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Contents

Plenary lectures

Manufacturing, properties and consolidation of metal powder: from powder metallurgy to metal additive manufacturing

Eduard Hryha
Chalmers University of Technology

Metal powder constitutes an important feedstock for number of powder-based technologies, starting from well-established powder metallurgy (PM) technologies as conventional press and sinter (P&S), metal injection molding (MIM) and hot isostatic pressing (HIP), to the relatively new powder-based metal additive manufacturing (AM) technologies, including powder bed fusion (laser beam PBF-LB, and electron beam - PBF-EB), binder jetting (BJT) and powder blown directed energy deposition (DED). There are number of powder manufacturing technologies, selection of which is determined by the alloy composition, powder properties required for a specific technology as well as cost. However, even if the same alloys systems are often used for both, PM and AM technologies, they have different requirements to the powder feedstock when it comes to its physical properties and chemistry and utilize different size fractions of the metal powder.

The main difference between PM and AM technologies are connected to the difference in requirements when it comes to the powder rheology during respective processes, processing conditions and kinetics during powder consolidation. In addition, powder has to be reused during AM that is typically not done in PM. Hence, in case of AM, changes in powder properties during manufacturing cycle have significant impact on the final component properties.

This talk summarizes recent experimental observations and thermodynamic simulations of the impact of powder surface chemistry and its changes during the powder consolidation for variety of PM and AM technologies. Generic model of the powder surface chemistry change and powder consolidation in dependance on initial powder properties and type of PM and AM process is elaborated. Effect of the reused powder on the defect formation during AM processing and its impact on material properties is discussed.

Materials for Electromobility and Renewable Energy

Gerhard Schneider
Aalen University

Renewable energy and electromobility are important future topics for climate-friendly technologies.

Functional materials such as magnets for electrical machines or electrode materials for batteries are of outstanding importance. These materials must be developed in the area of conflict between performance, economic efficiency, raw material criticality and sustainability. In the lecture, different strategies will be presented to overcome these challenges.

Special Session: Presenting Greek Associations in the area of advanced materials and research

Design of compositions and production of novel glass-ceramics in the CaO-MgO-SiO2 ternary system for dental applications

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This work aims to outline the synthesis and characterization (related to sintering, crystallization, microstructure, mechanical properties, and in vitro and in vivo biological performance) of novel alumina-free and alumina-containing (1 - 8 mol%) glass-ceramics (GCs) in the CaO-MgO-SiO2 system with additives of K2O, Na2O, P2O5, CaF2, and Al2O3 [1]. The presentation focuses on the prospects of the produced GCs in dentistry; more specifically, their possible fabrication by subtractive manufacturing technique (such as milling) for possible use as dental implant materials and in fixed all-ceramic prosthetic restorations (e.g., crowns, and bridges etc.).

A typical production process was followed. More specifically, glass frit was prepared via glass melting and then quenching. Thorough thermal analysis (DSC and dilatometry) was conducted to set the conditions for the optimal crystallization process and to determine the Tg, the crystallization temperature (Tc), the sintering window (Tc - Tg), as well as the activation energy (Ea) of glass crystallization and the crystal growth dimensionality represented by the Avrami exponent (nA). The microstructural features, mechanical properties, and the brittleness index (BI, parameter to estimate material's machinability) of the produced sintered and crystallized GCs along with bioactivity/bio-inertia performance were experimentally studied.

The alumina-free and 1 mol% Al2O3-containing GCs are bioactive, since they favor the spontaneous formation of hydroxyapatite (HA) on their surface after immersion in SBF at 37 oC. In vitro tests with cell cultures, in vivo implantation in experimental animals as well as clinical trials also provide evidence of biocompatibility and bioactivity. The K-free GCs consist of diopside, wollastonite, and fluorapatite, while, in the K-containing GCs, α-PMS is developed instead of wollastonite, as a result of the structural silica-units of the parent glasses (mainly Q2 and Q3). Their mechanical properties are better than those of titanium and zirconia dental implant materials, and their modulus of elasticity (27 - 34 GPa), microhardness (5.2 - 6.7 GPa), and fracture toughness (1.4 - 2.6 MPa.m0.5) are a good match to those of human jaw bone and dentine.

The addition of 8 mol% Al_2O_3 totally suppresses the bioactivity of the produced GCs (i.e. there is no evidence of HA formation on the surface of the GCs). The crystalline phases formed in the K-free GCs are melilite and diopside, and melilite and gehlenite in the K-containing GCs. The produced bioinert GCs satisfied the criteria described in the ISO 6872 Dentistry-Ceramic Materials [2], which refers to the mechanical properties of the dental restorative materials. More specifically, the mechanical properties of the produced bioinert GCs are a good match to the corresponding properties of enamel and dentine, i.e. flexural strength 120 - 171 MPa, modulus of elasticity 28 - 42 GPa, Vickers microhardness 6.3 - 7.0 GPa and fracture toughness 2.6 - 2.8 MPa.m0.5.

Finally, it is important to underline that the produced bioactive and bioinert GCs had a brittleness index in the range of 2.3 - 3.6 μm-0.5, which is very close or higher than 3 μm-0.5. These values lay within the range that suggests a good brittleness index for GC materials, since the brittleness index of glasses and ceramics generally varies in the range of 3 - 9 μm-0.5.

References:

[1] K. Dimitriadis, Ph.D. Thesis, University of Ioannina, 2020, Greece.

[2] ISO 6872, Dentistry – Ceramic Materials, third ed., International Organization for Standardization, Geneva, 2008.

Presentation of the “Micro & Nano Scientific Society of Greece”

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The Scientific Society Micro&Nano has been founded in 2004 as a civil non-profit non-governmental organization and is governed by the provisions of articles 741-748 of the Civil Code. Founding members of the company were 6 academic bodies and 65 Scientists/natural persons.

Micro & Nano's ambition is to act as a catalyst and framework for a dynamic synthesis of the entire Greek Academic community, research, technology, and industry (start-ups, small and medium-sized and large businesses) in order to actively meet international demands and to contribute decisively to the technological and economic use of the Greek scientific capital to the fields of Digital technologies, Micro(nano)electronics and Micro(Nano)technology and in particular in the fields of:

Micro(Nano)electronics

Micro(Nano)photonics

Nanotechnology-Nanomanufacturing

Integrated circuits and systems

(Bio)Microsystems

(Bio)Sensors and IoT

Lab-on-a-chip/Microfluidics

<u>Session:</u> Evaluation of the microstructural evolution of metallic materials during processing techniques

A review of industrial brass alloys towards high productivity machining processes

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Recently, new health and safety guidelines dictated regulations on the utilisation of hazardous substances on manufacturing sectors and consumers' products. Brass alloys (Cu-Zn system) are facing a significant challenge, since lead (Pb) is an excluded element from the enforced environmental and health & safety legislation. Pb has been a vital alloying addition as it affects both the machinability and the manufacturing process of brasses in terms of overall quality and efficiency. Therefore, the development of eco-friendly brasses consists a critical research field with significant industrial and environmental impact. This work aims to review the emergent innovative and sustainable material solutions in the manufacturing industry, in line with environmental regulations, by highlighting smart alloy design practices and promoting new and innovative approaches for material selection and manufacturing process optimisation. In the frame of the present review, the processing, structure and machinability aspects of leaded brasses are analysed aiming to underline the major guidelines and research methodologies required to overcome this technical challenge and further improve the mechanical properties and machinability of lead-free brass alloys. Two primary approaches for solving this technical challenge are identified. The design of novel brass compositions and a compositionally invariant route dependent on a series of heat treatments. Compositional modifications are primarily aimed at replicating the beneficial effects of Pb through the incorporation of second phase particles (consisted of intermetallic or single-element phase, un-dissolved in the alloy matrix), while the alternative route is intended to stabilise the β-phase which exhibits superior machinability and mechanical properties, compared to α-solid solution. Nevertheless, both approaches seem to be characterised by complementary benefits. As such, the optimal path towards the next generation of lead-free brasses lies most probably in the development of alloys that can utilise a combination of both design aspects.

Compressive mechanical properties of additively manufactured porous structures from Inconel 718

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The current development of additive technologies brings not only new possibilities but also new challenges. One of them is the use of regular cellular materials in various components and constructions so that they fully utilize the potential of porous structures and their advantages related to weight reduction and material saving while maintaining the required safety and operational reliability of devices containing such components. It is therefore very important to know the properties of such materials and their behaviour under different types of loads. The article deals with the investigation of the tensile mechanical properties of porous structures made by Direct Laser Metal Sintering (DLMS) of Inconel 718. Four types of structures with basic cells Gyroid, Diamond, Gyroid + Gyroid, and Gyroid + Diamond samples of three volume ratios (Vr = 10, 15 and 20 %) were studied to compare their properties. The compression testing procedure was performed at ambient temperature with a servohydraulic testing machine at testing speed 10 mm/min. The results showed that the diamond structure showed the best mechanical properties in compression.

Prediction of crystallographic texture in aluminium alloys using crystal plasticity methods

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Simulation engineering has long been utilised to increase the output of R&D departments in the metallurgical industry to meet the demands of modern and emerging markets. These efforts can be aided through Integrated Computational Material Engineering and its innovations which have started being applied in industrial applications by market leaders. One such innovation is the method for the prediction of crystallographic texture and the mechanical properties of aluminium alloys.

In the present work the prediction of the crystallographic texture of cold rolled AA5182-O was attempted by means of computer simulations of crystalline plasticity using Fourier transformations. A representative volume element (RVE) was established with experimental EBSD data and experimental data obtained from ELKEME S.A. as well as, bibliographical research. The formatted RVE was used to simulate a uniaxial strain test to extract strains and stresses in the crystalline level and attempt to predict the evolution of crystallographic texture. The results obtained pointed to the recognition of such evolution, a theory confirmed by previous academic work. Furthermore, a case study of the method simulating the aforementioned phenomena in a commercial pure alloy was developed to indicate how such information can facilitate the prediction of mechanical behaviour. The findings were conclusive and within the range provided by literature data.

The methodology and proof of concept developed in this work serve as the precursor to the possibilities of Integrated Computational Material Engineering field and the benefits it can bring to both research and industrial applications whilst enabling new forms of research and developments in an ever more demanding, and competitive market.

Simulation of Phase Transformations during Quenching and Partitioning Heat Treatment

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The aim of the present work is to simulate the evolution of the microstructure in steel during a Q&P (Quenching and Partitioning) thermal cycle. For this purpose, a low alloy medium carbon steel (42CrMo4) was utilized which had previously subjected to Q&P heat treatment via dilatometry. At each stage of Q&P thermal cycle, the phase transformations taking place were simulated using Thermo-Calc®, DICTRA and MICRESS softwares. The results showed that phases with complex morphology such as martensite and bainitic ferrite can be simulated by the phase-field simulation method. The martensite fraction formed during the first quench affects the percentage of bainitic ferrite as well as the percentage of retained austenite. Carbon diffusion before the isothermal soaking stage plays an important role in the calculation of the percentages of bainitic ferrite and retained austenite. During the bainitic transformation carbon diffuses from the bainitic ferrite into the residual austenite. The bainitic transformation stops when the carbon in the austenite reaches the value predicted by the para-equilibrium diagram. The simulation results are in agreement with microstructure characterization results from SEM and EBSD proving the reliability of the methodology followed.

The effect of stress state on the microstructure evolution during plastic deformation of Q&P treated martensitic stainless steels

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New solutions must be presented with the increasing demands for advanced materials in the automotive industry. A promising approach is to redesign already existing materials using innovative processes. In this manner, existing grades of martensitic stainless steels can be heat treated by quenching and partitioning (Q&P) to introduce retained austenite into microstructure, which, in turn, leads to a better balance of strength and ductility. Few papers on the microstructure and mechanical properties of Q&P treated martensitic stainless steels have already been published. However, their application-related properties, such as formability, have never been studied. The formability of steels with metastable retained austenite is to a great extend controlled by the transformation induced plasticity (TRIP) effect. This work explores the effect of stress state on the microstructure evolution during plastic deformation of Q&P treated martensitic stainless steels

Three grades of martensitic stainless steel (410 and 420) sheets were heat treated by Q&P process. Samples for Nakajima testing were machined from these sheets and tested. Microstructural analysis of selected samples was performed using SEM, EBSD, and TEM. The effect of stress state on the microstructure of the tested samples was analysed. Special emphasis was laid on the analysis of retained austenite, its stability during plastic deformation, and its effect on formability of the Q&P treated martensitic stainless steels.

<u>Session:</u> Corrosion and protection

A comparative study on the electrochemical corrosion performance of High Additive Manufactured and wrought Ti-6Al-4V alloys

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Plates of forged Ti-6Al-4V and 3D-printed (high additive manufacturing technique: laser-based powder bed fusion (LPBF)) Ti-6Al-4V have been evaluated in terms of microstructural examination and corrosion properties, with the objective to investigate the effect of the LPBF technique on the corrosion behavior of Ti-6-4, an alloy commonly used in biomedical applications. All the electrochemical tests were performed in aerated simulated body fluid (SBF), at 37 °C. A standard three electrode cell was employed, with Ag/AgCl/3.5MKCl, as the reference electrode and a platinum gauze as the counter electrode, connected with a galvanostat/potentiostat. Cyclic potentiodynamic polarization was adopted to investigate the resistance to localized corrosion.

Forging led to a lamellar αTi/β microstructure, whereas LPBF led to a finer grain size martensitic microstructure.

All forward anodic curves were characterized by very low corrosion rates (order of 10-5 mA/cm2), true passivity (order of 10-4 mA/cm2) in a great range of potentials. Actually, in the range of potentials tested, passivity breakdown did not occur. Neither of the alloys underwent localized corrosion. Nevertheless, the forged alloy presented lower corrosion rates and lower passivity currents.

