, for example, corrosion resistance, which requires the deposition process to be carried out in a controlled manner.

The work includes studies related to the production of flat wall models. Technological parameters of the deposition process were determined, which resulted in satisfactory model structure, without significant inconsistencies. The surface geometry conditions of the produced walls were characterized by non-contact measurements with the use of image-based techniques. The microscopic examination of the incrementally deposited 316L steel was performed, aimed at assessing the impact of the multiple thermal cycle on the properties of produced beads.

The non-contact tests of the geometries of the manufactured walls showed that the surface of these models is characterized by a high waviness, both in the direction of deposition and in the model's growth. Tests have shown that surface waviness can be reduced by controlling the amount of heat accumulated in the material. Microstructural studies revealed, among other things, strongly oriented structure in the form of columnar crystals. A large amount of heat accumulated in the material during multi-bead deposition may affect the mechanical properties of the obtained structures and their corrosion resistance.

Keywords: *WAAM additive manufacturing, steel 316L, microstructure, geometry*

Day I	ADDITIVE MANUFACTURING

Notes

Day I

ADDITIVE MANUFACTURING

Effect of shot peening on corrosion resistance of additive manufactured 17-4PH steel

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Components produced by additive manufacturing (AM) via direct metal laser sintering (DMLS) have typical as-fabricated surface defects. As a result, surface properties of AM products should be modified to increase their strength, anti-wear behaviour, and at the same time to ensure their high corrosion resistance. Surface modification via shot peening is considered suitable for additive manufacturing of engineering devices made of 17-4PH (X5CrNiCuNb16-4) stainless steel. The objective of this study was to determine the effect of three types of blasting media (CrNi steel shot, glass and ceramic beads) on the corrosion resistance of specimens of DMLS 17-4PH stainless steel. Results demonstrated that shot peening caused steel microstructure refinement and induced both martensite (α) formation and retained austenite (γ) reduction. 17-4PH specimens peened showed the increase in surface hardening. DMLS 17-4PH specimens modified by shot peening exhibited different surface morphology, hardness and microstructure, and thus these properties affect corrosion performance.

Keywords: *additive manufacturing, microstructure, shot peening, stainless steel, corrosion*

Day I	ADDITIVE MANUFACTURING

Notes

Day I

ADDITIVE MANUFACTURING

Filament-Based Metal Additive Manufacturing: Research on Porosity for 316L Steel Structures

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Most existing methods for additive manufacturing (AM) of metals generate very high operating costs due to the large investment in equipment, metal powders and work safety. A relatively new approach to metal parts production is Fused Deposition Modeling Sintering (FDMS) technology, which uses metal-plastic composite filaments. This method is distinguished by the lowest cost of devices and consumes significantly less energy compared to other metal additive technologies.

One of the most important issue in metal AM is the porosity of the structures, which affects the integrity and mechanical characteristics of the prints. In this work, based on the Taguchi design experiment, a set of samples was printed by using 316L-based composite filament. Four variables were included when designing the experiment, namely: (a) layer height, (b) print speed, (c) nozzle temperature, and (d) infill pattern. In order to analyze the porosity in printed samples the scanning electron microscopy (SEM), Archimedes density test, and computed tomography (CT) were performed. It has been observed that the shape of pores strictly depends on the method of filling the layers, and their size depends mainly on the height of the printed layers. Moreover, it was found that the greatest influence on the porosity has variable (a) layer height. This work demonstrates an analysis of the impact of printing process parameters on the porosity of metal structures and opens up research on further optimization of the FDMS process and increase in print quality.

Keywords: *FDMS technology, porosity, metal additive manufacturing, SEM, CT*

Day I	ADDITIVE MANUFACTURING

Notes

Day II

HVOF SPRAYING

Influence of nano-carbides addition on WC-Co coatings residual stresses

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Conventional WC-Co coatings have been recently modified with nano-sized particles in order to improve their properties. Modification of the coatings with nano-sized carbides may provide higher wear resistance or phase composition stability of the thermal sprayed coatings. This work characterized the changes of the residual stresses in the coatings induced by WC and TiC nanoparticles introduced into WC-Co coating.

Agglomerated and sintered WC-17Co feedstock powder was mixed with 5% nano-sized TiC, and 5% nano-sized WC and then deposited on a steel substrate by High Velocity Air Fuel spraying. The coatings were characterized by scanning electron microscopy, EBSD, and residual stresses were performed by XRD using sin 2 ψ method. In all examined coatings the residual stress were compressive in nature. Introduction of nano-sized WC resulted in two-fold reduction of linear stress and slight reduction of shear stress contribution. While nano-sized TiC addition into WC-Co coating reduced the stress significantly.

Day II	HVOF SPRAYING

Notes

Day II

HVOF SPRAYING

Improving the wear behaviour of AISI 431 stainless steel coatings by gas nitriding

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Surface hardening are established processes to improve the wear behavior of steel surfaces. The combination of thermal spraying of stainless steel and thermochemical post treatment has already been investigated. In particular, the gaseous processes, such as gas nitriding, offer the advantage of an increased hardness depth due to the characteristic porous microstructure of the coatings without prior surface activation. However, the primarily examined austenitic stainless steel coatings tend to delaminate at the edge or even completely during the thermochemical processes, which is unsuitable for industrial applications. Another disadvantage is the choice of substrate material. In the present work, therefore, the martensitic-ferritic material AISI 431 was deposited on a mild steel by HVOF spraying and gas nitrided. The samples showed no adhesion problems even in the edge area. A uniform hardness depth of 80 µm were proved by etched cross-sections, glow-discharge optical emission spectroscopy and hardness depth profiles. X-ray crystallography revealed an iron nitride layer of Fe_4N, results in a significant improvement of the wear behavior in ball-on-disc and reciprocating ball-on-plane tests against Al_2O_3 as well as in abrasive scratch test compared to the as-sprayed condition.

Keywords: *high velocity oxy-fuel (HVOF), AISI 431, stainless steel, thermochemical treatment, hardening, gas nitriding*

Day II	HVOF SPRAYING

Notes

Day II

HVOF SPRAYING

The Properties of the Gradient Layer obtained in the HVOF Spraying and Plasma Cladding Process

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The purpose of the thesis was to determine the possibility of the gradient layer fabrication between the plasma-deposited layers of Stellite 6 powder and the substrate of unalloyed steel S355JR, with the usage of HVOF spraying NiAl coating. The overlay welds were applied on various process parameters by changing current, travel speed and powder feed rate. The scope of the tests included the analysis of the chemical and phase compositions and hardness measurements, as well as the macro- and microscopic metallographic tests of cladding layers.

Keywords: *gradient layer, plasma cladding, Stellite 6, HVOF spraying*

Day II	HVOF SPRAYING

Notes

Day II

HVOF SPRAYING

Comparison of cavitation erosion resistance and tribological behaviour of WC-CoCr, WC-Co and WC-Cr_3 C_2-Ni coatings deposited via HVOF

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Paper investigates the cavitation erosion (CE) and sliding wear behaviour of cermet coatings deposited by HVOF. Coatings were deposited using the WC-CoCr, WC-Co and WC-Cr_3C_2 -Ni feedstock powder onto magnesim AZ31 substrates. Microstructure, porosity, hardness and phase composition were investigated. Cavitation erosion testing was done using ASTM G32 standard with stationary sample method. Cavitation erosion curves and erosion mechanisms of cermets were comparatively analyzed. The dry sliding wear results were done using ball on disc tribometer using WC-Co counterball and wear factor and friction coefficient were studied. Both cavitation erosion resistance and sliding wear properties of WC-CoCr coatings exceed those reported for WC-Co and WC-Cr_3C_2-Ni coatings. The sliding wear mechanisms were analyzed using microscopic and profilometric analysis with relation to WC-Co countersball. The cavitation erosion wear mechanisms of both coatings were observed using SEM-EDS. Differences relating to coatings time-erosion behavior were analyzed in relation to the coatings mechanical and microstructural properties. Finally, original CE model of cermet's combine the microstructural properties of the coatings has been proposed. This paper gives a remark for designing the thermal spray coating microstructure for both anti-erosive and anti-wear performance.

