Tribology and Mechanics of Coatings and Surfaces
Room Golden State Ballroom - Session MC-ThP

Tribology and Mechanics of Coatings and Surfaces Poster Session

MC-ThP-1 Role of Layer Position During Thermo-Mechanical Loading of Trilayers, ***Megan J. Cordill [megan.cordill@oeaw.ac.at]**, Claus O.W. Trost,* Erich Schmid Institute of Materials Science, Austrian Academy of Sciences, Austria

Thermo-mechanical loading of thin films on rigid substrates is common method to assess film stresses as a function of temperature. However, these experiments have historically only been performed on single layer films even though multilayers are used in all advanced thin film technology. To illustrate the feasibility of measuring the thermo-mechanically induced stresses of multiple layers simultaneously, different architectures of brittle-ductile-brittle and ductile-brittle-ductile trilayers on silicon were heated with in-situ X-ray diffraction (XRD). The use of XRD provides individual film stress evolution simultaneously to understand delamination mechanisms of the trilayer architecture. The main aspects presented will be the strain evolution under thermo-mechanical loading as a function of layer position. Following Mo and Cu films from next to the substrate, to the middle position, and as the top surface film found that position in the trilayer architecture significantly influences the stress-temperature curve, thus the deformation mechanism due to thermo-mechanical loading.

MC-ThP-2 The Effect of Surface Built-Up Defect on the Coating Process of Automotive Sheet, ***Jianfeng He [13166296136@163.COM]**,* Shanghai Jiao Tong University, China

At present, facing fierce competition in automotive sheet market,defects prevention has been the most important task during cold rolling production.As a key process of automotive sheet(eg. Outer panel), surface coating plays an important role to improve surface quality and errosion resistance. In order to analyze the effect of built-up defect to coating of automotive sheet surface treatment, 3-dimension morphology of build-up defect is measured.The build-up behavior in coating process is also investigated in this article,which is helpful for defect inspection and judgement.

MC-ThP-3 Investigation of Wear Resistance of 7075 Aluminum Alloy Modified Through Plasma Electrolytic Oxidation (PEO), ***Bruna Freitas [bruna.michelledefreitas@gmail.com]**, Ricardo Torres, Carlos Laurindo,* PUCPR - Pontifícia Universidade Católica do Paraná, Brazil*; Luciane Santos,* Vrije Universiteit Brussel, Belgium*; Paulo Soares,* PUCPR - Pontifícia Universidade Católica do Paraná, Brazil

The 7075-aluminum alloy is widely used in the aerospace and automotive industries due to its excellent mechanical properties. However, its relatively lower wear resistance may limit its applications. The PEO surface modification process is a method that can improve the surface properties of the 7075 alloy. Thus, this study evaluates the wear resistance of the 7075 alloys modified by PEO. The Al7075 samples were sanded with #500 and cleaned. The PEO process was carried out using a bipolar power source, with an electrolyte based on sodium phosphate and sodium hydroxide, with 352V, 350V, and 475V and a 1000 Hz frequency for 5, 10, and 20 minutes. The samples were characterized using SEM and EDS techniques, X-ray Diffraction, and wear tests. The results show that the oxide surface formed is homogeneous, porous, and crack-free. The XRD results indicate the presence of Al2O3 phases, and EDS showed that the elements Al and O were predominantly present in all coatings after treatment. The tribological resistance significantly improved compared to the substrate.

MC-ThP-4 Nanoindentation and Micropillar Compression at Cryogenic Temperatures, ***Eric Hintsala [eric.hintsala@bruker.com]**, Kevin Schmalbach, Douglas Stauffer,* Bruker Nano Surfaces, USA

Mechanical reliability at low temperatures is required for environments in energy and aerospace applications. Due to its highly localized measurement capabilities, nanomechanical approaches can be useful for isolating individual regions within a more complex microstructure or component or testing of thin films.In general, both modulus and yield strength gradually increase with decreasing temperature,but more sudden shifts in behavior can also be observed, such as phase transformations or ductile-to-brittle transitions. In situSEM testing enables visualization of the deformation mechanisms coupled with the measured mechanical properties helping complete the interpretation of the behavior.Alow temperature control system has been developed for the Hysitron PI89PicoIndenter (Bruker, USA) for in situ SEM testing that enables continuous temperature control from -130°C to 50°C. Independent temperature control on the tip and sample to enable proper temperature matching in vacuum and minimizes drift. The temperature dependent mechanical response of two metallic samples, Nitronic 50 and Tungsten, both by nanoindentation and micro-pillar compression.