A corrosion study in stainless steels using CO_2-loaded aqueous solution of monoethanolamine (MEA)

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Corrosion behavior of two stainless steels (316L and 304L) was evaluated by using a CO_2 -loaded aqueous solution of 30 wt% monoethanolamine (MEA) in a view to simulated corrosion related mechanisms in amine treatment procedures. Corrosion behavior was experimentally evaluated as a function of CO_2 loading and solution temperature, using electrochemical techniques (polarization curves, cyclic polarization and EIS measurement). The results reveal that the aqueous MEA solution containing CO_2 creates a favorable environment for the corrosion of both stainless steels. The rate of corrosion is accelerated when the temperature of the loaded MEA solution rises which was at-tributed to the thermal degradation of the loaded MEA thus causing higher kinetics of the cathodic reactions at higher temperatures. More specifically, for the SS 304L the corrosion rate is almost doubled when the solution temperature is increased from 25oC to 40oC and is quadrupled when the solution temperature rises to 80oC. For the SS 316L, the corrosion rate becomes almost threefold and sixfold with increasing the temperature of the load amine solution to 40oC and 80oC, respectively. The overall corrosion rate of SS 316L is lower with respect to the SS 304L for the same temperature and loading conditions. The essential dependency of corrosion rate on solution type (unloaded and loaded MEA solution) demonstrates that the corrosion process and reactions are controlled by a diffusion mechanism.

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Corrosion behavior of CoCrMo dental alloy fabricated with Soft Milling technique before and after heat treatment

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The present work investigates the effect of heat-treatment (HT) cycles, as applied in dental practice, to produce metal-ceramic restorations, on the microstructure, mechanical properties and corrosion resistance of CoCrW dental alloys, fabricated by the advanced digital technique of Soft Milling (with the aid of CAD technology). The prepared samples were equally divided into two groups. The samples in the first group, named ‘‘As Built (AB)’’, were the samples with no further treatment and the samples in the second group, named ‘‘Heat Treated (HT)’’, were subjected to four cycles of heat treatment. Microstructural analyses (by X-ray diffraction and SEM/EDX), mechanical property measurements (by nanoindentation) and corrosion resistance testing (by cyclic potentiodynamic polarization measurements in simulated body fluids, SBF at 37°C pH 7.4±0.1) were conducted in all prepared samples in order to evaluate the effect of the heat treatment on the respective properties.

At first sight, the similar shapes of the polarization curves of AB and HT specimens indicate similar corrosion mechanisms. In both groups (AB, HT) similar corrosion values (corrosion potentials, passivation potentials and current densities) and very high resistances to forms of localized corrosion were measured. It is therefore concluded that the heat treatment proposed in dental practice neither improved nor degraded the alloy’s corrosion resistance. The above behavior is discussed and justified as a function of the microstructure and the effect of heat treatment.

Corrosion Behaviour of Modified Plasma Spaying Hydroxyapatite Coatings on SMO 254 Super Austenitic Stainless Steel Substrate

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The present study examines the corrosion behaviour of modified plasma spraying hydroxyapatite (HAp) coatings on a SMO 254 super austenitic stainless steel substrate in order to evaluate their suitability for orthopaedic implant coating. The studied specimens were subjected to potentiodynamic polarization testing in Hanks' solution to resemble human body conditions. The corrosion conditions were 25°C and 37°C, as well as the studied pH were 3, 5.65 and 7. The study of corrosion products, the surface morphology and the study of cross-section samples was carried out by scanning electron microscopy (SEM), coupled with energy-dispersive spectroscopy (EDS) analysis. According to the results, parameters of the plasma spraying process (e.g. number of coating passages, preheating of the substrate, etc.) influence the corrosion resistance of the studied HAp coating-SMO 254 system.

Effect of aging treatment on the mechanical and surface degradation properties of Co-based superalloy L605

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In the present work, the effect of a novel aging treatment on the microstructure, mechanical and surface degradation properties of Co-base superalloy L605 (Co-20Cr-15W-10Ni) is investigated. Mirror polished samples were subjected to a homogenization treatment (1250 °C, 48 h, Ar, water quench), followed by a two-stage aging treatment (1000 °C, 8 h, Ar, water quench and 800°C, 48 h, Ar, water quench), with the objective to attain an improvement in the strength of the material. Both the non-heat treated and heat-treated samples were subjected to microhardness, nano-hardness and elastic modulus by nanoindentation measurements).

As aging does not always improve or even deteriorates the corrosion response, both the non-heat treated and heat treated specimens were subjected to high temperature oxidation testing (650 - 950 °C, 24 h), since the alloy is mainly targeted to high temperature applications. Both the non-heat treated and heat-treated samples were also tested for corrosion in simulated body fluid (SBF solution, 37°C, pH 7.4±0.1, cyclic potentiodynamic polarization) with the purpose to investigate the potential of expanding the use of L605 superalloy in biomedical applications. The above investigations were accompanied by SEM/EDX inspections on electro-etched specimens (microstructure determination) and on polished cross-sections (high-temperature oxidation and cyclic polarization). The mechanisms of surface degradation processes and the effect of aging treatment on them are being discussed.

Effect of combining low-cost corrosion inhibitors on the corrosion performance of stainless steel concrete rebars in acid rain

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The present study investigates the effect of fly ash (FA) combined with two low-cost corrosion inhibitors on the corrosion performance of concrete reinforced by 316L and 304L stainless steel rebars in acid rain. The first inhibitor, Inhibitor B, is a liquid diffuse organic multifunctional corrosion inhibitor. The second inhibitor, Inhibitor C, is a 3rd generation gas phase three stage corrosion inhibitor, which enhances the alkalinity of reinforced concrete. The corrosion performance of 316L and 304L rebars is studied by recording the Open Circuit Potential (OCP) variations when concrete cubes containing 0 wt.% & 20 wt.% FA in combination with inhibitors B and C (FA, FA + Inhibitor B & FA + Inhibitor C) and reinforced with 316L and 304L rebars, were immersed for 1 m in an acid rain simulating solution (pH $\approx$ 3.1). The corrosion experiments were accompanied by tensile testing of the rebars (before and after the OCP runs), pH measurements and SEM/EDX inspections of rebar cross-sections.

For both steels there was more than 90% probability that corrosion didn't occur in the cases of sole additions of FA, Inhibitor B and Inhibitor C, as well as in the case of combining 20 wt.% FA with Inhibitor B. 316L presented a better corrosion performance compared to 304L in the cases of 20 wt.% FA and 20 wt.% FA + Inhibitor B. Both Inhibitors B and C have improved the corrosion performance of 304L reinforced concrete cubes in the absence of FA. However, both Inhibitors have annulled the inhibiting effect of FA in case they are combined and vice versa. Moreover, the 20 wt% FA content had a beneficial effect on the corrosion behavior of both types stainless steel rebars compared to 0 wt.% FA, in the presence or absence of Inhibitor B, in agreement with previous authors' works.

Hysteretic response of corroded steel reinforcing bars including buckling phenomena

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Structural performance of Reinforced Concrete (RC) structures located in coastal areas is significantly degraded due to chloride induced corrosion of steel reinforcement. Especially in earthquake prone areas, longitudinal steel reinforcing bars are subjected to high dynamic loadings introducing low cycle fatigue and buckling phenomena. Aim of the present manuscript is to study the mechanical behavior of corroded steel bars under dynamic loadings simulating mainly the hysteretic response of steel reinforcement in old RC buildings. For this purpose, accelerated corrosion tests were conducted to embedded steel bars by inducing constant current density and mechanical tests under dynamic conditions with gradually increased deformations were carried out. From the experimental study, hysteretic models of steel were extracted for different type and level of corrosion damage; uniform and pitting corrosion. The main outcomes indicated that the mechanical response of steel reinforcing bars under dynamic loadings differs from the typical monotonic bilinear model, which is adopted by the technical regulations. In case of pitting corrosion significant deviation between the mean reduced cross-section and the actual residual cross-section of corroded steel bar was denoted up to 71.8%. Non-uniform damage due to pitting corrosion creates varying strong and weak bending axes along the bar which directly affects the buckling behavior of corroded bars. To conclude, pitting corrosion has huge negative impact on both bearing and ductility capacity of steel bar, which depends on the geometry of pits and the actual residual cross-section.

Influence of shot blasting on dynamic response of corroded steel reinforcement

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As it is widely known, chloride induced corrosion of steel reinforcement poses a real threat for reinforced concrete structures located in coastal areas. The corrosion phenomena, in synergy with repeated loads such as intense seismic events, adversely affect their useful service life. The current experimental study, presents the outcomes of the shot blasting treatment, parameters of which were adopted pursuant to several experimental tests, in respect to the anticorrosive resistance of steel reinforcing bars and the influence on their dynamic response. For this purpose, accelerated corrosion tests were conducted to bare and shot blasted steel bars at various times of exposure and low cycle fatigue tests at constant strain amplitudes of ± 0.5%, ± 0.75% and ± 1.25% were executed. The findings of the present manuscript demonstrated the beneficial effect of the shot blasting treatment of B500c steel, providing corrosion resistance, but mainly enhancement of the mechanical response under cyclic loading. Besides, an effort has been made to evaluate bare and shot blasted rebars, via a dynamic material index proposed by the authors, in terms of material quality and durability. The outcomes demonstrated the improved mechanical performance of shot blasted specimens vs. bare specimens, for medium range-imposed deformation in long terms.

Scandium adsorption from chloride solution of titanium oxide industry using ion exchange resins

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Scandium metal has gained a lot of interest during the past years due to the various crucial applications including solid oxide fuel cells, aeronautics and heat exchange systems. One of Europe's most promising sources for Sc supply are the liquid by-products of titanium oxide production, because of their considerably high concentration (10-140ppm Sc). These liquid by-products, are currently neutralized and the resulted precipitates are landfilled or sold in the chemical industry without valorising the Sc present. This study examines the potential utilization of a chloride-based solution of the TiO2 industry for Sc extraction through the ion-exchange purification technique. In particular, two different commercial resins are examined, VPOC1026 and TP260, in a fixed-bed column set up as for their adsorption of Sc and their metal impurities Zr, Ti, V. Different agents for the desorption of the resins are also evaluated. Results indicate that VPOC1026 resin is the most promising for Sc extraction with high co-extraction of Zr, Ti and V and NH4F is the most promising agent for Sc elution.

Session: Advanced materials: design, processing, mechanical behavior and surface properties

Design of novel low-density multicomponent alloys tailored to address engineering challenges

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Multicomponent alloys (MCAs) or complex concentrated alloys (CCAs) are a category of materials originating from the concept of high entropy alloys (HEAs), comprising of elevated additions of multiple alloying elements. Originally, HEAs were strictly defined in terms of the amounts and number of alloying elements and as such, the introduction of MCAs and CCAs allowed for a greater degree of design freedom. Such design principles seem to have since revolutionised the design process of alloys tailored to specific applications. In this work we shall present a series of case studies concerning MCAs designed to address a wide variety of engineering challenges. We initially touch upon the equiatomic AlTiVCr system which we demonstrate to possess elevated elastic properties surpassing those encountered in high modulus steel, although lacking in ductility. We will attempt to remedy this drawback through compositional modifications and heat-treatments. We shall also investigate the AlCuZnSn system to identify sustainable lightweight lead-free solutions to the environmental challenges that the brass industry is currently facing concerning the elimination of lead from potable water brass products. Computational and experimental design principles will be utilised to introduce the Al30Cu40Zn25Sn5 alloy as a suitable starting point for the development of novel high-entropy brasses. Lastly, we will design and demonstrate the production feasibility of high-strength, lightweight Al-based multicomponent alloys using widely accessible and affordable alloying elements. Computationally guided alloy design will be used to locate the Al58Mg18Zn12Cu5Si7 alloy as a reasonable candidate. The alloy is cast using a variety of molds and is subsequently heat-treated to investigate the phase stability and property evolution. A wide variety of computational and experimental techniques ranging from density functional theory calculations to transmission electron microscopy will be used to guide our search for the design, investigation and optimisation of this novel set of multicomponent alloys.