Keywords: *cavitation erosion, sliding wear, wear mechanism, microstructure, failure model, HVOF*

Day II	HVOF SPRAYING

Notes

Day II

DEVELOPMENTS IN MATERIALS

Development of $CoCr_{0.65}FeNi$-BsiC as self-fluxing high-entropy for thermal spraying

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Self-fluxing alloys are used as thermal spray coatings against strong tribological and corrosive stresses. In order to obtain a completely dense and strongly adherent coating, they are subsequently remelted. In particular, nickel- and cobalt-based alloys have been used so far. The extension of the alloying approach to complex alloys without a determining main alloying element promises a significant increase in the coating properties and thus an increase in component service life. The current work focuses on the alloy development of the high-entropy alloy $CoCr_{0.65}FeNi$-BSiC using an electric arc furnace, the subsequent powder production as well as the coating production by thermal spraying. The properties of the coatings are characterized and evaluated. The results confirm the potential of the new development approach.

Day II	DEVELOPMENTS IN MATERIALS

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Day II

DEVELOPMENTS IN MATERIALS

Recent developments in ultrasonic atomization for new materials design

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Recently rapid developments of new materials for spraying and additive manufacturing technologies are often limited by the supply of tailor-made powders. The ultrasonic method of powder production has been proven as an effective method for spherical powder production, yet the production of specific alloys still possesses different challenges.

During the presentation, several examples of new materials including refractory metals, precious superalloys, and volatile zinc-based composites are shown with respect to the manufacturing parameters. New hybrid plasma-ultrasonic and induction-ultrasonic powder production routes were optimized specifically for demanding materials. Complex in-situ heat treatment during powder processing could provide as well amorphous and relaxed crystalline structure depending on the parameters chosen. Double-transducer ultrasonic system was shown for Metal Matrix Composites production within the SiC-Al system. The final application of the powders is shown for Additive Manufacturing technologies as well as for coating development.

Keywords: *powder, atomization, ultrasonic, metallic glasses, metal matrix composites*

Day II	DEVELOPMENTS IN MATERIALS

Notes

Day II

DEVELOPMENTS IN MATERIALS

First Co-based Bulk Metallic Glass developed by Selective Laser Melting

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Bulk Metallic Glasses (BMG) also known as an amorphous metals are in interest of the scientist since the first non-crystalline alloy was obtained in 1960 (Au80Si20, Klement [1]). This alloy was obtained as a very thin foil (around 10 μm). The next scientist worked to invent an alloy with critical thickness greater than 5 mm, which was established 20 years later (Turnbull [2]). Now, instead of sizing up the critical thickness of amorphous alloys, the methods of their development are studied. The method should ensure the unlimited sizes of samples despite of their limitations in form of critical thickness. In this work, the method of Selective Laser Melting (SLM) was studied. The innovation in this article concerns the use of Co-based alloys with high glass forming ability. More specifically, two alloys based on Co were studied, CoBFeSiNb and CoBFeTaSiCu. As the feed-stock alloys were in powder form in size of 20–50 μm obtain by gas atomization. The printing was done with mLab ConceptLaser in an argon atmosphere with a straight line scanning strategy. Research contributed to testing the scanning speed and laser power. The research has two stages. The first parameters were taken from similar studies for Fe-based alloys. In the second stage, the best parameters from the first experiment were slightly modified to find the best sets of scanning speed and laser powder for each alloy. Samples from the first stage were validated by optical analysis. The samples from the second experiment were analysed by optical microscopy, scanning electron microscopy (SEM), X-ray diffractometer (XRD), and nanoindentation. Those studies show that the best printing parameters for CoBFeSiNb are 500 mm/s, 65W and for CoBFeTaSiCu 800 mm/s, 70 W. However, some improvements need to be made to reduce the number of cracks. Microscopy analysis showed the number of porosity and cracks in both alloys, but in CoBFeTaSiCu the cracks formed the dens grid, indicating low quality of the printed samples. The XRD analysis shows the presence of a peak in CoBFeSiNb around 44° (2θ angle). The CoBFeTaSiCu XRD analyse shows several strong crystallization peaks, which implicated that the crystallization process occurred in the whole volume of samples. The results show that it is possible to print Co-based BMG and the results will contribute to the better quality of the samples in further research.

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Day II	DEVELOPMENTS IN MATERIALS

Notes

Day II

DEVELOPMENTS IN MATERIALS

Ultrasonic atomization for metal powder production – technology demonstration

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In this work, the novel process of ultrasonic atomization for metal powder production is presented. The technology, namely *ULTRAMIZER*, is a response to the strict demands for metal powders given by additive manufacturing, thermal spraying, and other advanced production processes.

The general idea of ultrasonic atomization is discussed first, and the technology demonstrator is presented. Basic information on the sonotrode design, responsible for disintegration of feedstock melt, is given. Then, verification of the atomization phenomena taking place at the sonotrode surface when applying water or metal droplets is carried out. The occurrence of droplet breakdown is visualized by the shadowography-based diagnostic system.

Furthermore, the preliminary 316L stainless steel powders produced by means of ultrasonic atomization are compared to similar materials but manufactured by conventional gas atomization. It is shown that the ULTRAMIZER technology is capable of producing metal powders with a very narrow particle size distribution and with a very high sphericity ratio. This makes the technology fit well to the two important requirements posed by modern powder-based manufacturing processes.

Keywords: *ultrasonic atomization, sonotrode, metal powders, 316L powder*

Day II	DEVELOPMENTS IN MATERIALS

Notes

Day II | THERMAL SPRAY PROCESSES (I)

The influence of used thermal spray technology deposition on the NiCr coatings performance

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Ni-based thermally sprayed coatings are widely used for their resistance to corrosion and oxidation even in high temperature environment. With respect to the presence of other alloying elements, mechanical properties are expected – resistance to abrasion or erosion wear. In addition to the composition, the behavior of the coatings is also influenced by the applied technology used. In the paper, the influence of variable Ni-20Cr coatings microstructure, resulting from different thermal spraying technology (TWAS, HVOF and CS), is discussed with regard to the coating performance. Abrasive wear resistance in accordance with ASTM G-65, solid particle erosion resistance, cavitation erosion resistance and corrosion resistance were evaluated. The results showed the superior performance of cold sprayed NiCr coating namely under erosion and cavitation related load.

Keywords: *NiCr, thermal spray, cold spray, wear, corrosion*

Day II	THERMAL SPRAY PROCESSES (I)

Notes

Day II

THERMAL SPRAY PROCESSES (I)

Cold Spray Additive Manufacturing (CSAM) of space and aviation components

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In space and aviation industry, materials with high strength to weight ratios along with properties such as excellent tensile strength, fatigue strength and fracture toughness in combination with low specific weight are needed. However there are specific parts such as launcher propulsion system components, where the focus of the properties are on heat conductivity, mechanical strength at elevated temperatures and dissimilar material combinations. The manufacturing of highly complex components such as combustion chambers is straight forward by using cold spray process. While using Cold Spray Additive Manufacturing (CSAM) technology, it is possible to create a combustion chamber (used materials: high-strength Cu alloy and for outer jacket Inconel) without restrictions in terms of size and with properties that are superior to the AM process. Looking at the deposition rates of about 10 kg/h for Cu-alloy and 6.7 kg/h for Inconel the process is very economic, concerning manufacturing speed. Additionally, the CSAM process is known for very high deposition efficiencies (DE), in the discussed example values of 99% for Cu-alloy and of 79% for Inconel were measured and this also reduces the production costs compared to other AM technologies significantly.