MC-ThP-5 Effect of Phosphorus on Tribological Properties of Laser Clad AlCoCrFeNiTi High-Entropy Alloy Coating in 3.5% Nacl Solution, ***Xiulin Ji [xiulinji@gmail.com]**,* Shantou University, China

High-entropy alloys (HEAs) hold significant potential for marine engineering applications due to their excellent corrosion and wear resistance. This study investigates the effect of phosphorus (P) doping on the corrosion and wear properties of AlCoCrFeNiTi HEAs. AlCoCrFeNiTi-P*x* (*x* = 0, 0.08, 0.16, 0.23) HEA coatings with varying P contents were prepared using laser cladding technology, and their tribological performance was evaluated in a 3.5% NaCl solution. The results showed that the undoped AlCoCrFeNiTi coatings primarily exhibited an FCC phase, while phosphorus doping introduced a mixture of FCC, BCC phases, and phosphides. The hardness of the coatings increased significantly with phosphorus addition, particularly when the P content reached 23%, achieving an average hardness of 635.6 HV about 2.1 times higher than the undoped HEA coating. In the 3.5% NaCl solution, the phosphorus-doped HEA coatings demonstrated superior stability and oxidation resistance under corrosive wear conditions. Phosphorus doping effectively reduced both the friction coefficient and wear rate. For instance, under a 5 N load, the friction coefficient of the AlCoCrFeNiTi-P23 coating dropped significantly from 0.43 to 0.20, the lowest among all samples. Additionally, under a 10 N load, the wear rate of the phosphorus-doped coating was approximately 75% lower than that of the undoped AlCoCrFeNiTi coating. The primary wear mechanisms in the 3.5% NaCl solution for the undoped coating were abrasive and fatigue wear. However, with phosphorus doping, the wear mechanisms shifted to abrasive and adhesive wear under 5 N and 10 N loads. At a higher load of 20 N, corrosive wear became the dominant mechanism. In conclusion, phosphorus doping significantly enhances the hardness and tribological properties of AlCoCrFeNiTi HEA coatings, making them highly suitable for use in marine environments.

MC-ThP-6 Numerical and experimental evaluation of a borided Ti6Al4V alloy under cyclic contact loading., *Alfonso MENESES AMADOR, Hugo Alberto Pérez Terán, GERMAN ANIBAL RODRIGUEZ CASTRO,* ***Marco Antonio Melo-Pérez [esimemelo@gmail.com]**,* Instituto Politécnico Nacional, Mexico

In this work a Ti_6Al_4V alloy hardened by the boriding process was evaluated by cyclic contact loads. Powder-pack boriding process was used to modify the alloy surface where two phases TiB and TiB_2 were obtained on the sample due to the boron diffusion into the substrate material. The thermochemical treatment was carried out at a temperature of 1100°C for 10, 15 and 20 h of exposure time. Titanium borides (TiB and TiB_2) formed on the surface of the Ti_6Al_4V alloy was confirmed by means of the XRD analysis.Berkovich nanoindentation test was conducted to determine both hardness and Young’s modulus of the borided samples. Cyclic contact loads were applied on the borided sample using a MTS Acumen equipment to evaluate the quality of the titanium borides based on the damage caused on the sample surface. Finite element method was used to obtain the stress field due to cyclic contact loads. Results showed that the sample with thicker thickness because of longer treatment time showed the best mechanical behavior under cyclic contact loads.