Development of novel silver and copper oxide nanoparticle – based inks for LIFT-printing of electronics

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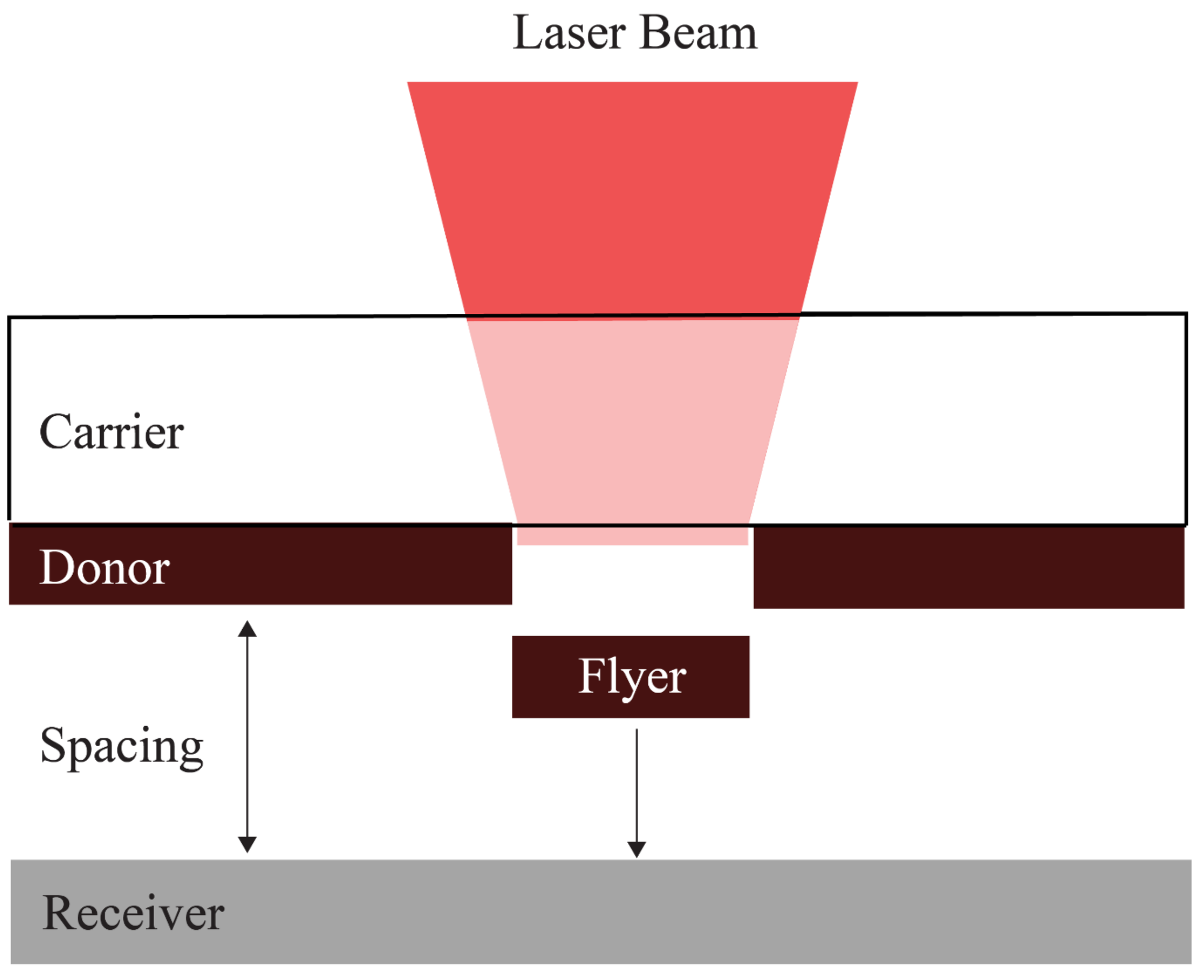
Following the demand for miniaturization of electronics, additive processes employed with functional nanotechnology-based inks appear to be a promising asset towards the microfabrication of high-resolution conductive patterns. Laser-Induced Forward Transfer (LIFT) has emerged as a digital technique allowing the high-speed microfabrication of high-quality components, with excellent electrical properties and flexible form [1]. LIFT uses a pulsed laser beam to project material from a donor thin film towards a substrate (Fig. 1) [2]. It works best with highly concentrated, viscous ink formulations with high-boiling point solvents [3]. Despite being a nozzle-free technique, thus tolerant of large particle sizes, LIFT prefers inks with small particles and uniform size distributions, which result in dense, highly conductive printed patterns. Although LIFT has been extensively studied, the same cannot be said for the inks used for LIFT. Most researchers employ LIFT with commercially available inks designed for other printing techniques, such as screen printing [4]. This work focuses on the preparation of highly concentrated silver and copper oxide nanoinks with properties corresponding to the requirements of the LIFT technique. The nanoparticles were dispersed in glycol-water co-solvent media. The particle concentration of the inks prepared varied between 20 and 60 wt.% and their viscosity was greater than 10 Pa·s. Thermogravimetric Analysis and Differential Scanning Calorimetry confirmed the smooth evaporation of the solvents. UV-Visible Spectroscopy verified the colloidal stability of the particles in the course of a few months. Transmission Electron Microscopy images revealed particles smaller than 100 nm, with unimodal size distribution. Thus, the properties of the inks were promising for LIFT. This research has been co-financed by the European Union and Greek national funds through the Operational Program Competitiveness, Entrepreneurship and Innovation, under the call RESEARCH – CREATE – INNOVATE (project code: T1EDK-04359).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In-Plane Shear Loading -Unloading Behavior of Aluminium 5052 Honeycomb Core Structure

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Abstract

Honeycomb sandwich structures due to their high stiffness to weight ratio and good impact behaviour have found use in aeronautical and aerospace applications and are continuously exploited as potential lightweight materials in other transport fields [1,2]. In primary structures, however, the high stresses involved demand for a better understanding of the quasi- static shear behaviour of the honeycomb core materials. In the present work the elastic loading- unloading shear behaviour of aluminium honeycomb structures has been investigated. Experiments have been conducted in aluminium 5052 honeycomb core material under quasi-static in-plane shear loading according to the ASTM-C273 standard. The shear modulus and elastic shear limit of the honeycomb core material have been determined in both L and W direction of the honeycomb core. Also, deformation modes during elastic shear loading were monitored to identify the onset of plasticity in honeycomb cell walls. Furthermore, the presence of perforations on the honeycomb core cell walls on the shear elastic properties has been evaluated.

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Microstructural Characterization of Novel Micro-Alloyed Single-Phase Nanoprecipitated Steels

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Micro-alloyed single-phase nanoprecpitated steels are a new generation of Advanced High Strength Steels (AHHS), mainly developed for lightweight automotive applications. These modern steel grades can present a tailor-made combination of high strength, ductility and complex formability performance, which originate from the lean alloy design and thermomechanical controlled processing (TMCP), which produce an essentially single-phase ferritic matrix strengthened by second-phase nanoprecipitates. These nanoprecipitates are mainly nitrides (MxNy), carbides (MxCy) and/or carbonitrides (Mx,(Cy, N1-y)), where M can be V, Nb, Mo, Ti, or a combination. In this research work, the microstructure of cold-rolled micro-alloyed single-phase V, Nb, and Mo-bearing strip steels are characterized to be evaluated for automotive applications. The microstructural investigation focuses on an extended characterization of the microstructure in micro, as well as, nano-scale via Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM) coupled with Energy Dispersive X-Ray (EDS) microanalysis.

The precipitation of κ-carbides through spinodal decomposition in austenitic low-density steels

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Low-density steels contain high amounts of manganese and aluminum, alloying elements that expand the crystal lattice, reducing the density. These lightweight materials exhibit excellent properties with tensile strengths around 1GPa and total elongations up to 80%. In the current work, a Fe-30Mn-9Al-1C steel is studied. The high manganese content ensures a stable, fully austenitic structure at room temperature, while the 9 wt.% aluminum leads to a reduction in density of around 20%. The steel was hot-rolled and aged under different conditions with no intermediate solution treatment. The precipitation of κ-carbides through spinodal decomposition is studied under different aging conditions with scanning and transmission electron microscopy. The study aims to characterize the precipitation mechanism fully and to correlate the microstructure of the steel with the mechanical properties.

It has been found that the precipitation of nano-sized κ-carbides begins at the early stages of aging at 550°C. Fluctuations of aluminum and manganese inside the austenite grains lead to the formation of the new phase, and after 8h of aging, the κ-carbides have a globular morphology and diameter of 4nm, while they are coherent with the austenite matrix. At this point, the steel exhibits the highest Vickers hardness (390HV), an ultimate tensile strength of 1050MPa, and Total Elongation of around 60%. Increasing the aging temperature by 100°C, the size of the carbides increases at 20nm, with a cuboidal morphology. Coarse, intergranular κ-carbides also form in this sample, followed by precipitation-free zones and loss of coherency, which are connected to severe deterioration of the properties. The quantitative analysis gives a clear correlation between the fraction/size of the precipitates and the properties; fine carbides favor the dislocation gliding, while coarser carbides will shear upon deformation.

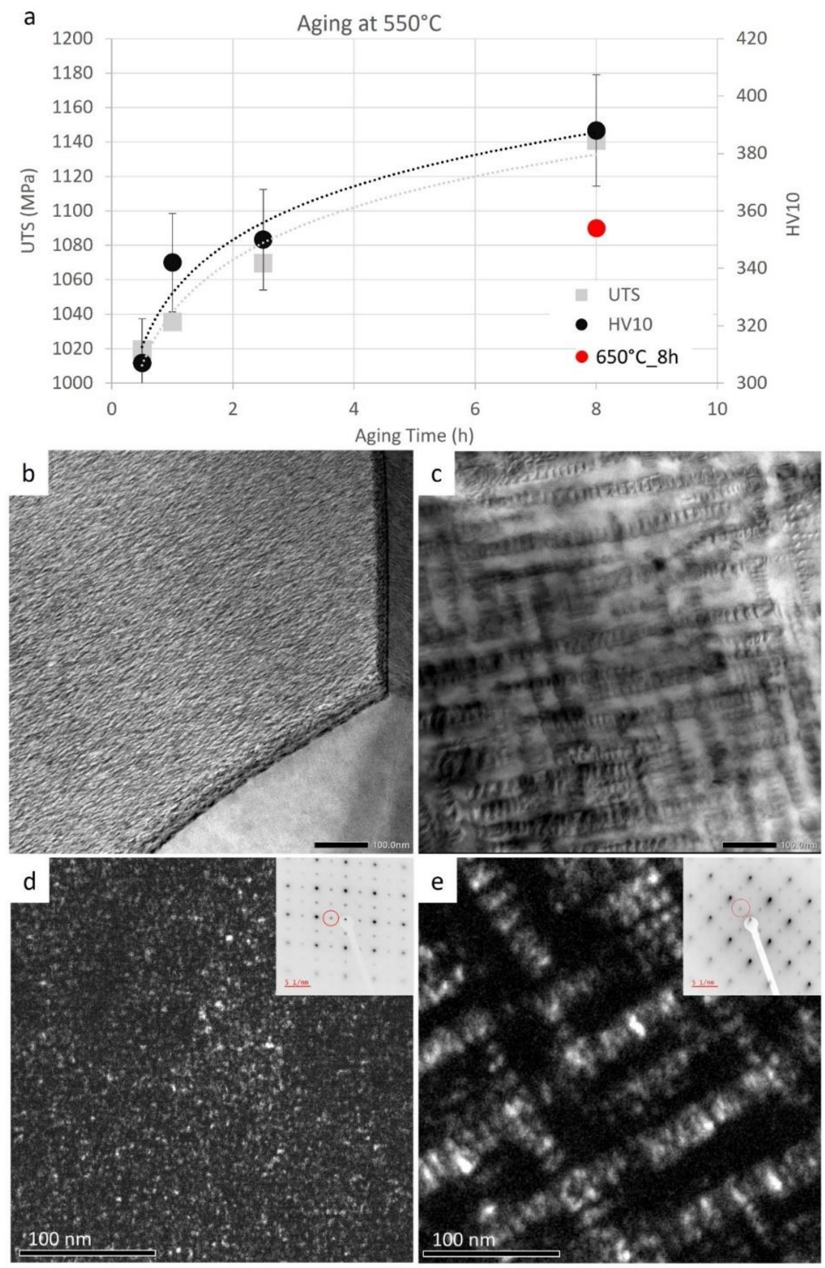

Figure 1: a) the Ultimate Tensile Strength and Vickers Hardness of the samples aged at 550°C for different aging times. The HV of the sample aged at 650°C for 8h has been added to the diagram for comparison. STEM images showing the morphology and size of the intragranular κ-carbides in the samples aged at b) 550°C and c) 650°C for 8h. d, e) Dark Field TEM images on the [001] zone axis, in which the κ-carbides are observed for the same samples, respectively.

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<u>Session:</u> Manufacturing techniques of engineering materials - mechanical characterization

Experimental characterization of fatigue crack growth in thermoplastic co-consolidated joints under various mode-mixities

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In the present work an experimental campaign has been carried on in order to fully characterize the crack growth behavior in thermoplastic matrix laminates joined via co-consolidation, under pure-mode and mixed-mode fatigue conditions. Specifically, the materials in question were T700 carbon fiber reinforced low-melt polyaryletherketone (LM-PAEK) laminates, stacked in a quasi-isotropic layup. The tested configurations for pure mode loading were the Double Cantilever Beam (DCB) and Edge Notch Flexure (ENF) coupons, while for mixed-mode loading the Cracked Lap Shear (CLS) specimen was studied. The crack length along the joined interface was monitored at predefined loading cycles in order to calculate the propagation rate for each test at given loading parameters. The constants for the exponential Paris' laws were extracted from the pure-mode tests subjected to displacement control while a constant propagation rate was retrieved for the force controlled CLS testing.

Hydrometallurgical treatment of calcium aluminate slags for alumina production – Potentials & Challenges

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Primary aluminium metal production is dependent on the uninterrupted flow of metallurgical grade alumina (MG Al_2O_3). MG Al_2O_3 is produced almost exclusively by the treatment of high-quality bauxite ore with the Bayer Process. Recently EU included bauxite in its list of Critical Raw Materials (CRM), recognizing the inelastic nature of its globalized supply chain. Moreover, the EU is a major importer of aluminium, as the majority of its bauxite reserves have been exhausted. In the light of these challenges, MG Al_2O_3 production from alternative raw materials and by use of alternative processes is under consideration. One of the alternative processes that have been considered since the beginning of the primary aluminium industry is the leaching of calcium aluminates with Na_2CO_3 solutions and the subsequent precipitation of $Al(OH)_3$ with CO_2 neutralization. In the 21st century, this process is being investigated to produce alumina in integrated processes for the circular economy transition, such as the treatment of Bauxite Residue and/or other alternative raw materials and the aluminothermic reduction of SiO_2.

The Technologies for Sustainable Metallurgy Group (TeSMeT) of NTUA is actively researching this particular technology for more than 5 years within the framework of numerous EU funded research projects. The work has been focusing on revealing the fundamental physicochemical mechanisms underpinning this technology, as well as its potential for intensification and optimization. Al-extraction yields exceeding 80% have been achieved under optimized conditions and aluminate solutions with more than 20g/L equivalent Al_2O_3 from suitably engineered slags. $Al(OH)_3$ precipitation from corresponding solutions, with CO_2 gas purging, has been studied and precipitation yields of >90% have been achieved. The present paper summarizes qualitatively and quantitatively key parameters for both processes and addresses the major challenges thereof and the direction of ongoing research towards their resolution.