Cold spraying is also a cost-effective technique for repairing and restoring industrial application products to refurbish and reuse the damaged parts. The properties of cold spraying for the deposition of materials in the solid state make it an attractive method for repairing/restoration, while maintaining the unique properties of the original components or improving the properties of the repaired components by depositing essential materials, especially in regard to corrosion and wear resistance.

Keywords: *cold spray; additive manufacturing; CSAM; propulsion system, combustion chamber, Inconel on Cu-alloy, repair and refurbishment*

Day II	THERMAL SPRAY PROCESSES (I)

Notes

Day II

THERMAL SPRAY PROCESSES (I)

Approach to design photocatalytic TiO_2 coatings – effects of low-pressure cold spray parameters on coatings characteristics

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The rapid increase of the demand for clear water roots the growth of the global photocatalyst market. Typically, the photocatalyst is used in the form of a powder dispersed in the wastewater. The high specific surface of such suspended photocatalysts is an indisputable advantage. But, on the other hand, the regeneration of the dispersed photocatalyst is a clear disadvantage of the slurry photocatalytic reactors. Therefore, simple and efficient methods that allow immobilizing the photocatalytic material on the support material are constantly progressing. One of them is thermal spraying techniques, in which melted/deformed powder material is sprayed onto a substrate. To produce an efficient photocatalytic coating of desirable crystalline structure and high specific surface, one has to avoid overheating the TiO_2 powder. Hence, choosing a low-temperature process such as low-pressure cold spray (LPCS) is most suitable. In this study, photocatalytic coatings were sprayed using self-synthesized TiO_2 powder. Surface and material features determine photocatalyst efficiency. Consequently topography and morphology of the coating surface along with the degree and the type of crystallographic structure of the coatings material were changed by modifying chosen LPCS process parameters. Sprayed coatings were characterised using: using confocal microscopy, scanning electron microscopy and X-ray diffraction; the photocatalytic performance was evaluated by the decomposition of MB under UV irradiation; the mechanical properties of the sprayed coatings were examined using the scratch-test method. The obtained results allowed to correlate coatings structure with photocatalytic activity and choose spraying parameters resulting in a coating with the most promising photocatalytic properties.

Keywords: *LPCS, coatings, TiO_2, photocatalysis*

Day II	THERMAL SPRAY PROCESSES (I)

Notes

Day II | THERMAL SPRAY PROCESSES (I)

Effect of rhenium additive on the microstructure, hardness, and abrasive wear of WC12Co Re coatings

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Rhenium is an alloying additive used to increase the heat resistance of components. It can also be used to modify the characteristics of surface layers by surface engineering methods. This paper presents the results of the analysis of WC12Co Re coatings plasma sprayed with APS from mixtures of WC12Co and Re powders and surface-coated with rhenium of WC12Co-Re powders. The study was designed to determine the effect of Re content, powder preparation method, and process parameters on the coatings' microstructure, hardness, and abrasive wear test according to ASTM G 65-04. The analysis results indicated that Re could be uniformly distributed in the structure of coatings obtained from WC12Co-Re powders. Furthermore, about 10% higher microhardness of layers with rhenium, applied from mixed powders concerning WC12Co coatings, reaching up to 1100HV(0.5). However, despite the average lower hardness measured for the WC12Co-Re specimens, these coatings exhibited slightly lower, by about 2%, values of the weight wear coefficients Kb concerning the properties of the WC12Co coatings. The results indicate that rhenium added to WC12Co-Re coatings can increase their tribological properties, but a slightly increased hardness and abrasive wear resistance do not compensate for the much higher cost of the coating materials.

Day II	THERMAL SPRAY PROCESSES (I)

Notes

Day II

THERMAL SPRAY PROCESSES (I)

The studies on microstructure, tribological and cavitation erosion performance of Al_2O_3–TiO_2 coatings sprayed by APS, SPS and S-HVOF

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In current work, different alumina-titania coatings, i.e., pure Al_2O_3, Al_2O_3+13 wt. % TiO_2 and Al_2O_3+40 wt% TiO_2, produced by various thermal spray processes, namely: (i) atmospheric plasma spraying (APS), (ii) suspension plasma spraying (SPS), and (iii) suspension high-velocity oxy fuel spraying (S-HVOF), were investigated. Micrometer-sized powders and water-based suspensions of fine submicrometer-sized powders were used as a feedstock. The main aim of the studies was to investigate the influence of spray technology and spray feedstock characteristics, mainly chemical composition, i.e., TiO_2 content, on the properties of the manufacturing coating. The deposited coatings were characterised in terms of selected properties, including instrumental hardness, Young's modulus, sliding wear resistance, and cavitation erosion resistance. The obtained results showed that the sliding wear rate decreased with the increasing content of the α-Al_2O_3 phase in the coating hardness, which also caused increasing of hardness and elastic modulus. In the investigated coatings, the dominant wear mechanism was fatigue-induced brittle delamination, followed by the adhesive smearing of the wear debris. Results revealed that the dense microstructures characterised by a high hardness and high content of α-Al_2O_3 phase favored the resistance of coatings to cavitation erosion. Cavitation erosion was initiated at the microstructural discontinuities like pores or microcracks, resulting in damage by brittle failure with cracking and spallation, which ended up forming large cavitation craters.

Keywords: *thermal spraying, alumina-titania coatings, suspension, microstructure, phase analysis, wear resistance, cavitation erosion*

Day II	THERMAL SPRAY PROCESSES (I)

Notes

Day II

HARDFACING PROCESSES (I)

Wear Resistance of Structural Steel Surfaces Obtained by Plasma Transferred Arc Welding

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The adaptation of structural steel in modern day production keeps increasing owing to its cost effectiveness, excellent strength, greenness, and quality, with typical applications seen in manufacturing, handling and transportation of raw materials in agriculture, oil and gas, mining, utilities and recycling. The demanding nature of tasks to which these steels are exposed, subjects them to severe wear and an eventual material failure over a short period. This has prompted the need for ways to improve upon the wear resistance of structural steel for such applications. In this study, powder plasma transferred arc welding (PPTAW) technology was used to coat the surface of structural steel with metal matrix composite (MMC) powders composed of Nickel matrix and tungsten carbide (WC) reinforcement. The concentration of WC reinforcement as well as the PPTAW process parameters, plasma transferred arc (PTA) current and plasma gas flow rate (PGFR) were varied to determine the optimal parameters with the best performance. Influence of process parameters on the microstructure, wear resistance and the mechanism of wear and anti-wear protection were investigated by means of scanning electron microscopy (SEM) and light microscopy. The relative abrasive wear resistance of the as-deposited layers was investigated against the performance of abrasive wear resistant steel, Hardox 400, which has an approximate nominal hardness of 400 HV. The resulting wear resistance was found to have increased in magnitude up to 5.7 times. The use of Cr as an alloying element enhanced the wear resistance and the surface hardness by 29.4%.

