Protective and High-temperature Coatings
Room Town & Country A - Session MA-ThP
Protective and High-temperature Coatings Poster Session

MA-ThP-1 Multienvironment Tribological Assessment of TiB_2:h-BN:a-C Coatings Deposited on 316L Stainless Steel, ***Ihsan Efeoglu [iefeoglu@atauni.edu.tr]***, *Gokhan Gulten, Banu Yaylali, Mustafa Yesilyurt, Ali Emre, Yasar Totik,* Atatürk University, Turkey*; Justyna Kulczyk-Malecka, Peter Kelly,* Manchester Metropolitan University, UK

AISI 316L stainless steel is widely employed in mechanical and aerospace components; however, its tribological performance is often limited under dry and high-temperature sliding conditions. In this study, a solid-lubricating TiB_2:h-BN:a-C nanocomposite coating was deposited on 316L substrates using closed-field unbalanced magnetron sputtering (CFUBMS) with a hybrid HiPIMS + pulsed-DC power configuration. The coating architecture integrates hard TiB_2 domains for load support, h-BN for lamellar lubrication and thermal stability, and amorphous carbon for low shear and transfer-film formation. A Cr interlayer was introduced to improve interfacial bonding and accommodate residual stresses at the film–substrate interface. The tribological response of the coatings was evaluated under three different environments: dry sliding at room temperature, elevated temperature (300 °C), and boundary-lubricated contact with SAE 50 oil. Results demonstrated that the TiB_2:h-BN:a-C coating effectively reduced friction and wear compared with the uncoated steel, maintaining stable performance across varying temperature and lubrication regimes. Scratch testing further indicated strong adhesion and cohesive integrity. These findings confirm the effectiveness of TiB_2:h-BN:a-C nanocomposites as multifunctional protective coatings for extending the durability of stainless steel components operating under diverse tribo-mechanical conditions.

MA-ThP-2 Understanding Solid Particle Erosion in Multicomponent $Ti_{1-x}Al_xN$ Based Coatings Using Synchrotron Nanodiffraction, ***Anna Hirle [anna.hirle@tuwien.ac.at]***, *Rainer Hahn, Philip Kutrowatz, Tomasz Wojcik,* Christian Doppler Laboratory for Surface Engineering of High-performance Components, TU Wien, Vienna, Austria*; Anton Davydok,* Helmholtz-Zentrum Hereon, Institute of Materials Physics, Hamburg, Germany*; Szilard Kolozsvári, Peter Polcik,* Plansee Composite Materials GmbH, Lechbruck am See, Germany*; Anders.O Eriksson, Carmen Jerg, Klaus Boebel,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Balzers, Liechtenstein*; Helmut Riedl,* Christian Doppler Laboratory for Surface Engineering of High-performance Components, TU Wien, Vienna, Austria; Institute of Materials Science and Technology, TU Wien, Vienna, Austria

Protecting components operating in harsh environments, such as in energy production, aviation, and the tooling industry, is essential for ensuring sustainability and long service life. Solid particle erosion (SPE) occurs when high-velocity solid particles impact a material surface, leading to repeated mechanical damage and material loss. This phenomenon critically affects components such as turbine blades, compressor parts, and piping systems. A thorough understanding of SPE is therefore key to improving material durability and performance under erosive conditions. $Ti_{1-x}Al_xN$ protective coatings are widely applied due to their excellent oxidation, corrosion, and erosion resistance. However, increasing operational temperatures demand the development of new coating materials. Alloying $Ti_{1-x}Al_xN$ with Ta and Si has shown promising improvements in oxidation and corrosion resistance [1,2], yet their behavior under SPE conditions remains insufficiently understood.