MC-ThP-7 Investigating Arctic Environmental Effects on Dry Sliding Wear Behavior of Protective Coatings, ***Elyse Jensen [elyse.jensen@mines.sdsmt.edu]**, Austin McCracken,* South Dakota School of Mines and Technology, USA*; Emily Asenath-Smith,* Cold Regions Research and Engineering Laboratory, USA*; Grant Crawford, Forest Thompson,* South Dakota School of Mines and Technology, USA

Understanding the tribological response of protective coatings to environmental conditions is required in order to tailor their functionality for extreme service conditions. This study establishes a methodology for evaluating the sliding wear performance of protective coatings in conditions representative of Arctic environments. A low temperature ball-on-flat tribometer was modified to enable control over dewpoint within the testing enclosure. CrN-coated high strength stainless steel flats and alumina ball bearings were used as model wear couples. Dry sliding wear tests were performed on various CrN architectures at cold (-20 °C) and warm (30 °C) surface temperatures in low dew point air (<-20 °C). The repeatability of the testing approach was established by replicating environmental test conditions across multiple tests on the same flat sample. Wear scars were analyzed using laser scanning confocal microscopy and optical microscopy. Comparisons of coefficient of friction behavior as a function of sliding distance revealed that specific protective coating architectures respond differently to Arctic conditions.

MC-ThP-8 Development of Durable Multilayer Carbon Coatings for High-Contact Stress Engineering Applications Through Systematic Investigations*, Muhammad Usman [muusman2-c@my.cityu.edu.hk],* City University of Hong Kong

Diamond-like carbon (DLC) coatings are widely employed due to excellent tribological performance. Many thick DLC films/coatings can be found working at low contact stress (< 2 GPa) because inherent high compressive residual stresses induced during deposition cause brittle failure under high loading. Therefore, thick DLC tribological studies under high-contact stress are scarce in the literature. In our previously published articles, multilayer C/C DLC coatings were systematically investigated for high-contact stress applications. Herein, based on expertise, a series of overall thicknesses was synthesized, e.g., 0.5, 1, 2, 3, and 4 μm using a closed-field unbalanced magnetron sputtering system in order to examine the possibility of extended service life of C/C multilayer DLC. Therefore, the impact of overall thickness was investigated on the tribological performance of multilayer DLC, particularly under high-contact stress (~2.0, ~2.7, ~3.0, ~3.5 GPa). A reduction in graphitization with an increase in overall thickness was observed. The different crack type under scratch adhesion was explored for 4 μm specimen using a focused ion beam. Surface topography changed from small craters to bumpy-like surfaces for ≥ 2 μm thickness, significantly deteriorating wear performance due to increased roughness. The wear rate was found to be high, with an increase in roughness for both low and high sliding contact stress. Our design extended to 4 μm thickness not only survived under high-contact stress ~3.5 GPa but also produced an exceptional ~9.9 x 10^{-8} mm^3/Nm specific wear rate over a longer period (31,500 cycles) using a pin-on-disc tribometer. Therefore, through systematic investigation, a durable solution has been provided for tribological applications under high-contact stress.

MC-ThP-9 Analysis of Erosion Micromechanisms of a-C Coated SuperDuplex 2507 Steel*, Newton Fukumasu [fukumasu@gmail.com],* University of São Paulo, Brazil*; Juliana de Oliveira, Rubson M. Camporez, Lucas L. de Souza, Nathan F. Strey, Cherlio Scandian,* Federal University of Espirito Santo, Brazil*; André P. Tschiptschin, Roberto M. de Souza,* University of Sao Paulo, Brazil

Erosion from solid particle impacts in multiphase flows is a major concern in the oil and gas industry, leading to material loss and reduced operational life of critical components. This study investigates the micromechanisms governing the erosion behavior of an amorphous carbon-based coating under low-angle impact conditions. The selected a-C coating was deposited on the superduplex 2507 substrates using a pulsed direct current magnetron sputtering system. Mechanical properties were characterized using instrumented indentation, while adhesion strength was evaluated through scratch testing. Slurry jet erosion tests, using standard sand particles carried by water flow, were conducted to assess material removal rates and identify dominant erosion mechanisms. Eroded surfaces were further analyzed by scanning electron microscopy (SEM), Raman spectroscopy, and optical profilometry to correlate microstructural changes with surface durability. Finite element analysis (FEA) was employed to evaluate the stress distribution and deformation throughout the thickness of the film, improving the understanding of damage evolution. Results indicate that erosion under tested conditions in this work was primarily driven by surface ploughing, microcutting and fatigue-induced coating delamination. Comparisons with uncoated substrate indicated a significant increase in erosion resistance promoted by the coating, minimizing material loss and modifying the failure mechanisms. These findings provide insight into the complex interactions between particle impact, coating microstructure, and erosion resistance, contributing to the development of protective DLC-based coatings for extreme service conditions in oil and gas applications.