Day II	HARDFACING PROCESSES (I)

Notes

Day II

HARDFACING PROCESSES (I)

Surfacing of low-alloy steel with austenitic flux-cored wire

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Difficult operating conditions of power devices require the use of materials with high resistance to exploitation factors. In many applications, it is economically justified to use bimetallic elements obtained by surfacing processes. The article deals with verification of the possibility of surfacing the S355J2C + N low-alloy steel heat exchanger elements with the FCAW (flux cored arc welding) process using 316L austenitic flux cored wire. Padding welds were made with a buffer layer of 309MoL wire, some of them were interpass cooled with a stream of compressed air. The samples were subjected to visual, penetration, ultrasonic testing as well as micro- and macroscopic metallographic test, bending test, chemical composition analysis, hardness and ferrite content measurements. It was found that the proposed procedure provides components with properties suitable for use in the operating conditions of heat exchangers. In addition, the use of interpass cooling with the use of compressed air made it possible to reduce the cooling time of the padding welds to the temperature of 150°C from 5–10 minutes to the range of 30–45 s.

Keywords: *low-alloy steel, austenitic stainless steel, flux cored wire, surfacing*

Day II	HARDFACING PROCESSES (I)

Notes

Day II

HARDFACING PROCESSES (I)

Effect of in-situ synthesis of TiC in cobalt-based coatings on erosive wear resistance

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The aim of the study was to improve the erosive wear resistance of the Stellite 6 alloy by *in-situ* synthesis of titanium carbide in laser cladding process. The influence of Ti, W and C alloy additives on the changes in the microstructure was analyzed. The coatings were characterized by low dilution and absence of welding imperfections in the form of cracks or porosity. Tests carried out on the transmission electron microscope (TEM) showed that addition of titanium enables the formation of complex carbide phases of (Ti,W)C types. As the (Ti,W)C content increases, decrease in microhardness was observed due to the absence of $Cr_7C_3/Cr_{23}C_6$ eutectic carbides. Comparative erosion tests between metallic Stellite 6 an composite Stellite 6/(Ti,W)C coatings showed that composite coatings exhibit superior erosion resistance mainly at the oblique impingement conditions.

Day II	HARDFACING PROCESSES (I)

Notes

Day II

HARDFACING PROCESSES (I)

Pad welding of ultra-high strength steel in water environment

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The number of marine and offshore structures made with ultra-high strength steel (UHSS) is developing annually. These kind of constructions may undergo failures, with the necessity of repairs. To avoid high-cost of the process, many repairs are performed direct in the water. However, the weldability of UHSS in the water environment is unknown. In the presentatin, the possibility of underwater wet welding by covered electrodes of S1300 ultra-high strength steel has been described. For tests, 4 mm and 10 mm thick plates were selected. The visual, metallographic macro- and microscopic tests, and Vickers HV10 measurements of specimens welded with two nonparallel beads were performed. Following performed tests, the effectiveness of temper bead welding (TBW) technique was verified. It was proved that proposed technique leads to positive microstructural changes. Also, it allows to reduce the number of cracks in different areas of welded joints. Moreover, it was found that TBW leads to decrease the hardness of S1300 UHSS joint by 30–80 HV10 in the weld metal and 40–100 HV10 in heat-affected zone (HAZ). Finally, it was stated that the thickness of the base material does not affect the effectiveness of the TBW technique.

Keywords: *underwater welding, ultra-high strength steel, covered electrodes, temper bead welding*

Day II	THERMAL SPRAY PROCESSES (I)

Notes

Day II

HARDFACING PROCESSES (I)

Reuse of heat- and high-temperature creep resisting powder materials possibility to surfacing by multimode laser welding in power plants parts

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This description presents the possibilities of using the spheroidal powder material belonging to the group of heat-resisting and high-temperaturecreep resisting welding consumables. The material is dedicated to protecting the power boiler plants parts, especially heat exchangers – water walls. This powder was obtained in the welding waste treatment process. Full process and application suitability the treated powder has been demonstrated. It was put on test to a laser surfacing by welding process using a direct multimode laser with a rectangular adjustable spot as a HighLight DD High Power Laser Coherent, cooperating with the KUKA KR 30 robot. The chemical composition of work environment and the treated powder determined with the Mira 3 TESCAN scanning microscope with the Ultim Max 65 OXFORD analyser. Chemical microanalysis of padding welds was carried out too. To Vickers method micro-hardness measurements used the INNOVATEST Nexus equipment and the padding welds erosion resistance defined accordance with ASTM G 76. The padding welds abrasion resistance in accordance with ASTM G 65 were carried out too. Moreover high-temperature gas corrosion resistance was determined using the gravimetric method on a stand equipped with a L9/12/SW Nabertherm furnace with the Radwag AS 220.R2 PLUS analytical balance, the corrosion resistance was determined using the Potentiostat 1285 Solartron apparatus. All tests were performed at the Institute of Materials Science and Engineering of the Poznan University of Technology.

Keywords: *reuse welding consumables, direct laser, surfacing by welding, power engineering unit, water walls*

Day II	HARDFACING PROCESSES (I)

Notes

Day II

THERMAL SPRAY PROCESSES (II)

Solution precursor plasma spraying of TiO_2-based coatings using catalyst-free precursors

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Titanium dioxide (TiO_2) has been regarded as one of the promising metal oxide semiconductors due to its unique mechanical and chemical resistance and photocatalytic properties. The photocatalytic activity of TiO_2 depends strongly on the phase composition and porosity. The coatings deposited via solution precursor plasma spray (SPPS) process typically possess a highly porous structure and high specific surface area. This work reports the deposition of TiO_2 coatings from a catalyst-free solution precursor. Effects of varying the solution concentration, injection feed rate, plasma power and spray distance on coating phase composition and microstructure were investigated. Thermal behavior of the solution precursor was altered when the solution concentration was increased from 0.3 M to 0.6 M. Scanning electron micrographs show the nano-/submicron-sized spherical particles (<1 μm) with sintered and melted particles at the coatings' surface. The cross-sections presented porous coating microstructure, a thickness of about 5 μm–8 μm and the coating follows the surface orientation of the substrate. XRD analyses confirm that the coating is composed of anatase and rutile TiO_2. With the increase of the concentration of the solution precursor, the rutile content increases and anatase content decreases. When added with Fe ion, the phase transition temperature increases indicating the prolonged phase formation of crystalline TiO_2 . These observations imply that the properties of TiO_2 coating can be manipulated by combination of process parameters for a specific application.

Keywords: *SPPS, TiO_2 coatings, TiO_2-based coatings, thermal behavior*

Day II	THERMAL SPRAY PROCESSES (II)

Notes

Day II

THERMAL SPRAY PROCESSES (II)

Coatings kinetic deposition using powder materials synthesized by High Energy Ball Milling and Spark Plasma Sintering route

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The kinetic deposition technologies like Low Pressure Cold Spraying (LPCS) and Aerosol Deposition (AD) allow the deposition of films by deformation and fracture of the powder particles without the interference in their phase structure. In order to achieve high deposition efficiency and coatings quality, the crucial step in those methods is the powder preparation. In the case of novel-type materials, the high cost and poor phase quality are barriers to acquiring repeatable and reliable results. This study presents an alternative route for synthesis of powder materials from commercially available elementary materials using planetary High Energy Ball Milling (Pulverisette 5 Premium Line, Fritsch) and Spark Plasma Sintering (HP D 25/3, FCT Systeme). A study using two modes of kinetic deposition (LPCS and AD) was conducted. The changes in phase and crystal structure of the powder materials after each process were observed. The coatings microstructure and mechanical properties were assessed.