The objective of the present study is to investigate the solid particle erosion resistance of $Ti_{1-x}Al_xN$ and $Ti_{1-x-y-z}Al_xTa_ySi_zN$ thin films. Accordingly, the coatings were deposited via cathodic arc evaporation using an industrial-scale Oerlikon Balzers INNOVA 1.0 system. SPE tests were performed employing a Jet Erosion Tester with corundum (Al_2O_3) particles at 70 m/s and impingement angles of 30° and 90°. Crater analysis by synchrotron nano-diffraction was employed to assess stress evolution induced by SPE, complemented by profilometry, scanning electron microscopy and transmission electron microscopy characterization. Both coatings demonstrate a significant reduction in mass erosion rates, with approximately 90% decrease compared to uncoated substrates. Synchrotron measurements reveal a clear influence of the as-deposited residual stress state on the stresses induced during erosion.

These results provide new insights into the interplay between residual stress and erosion-induced deformation in multicomponent $Ti_{1-x}Al_xN$ based coatings, contributing to the development of next-generation protective materials for high-temperature and erosive environments.

[1] X. Sun et al., Surf. Coat. Technol. 461 (2023) 129428.
[2] A.R. Shugurov et al., Vacuum. 216 (2023) 112422.

MA-ThP-3 Applicability of Mos2-Asic Heterostructure for Durable Supercapacitance and No2 Gas Sensing in Harsh Environment, ***Habeebur Rahman [habeeb.physics10@gmail.com]***, *Davinder Kaur,* Indian Institute of Technology Roorkee, India

In the present work, the heterostructure of molybdenum disulfide (MoS_2)with amorphous silicon carbide (aSiC) on stainless steel (SS) and Si substrates was fabricated using a DC magnetron sputtering system. This unique heterostructure was examined for energy storage and NO_2 gas sensing applications suitable for harsh environmental conditions. The 2D MoS_2 nanostructured with dissolution resistive aSiC supercapacitor electrode delivers 1.5-fold enhancement in the gravimetric capacitance, a voltage window enlargement from 0.8V to 1.8 V, and an excellent stability of more than 4,000 charge-discharge cycles. Further, the high concentration NO_2 gas sensing performance of the MoS_2-aSiC on Si substrate revealed the stable and recoverable response at high operating temperatures. Therefore, loading aSiC with 2D MoS_2 enables durable electrode material for energy storage and NO_2 gas sensing applications in adverse conditions. The as-fabricated heterostructure was systematically studied by various material and electrochemical characterizations.

MA-ThP-4 Comparative Analysis of the Mechanical Properties of Layers Obtained in Three Different Steels by Atomic Diffusion of Boron., *Enrique Hernández Sánchez,* ***Luz Alejandra Linares Duarte [alejandra.linarespr@gmail.com]***, *Diego Hernández Domínguez, Yesenia Sánchez Fuentes,* Instituto Politécnico Nacional, Mexico*; Raúl Tadeo Rosas,* Universidad Autónoma de Coahuila, Mexico*; José Guadalupe Miranda Hernández,* Centro Universitario UAEM Valle de México*; Rafael Carrera Espinoza, Melvyn Alvarez Vera,* Universidad de las Américas Puebla, Mexico*; Jonathan Jorge Ruíz Domínguez,* Instituto Méxicano de la Propiedad Industrial, Mexico

The boriding process was applied to generate hard layers on three different steels —AISI 1018, AISI 316L stainless steel, and AISI 4340 crankshaft steel —with varying treatment times and temperatures (2, 4 and 6h, and 900, 950, and 1000 °C). X-ray diffraction analyses were performed to characterize the phases formed in the coatings. Microscopy techniques were used to evaluate the morphology and thickness of the layers. In addition, micro- and nano-scale mechanical tests were performed to determine the change in the structural and functional properties of the steel. These steels, due to their nature, are subject to wear processes under operating conditions. Therefore, coating these steels with a hard layer that exhibits better properties could help them withstand the working conditions. The boride layers formed on the different steels exhibited varying morphologies. On the one hand, layers with a strong sawtoothed morphology formed on AISI 1018 steel. On the other hand, extremely flat layers were observed on AISI 316L stainless steel, and, finally, layers with a moderate front of growth were obtained on AISI 4340 crankshaft steel. The results indicated that not only were the layers' morphologies different, but also their chemical composition and mechanical properties changed. The layers obtained on AISI 1018 and the 4340 crankshaft steel were of monophasic Fe_2B nature with an 8.83% wt. of boron content, while the nature of those obtained on AISI 316L stainless steel was biphasic FeB/Fe_2B, with a 16.23% wt. of boron content. That difference in composition gives the layers different properties. The higher content of boron gives the biphasic layers the highest hardness, but also makes them more brittle than the monophasic layers. Therefore, it is essential to assess the characteristics of the resulting layers in relation to a specific application.