MC-ThP-10 Validity of the 10% Rule of Thumb in Coatings Nanoindentation*, Esteban Broitman [ebroitm@hotmail.com],* EDB Engineering Consulting, France

When an indenter penetrates the surface of a film deposited onto a substrate, the mechanical response of the coating will be influenced by the mechanical properties of the substrate, according to its penetration depth h and the film thickness t. As the depth of penetration h increases, more of the mechanical contribution will come from the substrate.

The first who tried to separate the contribution of the substrate from the total measured hardness at the microscale was Bückle, who suggested a 10% rule of thumb: to indent no more than 1/10 of the film thickness to avoid the influence from the substrate. The rule has been adopted later by many researchers for nanoindentation experiments and extended also as valid for the elastic modulus. However, there are many experimental studies and numerical simulations showing that this rule is too strict for a hard coating on a very soft substrate and too loose for a soft coating on a hard substrate [1].

In this presentation, we will review the issue, and will discuss all factors that affect the maximum penetration depth for independent coating measurements. We will also present a simple experimental methodology that, in most of cases, gives the correct values for hardness and elastic modulus, independently of the coating/substrate system.

[1] E. Broitman, Indentation Hardness Measurements at Macro-, Micro-, and Nanoscale: A Critical Overview. Tribol. Lett. 65 (2017) 23.

MC-ThP-11 Enhancing the High-cycle Fatigue Strength of Ti-Al-N Coated Ti-6Al-4V by Residual Stress Design*, Arno Gitschthaler [arno.gitschthaler@tuwien.ac.at],* *Rainer Hahn, Lukas Zauner, Tomasz Wojcik,* TU Wien, Institute of Materials Science and Technology, Austria*; Florian Fahrnberger, Herbert Hutter,* TU Wien, Austria*; Anton Davydok, Christina Krywka,* Helmholtz Zentrum Hereon, Institute of Materials Physics, Germany*; Jürgen Ramm, Anders Eriksson,* Oerlikon Balzers, Oerlikon Surface Solution AG, Liechtenstein*; Szilard Kolozsvari, Peter Polcik,* Plansee Composite Materials, Germany*; Helmut Riedl,* TU Wien, Institute of Materials Science and Technology, Austria

Physical vapor deposited ceramic coatings are widely utilized to protect components operating in harsh environments, yet their influence on the high-cycle fatigue behavior of metallic substrates remains a subject of debate. In this study, the residual stress-dependent effect of arc evaporated TiAlN-based thin films on the fatigue life of Ti-6Al-4V was investigated. By employing various stress-modifying strategies — *(i)* including a substrate bias variation, *(ii)* a tantalum-based alloying approach, *(iii)* and a tailored interlayer design — we systematically modified the residual stress profiles within the coating and interface near substrate region. High-cycle fatigue tests, performed in a single cantilever configuration using a dynamic mechanical analyzer, revealed that a sufficiently pronounced residual compressive stress state within the TiAlN layer is critical to preventing premature failure. Once the residual compressive stress field effectively shifts fatigue crack nucleation into the bulk material, an improvement in the high-cycle fatigue limitof over 50% was achieved compared to the uncoated titanium alloy (from 420 MPa to 628 MPa at 10^7 cycles).

To clarify the underlying mechanisms, a combination of high-resolution characterization techniques — namely high-resolution transmission electron microscopy (HR-TEM), transmission electron backscatter diffraction (t-EBSD), time-of-flight secondary ion mass spectrometry (ToF-SIMS), transmission X-ray nanodiffraction (CSnanoXRD), and micro-mechanical synchrotron-based experiments at DESY's PETRA-III — was employed. These experimental insights were integrated into a simple linear-elastic stress-failure model, providing an analytical framework to support the experimentally observed fatigue enhancements. The study not only resolves previous contradictory findings regarding the detrimental versus beneficial effects of hard ceramic coatings on fatigue performance but also establishes clear criteria for optimizing coating design. In particular, our results demonstrate that an optimized residual stress distribution is key to deploying the full potential of HCF-resistant TiAlN-based coatings. Adjusting process parameters and designing the interlayer helps maximize TiAlN coatings' effectiveness for extending the lifespan of Ti-6Al-4V parts.

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