Keywords: *abstract, conference, low pressure cold spraying, aerosol deposition, powder metallurgy, spark plasma sintering, high energy ball milling*

Day II	THERMAL SPRAY PROCESSES (II)

Notes

Day II

THERMAL SPRAY PROCESSES (II)

Comparative analysis of microstructure and selected properties of WC-Co-Cr coatings sprayed by HVOF on different substrate materials

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The purpose of the study was to compare the microstructure and selected mechanical properties of WC-Co-Cr coatings deposited by High Velocity Oxy Fuel (HVOF) method onto two types of substrate material, structural steel S235 and magnesium alloy AZ31. The influence of the substrate material on the microstructure, changes in the phase composition, porosity, microhardness and fracture toughness was investigated. In both cases the deposited coatings were characterized with fine grained microstructure. The X-ray diffraction (XRD) revealed presence of following phases, for steel substrate there were: WC, W_2C, WC_{1-x}, $Co_3W_9C_4$ and for magnesium one: WC, W_2C and $Co_{0.9}W_{0.1}$. The WC phase is the most desirable and stable one. The results of porosity: 2.71 ± 0.5 vol. % and 2.87 ± 0.8 vol. % for AZ31 and S235, respectively, as well as microhardness: 1235 ± 113 HV0.1 and 1255 ± 124 HV0.1 showed slightly differences, in range of standard deviation. Conducted investigations revealed that it is possible to replace substrate material with another, in this case much lighter, without deterioration of the coating properties.

Keywords: *different substrate materials, WC-Co-Cr coating, HVOF, microstructure, properties*

Day II	THERMAL SPRAY PROCESSES (II)

Notes

Day II

HARDFACING PROCESSES (II)

The structure and properties of laser cladded Inconel 625/TiC composite coatings

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The article presents the research in the field of production of metal-matrix composite coatings using laser cladding technology. The general purpose of producing composite coatings is the improvement of the materials surface wear resistance. In the research, Inconel 625 was used as a matrix material. Nickel-based superalloys are commonly used in industry because they show a number of beneficial properties including high tensile and fatigue strengths and resistance to high-temperature corrosion in aggressive environments. However, this alloy shows low wear resistance of the surface, therefore for the tests, the Inconel 625-based composite coatings were produced with the addition of 10, 20 and 40 vol.% of TiC particles as reinforcement. In general, the addition of TiC particles had a positive effect on the erosion resistance of the surface. The aim of the current research was to test the influence of TiC particles reinforcement of Inconel 625 laser cladded coatings on the surface corrosion resistance. For the tests, homogeneous laser cladded composite coatings were produced. The proceeded tests included penetrant tests, macrostructure and microstructure analysis, X-Ray Diffraction, microhardness and corrosion resistance tests.

Keywords: *composite coatings, nickel-based superalloys, laser cladding*

Day II	HARDFACING PROCESSES (II)

Notes

Day II

HARDFACING PROCESSES (II)

Cavitation erosion and water environment sliding wear of structural steel overalys deposited by underwater wet welding

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The participation of high strength steels in marine and offshore structures is increasing, which makes it necessary to develop recommendations for underwater repair welding works. Thus this paper presents the results of cavitation erosion and sliding wear testing done in water environment of structural steel hardfacings deposited by underwater wet welding. Steel overalys were underwater welded by MMA method on high-strength, low-alloy (HSLA) steel. Different filler materials were deposited using selected welding current values. The microstructure, dilution and hardness of the overlays were investigated and combined with the operational results. Cavitation erosion tests were conducted using the vibratory method in accordance with the ASTM G32 standard. Sliding wear was examined with the use of a ball-on-disc tribometer, and friction coefficients were measured. The sliding and cavitation wear mechanisms were identified with the SEM method. Wear results were compared with the reference structural steels grades namely S355J2, S420G2, S460ML. Microstructure of overlays and hardness has a tremendous Welding parameters and appropriate selection of the filler material influences the underwater operational performance of underwater wet welding overlays.

Keywords: *overlay welding, MMA welding, cavitation erosion, tribology, friction coefficient, underwater wet welding*

Day II	HARDFACING PROCESSES (II)

Notes

Day II

HARDFACING PROCESSES (II)

On the influence of technological parameters of numerically-controlled GMAW hardfacing process on the hardness of wear-resistant layers fabricated with TC-enriched flux-cored wires.

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In this paper the authors analyzed the influence of technological parameters of flux-cored hardfacing process on the weld bead geometry and hardness using Taguchi robust design of experiment. Macrocrystalline tungsten carbides embedded in nickel-based matrix were applied on C45 steel bars with independent variables being the electrode stick-out, voltage and levels of wire feed and head velocity quotient. The authors tested the robustness of the process in order to ensure maximum hardness and overall quality of the GMAW applied abrasion-resistant layers. In order to perform the measurements, the padded steel bars were cut, polished and etched in order to reveal the microstructure, precise geometry of the bead and allow to examine the Vickers hardness near the weld face, inside the padding and near the HAZ zone. The conducted study can help in developing a strategy for strenghtening rock-cutting tools on a specific example of a conical pick, used in mining industry as a consumable.

Day II	HARDFACING PROCESSES (II)

Notes

P1 **POSTER SESSION**

The microstructure and mechanical properties of cold sprayed Cr_3C_2-25(Ni25C) and (Cr_3C_2-25(Ni25C))-(Ni-graphite) coatings

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The Cr_3C_2-25(Ni20Cr) and (Cr_3C_2-25(Ni20Cr))-(Ni-graphite) cermet coatings were cold sprayed on Al 7075 alloy substrates using an Impact Innovations 5/8 cold spray system with robot Fanuc M-20iA. The coating microstructure, surface morphology, phase composition, hardness, friction coefficient, wear-resistance and flexural strength have been characterised. The Cr_3C_2-25(Ni20Cr) deposit consisted of the nickel-chromium matrix formed by elongated plastically deformed Ni20Cr particles, into which the Cr_3C_2 were distributed. The (Cr_3C_2-25(Ni20Cr))-(Ni-graphite) deposits besides those components contained Ni and the solid lubricant (graphite) mainly distributed between crushed Cr_3C_2 particles or the deformed Ni20Cr matrix. They revealed a lower friction coefficient determined during ball-on-disc tests. The other tribological properties, such as wear index and the wear resistance with Al_2O_3 loose abrasive particles, were similar in both coatings. The graphite incorporation in the deposit structure resulted in lower hardness. To show the influence of graphite on the coating-substrate adhesion and susceptibility to the cracking three-point bending tests were performed under constant velocity or cyclic load. In the (Cr_3C_2-25(Ni20Cr))-(Ni25C), the force required to destroy the durability of the coating-substrate system was significantly higher than that without the solid lubricant. The three-point bending under cyclic load showed that a small amount of the graphite in the cermet coating prevents the formation of crack nuclei at room temperature and reduces the size of cracks in the deposit at 200 °C. They were observed only in the coating-substrate interface area.

Acknowledgements: This work is financially supported by the National Science Centre, Poland (Project No 2017/25/B/ST8/02228).

Keywords: *cold spraying, cermet coating, mechanical properties, flexural strength*

P2 **POSTER SESSION**

The effect of the annealing on the microstructure, mechanical and tribological properties of cold sprayed (Cr_3C_2-25(Ni20Cr))-5(Ni25C) cermet coatings

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Coatings produced using the cold sprayed method are characterised by several advantages over other thermal spray methods, e.g., no change in phase composition after deposition, negligible porosity and a homogeneous microstructure. The properties of the cold sprayed (Cr_3C_2-25(Ni20Cr))-5(Ni25C) coatings combine good mechanical properties through hard ceramic particles, and a compact microstructure thought to the use of a metal matrix. In turn, the addition of solid lubricant as graphite improves the tribological properties of the deposits. The use of an annealing improves the coating mechanical and tribological properties, which favours longer operation of the working elements, however, it causes significant changes in their phase composition and microstructure.

The coatings were sprayed using the Impact Innovations 5/8 cold spray system with a Fanuc M-20iA robot arm using commercially available powders: Cr_3C_2-25(Ni20Cr) and Ni25C on a 1H18N9T steel substrate. The annealing of the coatings was carried out in a furnace at 500°C and 800°C for 72 hours. The phase and chemical composition, micro- and nanostructure, hardness, wear resistance, friction coefficient and adhesion of coatings were characterised.