Synthesis and evaluation of bulk mechanical properties of a bio-based resin doped with self-healing micro-capsules

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In the last decade, there is a tendency towards green energy and renewable sources, and therefore there has been a rapid increase in the necessity of environmentally friendly and bio-based materials. In order to increase the operating time of a bio-based resin, it has been doped with self-healing micro-capsules that contain isocyanate. For the experimental evaluation, two different micro-capsule types have been used. The first one is encapsuled with PU and contain 43%wt isocyanate, and the second one is encapsuled with PBAT and contain 63%wt isocyanate. Both materials have a total concentration of 2.5%wt isocyanate. The resin is mixed with the capsules, and the mixture is degassed and dispersed in vacuum. Afterwards the mixture is degassed again and the proper amount of catalyst is added and stirred, before adding the final polymer in the molds and curing it. Two types of specimen have been produced for each material, the fracture toughness and tensile specimens, as ASTM D5045-14 and ASTM D638-14 respectively indicate. The fracture toughness properties (KIc, GIc) and the mechanical properties (Sy, E, εfr) of the materials are calculated and compared to each other and those of the unmodified resin. The micro-capsule addition has been shown to increase significantly the fracture toughness properties and decrease the mechanical properties. Both micro-capsule types seem to contribute to the brittleness of the final material.

<u>Session:</u> Fatigue performance and crack growth prediction of engineering materials

An experimental investigation of fatigue performance of aluminum alloy AA7075-T6: the role of grain orientation and environmental factors

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Nanofluids are solid-liquid mixtures composed of solid nanofibers or nanoparticles, that suspend in a fluid with sizes that range from 1 to 100 nm.

Their applications span from cooling engines and electronics, heat exchange in solar collectors, heat storage systems and coolants in manufacturing. The use of nanofluids has been proved to offer a positive effect on the corrosion resistance in some cases. Aluminum is a light material that has remarkable fatigue resistance even in harsh environmental conditions such as air, water, and sea, as well as chemical resistance.

The aim of this study was to evaluate the fatigue performance of a cold-rolled AA 7075-T6 plate both in normal and corrosive environments such as Cu nanofluid. A three-point bending fatigue device was specially designed and manufactured for this case. The tests were performed at frequencies of 25 Hz, R=1 and ambient temperature. Fatigue Wohler-like curves along the long transverse (T), short-transverse (S) and rolling (L) directions of the plate were extracted. Also, 10^6 cycles were considered as the fatigue life limit (endurance limit).

The results were interpreted against the forming direction and revealed significant differences in fatigue and corrosion-fatigue life. The nanofluid impact on aluminum fatigue life was evaluated as a parameter with high potential which deserves further investigation. The research has been realized within the framework of the research project T7DKI-00054 (bilateral scientific and technological cooperation between Greece and P.R. China) funded by the European Union and Greek national funds (Competitiveness, Entrepreneurship and Innovation).

Fatigue crack growth prediction in plastically prestrained high strength steels

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Cold roll forming used in the manufacturing of lightweight structural steel profiles is accompanied by the introduction of local, non-uniform plastic deformation [1] in specific locations of design details. Under alternating loads, the plastic deformation inducing local hardening/softening phenomena and the residual stresses due to processing, can significantly affect the fatigue crack growth performance of the steel sections. Reliable tools for analytical assessment of the fatigue crack growth behavior in such locations is useful for extending the life of the components and avoid structural damage and the associated economical impact for repairs.

The fatigue crack growth of the HSLA S355 and S460 steels with existing plastic deformation has been assessed using an in-house developed analytical fatigue crack growth model. The model is based on the energy concept used in the analytical work of Kermanidis and Tzamtzis [2] and combines the critical strain energy approach proposed by Morrow [3] and the strain energy density (SED) criterion [4]. The model considers cyclic material properties and the cyclic strain hardening mechanism at the tip of the crack for fatigue crack growth rate prediction. The analytical results are compared against fatigue crack growth experiments on plastically prestrained S355 and S460 steels and show satisfactory agreement.

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Multiaxial fatigue calculation of hot formed stabilizer bars

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This study investigates both experimentally and theoretically the fatigue life of heat treated and shot peened stabilizer bars (also known as anti-roll bars), for heavy-duty trucks. Test results are compared with the theoretical approach of the FKM guidelines, in which monotonic material properties, as well as life influencing factors (roughness, residual stresses) are taken into consideration. Furthermore, a Finite Element Analysis was used to reveal the highly stressed locations of the component and the acting multiaxial stress state. Also, a microstructure inspection and Vickers micro-hardness measurements are performed to examine the existence of decarburization zone and shot peening effect, resulted during manufacturing process. Additionally, a very close agreement between experimental and theoretical results is exhibited, and the theoretical analysis' results, lie on the conservative side of fatigue life. This indicates the capabilities of FKM recommendations in sufficiently estimating fatigue life regarding safety in an early stage of design despite the complexity of this problem.

The effect of microstructure on fatigue behaviour of a Fe-Mn-Al-C steel

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Fe-Mn-Al-C steels have been extensively researched over the past several decades due to their low density, high specific strength and stiffness. These low-density steels can have a transformative effect on the light-weighting of steel structures for transportation. The Fe-Mn–Al-C steels can show a variety of microstructures and achieve a wide range of properties. They can be classified into four categories: ferritic steels, ferrite based duplex steels, austenite based duplex steels, and austenitic steels. The austenitic steels are the most promising in terms of properties and processing. There is a body of research focusing on their microstructure and tensile mechanical properties. The effect of alloy chemistry and heat treatments on the microstructure and mechanical properties has been understood to certain level. However, their application-related properties, such as fatigue resistance, have not been studied yet.

The main objective of this work is to explore the high cycle fatigue behaviour of an austenitic Fe-30Mn-9Al-1C alloy. The hot-rolled material was solution treated and aged to introduce nanoscale kappa-carbides into the microstructure. The microstructure of the material was studied using optical microscopy, EBSD and HRTEM techniques, and special emphasis was laid on the analysis of kappa-carbides. High cycle fatigue tests were performed, and S-N curves were plotted. The fatigue fracture surface of the tested samples was studied in SEM, and the mechanisms of fatigue crack initiation and crack propagation were identified. The effect of kappa-carbides on the fatigue behaviour and mechanisms of fatigue crack initiation and propagation was analyzed. The fatigue performance of the Fe-30Mn-9Al-1C alloy after different heat treatments was compared to that of other advanced high strength steels.

<u>Session:</u> Surface treatments and coatings

A methodology to predict the life span of tools applied in cheese cutting machines and its improvement via the application of PVD TiN coating

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The potential to increase the life span of tools applied in cheese cutting machines is of great importance considering their cost and the risk of fragmented metallic parts of the tool being inserted into the cheese. Such tools are commonly manufactured by annealed stainless steel 405 and are subjected to dynamic loads during their operation, leading to fatigue failure. An efficient method to overcome this sudden failure is the application of coating on this type of tools. In this work, the potential to increase the life span of tools via the deposition of TiN-coating was investigated. In this context, a methodology was developed for predicting the number of impacts until the first fatigue fracture, enabling a preventive replacement of the tool. This methodology was based on the construction of a pneumatic system for the precise cutting of cheese and the simultaneous measurement of the forces developed. Additionally, the entire cheese cutting process is simulated by appropriate FEA modeling. According to the attained results, the application of TiN coating on steel tools improves significantly the resistance against dynamic loads and thus the life span of tools applied in cheese cutting machines.

Acknowledgement: This research was carried out as part of the project «DESIGN, DEVELOPMENT & OPTIMIZATION OF AN INNOVATIVE CHEESE CUTTING MACHINE » (Project code: KMP6-0077379) under the framework of the Action «Investment Plans of Innovation» of the Operational Program «Central Macedonia 2014 2020», that is co-funded by the European Regional Development Fund and Greece.

Block on ring wear tests of artificial textured and coated surfaces under starved lubrication conditions with fullerene C60 additives: The scuffing mechanism investigation

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Artificial coated surfaces and alternative synthetic lubricants can provide a solution for overall efficiency and wear protection of engine components in hybrid powertrains. A detailed experimental investigation of scuffing mechanism of the artificial coated segments is the major contribution of this paper in inadequately lubricated tribo-systems. This paper presents experimental results regarding the surface roughness, hardness, and wear of artificial textured and coated surfaces. Block on ring wear tests were carried under starved lubrication conditions and different velocities. The temperature field was also monitored through a thermal imagine camera. The base tribo-pair consisted of a steel block and an aluminum disc. Block samples of rectangular pockets were tested using different densities and coatings. Electroplated chromium and nickel tailored surfaces were created in block samples. The effect of fullerene C60 nanoparticles was studied compared to a base oil. Tailored coated samples were measured and compared through microhardness tester and scanning electron microscopy. The effect of the surface morphology and input flow conditions can be considered detrimental in rolling-sliding motion.

Improvement of the wear behavior of CrAlN coated tools in manufacturing processes with continuous or interrupted cutting loads via appropriate annealing

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The present paper aims at investigating the potential to improve the mechanical properties and thus the wear behavior of coated tools in manufacturing processes with continuous or interrupted cutting loads via appropriate annealing which could be potential be used for the processing of thermoelectric material. In this context, PVD CrAlN coatings were deposited on cemented carbide inserts. The annealing temperature was set equal to 400oC in order the substrate properties to remain invariable, whereas the annealing time was varied up to 60 min. Nanoindentations were conducted for evaluating the film hardness after annealing. Moreover, perpendicular and inclined impact tests were conducted for capturing the remaining imprint depths with the aid of confocal microscopy and in this way, to evaluate the film fatigue and adhesion after annealing. Finally, turning and milling experiments were carried out using GG30 cast iron and 42CrMo4 as workpiece materials for producing interrupted or continuous chips. As a consequence, the cutting edges of the coated inserts were dynamically or statically loaded. According to the attained results, the film hardness and fatigue strength are optimized after only a short period about 5min, maximizing the life span of coated tools. The increase of the life span is more intense in the case of manufacturing processes with interrupted cutting loads.

Acknowledgments: This research was carried out as part of the project «Design and implementation of innovative lift's air-conditioning systems by using thermoelectric devices» (Project code: KMP6-0074109) under the framework of the Action «Investment Plans of Innovation» of the Operational Program «Central Macedonia 2014 2020», that is co-funded by the European Regional Development Fund and Greece.

Preparation of durable superhydrophobic copper foams for efficient filtration of oil/water mixtures

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Marine environments are vulnerable to oil leakage causing irreparable harm to the ecosystem. Oil sorbent materials are often favored for oil-splits cleanup methods due to their low cost, ease of usage and high efficiency.

In this work a simple two-stage chemical solution process is reported, to deposite a superhydrophobic silver film on copper foams with a view to be employed in oil absorption or filtration procedures. The first stage includes the growth of a silver layer to increase micro roughness and the second evolves the modification of the film using stearic acid. The whole process has the advantage of being time-saving low cost and versatile. UV-Vis spectroscopy was employed to determine optimum deposition durations and detect potential film detachments during the synthesis process. Scanning electron microscopy (SEM) and X-ray diffraction (XRD) were used to examine the film structure. Surface functional groups were detected by Fourier transform infrared (FTIR) spectroscopy. An adherent superhydrophobic silver coating was achieved under optimum deposition durations. A feather-like structured morphology appeared from silver deposition and spherical, microflower morphologies from copper stearate deposition. The influence of process conditions on wettability and the obtained silver film morphology and topography were examined and clarified. Thermal and chemical stability were examined for acidic, alkaline, and salty environments under several temperatures. Filtration capacity under free and forced flow along with oil absorption capacity were also evaluated for the optimum superhydrophobic copper foams. The results show that the produced superhydrophobic foams can potentially be used to oil/water separation applications.

Tribological performance of thermal sprayed coatings under abrasive conditions

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In this work the tribological behavior of thermal sprayed titanium and chromium ceramic-based coatings was investigated under abrasive conditions. Their structure was studied using an X-ray diffractometer (XRD) and a scanning electron microscope (SEM), while their hardness was evaluated using a microhardness tester. To study the strength of these ceramic coatings under abrasion conditions, reciprocating sliding experiments were carried out in a high-precision pin-on-disk apparatus and by using a 6 mm Ø corundum ball to generate high contact pressures (1.5 MPa). In order to thoroughly investigate the friction evolution of the tribo-system, three-dimensional mapping of the tangential friction forces (triboscopy) was performed. Following the abrasion experiments, the wear of these coatings was measured using confocal microscopy. The obtained friction and wear results were compared to state-of-the-art materials and coatings that are currently being used in various industrial applications. From this comparison, it was found that the titanium and chromium ceramic-based coatings have comparable if not better tribological properties for the given conditions. The main friction mechanisms were two body abrasion due to the surface roughness of the counter-material, as well as three body abrasion due to the formation of debris at the interface.

Session: Advances in Additive Manufacturing

Additive Manufacturing: a Tool for Engineering Microstructures and Mechanical behavior

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Laser Powder bed fusion (L-PBF) has attracted a lot of interest in recent years, not only for its profound advantage of producing metallic components of complex geometries but also for the possibility of manipulating microstructures and crystallographic textures. Additionally, recent observations on wrought austenitic steels have revealed the strong dependence of the transformation induced plasticity (TRIP) effect in metastable stainless steels on the crystallographic texture. [1–3] Taking the aforementioned observations into consideration, we can now process TRIP steels such as 304L or High Mn Steels by L-PBF, in order to manipulate the TRIP effect [4] and achieve superior work hardening and fatigue behaviors. In this contribution, in situ mechanical testing with neutron diffraction, is the key method for monitoring the microstructural evolution during deformation. The present study highlights how different microstructures, produced by L-PBF, lead to different deformation behavior in austenitic stainless steels and paves the way for tailored microstructures in different types of steels and for studies under different loading conditions.