MA-ThP-5 Reactively Sputtered High-Entropy Metal-Sublattice Carbide Thin Films Based on Al-Cr-Nb-Ta-Ti, ***Thomas Astecker [thomas.astecker@tuwien.ac.at]***, TU Wien, Austria*; Peter Polcik,* Plansee SE, Austria*; Alexander Kirnbauer, Paul Heinz Mayrhofer,* TU Wien, Austria

High-entropy metal-sublattice carbide thin films based on the equimolar Al-Cr-Nb-Ta-Ti system were synthesized by reactive magnetron sputtering in an acetylene-argon (C_2H_2-Ar) atmosphere. Films were deposited at varying reactive gas flow ratios and substrate temperatures between 450 and 650 °C, yielding single-phase rock-salt structured (fcc) solid solutions. Compositional analysis revealed the presence of an amorphous carbon phase and/or metallic sublattice vacancies. To explore the effect of silicon alloying, additional coatings containing 2.6, 6, and 8.8 at.% Si were prepared, which retained the single-phase crystal structure. The Si-free film exhibited an indentation hardness of 32.8 ± 0.4 GPa, decreasing slightly to

29.5 ± 1.1 GPa for the 8.8 at.% Si film, accompanied by a reduction in the average columnar grain width from 113 nm to 18 nm. No secondary phases formed during vacuum annealing up to 1000 °C for 15 min. While the unalloyed film softened significantly after the thermal treatment starting at 900 °C, the Si-containing coatings maintained their structural stability. Oxidation behavior in ambient air strongly depended on the Si content: at 800 °C, the Si-free film developed a thick (~7.8 µm) rutile-type oxide scale after 1 h, whereas the film with the highest Si-content formed only a dense, thin “passive” oxide layer, even after prolonged exposure at 1000 °C. These results highlight the pronounced beneficial effect of Si alloying on the thermal and oxidative stability of high-entropy carbide coatings, without compromising phase stability or mechanical properties.

MA-ThP-7 Synergistic Alloying Effects of Si and Y in Cr-Mn-Mo-N Thin Films: A Combined Experimental and DFT Study*, **Christian Gutschka [christian.gutschka@tuwien.ac.at]**,* TU Wien, Austria*; Lukáš Vrána, Matej Fekete,* Masaryk University, Czechia*; Zsolt Czigány,* Hungarian Academy of Sciences, Hungary*; Tatiana Pitoňáková,* Masaryk University, Czechia*; Katalin Balázsi,* Hungarian Academy of Sciences, Hungary*; Pavel Souček,* Masaryk University, Czechia*; Helmut Riedl-Tragenreif,* TU Wien, Austria

This study investigates the impact of Si and Y alloying on the microstructure and mechanical properties of Cr–Mn–Mo-based high- and medium-entropy nitride thin films. These films are fabricated by reactive DC magnetron sputtering, employing a combination of both ab initio calculations and experimental analysis. While the Cr–Mn–Mo–N system, in its pure form, displays a stable face-centred cubic (fcc) structure with a negative formation energy (E_f), the latter is known to decrease further with alloying with Si, Y, or both, thus enhancing thermodynamic stability. However, the process of alloying is accompanied by an increase in unit cell distortion, which in turn leads to the destabilization of the crystal structure – manifesting itself in amorphization of experimental thin films, with increasing alloying contents.