XRD, SEM and TEM examinations showed the presence of new phases, i.a., Cr_7C_3 and Cr_2O_3, apart from these existing in the as-sprayed coatings, i.a., Cr_3C_2, and Ni-Cr ($Cr_{0.25}Ni_{0.75}$). The change in phase composition was related to the Cr_3C_2 transformation and carbide dissolution in the Ni-Cr matrix. The Cr_2O_3 chromium oxide was only visible on the surface of the modified coatings. The tribological tests showed a significantly lower wear index of annealed deposits when using loads of 5 N, 10 N and 15 N, compared to the as-sprayed deposits, regardless of the temperature used. The coatings heat-treated at 500°C examined under 20 N load revealed a similar wear index as the cold sprayed ones, whereas those annealed at 800°C showed their value less than twice. A higher friction coefficient was observed in the case of annealed coatings as compared to the as-sprayed ones.

Acknowledgements: This work is financially supported by the National Science Centre, Poland (Project No 2017/25/B/ST8/02228).

Keywords: *cold spraying, cermet coating, microstructure, hardness, wear index*

P3 **POSTER SESSION**

Microplasma sprayed multilayered coatings for resistance heating elements

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Electric heaters are widely used in domestic and industrial applications. The main part of the electric heater is the resistive heating element (RHE). The paper presents an analysis of the design features of resistive heating elements and areas of their practical application, as well as materials and technologies used in the manufacture of RHE and new results on application of microplasma spraying method for manufacturing RHE.

A microplasma spraying (MPS) method was used to fabricate a RHE consisting of a St3 steel plate with a sprayed electrically insulating sublayer of Al_2O_3 300 μm thick and resistive paths made of TiO_2 4 mm wide and 150 ± 50 μm thick. Measurements of the heating temperature of the resistive track using an IRISYS 1020 thermal imager made it possible to establish the operating temperatures and heat distribution over the surface of the RHE. The tests carried out showed the efficiency of the sprayed RHE up to a temperature of 200˚C.

The results of studying the causes of material losses in the process of MPS of resistive paths (TiO_2) are presented and the choice of optimal parameters for efficient MPS of coatings in the form of narrow paths on steel substrates is substantiated. Using the methods of regression analysis of the experimental results, equations were obtained to assess the degree of influence of MPS parameters on the material utilization coefficient (MUC). It has been established that such process parameters as the electric current and the plasma-forming gas flow rate have the greatest influence on MUC.

As a result of the experiment, a high efficiency of using the sprayed material during MPS of resistive paths from TiO_2 powder was established (the maximum MUC reached 89%), which indicates the prospects for using MPS technology in the production of RHE for direct heating and maintaining the temperature of product surfaces up to 200 ˚C.

Keywords: *microplasma spraying (MPS), multilayer coatings, resistance heating element (RHE), material utilization coefficient (MUC)*

P4 **POSTER SESSION**

Application of thermal plasma spraying of hydroxyapatite coatings on titanium trabecular substrates

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Nowadays, additive manufactured endoprostheses are becoming more and more widespread. The first case of installing an acetabular implant made of trabecular titanium printed on a 3D printer dates back to 2007, which coincided with the appearance of the second generation of 3D printers. Currently, more than 100 medical 3D printers operate in the US alone, manufacturing serial and individual components for maxillofacial surgery, neurosurgery, thoracic surgery, oncology and orthopaedics. The main technologies for 3D printing of implants are: selective laser melting (SLM), electron beam melting (EBM) and direct metal laser sintering (DMLS).

3D printed Ti-6Al-4V titanium alloy components for primary and revision hip arthroplasty are also available on the market. These products are manufactured by companies such as: Zimmer Biomet, Lima Corporate, Gruppo Bioimpianti, Permedica Orthopedics. Clinical studies have confirmed the efficacy of titanium alloy endoprostheses, which are bioinert materials, but in some cases such implants have been rejected in patients. In this regard, an urgent task is to increase the biocompatibility of endoprostheses functioning in the human body. This can be done by forming a layer of calcium phosphate ceramics (hydroxyapatite) on the implant surface. The adhesion strength of the hydroxyapatite (HA) coating to the endoprosthesis surface is one of the key characteristics of the HA coating, which must meet the requirements of ISO 13779-2:2018.

The authors of this paper are studying the possibilities of using technologies of thermal plasma spraying of HA on medical implants. In this work, the adhesion strength of a microplasma sprayed HA coating on a cylindrical sample with a trabecular structure made from titanium alloy by the SLM method was tested. The adhesion strength of the HA coating measured according to ASTM F1147 was 24.7±5.7 MPa, which satisfies the requirements of ISO 13779-2:2018. Thus, the results show the promise of using microplasma spraying of HA coatings on titanium trabecular implants to improve the biocompatibility of the implant surface.

Keywords: *thermal plasma spraying. microplasma spraying, selective laser melting (SLM), hydroxyapatite (HA)*

P5 **POSTER SESSION**

Structure and properties of HSLA steel melted by welding heat sources

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The main objective of the study was to investigate the effect of impacts in melting laser beam, plasma arc and using the TIG method on the properties and structure of steel microalloyed HSLA – 28MnTiNbVB (UTS = 1600 MPa) 12 mm thick. Remelting process was carried with variable linear energy. The resulting melted after a visual inspection on the basis of the requirements of the standard were tested destructive in so far as macroscopic and microscopic metallographic, hardness measurement, determining the area of the melting zone. Carried examinations have shown that laser beam remelted zones have correct geometry, but include gas pores that could be caused by very high cooling rates resulting in hindering gas evacuation from remelted zone. This gas pores are caused by trapping gases dissolved in metal or vaporizing alloying elements. Remelted zone is martensitic with lath structure a hardness of up to 600 HV10. Laths are smaller additionally smaller precipitations are more tightly packed compared to parent material. Plasma arc remelting process was carried with variable linear energy in range from 6 to 15 kJ/cm. Carried examinations have shown that plasma arc remelted zones have correct geometry, remelted zone is martensitic with lath structure a hardness of up to 580 HV10. In the case of remelting using the TIG method, the correct shape of the remelting was also obtained, with a martensitic structure with a hardness of 560 HV10. Examination results show that steel 28MnTiNbVB exhibits limited weldability.

Keywords: *HSLA-type steel, plasma arc, laser beam, TIG, remelting welding, martensite, tempering*

P6 **POSTER SESSION**

Investigations on the microstructure and corrosion resistance of different cermet coatings deposited by HVOF process onto light construction materials substrate

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The HVOF (High Velocity Oxy Fuel) thermal spraying technique has been widely adopted in many industries due to its flexibility and cost effectiveness. Standard applications of such coatings are connected with protection against wear, heat and corrosion. Hardmetal coatings deposited by HVOF process exhibit high density and mechanical strength. The properties of thermal sprayed hardmetal coatings, including their wear resistance in different tribological conditions, may however vary as a function of the feedstock powder properties, deposition technique and the process parameters. The HVOF method offers wide opportunities for engineering improved wear and corrosion protection, especially in situations demanding high wear resistance.

The present investigations focus on the microstructure and corrosion resistance of deposited WC-based commercial powders onto AZ91 magnesium alloy substrate. The aim of this work was to investigate the influence of feedstock material and its interaction with substrate in order to achieve the protection properties of deposited by HVOF process coatings. Three commercial available powders namely WC-Co-Cr, WC-Co and WC-Cr_3C_2-Ni were deposited onto AZ91 magnesium alloy with 400 mm spraying distance.