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Investigation of Fe-Cu Bimetal Structures through Additive Manufacturing and Inducting Melting

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Bimetal structures have gained interest during last years, since the combination of different alloys can result in structures with improved mechanical and thermophysical properties. A special category of bimetal structures are the so-called metal-metal composites, where the one alloy plays the role of the reinforcing phase, dispersed inside the matrix of the second alloy. Powder metallurgy, extensive plastic deformation and additive manufacturing have been implemented for the fabrication of such composite materials. Additive Manufacturing can play a vital role in fabricating metal-metal composites, providing internal structures with unique geometrical complexity, later processed through other manufacturing routes, including casting and welding. The present work focuses on the couple of 316L austenitic stainless steel with CuCrZr alloy. On the first part of the work, a hybrid additive manufacturing & induction melting process is proposed: laser powder bed fusion is applied for the fabrication of 316L stainless steel cylinders, with internal lattices as reinforcing structures, which are then infiltrated with CuCrZr powder, melted through induction heating. On the second part of the work, bimetal structures have been fabricated exclusively through LPBF, utilizing the miniSLM device at the Swiss Light Source of Paul Scherrer Institut. The focus is given on the analysis of the metallurgical bonding in the interface between steel and copper, while neutron imaging techniques assess the 3D reconstruction of the samples and operando X-Ray Diffraction is used for the layer by layer phase analysis of the 3D printed bimetal material. Finally, compression tests evaluate the overall mechanical strength of the composite structures.

Microstructural and thermomechanical modeling and simulation of selective laser melting in austenitic stainless steels

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In this study, a complete thermomechanical analysis coupled with microstructural evolution models is used to simulate Selective Laser Melting (SLM) in austenitic stainless steels. A framework is developed for the simulation of solidification based on CALPHAD and diffusion transformation kinetics, that takes into account the variance in solidification type for the extensive constitutional domain as well as growth mode. The indicated modeling is applied to predict non-equilibrium thermophysical properties under rapid cooling conditions in order to be employed in transient heat transfer calculations. Heat transfer, diffusion and mechanical analyses are then carried out in sequence. Thermomechanical simulations were performed using FEM, considering the effect of the powder during the manufacturing. The resulting temperature history is provided as input for the microstructural simulation of solidification and solid-state transformations upon rapid cooling and thermal cycling conditions, for the prediction of the distribution of phases and alloying elements. Consequently, a mechanical analysis deployed the ensued microstructural information to evaluate the residual stresses and terminal mechanical properties. The methodology is applied on an AISI 316L austenitic stainless steel as a case study to establish a benchmark simulation methodology for SLM as well as Additive Manufacturing (AM) processes.

Optimization of post-built annealing of Ni Alloy718 processed by powder bed fusion: a synergy of neutron and synchrotron X-ray diffraction

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Laser powder bed fusion (LBPF) provides valuable prospects for processing nickel-based superalloys that are used in the aerospace industry or other high temperature applications. However, the microstructure and mechanical properties of these materials are especially sensitive to the manufacturing conditions and post-built annealing treatments that are applied to relieve the internal stresses, as they are susceptible to the formation of different types of precipitates, depending on the alloy chemistry, temperature and time. A combination of in situ high-temperature neutron diffraction and synchrotron X-ray diffraction was used to study the evolution of residual stresses and precipitation in nickel based Alloy 718 processed by LPBF for a temperature range from 600°C to 1000°C. At the Engin-X instrument, in ISIS UK, it was possible to follow the relaxation of the residual stress as a function of temperature and time. X-Ray diffraction was used to evaluate the initial phase composition and its evolution during annealing. These results allow for the optimization of one-step annealing treatments to relieve the residual stresses and to control the microstructure. The optimized one-step annealing strategies are applied to tensile specimens and the subsequent mechanical tests reveal that superior mechanical properties can be achieved compared to the commonly used two-step annealing, i.e. solution annealing plus aging.

Tuning the shape memory polymer properties through 3D printing strategy: An experimental study

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Shape memory polymers (SMPs) are a class of smart materials constituting an exceptional solution for critical applications in biomedical, aerospace, energy and construction sectors owing to their unique thermal shape recovery and chemical stability. Although additive manufacturing (AM) emerges as a promising method for handling SMPs to fabricate functionally graded freeform structures and smart structural components while overcoming geometry limitations, the effect of AM process signature and printing strategy on the shape recovery characteristics has yet to be investigated.

To that end, a new pneumatic extrusion system was developed to benchmark the shape programming and recovery of a polyurethane based SMP against a conventional fused filament fabrication (FFF) process eliminating the restriction of using filaments (typical FFF) and erasing the thermomechanical history caused due to the filament production, while evaluating different printing strategies and parameters. To demonstrate that shape recovery characteristics, such as parameters of shape fixity, recovery and transition temperature can be significantly enhanced and 'programmed' through a variation of AM building strategies and process parameters beyond tuning of material compositions alone, an experimental study was developed. In-situ thermo-micro-mechanical testing was applied to capture the shape memory properties, both during shape programming and post that. The pneumatic extrusion system offered higher consistency and better shape recovery characteristics compared to the conventional FFF. Finally, different shape memory response and recovery were observed through various AM process parameters proving that it is possible to modify the shape memory polymer properties by controlling the 3D printing strategy.

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Session: Design of mechanical components for engineering applications

Isolation of Copper from Waste Printed Circuit Boards and its Reusability in Additive Manufacturing applications

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Isolation and recovery of metals from waste electric and electronic equipment-(WEEE) and their reuse as fillers, in Additive Manufacturing-(AM) applications, has significant environmental and economic benefits. Copper-(Cu) is an abundant critical metal in waste Printed Circuit Boards-(PCB). PCB were treated, for the isolation of Cu and Cu was processed to be used as additive in PLA filaments. SEM analysis confirmed Cu and oxygen as main elements. DSC analysis showed that cold crystallization and melting temperatures where mainly affected by the addition of 5%-Cu, whereas rheological analysis showed that viscosity was mainly affected by the addition of 10%-Cu. Finally, mechanical performance analysis showed that Cu as additive, affected Young's modulus, flexural modulus and elongation of the composite materials differently.

Additive Manufacturing (AM) is a technically versatile, layer-by-layer manufacturing procedure, with short production times and little material waste that can easily prepare complex and customizable shapes and is gradually integrated into various applications (medicine, electronics, sensors, automation)2.

Introducing CRM recovered from WEEE as additives to materials employed by AM applications can have a tremendous potential for both the performance and the commercialization of the final 3D-printed products, by adding novel characteristics, such as antibacterial properties, photoluminescence, enhanced mechanical properties, magnetic properties, thermal and electrical conductivity and others3.

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Methodology, co-financed by the: Greek State, EU, ERDF, in the framework of the Operational Program Region of Central Macedonia of the NSRF2014-2020-Investment Innovation Plans.

Microstructural and mechanical properties evaluation of Gas Tungsten Arc Welded Ti-6Al-4V to Inconel ® X-750

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Dissimilar metal welding between titanium alloys and nickel-based superalloys can contribute to acquiring light, heat-resistant frameworks of enhanced efficiency and reduced environmental footprint, especially for aerospace applications. However, dissimilarities in thermo-physical and metallurgical properties, as well as the precipitation of brittle TixNiy intermetallic compounds (IMCs) often deteriorate the mechanical properties of such welds. The current study constitutes an attempt to obtain defect free joints, investigating the beneficial impact of copper on the microstructure of the weld metal, through precipitation of ternary Ti-Ni-Cu IMCs instead of binary Ti-Ni IMCs, reported as more brittle in previous studies. Gas Tungsten Arc Welding (GTAW) was performed between Ti-6Al-4V and Inconel ® X-750, varying the welding current and using different filler wires. Crack free joints were obtained, though with the presence of Ti-Ni, Ti-Cu and Ti-Ni-Cu IMCs as well as titanium carbides (TiC). The main purpose of the work was to investigate the microstructure of Weld Metal (WM) and Heat-Affected Zone (HAZ), correlating it with the composition of used electrodes and variation of welding current. The microstructural characterization of the weldment was conducted by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS), while phase identification was performed by X-Ray Diffraction (XRD). Additionally, the mechanical properties of the tested specimens were investigated through microhardness Vickers measurements and tensile tests.

Reduced-Order Phase-Field Modeling of Static Recrystallization

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From a materials engineering standpoint, process parameter optimization can take place through a combination of experimental and computational methods. To this end, phase-field modeling is widely used to predict the microstructural evolution, at the mesoscale, during a variety of materials processes. However, because of its high computational cost, the exploration of the vast process parameters and composition space is challenging. Here, we develop a surrogate (or reduced-order) model for the phase-field simulation of static recrystallization of a copper-nickel alloy. We adaptively sample the parameter space of annealing temperature and duration to build an accurate model with as few data points as possible. We use n-point spatial correlations to effectively quantify the ensemble of final microstructures and principal component analysis to derive their low-dimensional representations. A Gaussian process regression model is then trained by treating both temperature and duration as inputs and the final low-dimensional representations of the microstructures as outputs. Therefore, by facilitating the exploration of the annealing parameter space, we accelerate the development of process-microstructure linkages for copper alloys.

Rim replacement of a bucket wheel excavator

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The present work focuses on the method and the procedure of replacing the rim of a KRUPP SchRs 600 bucket wheel excavator operating in an open lignite mine of the Western Macedonia Lignite Centre. The technical features of the KRUPP SchRs 600 Excavator are presented and the main operational problems of the bucket wheel excavator that lead to the replacement of the rim are highlighted. The design and detailed preparation, welding and inspection procedures to be followed during the replacement are suggested.

Stress Tensor Distribution Monitoring & Rehabilitation in Steels

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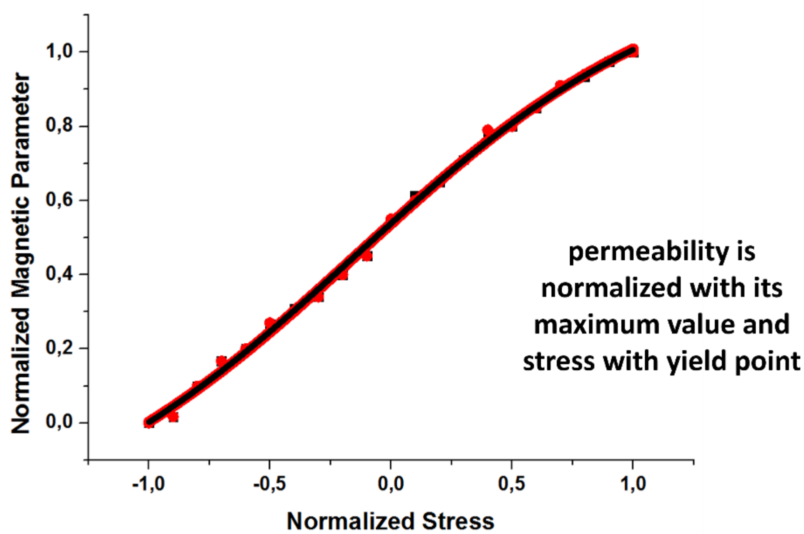
We have developed a method and the corresponding instruments, able to provide surface and bulk residual stress, as well as plastic deformation distribution monitoring in ferromagnetic steels and their welds. The method is based on the correlation of the classic reference methods of stress tensor determination on the surface and the bulk of steels, namely X-ray Bragg-Brentano diffraction (XRD-BB) and neutron diffraction (ND) respectively, with the corresponding surface or bulk magnetic permeability and magnetostriction, resulting in reference magnetic stress calibration curves (MASC) for each different type of steel, as well as in a universal dependence of stresses on magnetic properties concerning either residual or hydraulic stresses. The sensing method is also accompanied by a localized stress rehabilitation, using localized induction heating probes. The system is accompanied by the proper software code, advancing our stress monitoring method in an automated stress testing & rehabilitation system, meeting the needs for the modern & advanced steel production and manufacturing.

Universal law of stress dependence on magnetic properties



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<u>Session:</u> Heat treatments on Aluminum alloys

Coupled Eulerian-Lagrangian (CEL) prediction of temperature distribution on dissimilar friction stir welding of copper to aluminum 6061-T6

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Friction stir welding is a feasible welding process to join dissimilar materials due to its solid-state nature. The aim of the current work was to predict the temperature distribution on dissimilar friction stir welding of pure copper to aluminum 6061-T6. The Coupled Eulerian-Lagrangian (CEL) approach was applied in order to evaluate the effects of the parameters on the microstructure and as a consequence on the thermomechanical and electrical properties. Three welding conditions were studied using the rotational speed as a variable parameter. The rotational speeds chosen are typical for FSW: 1000, 1150, and 1300 rpm. The variation of the heat input from the process is carefully studied. The prediction of the temperature field confirmed the existence of four zones. The maximum temperature reached 522 ℃ at 1000 rpm. Accordingly, it was calculated to be 536 ℃ at 1150 rpm and 552 ℃ at 1300 rpm, respectively. Among the three welding conditions, the most promising welding process for electrical applications is the one with 1000 rpm due to the temperature distribution that develops. The maximum temperature of 522 ℃ is the key factor for desired welding according to the Arora model. The maximum temperature at 1150 rpm and at 1300 rpm is very close to the melting point of the aluminum alloy and, thus, cannot be selected.