Chemical analysis of the grown films revealed that silicon and yttrium promoted nitrogen incorporation. However, complete stoichiometric metal-to-nitrogen ratios were not achieved, and systems with a considerable amount of nitrogen vacancies are formed. Similarly, simulations elucidated a prominent trend of nitrogen vacancies to relax alloy related cell distortions. Structural analyses confirmed the formation of a single-phase fcc solid solution presented here, with lattice expansion and crystallite size refinement being induced by increasing alloying concentrations. Furthermore, the simulations determined both nitrogen vacancy concentration and chemical composition to have a significant impact on ductility, with the highest levels of this property being observed at low nitrogen vacancy levels and when alloying with either Si or Y individually. These predictions showed a fair match with ductility estimates from experiment. More prominently, predictions of elastic properties from experiment and simulation agreed within error range, demonstrating that alloying has a beneficial effect on hardness without compromising the material's elasticity, with Si alloying alone achieving the highest hardness values of 20.5 GPa. An analysis of chemical bonding in the compounds found a synergistic sharing of nitrogen atoms between tetrahedral coordinated silicon species and yttrium atoms, mediated through N-vacancy introduction, as possible explanation for the good mechanical performance of the thin films.

MA-ThP-9 Thermal Stability and Mechanical Performance of Si-Modified High-Entropy (Al,Mo,Ta,V,W)C Coatings*, Muhammad Awais Altaf,* ***Balint Istvan Hajas [balint.hajas@tuwien.ac.at]**,* TU Wien, Institute of Materials Science and Technology, Austria*; Szilard Kolozsvari,* Plansee Composite Materials GmbH, Germany*; Tomasz Wojcik, Alexander Kirnbauer, Paul Heinz Mayrhofer,* TU Wien, Institute of Materials Science and Technology, Austria

High-entropy carbide (HEC) thin films (Al,Mo,Ta,V,W)C were reactively deposited on sapphire substrates with varying Si content to investigate its influence on microstructure, mechanical performance, thermal stability, and oxidation behavior. All coatings exhibit a single-phase face-centered cubic structure, with lattice parameters decreasing from ~4.34 Å for Si-free HEC to ~4.24 Å for the 7-at%-Si containing HEC-Si7, indicating preferential substitution of Si into the metallic sublattice, because fcc-SiC would have a lattice parameter of 4.35 Å. Si addition transformed the microstructure from coarse, columnar grains to smooth, dense, and near-amorphous surfaces, and shifted the preferred growth orientation from random to (200).

Nanoindentation revealed that as-deposited coatings exhibit hardness and elastic modulus of 30.7 GPa and 506 GPa for HEC, which decrease with increasing Si content to 28.0 GPa and 383 GPa for HEC-Si7. Upon vacuum annealing at different temperatures T_a, HEC degraded significantly, with hardness and modulus dropping to 14.4 GPa and 168 GPa for T_a = 1000 °C, whereas HEC-Si7 retained high mechanical stability, maintaining 26.3 GPa hardness and 381 GPa elastic modulus for T_a = 1000 °C and 24.2 GPa and 389 GPa for T_a = 1200 °C. Isothermal oxidation experiments at 600 and 800 °C for 1 h showed no protective oxide scale formation with or without Si, as already at 600 °C all coatings are oxidized through. However, the stability during vacuum annealing treatment demonstrate that controlled Si incorporation enhances microstructural integrity and mechanical robustness of these high-entropy carbide coatings, offering a promising route for high-temperature protective applications.