The paper presents results of the microstructure and corrosion resistance investigations. The microstructure of the as sprayed coatings were examined using electron scanning microscopy (SEM) and the corrosion investigation by the electrochemical corrosion tests. The corrosion resistance of coated and uncoated samples was compared. Electrochemical corrosion investigations (both methods, Stern and Tafel) were carried out in 3.5 NaCl solution. Based on obtained results it was found that the best corrosion resistance exhibit WC-Co coating. Also good resistance was characteristic for WC-Co-Cr coating. In case of WC-Cr_3C_2-NiCr coating the corrosion resistance was similar like uncoated AZ91 substrate.

Keywords: *HVOF, microstructure, corrosion resistance, WC-based coatings, light construction material*

P7 **POSTER SESSION**

Analysis of Adhesion of HVOF Sprayed Coatings on Laser Textured Steel and Ceramic Substrates

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Surface preparation prior thermal spraying is a key element to achieve good bonding strength of applied coatings. There are tendencies to find a suitable substitute for traditional grit blasting from ecological and economical aspects. Promising technology is a laser surface texturing. Within the research project, the main focus is to achieve processing times of laser treatment comparable with grit blasting, while achieving quality bonding of applied thermally sprayed coatings. This study is focused on HVOF spraying and two combinations of substrate-coating. The first combination is a Stellite 6 coating on steel samples and the second is WC-CoCr coating sprayed on pure ceramic substrates. The study presents the analysis of laser textures on substrates, analysis of substrate-coating interface and adhesion tests by tensile test according to ČSN EN ISO 14916. The most suitable textures for each combination will be selected based on laser processing times and adhesion of coating.

P8 **POSTER SESSION**

The influence of Cu-based powder preparation on its coating deposition kinetics

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Cold spraying is an innovative and economic technique for metal, ceramic, or composite solid-state deposition, significant for reducing the consumption of specific and expensive materials, thanks to its low energy and process gas consumption. This technique is also excellent for depositing thermally sensitive materials as the temperature of the process does not influence their properties. There are a few factors that are important to obtain a coating: for example, the preparation of the powder mixture, powder grain size, carrier gas, velocity, or the nozzle-to-substrate distance.

Metal matrix composites (MMC) are gaining increasingly more attention as wear resistant materials. It is difficult to obtain a coating with the same composition as the prepared powder due to difference between deposition properties of the materials. The question is how to improve the ceramic phase deposition of the MMC powder mixture.

The research concerns the influence of the Cu-Al_2O_3 powder mixture preparation method with two methods, shaker mixing and high energy ball milling, on the deposition efficiency and phase composition. Energy dispersive spectroscopy and X-ray diffractometry were used for quantitative composition analysis of the coatings.

Keywords: *metal matrix composite, high energy ball milling, aerosol deposition, cold spraying*

P9 **POSTER SESSION**

Adhesion and hardness of titanium coatings applied with the Cold Spray method on substrates with different mechanical properties

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The essence of applying regenerative or protective coatings is their adhesion to the substrate. The aim of the research was to analyze the adhesive forces depending on the hardness value and modulus of elasticity of the substrate. Irregularly shaped Ti grain coatings were applied to sandblasted substrates of various hardness and composition. The coatings were applied by the Cold Spray method. Adhesion forces were measured with a two-way lever. The analyzes were supplemented with SEM electron microscopy studies. The relationship between the hardness of the coating and the adhesion value was assessed. The mechanical and specific adhesion depending on the hardness and modulus of elasticity of the substrate was checked.

Keywords: *Cold Spray, adhesive, hardness, elastic modulus*

P10 **POSTER SESSION**

A Comparative Study of Aluminium and Titanium Warm Sprayed Coatings on AZ91E Magnesium Alloy

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Aluminium (Al) and titanium (Ti) coatings were applied on AZ91E magnesium alloy using a low-pressure warm spray (WS) method. The deposition was completed using three different nitrogen flow rates (NFR) for both coatings. NFR effects on coating microstructure and other physical properties were systematically studied. Microstructural characterization was performed using scanning electron microscopy (SEM), and the porosity was estimated using image analysis and X-ray microtomography. The coating adhesion strength, wear resistance, and hardness was examined. The protective properties of the coatings were verified via a salt spray test. Decreasing NFR during coating deposition produced more dense and compact coatings. However, these conditions increased the oxidation of the powder. Al coatings showed lower hardness and wear resistance than Ti coatings, although they are more suitable for corrosion protection due to their low porosity and high compactness.

Keywords: *warm spraying, thermal spraying, aluminium coatings, titanium coatings, corrosion resistance, magnesium alloys*

P11 **POSTER SESSION**

Alumina-titania coatings produced by hybrid suspension plasma spraying approaches

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The paper deals with the topic of hybrid plasma spraying of commercial alumina and titania suspensions. The approach concerns production of coatings with various alumina to titania contents by so-called intermixed or double injection spraying.

The first method shows the spray experiment which uses two separate injectors and mixing of the feedstocks took place directly in the plasma jet. The second method focuses on intermixing one suspension with another prior spraying. Mechanically mixed suspensions were fed into the plasma stream by one injector in such case. In this work, a total of six types of coatings were sprayed, three by each concept. The coatings differed also in terms of chemical composition. The three various aluminia/ titatnia contents were considered here: Al_2O_3 + 3 wt.% TiO_2, Al_2O_3 + 13 wt. % TiO_2, and Al_2O_3 + 40 wt. % TiO_2.

The microstructural observations showed that all coatings were characterized by columnar structure, while the coatings with a higher content of titanium were characterized by denser packing of the columns. In addition, the use of intermixed suspension introduced to the plasma jet by one injector allowed for easier formulation of desired chemical compositions and more effective coating growth-up. This significantly reduces the spraying time. An important advantage of the presented methods is the possibility of depositing coatings of complex chemical composition even when using commercial, ready-to-spray feedstocks.

Keywords: *thermal spraying, SPS, hybrid spraying, alumina, titania*

P12 **POSTER SESSION**

Application of Aerosol Cold Spraying technology for coating deposition on veterinary implants

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The development of medicine and implantology makes prostheses and implants a popular solution in the treatment of not only humans but also animals. Nowadays, it is becoming increasingly more common that animals require medical attention and treatment in the same way as humans, especially with so many resulting limb fractures. For many years, much attention has been paid to the modification of the surface of metallic biomaterials aimed at improving their properties, among others, in the context of induced biological reactions. One of the most frequently proposed solutions is a coating applied on the metal implant surface. Coatings applied on medical implants can also fulfill additional functions in the context of targeted biological reactions.

Aerosol Cold Spray technology was used in the research as one of the most modern technologies for obtaining thin coatings. This technology does work when dealing with materials that are sensitive to high temperatures, such as nanomaterials and materials with a high affinity for oxygen. The use of bioactive ceramic coatings with nano additives in the form of copper nanoparticles on the surface of veterinary implants allowed a more durable connection of bone tissue with the coating and antibacterial properties were obtained, which were confirmed in biological and mechanical tests.