Determination of the morphological alterations of intermetallic particles during homogenization of 6xxx series Al alloy billets

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3. ANOXAL

A crucial stage in the manufacturing of extruded profiles for the automotive industry is the homogenization thermal treatment following the casting process. This will enable the attainment of high strength parts by artificial aging taking advantage of Mg and Si which is brought into solid solution during homogenization and will also allow for improved extrudability of the billets. During homogenization β → α transformation of the intermetallic particles is taking place accompanied by morphological alterations due to minimization of interfacial energy. However, no commonly accepted specific method, characteristic of the progress of the homogenization process has been established. In the current study the morphological attributes of intermetallic particles in 6xxx series alloy billets in as cast and homogenized conditions are examined, with the aim to determine the most representative parameters resulting from the transformation. The findings of this work will enable an accurate calculation of a homogenization efficiency index, offering the Aluminum industry the potential for optimization of homogenization process.

Examination of 6xxx series Al alloy extruded profiles heat treatments for optimization of the mechanical properties

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Extruded profiles of 6xxx series aluminium (Al) alloys find a broad application in the automotive industry. Aging (heat treatment) is an essential part of the manufacturing process for the extruded profiles that tailors their mechanical properties. This work focusses on the effect aging conditions on the final mechnical properties. Specimens from extruded Al 6xxx alloys were aged according to different schedules followed by either water quenching or air cooling and the resulting microstructure-property relationships where thoroughly studied. The effect of natural aging prior to artificial aging but also high temperature aging was considered as well. Furthermore, a comparison between industrial practice and the laboratory aging is performed in order to elucidate on found differences in response to the heat treatments. The results to be presented here include findings from microstructure analysis, electron fractography, tensile and compression test data. These results are used for optimization of the heat treatment for attaining the most appropriate combination of strength and formability in the final products.

Finite element analysis of the temperature distribution of friction stir welded dissimilar aluminum alloys Al 5083-H111 and Al 6082-T4

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Friction Stir Welding is a new welding technique for joining and processing metals. In this paper, a numerical model is created based on scientific knowledge with the aim to provide a useful tool for heat generation prediction of the temperature gradients that develop during the FSW of dissimilar aluminum alloys (Al 5083-H111 and Al 6082-T4). The software used for this analysis is Abaqus/Explicit and a dynamic explicit analysis is carried out.

A three-dimensional (3D) thermomechanical problem of the FSW procedure is developed and the behavior of the temperature is studied during the 3 phases (plunging, dwelling, welding). Following the volume-of-fraction approach, a coupled Eulerian-Lagrangian method is utilized for the simulation. The workpiece is modeled using the Eulerian formulation, while the tool is modeled using the Lagrangian approach. Coulomb's frictional contact model is adopted to define the tool-workpiece interaction while the welding speed is defined by material inflow and outflow velocities.

The influence of different operating parameters such as the tool tilt angle (0^o,1^o,2^o) and the rotational speed of the tool (800 RPM, 1200 RPM) on the maximum temperature and the development of the process zones are studied. With the data obtained from the simulated models, various observations are made by changing the input process parameters.

More specifically, the highest temperature during the FSW is found to range between 536^{o}C and 542^{o}C, depending on the process parameters entered during the modeling. It is also noted that in all combinations of parameters, the temperature that develops on the advancing side remains higher throughout the whole process than that on the retreating side due to the laws concerning the heat production on each side. It is also observed that as the rotating speed of the tool increases, so does the maximum temperature along the welding zone and on the rest of the workpiece.

Implementation and characterization of the influence of misorientations in microstructure-based simulations

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The utilization of computational approaches for the design and the examination of mechanisms that happen in materials, under the scope of Integrated Computational Materials Engineering (I.C.M.E.), has grown in popularity in the recent years due to improvements in the software and hardware fronts, making those approaches both viable economically and accurate on their results. Microstructure-based analyses, both experimental and simulation, are of the utmost importance for the properties characterization and phenomena explanation that occurs in metallic alloys. The synthesis of statistically Representative Volume Elements (sRVEs), coupled with a Crystal Plasticity (CP) model, approach has proved to be accurate, successfully taking into consideration the orientation of individual grains, and the texture, producing results close to the experimental ones. In this novel research, the misorientation of neighboring elements of the microstructure feature will be implemented on the R.W.T.H. Aachen’s developed RVE-Generator DRAG-Gen. To characterize the influence of misorientations in such simulations, sRVEs of various steel grades were created, with and without the consideration of the feature, as inputs for the DAMASK CP-Simulation program. This work is in progress.

<u>Session:</u> Physical-Extractive and thermodynamics Metallurgy

Alumina production from alternative domestic EU resources by an HCl route

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The recent inclusion of bauxite, the precursor to the production of metallurgical grade alumina (MG Al2O3), in the EU's Critical Raw Materials (CRM) list reflects its concerns about the stability of the primary aluminium (Al) supply chain. In more detail, the chain consists of three interlinked stages, mining of high-quality bauxite, processing of this material in Bayer Process refineries for the production of MG Al2O3 and reduction of the latter in electrolysis cells for the production of Al metal. With its domestic high quality bauxite resources depleted, the EU is heavily dependent on aluminium imports to meet its market demand. To ensure its future strategic autonomy, the EU is already considering alternative resources and processes for the production of alumina. One group of materials that are abundant within EU borders are aluminosilicate rocks such as kaolin, nepheline syenite, anorthosite and industrial by products such as Si-rich aluminate slags. For this group of materials acid hydrometallurgical processes are proposed, based on the high solubility of Al and corresponding low solubility of Si in acid aqueous solutions, the latter being removed as a siliceous leaching residue.

The Technologies for Sustainable Metallurgy Group (TeSMeT) of NTUA has performed significant research work in this field, developing novel hydrometallurgical technologies for the processing of aluminosilicate materials with HCl. In more detail, high Al extraction rates (>80%) have been achieved with kaolin, nepheline syenite and Si-rich calcium aluminate slags. The aluminium chloride solutions produced undergo HCl gas purging for the precipitation of Aluminium Chloride Hexahydrate (ACH), a precursor for the production of Al2O3. Precipitation yields >95% have been achieved on a laboratory scale. This paper summarizes the results produced by this technology in the framework of several EU funded projects and highlights the main challenges encountered in both processes and for different aluminosilicate materials.

Characterization of metastable retained austenite on novel multiphase TRIP automotive steel

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Third generation advanced high strength steels pursue outstanding mechanical properties in tandem with high productivity, low CO2 (production and in-service) emissions, in service structural integrity, safety and a prolonged life-cycle. Modern research and industry practices such as press hardening or hot stamping take advantage of combining high formability of steel in high temperatures with tailor-made thermal processing routes and strategic alloy additions. Ongoing microscopical research on automotive steels with multiphase microstructure, containing retained austenite, shows that could exhibit the desired micro and nano constituents to yield enhanced mechanical properties. Further study of paraequilibrium phase transformation through microscopical techniques, is vital to utilize modern physical metallurgy into upcoming production technologies and further downgauging in engineering applications. An experimental thermal simulation was carried out on a cold-rolled annealed C-Mn-Si TRIP steel. Isothermal bainitic quenching preceded by austenitisation, with a critical cooling rate, took place at temperature ranges between 250oC - 450oC for several seconds and water quenching at ambient. Examination of the microstructure conducted via Scanning and Transmission electron microscopy. Bright field imaging, electron diffraction and EDS spot microanalysis, employing parallel or convergent beam modes, took place on transmission electron microscopy characterization. The purpose of this experimental study is to perform a detailed microscopical characterization of obtained metastable retained austenite and other mixed morphologies, assess and quantify attained volume fractions, spatial distribution characteristics, crystallographic indexing, local chemical compositions, and finally to bring about thorough understanding of paraequilibrium, diffusive and displacive solid-state phase transformations on the nanoscale.

Metallurgical Options for the Valorization of Greek BR: Industrial Pilot Modules

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Bauxite residue (BR) refers to the insoluble solid material, generated during the extraction of alumina (Al2O3) from Bauxite ore using the Bayer process. As the global demand for primary aluminium metal increases so does the BR production, currently in excess of 150 million tonnes per year (worldwide). This is generated at some 60 active alumina refining plants. In addition, there are at least another 50 closed legacy sites, so the combined stockpile of bauxite residue at active and legacy sites is estimated at between three and four thousand million tons. MYTILINEOS' since 1991 has been pioneering research on BR handling and reuse, focusing initially on massive low value applications such as use as a raw material for cement clinker production, iron production, bricks and tile production, soil and road substrate and others. From such approaches, only re-use in the cement sector has found industrial application leading to a current recycling of a 10 % of the annual BR production in various cement plants in Greece and Cyprus. To increase the BR reuse potential, MYTILINEOS and NTUA investigate BR-centric processes aiming to recover iron, aluminium, sodium and scandium from BR in a near-zero waste and break-even processing flowsheet which could be applied in a context of industrial symbiosis. To this end, lab-scale and industrial pilot scale research are combined to produce reliable data that will allow a comprehensive techno-economic evaluation that can lead to a viable solution. This paper will present several stand-alone processes and provide insight on the possibilities of interconnecting them.

Thermodynamic study of the Cu-Fe alloy anodic dissolution at H2SO4 solution

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One of the most promising technological approach to achieve a CO2-emission free metallurgical industry is the reduction of Cu-slag by H2 and the separation and recovery of the copper, from a Fe-Cu alloy, by electrochemical techniques.

In this study, we examine theoretically and experimentally the anodic dissolution of a Fe-Cu alloy, in H2SO4 solutions, obtained from H2-reduction of an industrial Cu-slag, as an alternative green pathway for the separation and recovery of copper from other metal species. Thermodynamic Eh-pH diagrams are produced for the identified metals in the Fe-Cu alloy (Fe, Cu, Mo, Pb, As, Sb and Ni) for low, medium and high molalities. The Eh-pH diagrams indicate that all the metal species of the Fe-Cu alloy will be dissolved anodically and their hydrated metal ions will be present in the bulk electrolyte.

Although, the anodic electrodissolution is predicted thermodynamically and observed experimentally, the parallel phenomenon of the anode passivation occurs and is thoroughly revisited. The anode passivation is a complex process including the formation of an oxide film that blocks the electrodissolution of copper, leading to greater overpotentials. Also, this study examines the interesting phenomenon of the self-purification of the bulk electrolyte, in which As(III), As(V), Sb(III) and Sb(V) react and form arsenato antimonates by precipitation. This process is of high importance for the self-purification of the electrolyte, because of the As, Sb and Bi species removal that tend to deposit to the cathode, as prior

scientific studies show.

Alongside the theoretical study of the anodic dissolution of Fe-Cu alloy in H2SO4 solutions, preliminary experimental results are presented, showing the electrochemical response of the anodic electrodissolution of the Fe-Cu alloy.

<u>Session:</u> Environmental aspects of the materials used in engineering applications

Design and production control criteria of Recycled Aluminum products with low energy and environmental footprint (DeReAL) – An overview

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The DeReAL project aims to develop a methodology for controlling and evaluating the impact of adding aluminum scrap to the production of primary aluminum products, thus decreasing the need of energy consumption and contributing to environmental footprint reduction of a smelter. The project focuses on both heat treatable and non-heat treatable aluminum products, ensuring that their final properties are not degraded in the first stage of the production process (casting). The sub-objectives of the project are the optimal separation and the most efficient grouping of the scrap and its management in terms of cost and storage as well as the thorough mapping of the internal structure of the slabs and the billets. The specifications, which were accurately established with regard to chemical composition of the recycled alloys, set the acceptable limits for each alloy to be studied and constituted the basis for the measure-comparison-evaluation process. This paper studies the effect of scrap addition in the microstructure of several aluminum alloys taking into account the specifications. Characterization of the Al alloys via metallography combining optical microscopy and SEM/EDX analysis and mechanical testing were performed for several alloys. Critical microstructural characteristics like the presence of the intermetallic phases regarding their chemical composition and their distribution into the matrix were investigated. Overall evaluation of all the microstructural variables revealed a path for determining the final properties of the as-cast products and identifying which process steps are critical and must adapt to the increased use of aluminum scrap

Impact of material selection on aircraft structures sustainability by accounting for performance, cost, ecological and circularity aspects

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Meeting the goal of a sustainable and circular aviation is linked to great challenges, including an emission-free aviation and implementation of circular economy (CE) principles. Hence, when considering material selection from a variety of alternatives, sustainability assessment must also incorporate CE aspects. The present work aims to contribute to the understanding of the impact of material selection on aviation sustainability, by proposing a material selection approach accounting for performance, cost, ecological and circularity aspects. The present work suggests that a product can be considered as sustainable if it is competitive in terms of performance, as compared to other similar products available in the market, and additionally is sustainable from the financial and ecological viewpoint, with the latter including both the environmental impact and circularity. The efficiency of the circularity approach implemented is assessed by proposing appropriate quantitative metrics; in the frame of this study, circularity is linked to the mechanical performance of the recycled material/component considered, being also able to assess the potential for subsequent recycling loops.

The current approach is based on a multi-criteria decision making (MCDM) methodology, combining the Analytic Hierarchy Process (AHP) to derive the criteria weights and a linear aggregation method. To demonstrate the feasibility of the tool, two primary aviation materials have been considered for the component production, namely, aluminum and CFRP, both virgin and recycled ones. Furthermore, the impact of the fuel type used, namely either either jet fuel or liquid hydrogen, during the use phase of the considered components, has been considered. To identify the best-performing component, an aggregated metric of sustainability is derived as the output of the tool. The components ranking highlights the clear advantage of virgin CFRP under the scope of hydrogen fuel propulsion, followed by the CFRP component composed of recycled aligned fibers.