MA-ThP-10 Influence of the Ti/Al Ratio on the Performance of Ti-Al-N Coated Tools in the Machining of Stainless Steel 304*, **Felipe Batista dos Anjos [batista.anjos@pucpr.edu.br]**,* *Carlos Bernardo Gouvêa Pereira, Carlos Augusto Henning Laurindo, Fred Lacerda Amorim, Michelle Sostag Meruvia, Paulo Cesar Soares Junior, Ricardo Diego Torres,* Pontificia Universidade Católica do Paraná, Brazil

Machining austenitic stainless steel presents significant challenges due to various factors. One key issue is the material's low thermal conductivity, which can lead to thermal overload on the cutting tool. Additionally, these materials tend to adhere to the tool's cutting edge, resulting in adhesive wear and the formation of a built-up edge. To enhance tool performance, ceramic coatings can be applied, as they improve hot hardness and provide thermal and chemical insulation.

This study focused on evaluating the effect of the Ti/Al ratio in titanium, aluminum, and nitrogen-based coatings during the turning process of AISI 304 stainless steel. The coatings investigated were Ti0.56Al0.44N (TiAlN – Futura Nano®) and Ti0.37Al0.63N (AlTiN – Latuma®), both produced by Oerlikon Balzers Revestimentos Metálicos LTDA. Characterization of the coatings through Energy Dispersive X-ray Spectroscopy (EDS) revealed that the atomic ratio of Ti to Al in the Ti0.56Al0.44N coating is 1.27, while for the Ti0.37Al0.63N coating, the ratio is 0.59.

Machining tests were conducted on a CNC lathe equipped for cutting force acquisition, which was monitored over time until the end of the tool's life. To assess tool wear, the surface roughness of the workpiece was measured using a profilometer after each force test, and the tool geometry was analyzed using a scanning electron microscope (SEM). Preliminary results suggest that the tool coated with Ti0.37Al0.63N may exhibit lower cutting forces and a longer tool life compared to the Ti0.56Al0.44N coating. Additionally, nanoindentation tests indicated that the Ti0.37Al0.63N coating has a higher hardness than the Ti0.56Al0.44N coating, resulting in greater wear resistance.

Keywords: PVD Coatings, Tool Wear, Cutting Forces.

MA-ThP-13 Nitrogen-Dependent Structural and Mechanical Properties Evolution of $AlCrNbSiTiN_x$ High Entropy Alloy Nitride Coatings Deposited by HiPIMS*, Sheng-Jui Tseng,* National Taipei University of Technology, Taiwan*; **Jyh-Wei Lee [jefflee@mail.mcut.edu.tw]**,* Ming Chi University of Science and Technology, Taiwan*; Yung-Chin Yung,* National Taipei University of Technology, Taiwan*; Bih-Show Lou,* Chang Gung University, Taiwan*; Chia-Lin Li,* Ming Chi University of Science and Technology, Taiwan

High entropy alloy (HEA) nitride coatings have drawn significant attention owing to their excellent mechanical strength, corrosion resistance, and superior thermal stability. In this study, AlCrNbSiTiNx HEA nitride coatings were deposited on Si wafers, AISI 420, and 304 stainless steel substrates using high power impulse magnetron sputtering (HiPIMS). The effect of nitrogen content on the target poisoning behavior of the equimolar AlCrNbSiTi target was monitored and controlled through a plasma emission monitoring (PEM) feedback control system. Target poisoning ratios ranging from 10% to 90% were systematically examined to evaluate their influence on the microstructure and properties of the coatings. The nitrogen-free AlCrNbSiTi coating exhibited an amorphous structure, while the introduction of nitrogen promoted the formation of a face-centered cubic (FCC) nitride phase. Both the hardness and elastic modulus increased with nitrogen addition due to solid-solution strengthening and the formation of metal nitrides. Thermogravimetric analysis (TGA) conducted at 950 °C in air demonstrated that the AlCrNbSiTiNx coatings possessed excellent oxidation resistance. The relationship between nitrogen content, target poisoning ratio, mechanical properties, and oxidation behavior at 950 °C of the AlCrNbSiTiNx coatings was comprehensively studied in this work.

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