Keywords: *hydroxyapatite, nanoparticles, aerosol deposition, veterinary implants*

P13 **POSTER SESSION**

Effect of nitrogen ion implantation on the cavitation erosion resistance of Stellite 12 and Stellite 6 hardfacings

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The research two stellite hardfacings namely, Stellite 12 and Stellite 6 layers were post-treated using nitrogen ion implantation and their cavitation erosion resistance was investigated. Paper studies the cavitation erosion resistance, deterioration behaviour and presents a phenomenological model of unimplanted and ion-implanted satellite hardfacings. Grounded and polished TIG-deposited layers were treated via nitrogen ion implantation by 120 keV N^+ ions and fluence of 1×10^{17} cm^{-2}. The microstructure, hardness and phase composition of hardfacings were studied. The cavitation erosion tests were conducted acc. ASTM G32 standard using stainless steel AISI 304 as a reference sample with the stationary specimens method. Cavitation experiments were done in distilled water and water slurry. The damaged surfaces of unimplanted and implanted coatings were qualitatively studied using atomic force microscopy (AFM), 3D roughness profilometer, scanning electron microscopy (SEM). Moreover, phase development due to ion-implantation and cavitation erosion were analysed using X-ray diffraction (XRD). Findings indicate the positive effect of ion implantation on the cavitation erosion resistance of stellites. Hardfacings presents almost 100 times higher resistance to cavitation than reference stainless steel specimens. The prolonged incubation period of cobalt coatings seems crucial for their superior anti-cavitation behaviour. Analysis of the cavitation curves, surface development, phase changes and microscopic studies allows elaborating the original model of implanted stellites cavitation erosion resistance.

Keywords: *hardfacing, cavitation erosion, sliding wear, wear mechanism, microstructure, failure model, XRD, HVOAF, HFPD*

P14 **POSTER SESSION**

Effect of TiO_2 addition in alumina-titania APS sprayed coatings on sliding wear and cavitation erosion resistance

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In this work, the results of microscopic and tribological studies of alumina-titania coatings with different amount of TiO_2, manufactured by atmospheric plasma spraying (APS) are presented. Three types of powders were used, namely: Al_2O_3 (AT0), Al_2O_3 + 13 wt. % TiO_2 (AT13) and Al_2O_3 + 40 wt. % TiO_2 (AT40). The aim of the study was to investigate the differences in the structure and tribological performance. The morphology of obtained coatings was analyzed by scanning electron microscope (SEM), while the microstructure was investigated by light optical microscopy (LOM) and SEM. Phase analysis was carried out by X-ray diffraction. Tribological examinations were made in the ball-on-disc mode in dry friction conditions compiling ASTM G99. Cavitation erosion tests were conducted on vibratory test rig according to ASTM G32. The addition of the TiO_2 to Al_2O_3 effects on the increase of wear factor K but decrease the coefficient of friction (COF). Also presence of titania increases the cavitation erosion resistance of coatings and elongated the incubation period of cavitation erosion. Sliding wear mechanism that relies on the fatigue inducted spallation of splats, intensified by the secondary wear mechanisms namely abrasion, adhesion and smearing of debris material. The addition of titania intensifies the adhesive wear mode. The addition of titania intensifies the adhesive wear mode. Cavitation erosion mechanism of sprayed coatings relies on brittle cracking, coatings unmeted particle, porosity and initial cracks accelerate the material loss. Coating cracking and fragmentation proceeded through the splat columnar-grains. Presence of titania in AT13 densifies microstructure, improves the contact between splats with finally changes the wear mode to “layer-like” and prevents the alumina from severe fragmentation and spallation consequently prolonged the cavitation life of AT13 coatings.

Keywords: *atmospheric plasma spraying, alumina, titania, microstructure, sliding wear, friction, cavitation erosion, cyclic fatigue*

P15 **POSTER SESSION**

Analysis on the microstructure of thermal spraying coatings after remelting

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The thermal plasma spray technology allows spraying a wide variety of materials including Ni-Cr- Re alloy. Atmospheric plasma spraying (APS) consists in injecting a powder feedstock material in a plasma jet to melt and accelerate the injected particles and spray them onto a substrate. The coating growth is thus realized by the impingement and spreading of sprayed particles. This mechanism of coating formation induces the presence of pores, micro-cracks and other defects. In order to eliminate those defects, laser or electron beam remleting may be used. The improvement the properties and performances of plasma sprayed coatings can be achieved. In the present paper, the NiCr + Re coating fabricated by plasma spraying on stainless steel substrate were remelted by lase and electron beam, and the effect of remelting on microstructure and hardness of plasma sprayed coating were studied. The microstructure of plasma sprayed and remelted coatings were analyzed using (SEM) and energy disperse spectroscopy (EDS). The micro-hardness of coating was measured using microhardness tester. The results show that the remelted coating becomes much denser moreover, the chemical composition of the coatings becomes homogeneous.

Keywords: *coatings, rhenium, thermal spraying, laser remelting, electron remelting, microstructure*

P16 **POSTER SESSION**

Properties investigation of cold sprayed titanium coatings after laser surface modification

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The last years in production engineering were marked by considerable development of additive manufacturing (AM), e.g., binder jetting, powder bed fusion, or cold spray (CS). A distinctive feature of the latter technique is the fact that powder particles are not melted during the process and bonding is due to high kinetic energy converted to plastic deformation. CS is a commonly used technology in the aerospace and automotive industries. Amongst its main applications deposition of coatings, repairing machine parts, and manufacturing new components should be highlighted. Similar to other AM techniques, titanium and its alloys are among the most popular materials. They exhibit an advantageous combination of low specific weight, great mechanical properties, and corrosion resistance. Such properties of Ti and Ti alloys result in a wide range of these materials' applications.

Unfortunately, an inherent downside of the CS method is the surface quality that in particular cases may require post-processing. Therefore, in this paper, we report on our latest attempt at laser surface modification of cold sprayed titanium and titanium alloy (Ti6Al4V) coatings deposited on an aluminum substrate. The influence of laser beam interaction time on the coatings' properties was investigated. For assessing changes in chemical and phase composition energy-dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD) were utilized. Microstructure observations were performed via scanning electron microscopy (SEM). The sin2ψ method was used for measuring surface residual stresses after CS and laser modification. The influence of laser modification on a wetting angle, surface roughness, and Vickers hardness was also determined.

Keywords: *Cold Spray, laser surface modification, titanium coating*

P17 **POSTER SESSION**

Influence of pulsed laser application on the properties of metallic glass

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Fe-based metallic glasses attract interest due to their high mechanical strength close to the theoretical one, good corrosion resistance, and reasonable price. The main problems to overcome include lack of plastic deformation and element size limitation in the case of contemporary manufacturing techniques. Therefore, the research focus goes towards generative methods, including the selective laser melting process (SLM). It provides enough cooling rate of a melted spot and allows for the production of elements with theoretically unlimited size. However, there are cracks and crystallized areas in the obtained parts. The crack formation is usually prescribed to the loss of plasticity caused by crystallization and reduction of free volume. To get deeper insight in this phenomenon two heat treatments: i) oven and ii) laser have been carried out on $Fe_{62}Ni_{18}P_{13}C_7$ casted ribbons. The samples were then characterized in terms of microstructure and hardness. Finally, the obtained results are compared to one obtained in the SLM printed samples.

P18 **POSTER SESSION**

Abrasive wear of various hardfacing layers manufactured by flux-cored wire GMA welding

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This work focuses on regenerative hardfacing of components exposed to abrasive wear conditions. The three various materials, namely: (i) 307Si, (ii) SK 600-G and (iii) SK 900 Ni RTC-G, were deposited by means of GMA welding. The welds were then subjected to microstructural studies, by digital and scanning electron microscopy and to hardness measurements carried out by Vickers method. The main focus was paid to abrasive wear resistance, which was studied by means of rubber wheel testing method. Then, the wear modes were studied by microscopic observations but also a non-destructive, scanning acoustic microscopy method, was used to visualize the microstructural effect at the sub-surface region and at the interface between weld deposit and base material. All samples showed better wear resistance than reference sample, which was uncoated steel. The mass lost was even three times lower for hardfacing layers.

Keywords: *hardfacing, GMA welding, microstructure, hardness, abrasive wear, scanning acoustic microscopy*