Modification and Characterization of Ag Nanofluids for the enhancement of stability and thermal conductivity

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An innovative method of improving heat transfer capability in modern cooling and heating systems is the use of nanofluids. Enriched fluids with nanoparticles, compared to conventional ones, increase the efficiency of these systems, due to their improved thermophysical properties. Experimental measurements carried out when heating buildings, using nanofluids showed that their application can result in up to a 38% reduction in energy needs [1]. However, instability (formation of aggregates, sedimentation) has been observed in the behaviour of nanofluids, which reduces their performance.

In the present work, silver nanoparticles suspended in deionized water (Ag/ DIW) were studied under different pH and temperature conditions in order to find the region of maximum stability. Experiments were performed to characterize Ag nanofluids by obtaining UV-Vis spectra, changing the concentration, pH value and dispersion medium from deionized water to deionized water/ glycol mixtures and then their stability under different temperature conditions was studied. A nanofluid of suspended silver nanoparticles in ethylene glycol (Ag/EG), with different surfactant was synthesized and characterized to be compared in terms of stability. In addition, the enhancement of thermal conductivity of water and ethylene glycol in the presence of Ag nanoparticles was investigated.

Experimental results have shown that Ag/ DIW, Ag /DIW /EG, Ag/EG nanofluids under distinct acidity (pH) and temperature conditions exhibit increased stability, strengthening the need for further research.

Keywords: Ag Nanofluids, Stability, Heating-cooling systems.

Acknowledgments

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Thermo-mechanical simulation of a liquid hydrogen fuel tank for use in general aviation

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Hydrogen is currently considered as a promising alternative fuel for the future. Provided that the transport segment comprises about one-third of the total CO2 emissions in the European Union, hydrogen is promising for greenhouse gas reduction achievement. Specifically for the aviation sector, hydrogen when produced carbon-free, presents several advantages, as it allows for the elimination of CO2 emissions in flight. Its usage in fuel cells allows for zero emission propulsion, as only water is produced. When burnt in a turbine engine, exceptionally low particle emissions can be expected, as well as reduced NOx emissions, provided that the combustion system is optimized.

The significant advantage of liquid hydrogen as an aircraft fuel lies on the high specific heat of combustion, as it has a gravimetric energy density of 33.3 kWh/kg compared to kerosene having 12 kWh/kg, i.e., hydrogen is about 2.8 times more efficient compared to conventional jet fuel. A typical investigation of the feasibility of liquid hydrogen as aviation fuel is, among others, the Cryoplane project. However, the mass advantage of the liquid hydrogen fuel may result in a mass disadvantage for the complete fuel system if the liquid hydrogen tank and its insulation mass are not minimized. Therefore, a big challenge lies in the design and manufacturing a tank that meets the mass requirements, while insulating the cryogenic liquid hydrogen well enough to prevent excessive heat leak and boil off.

The key elements of the liquid hydrogen commercial aircraft technology are still at very low Technology Readiness Level and for this reason, advanced parametric modelling is required to support an optimized tank design. In this direction, the present work refers to the development of a detailed thermo-mechanical simulation model of a small-scale liquid hydrogen fuel tank for aviation applications. The design considers a tank equivalent to a typical general aviation gasoline tank of a capacity of about 250 L. For the same energy content, about 70-75 kg of liquid hydrogen are needed. Assuming a mean density of liquid hydrogen equal to 70.85 kg/m3, the tank capacity should have a capacity of around 1000 L. A 2 bar design pressure, 6 bar maximum overpressure and 20K design temperature are investigated. The multi-parametric model developed allows different design geometries to be modelled, yet a cylindrical tank with elliptical caps is considered.

The liquid hydrogen tank insulation must meet conflicting requirements, as it has to demonstrate very low heat losses in order to meet the boil off requirements, while at the same time to be a light-weight system, fulfilling the tank mass requirements. Considering the low operating pressure, aluminum alloy materials are used in the tank construction, as composites could lead to marginal mass reductions, at a high-cost penalty. Such a selection is in line with NASA studies e.g., suggesting that aluminum alloy 2219 fulfils all requirements of a LH2 tank design. For the insulation system, silica aerogel, a novel insulation material with extremely low conductivity and density, is currently considered.

The developed thermo-mechanical simulation methodology accounts for all the distinctive and critical parameters regarding the simulation of cryogenic metallic hydrogen tanks. The model comprises a thermo-mechanical module to account for temperature history effects on the mechanical response and a structural module to account for thermo-mechanical stress analysis. Modelling approaches combining solid elements with thin-shell element approaches are applied and parametric studies for different tank variations having variable wall thickness of the double-walled aluminum vessel and variable spacing between the walls for introduction of the aerogel thermal insulation have been successively performed. The developed model is used to draw conclusions about the structural performance of the tank and its mass efficiency as function of its sizing parameters.

<u>Session:</u> Metallic materials: Simulation studies, porosity and tribology

An isotropic elastic-plastic model for porous metals accounting for void shape effects

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An isotropic elastic-plastic (rate-independent) constitutive model for porous metals accounting for void shape effects is presented. The model can be used for the numerical simulation of problems related to ductile fracture of mechanical structures and components. The new model results from simple modifications of the homogenized anisotropic model proposed by Kailasam & Ponte Castaneda (1997, 1998) and Danas & Aravas (2012) and is based on the equivalence between orientational averaging and projection in the space of isotropic tensors (Gatt et. al. 2005). The microstructure assumes a random distribution of spheroidal voids (oblate or prolate) with a predefined aspect ratio in an isotropic metal matrix. The internal variables characterizing the microstructure at every material point are the volume fraction of the voids (or porosity) and the equivalent plastic strain of the matrix material. An algorithm for the numerical integration of the constitutive equations is developed and implemented using a UMAT user subroutine in the commercial finite element program ABAQUS. For the validation of the model, its predictions are compared to numerical calculations which are carried out using periodic 3-dimensional unit cells subjected to finite deformations under stress triaxiality and lode angle control. Preliminary simple 2- and 3-dimensional finite element simulations reveal strong effect of the initial void shape on porosity evolution.

Correlation of cutting force components in turning to corresponding ones in slot milling

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The specific cutting force components (SCF) are required to describe the time course of the resultant cutting force components in various cutting processes. SCF are associated with concrete workpart and tool data as well as cutting kinematics. Recently, an innovative analytical experimental method to define SCF by conducting single measurements in slot milling has been introduced. In this context, it was necessary to clarify the effect of chip thicknesses, shear angle and developed stress fields on the resultant cutting force components during the chip formation. In this paper, a method is presented to correlate the resultant forces in longitudinal turning with corresponding ones in slot milling. The experiments were carried out on hardened steel by monitoring the cutting force components.

Modelling of lubricated contacts on Elastohydrodynamic Lubrication under the effect of roughness and application on rolling bearings

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Rolling bearings are critical machine parts, as a result the study of this mechanism is very valuable. The aim is to understand the significance of lubricant and surface roughness on the function of the rolling bearing. To achieve this, some figures are created from computer simulations using Ansys Fluent. This work presents pressure distributions and film thickness diagrams for various roughness profiles of the roller and different lubricants. The simulations are carried out under elastohydrodynamic lubrication conditions. The geometry of the model represents the contact area as realistically as possible. In order to examine the effect of surface roughness, different average widths of roughness are used. In the same manner, to study the influence of lubricant, specific values of viscosity at atmospheric pressure are selected. The parameters of the simulation such as velocities and applied load are set to correspond with reality. From the figures that arise it is concluded that roughness and lubricant determine the pressure distribution and the film thickness.

<u>Session:</u> Simulation of advanced techniques

A predictive damage-tolerant modelling framework for the assessment of fatigue strength of additive manufacturing materials

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Additive Manufacturing (AM) processes have been utilized for the fabrication of complex and structural parts with complex geometries which were very difficult to be fabricated with conventional manufacturing methods for over a decade [1-2]. Their inherent unique feature of layer-by-layer fabrication of parts gives the design freedom for the fabrication of advanced parts that combine high strength with low weight, characteristics that attract the aerospace, automotive and medical industrial sectors [3]. Despite their advantages, AM parts presented considerable variabilities in their strength during cyclic loading conditions – their main service conditions. In particular, AM materials have presented decreased fatigue strength properties compared to their counterpart materials fabricated by conventional manufacturing methods.

One of the main reasons for decreased fatigue properties of AM materials is the presence of defects formed during the process. The main types of defects in found in AM processes are lack-of-fusion (LOF), keyhole, balling and gas pores [4]. Among these LOF defects pose as the most critical, due to their irregular shape leading to excessive stresses at the region of their edges [5]. Nevertheless, the significant progress in AM technologies during the last years the formation of defects cannot be completely avoided due to process instabilities or uncertainties related to the processes. For this reason, defects and their effect on fatigue life must be considered during the design and service of AM materials and parts.

In the present work, a predictive modelling framework based on a damage-tolerant approach is developed and examined. The procedure aims at the prediction of fatigue life of AM materials considering the defects and their characteristics. Defects are considered as initial cracks from which the critical fatigue failure is possible to initiate. At the first step of analysis, a finite element thermal simulation analysis of the AM process for the fabrication of material is performed. The main output of this simulation are the melt pool characteristics within the built parts. The size of melt pool is the most characteristic indication for the quality of the bonding between the successive layers and parts [6]. By the assessment of the melt pools, the critical areas for defect formation are determined. Then, a fracture mechanics approach for the estimation of fatigue life of materials in High Cycle Fatigue (HCF) is employed. The fracture mechanics approach is based on the selection of suitable Stress Intensity Factor (SIF) taking into account the characteristics of the most critical defect and the fatigue crack growth rate properties of AM materials. The results of modelling procedure are compared with available from the literature experimental data, verifying the current approach.

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An investigation of stress peening using a 2D FEM-based simulation approach

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Shot peening (SP) is one of the most widely used surface treatment processes. Repetitive impacts from small spheres causes a local deformation on the surface of the component. This permanent deformation develops a compressive stress field, in a depth up to 300-400 μm and provides a significant in the fatigue life of the component. An enhanced version of SP, which is widely used in leaf spring industry, is performed applying a pretension on the treated part, and it is known as stress shot peening (SSP). This modified process has been proved beneficial for the fatigue life and durability of leaf springs; therefore, further weight reduction is allowed.

Current study presents a structured modelling approach for stress shot peening, using a 2-dimensional plane (2D) strain Finite Element approach, capable of implementing important process parameters considering also the stochastic nature of the used shots. This 2D approach reduces significantly the calculation time and enables the examination of multiple scenarios since the demand on computational resources is limited with respect to 3D FEA models. In the present study an overview of stress shot peening is presented, alongside with a comparison with the conventional shot peening process, in terms of compressive residual stresses and surface roughness. Also, the model is validated on both shot and stress peening processes, and the comparison with measured residual stress values is presented.

Experimental validation of a cohesive zone-based stacked-shell numerical model for delamination prediction in composite materials

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The use of composite materials is increasingly growing in a wide range of applications, where the inherent advantages of composites are required for the development of lightweight structures that should exhibit high stiffness, increased strength and fatigue resistance characteristics. The most significant among their restrictive characteristics is related to their reduced resistance to out-of-plane loads, which often results to separation along the interface of neighbouring plies. This failure phenomenon, which is widely known as delamination, could be a risk for the load-bearing capacity of a structural component.

Delamination may be considered as a crack that propagates through the matrix of a laminate. Three separate fracture modes are usually utilized to describe the complex phenomena that arise at the region of the crack tip, namely Mode-I, Mode-II and Mode-III. The primary experimental approaches used for fracture toughness evaluation are the Double-Cantilever Beam (DCB), End-Notched Flexure and Edge Crack Torsion tests.

Several approaches for numerical prediction of delamination are based on a Fracture Mechanics foundation. Among the different numerical models that have been proposed for delamination prediction, the Cohesive Zone Model has been extensively applied due to the accuracy and efficiency it presents. However, definition of all parameters that are relevant to delamination initiation and propagation is an intricate task that requires extensive investigation, in order to establish a reliable numerical prediction. In the present work, a strategy based on finite element analysis is developed for the simulation of composite materials, with emphasis on interlaminar damage prediction. The modelling technique is developed based on a stacked-shell approach for the simulation of composite materials. The prediction capabilities of the developed methodology are validated through comparison of numerical results to corresponding experimental data of a Mode-I DCB experimental campaign, with emphasis on the future application of the developed methodology to medium and large-scale structures.

Poster Session

3D printing for metal-ceramic dental restorations

E.Garmpi, G. Ioannou , A. Papanicolaou , I. Kitsou, E. Roussi, P. Angelopoulou, C. Andreouli, A. Tsetsekou

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NOVAMIND

For dental applications, 3D-printing is today one of the most important developments, as it contributes to the faster production of dental structures of high precision and complex geometry.

Specifically, high quality metal frames of crowns, bridges and some tooth elements can be produced in a day using Co-Cr or Ti-based alloys, with the technique of SLS-Selective Laser Sintering.

Although metal restorations have superior mechanical properties, posterior restorations with a porcelain veneer are needed for improving their aesthetics and obtain a natural tooth-like appearance.

In the present work, commercial Co-Cr powder was used, and metal substrates were printed using the SLS process. Critical printing parameters were studied, and the specimens were coated with dental porcelain, which is widely used in dental restorations. Critical parameters affecting the microstructure of the metal-ceramic specimens were studied.

Development of a double layered zirconia-based coating in order to improve Titanium-Porcelain Bonding

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Titanium and its alloys are attractive materials for biomedical applications. However, Ti tends to react with oxygen at high temperatures, which results in a thick oxidization surface layer. This oxidization layer on the Ti surface impacts the bond strength of the Ti-porcelain prosthetic appliance. Literature studies propose the introduction of intermediate ceramic coating layers between the Ti substrate and the porcelain to improve Ti-ceramic adhesion. In this work, a process based on covalently attaching a hybrid organic-inorganic layer on Ti surface is developed, in order to improve porcelain-substrate adhesion strength. A silica-zirconia hybrid sol-gel layer is deposited on Ti as a first layer and yttria stabilized zirconia (YSZ) is plasma sprayed as a second layer before dental porcelains' deposition. The Si/Zr sol-gel process involves the preparation and mixing of two different sols: an organosiloxane and an alcosol that serves as a source of hydrolyzable zirconium. A dip coating process has been employed to coat the Ti, involving its dipping into the final sol for several time frames, followed by controlled ascension and curing at different temperatures. Also, various surface modifications like grinding, sand blasting, chemical treatments have been investigated. The main mechanical features of the coating system including the sol-gel, the thermal spray approach and finally the porcelain have been investigated with particular focus on roughness, thickness, and adhesion to the substrate. The morphology and integrity of the coatings-porcelain system have been evaluated by SEM and the chemical structure of the coatings, which also involves the coating-substrate adhesion, has been investigated by FTIR studies.

Experimental testing and simulation of fuselage stiffened panels representative of aircraft fuselage sections

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The fuselage of an aircraft is expected to undergo combinations of axial, bending, shear, torsion and differential pressure loads. The validation of such a complex metallic structure for these types of loads and their combinations is usually performed by aircraft manufacturers at the full-scale fuselage barrel level, which is considered neither cost nor time effective. The decision to scale-down the experimentation at the stiffened panel level presents the opportunity to validate state-of-the-art designs at higher rates than previously attainable. Tests for characterizing stiffened aeronautical sub-components during experimental campaigns consist of quasi-static loading, with loads that induce stresses a percentage of the material's limit stress, investigation into buckling phenomena and their associated critical factors and modes, and fatigue testing that aims to simulate realistic in-flight stress cycles and study the accumulated damage.

In order to successfully carry out such tests, it is necessary to develop test-rigs that are able to introduce simultaneously and independently a set of distinct load types (i.e., internal overpressure together with tension and shear), while appropriately constraining the stiffened panel at its boundaries. The parameters for designing the experimental rig are such so as to recreate at a smaller scale a, similar to the full-scale component's (i.e, fuselage), structural response for typical loading scenarios that would occur during an aircraft's operational life. For example, bending due to wing's lift and fuselage's weight together with torsion from the vertical wing and the cabin's internal pressure.

This paper's objective is to simulate inside a virtual finite element environment the elastic behavior of a fuselage when subjected to representative stress-states and then compare it with that of a properly constrained and loaded panel taken from the fuselage. After defining an optimal concept for the stiffened panel test-rig, linear elastic numerical simulations are performed for a variety of load cases. Then an eigenvalue buckling analysis is carried out for compression and shear respectively and finally a non-linear, large deformation theory, analysis is implemented into the model for the compression load case up to final failure of the panel.

Influence of Post-Weld Heat Treatment Modification on the Microstructure and Mechanical Properties of Inconel® 718 and 42CrMo4 Steel Electron Beam Dissimilar Welding

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Dissimilar welding of Ni-based superalloys and steels is a crucial procedure especially in aeronautical applications. However, the post-weld microstructural constituents and their mechanical properties may present unwanted phenomena (e.g. very unstable mechanical response) during these kind of applications. Therefore, the need of post-weld heat-treatment investigation is emerged. This research study focuses on the microstructural evolution and mechanical properties assessment of the post-weld heat treatment modification influence on Electron Beam (EB) dissimilar welded Inconel® 718 and 42CrMo4 steel. The microstructure study was carried out by light optical (LOM) and scanning electron microscopy (SEM), coupled with energy-dispersive spectroscopy (EDS) analysis. Mechanical properties were investigated via tensile and Vickers hardness testing. The identification of the microstructural phases was achieved through the use of X-Ray Diffraction (XRD). The results present the improvement of microstructural and mechanical response stability via post-weld heat treatment effect modification.

Microstructure Analysis, Mechanical Properties and Corrosion Behavior of Grey Cast Iron/Low Alloy Steel Dissimilar Brazing Joints with Silver Base Filler Metal

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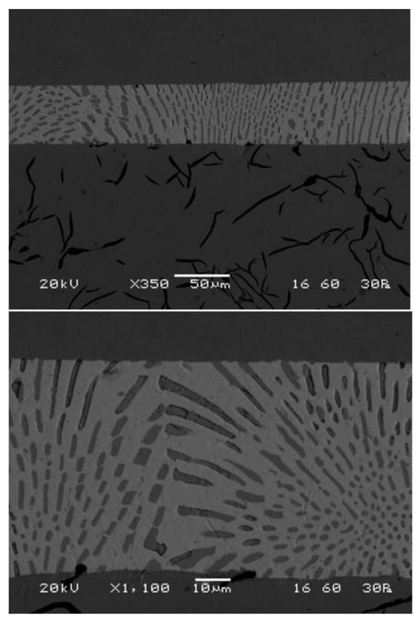
The present research work focuses on the study of the microstructure evolution, corrosion resistance, and mechanical properties of GG25 grey cast iron/AISI 4140 low alloy steel dissimilar brazing joints, using a eutectic type, free-flowing Ag base filler metal. Those types of fillers are commonly used for brazing various ferrous and nonferrous metal alloys, due to their relatively low brazing temperature, offering excellent fluidity and good corrosion resistance, mainly because of the high Ag content. The welding zone microstructure study was carried out through optical (OM) and scanning electron microscopy (SEM), in conjunction with an energy-dispersive X-ray detector (EDS). Weld joints' mechanical properties were investigated through tensile tests, as well as detecting the Vickers microhardness across the microstructure's zones. For the assessment of the joints' corrosion resistance, potentiodynamic polarization tests were performed in 3.5 wt% NaCl solution, at various temperatures. The evaluation of the corrosion products was carried out by both X-ray Diffraction (XRD) and scanning electron microscopy (SEM).



Modelling the acoustic emission field of the compression ring-cylinder liner tribo-pair in an internal combustion engine

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An attempt to interconnect the analysis of a tribological system with the modeling and analysis of acoustic emissions (AE) is conducted. The aim is to construct a fully customisable model, capable of evaluating the operating conditions of the piston compression ring-engine cylinder tribosystem, in a four-stroke internal combustion engine, which will also calculate the AE output. The model developed can be distinguished in three parts. The tribological model simulates the compression ring-cylinder liner sliding contact behavior during engine operation, in the presence of lubricating film. Based on the Greenwood and Tripp contact theory and numerical solving of the Navier-Stokes equations, this model can calculate the forces exerted on the compression ring, determine the lubrication conditions of the tribosystem and the consequent power losses. The AE generation model is also based on the Greenwood and Tripp contact theory and calculates the power of the AE signal produced, due to the contact of the ring's and cylinder's asperities, by using as input the data of the calculated tribological analysis. Finally, the AE attenuation model was developed for the proof-of-concept phase of the model, where the calculated AE power is compared to the signal power of an experimentally measured AE signal, detected by a sensor on the surface of the modeled engine. Based on the corresponding theory, this model calculates the attenuation coefficients of the cylinder material and considers phenomena such as the geometric spreading of the waves, to estimate the effect of distortion and energy absorption phenomena on the AE signal as it propagates from its source to the sensor.

Numerical simulation of the high velocity plate impact test for the calculation of spall strength of metallic alloys

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Spall fracture constitutes the main failure mechanism in hypervelocity impacts. These types of impacts can be met in defense, aerospace and aeronautical applications. Measuring the spall stress threshold via experiments is a challenging process for which gas guns or lasers are used to create a high strain rate loading to the tested material. This threshold depends on the loading characteristics, material properties and geometry. A common experiment is the plate impact in which spall stress thresholds are calculated by pullback velocity measurements. Numerical models can be used for a further study of spall phenomena and its dependence to some parameters, without the need of various specimens. In addition, detailed stress field and potential failure of the material can be predicted. A finite element (FE) model that simulate the hypervelocity impact of two plates has been developed. Given the impact velocity as input, this model can simulate the impact induced shock wave in terms of stress field and material velocities. After the validation of the FE model a parametric study has been performed which focuses on the effect of different metallic alloy impactor, material geometry and impact velocity on the spall strength.

Optimized wear resistant coatings used as alternative solutions in industrial applications

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The need for wear resistant coatings in a wide range of industrial applications is continuously increasing. Thermal spraying provides the flexibility of being suitable to deposit a wide range of materials (alloys, ceramics, cermets, composites etc) on large surfaces with complex geometry simultaneously being a low cost technique compared to others. For those reasons thermal spray coatings are used to prolong the service life and/or dimension restoration of different worn components. These layers aim to prevent different types and mechanisms of wear such as abrasion, sliding wear, corrosive wear, erosion and their combinations. Furthermore, coatings deposited using thermal spray techniques can be used as a viable alternative to the environmentally harmful electrolytic hard chrome plating.

In this study the results of Atmospheric Plasma Spraying deposition parameters optimization of different alloys (Ni and Mo based) and cermet (WC-Co, Cr2C3-NiCr) coatings are presented. Correlation of the factors and mechanisms that significantly affect their tribological behavior with the deposition parameters is also performed. Finally, parts from an industrial milling process were selected for deposition of the optimized thermally sprayed coatings.

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Superhydrophobic aluminum surfaces for dropwise condensation

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More than 80% of the global electricity generation, is based on the steam cycle that uses fossil fuels and nuclear fission. This results in power generation being the largest contributor to greenhouse gas emissions. Even a small improvement in plant efficiency can reap rich dividends in terms of reduction in fossil fuel consumption. This can be accomplished by increasing the phase change efficiency of industrial condensers. Typically, condensation in industrial surface condensers involves formation of a liquid condensate film on the cooled tubes made from metals such as aluminum and copper. This is due to the inherent hydrophilicity of metals and it limits the efficiency of phase change thermal transport.

Condensation can be enhanced by causing the water to condense as distinct drops that are regularly shed from surface, referred to as dropwise condensation (DWC), rather than forming a continuous liquid condensate film. DWC can be accomplished by turning the metallic surfaces to superhydrophobic. Superhydrophobicity requires the existence of appropriate micro-nano-topography in combination with low surface energy. Here, hierarchical superhydrophobic aluminum surfaces are fabricated in order to improve the condensation efficiency and simultaneously achieving self-cleaning properties.

Micro-texturing in aluminum surfaces conducted through chemical etching with an aqueous solution of hydrochloric acid while nano structuring achieved after boehmitage process resulting to grass-like nanostructures of 150-200 nm. After the micro/nano structuring, a Diamond Like Coating was deposited for corrosion protection and enhancement of nanostructures stability. Lowering of surface energy was conducted through C4F8 plasma deposition in an Inductively Coupled Plasma reactor. The fabricated surfaces achieved contact angles higher than 170° and hysteresis under 3° while exhibiting strong self-cleaning properties. Heat transfer coefficient during condensation of saturated steam on such surfaces showed an improvement of 225% compared to a flat hydrophobic.

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Use of graphene based nanomaterials as lubrication facilitators for wear resistant thermally sprayed coatings

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Metal Matrix Composite materials have been widely used since many years in every day industrial practice as coatings to provide higher mechanical strength, elastic modulus, yield strength, wear and abrasion resistance compared to monolithic metal components. Thermal spray is for many decades a well-established technology for the deposition of these coatings.

Lately Graphene Family materials such as carbon nanotubes, graphene oxide etc. are potential candidates as reinforcement particulates in metal matrix composites due to their exceptional mechanical, electrical and thermal properties with additional interest in their micron to nano scale size.

In the current study the deposition parameters optimization affecting the tribological behavior of hybrid thermal spray coatings is presented. Coatings consist of metal matrix composite powders (e.g WC-Co, Cr3C2-NiCr) combined with graphene materials. The mixing and homogenization processing of the feedstock powders is thoroughly discussed along with the effect of deposition parameters on the uniformity and quality of the developed coatings. Finally, their wear resistance is quantified through pin-on-disc measurements. Apart from their increased wear resistance they exhibit self-lubricating conditions in service thus revealing their hybrid functionality.

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Enhancing the de-icing performance of aerospace composite materials by nanoparticles: A numerical feasibility study

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The last few years the aircraft industry has invested in using new materials and new methods for increasing the thermal and electrical conductivity of specific parts of an aircraft in order to improve the existing de-icing and anti-icing systems. The interest has turned to nano-composite materials, such as graphene nanoplatelets (GNPs), multi-walled carbon nanotubes (MWCNTs), graphene nanoribbons (GNRs) and some metallic particles such as copper, which are added to the existing composite materials. In this preliminary research, it is examined the contribution of severe nanoparticles (GNPs, CNTs) in mechanical and thermal conductivity of the polymer and of the composite. Except from the increased content of nanoparticles, it is also examined the morphological characteristics (size, aspect ratio (AR), length, thickness, surface area, orientation) and the thermal network which is developed. A numerical verification in existing experimental results was also part of this research, which confirmed the difficulties of simulation and the inaccuracies and limitations of available software packages. From the numerical analyses came up that with the increasing content of nanoparticles both the mechanical and thermal properties were increased – always taking consideration the direction of applied loading (mechanical & thermal). Particularly, the composites have enhanced mechanical characteristics in the longitudinal orientation for CNT-reinforced polymer and in the transversal orientation for GNP-reinforced polymer. The use of CNTs offered quicker increase of thermal conductivity in comparison to GNPs – but up to 5% are not manufacturable due to effect of viscoelasticity. The deviations between numerical and experimental results can be justified through the huge dependence of the manufacturing methods of composites including nanoparticles (dispersion factor, local entanglements, poor densification, impurities). For the numerical analyses Digimat 2017.0 and module Material Designer of Ansys Workbench 2020.0 were used. The enhanced conductive nature of the new materials is a rapid and scalable alternative to increase the thermal and electrical conductivity of bulk carbon nanotube materials.