Tribology and Mechanics of Coatings and Surfaces
Room Town & Country B - Session MC3-3-FrM

Tribology of Coatings and Surfaces for Industrial Applications III

Moderators: Osman Eryilmaz, Argonne National Laboratory, USA, **Stephan Tremmel**, University of Bayreuth, Germany

8:00am **MC3-3-FrM-1 High-performance ta-C-based coatings for tribological applications deposited by laser-arc technique**, *Volker Weihnacht [volker.weihnacht@iws.fraunhofer.de], Frank Kaulfuss, Stefan Makowski, Falko Hofmann, Fabian Härtwig, Martin Zawischa,* Fraunhofer IWS, Germany **INVITED**

Tetrahedral amorphous carbon (ta-C) coatings are increasingly used in tribological contacts and can be found in numerous industrial applications due to their wear resistance caused by super hardness in combination with generally low friction. Fraunhofer IWS has developed a deposition technique for stable industrial coating processes for ta-C using a pulsed, laser-triggered arc discharge on graphite cathodes. The laser-arc technique can be combined with plasma filtering to reduce the density of particle-induced defects in the ta-C coatings. In addition to the further development of plasma filter technology, IWS has currently focused on the development of doped ta-C(:X) coatings by using graphite composite cathodes. In this contribution, it will be shown how doping affects the deposition behavior as well as the structure and properties of the grown ta-C:X coatings. Special emphasis is placed on the tribological properties using various engine oils and alternative, environmentally friendly lubricants.

8:40am **MC3-3-FrM-3 Effect of Boriding on the Surface Hardness and Wear Resistance of Low Carbon Steel Fabricated by Wire Arc Additive Manufacturing (WAAM)**, *Abraham Molina-Sanchez [A01363512@tec.mx], Cesar David Resendiz-Calderon, Leonardo Israel Farfan-Cabrera, Christian Ricardo Cuba-Amesquita,* Tecnológico de Monterrey, Mexico

Wire and Arc Additive Manufacturing (WAAM) enables the production of large-scale, geometrically complex components at a significantly lower cost compared to other additive manufacturing (AM) technologies. It offers extensive material availability, including low-carbon steel, which is widely used in mechanical and structural components. However, due to its low hardness and corrosion resistance compared to other steels, its use is limited in high-demand environments. This study evaluates the effect of boriding on the surface hardness and wear resistance of low-carbon steel fabricated using the WAAM technique. WAAM-built low-carbon steel plates were printed layer by layer to complete 60 layers per sample using ER70S-6 steel wire (0.8 mm diameter). The parameters included a welding voltage of 19.7 V, 67 A current, 5 mm/s travel speed, and a shielding gas of 100% CO_2 supplied at 15 L/min. These samples were subjected to a boriding process wherein a sealed container with Ekabor 2 powder as the boron donor was used, heated at 950°C for 3 hours, and cooled at room temperature. A boride layer with an average thickness of 93.5 ± 32.6 µm composed of FeB and Fe_2B phases was formed, as confirmed by X-ray diffraction (XRD). The adhesion of the boride layer on the as-built (AB) samples was evaluated using a progressive scratch test, and nanoindentation revealed an increase in hardness with no significant changes along the material deposition direction. Dry-sliding tests measured the coefficient of friction (CoF) between AB and borided samples, and a considerable wear volume decrease of 20% was observed with the boride layer, as measured by optical profilometry. These results demonstrate no significant changes along the build direction in phase composition, hardness, or tribological behavior, indicating that boriding is an effective surface treatment for enhancing wear resistance in WAAM-fabricated low-carbon steel.

9:00am **MC3-3-FrM-4 Tribological Performance of Epoxy Coatings for Semi-Rigid Packaging Applications**, *SIDDHANT VYAVAHARE [siddhant.vyavahare@adityabirla.com], AKSHTA VAISH, HARSHADKUMAR PANDIT,* Hindalco Industries Ltd, India

Epoxy-based coatings play a critical role in the performance and reliability of semi-rigid packaging containers, where they must endure both mechanical forming stresses and tribological contact during service. This study examines the balance between coating brittleness, moulding stresses, and frictional behaviour, with the objective of improving coating solutions for industrial packaging applications.

Formulations were developed using bisphenol-A-based epoxy resin and phenolic resin cured with amine hardeners, with tailored additives to optimize flexibility and hardness. Coatings were applied and thermally cured under industrially relevant processing conditions. Mechanical performance was evaluated through bend, cupping, crosshatch adhesion, and impact resistance tests, simulating forming and handling stresses encountered in production. Results demonstrated that higher crosslink density, while enhancing hardness, increased brittleness and led to premature microcracking during deformation.

Tribological evaluation, performed using a multi-tribometer under dry sliding, revealed a strong correlation between brittleness and increased wear rates, with stiffer coatings exhibiting elevated coefficients of friction (COF) due to reduced surface compliance. Post-test analyses by profilometry and SEM confirmed brittle fracture-driven wear mechanisms such as micro-spallation and delamination.

These findings highlight the need for epoxy coatings engineered with a balance of hardness and flexibility, enabling them to survive forming operations while maintaining low wear and stable friction during service. The outcomes provide practical design guidelines for coating engineers to develop next-generation epoxy systems that improve both manufacturing reliability and end-use performance in semi-rigid container applications.

Keywords — Epoxy coatings, Tribology, Semi-rigid packaging, Industrial coatings.

9:20am **MC3-3-FrM-5 The Development of Amorphous-Based Multi-Component Alloys for the Nanocomposite Coatings and their Properties**, *Kyoung Il Moon [kimoon@kitech.re.kr], Gi hoon Kwon, Hae Won Yoon, Byoungho Choi, Kyong jun An,* Korea Institute of Industrial Technology, Republic of Korea; *Sung Chul Cha,* Hyundai Motor Group-Hyundai Kefico, Republic of Korea

While modern industries are becoming more sophisticated, diversified, and globalized, they requires the development of smart materials have multi-functionality, high mechanical properties, and extreme durability. Also they could be prepared environmentally friendly and energy efficiently. At the same point of view, the smart coating materials capable of simultaneously expressing various mechanical properties or opposite properties such as high hardness with high toughness, high electricity with high corrosion resistance are attracting attentions as an versatile and useful materials in the future. In particular, there is an urgent needs to develop a novel coating materials capable of stably maintaining microstructures and mechanical properties in various external environments, unlike conventional coating materials whose properties and structures are easily changed by the some harsh environments. To get this kinds of objects, the coating material with multi-components are essential. But if the materials should be prepared with one phase with multi components, they could have only one properties. So, nano-composites with various phases should be formed to realize the various properties. So, it is necessary to develop a coating layer composed of various components those could be formed various phases and more complex structures with multifunctional properties.

In this study, various single alloy target materials with various compositions based on the Zr-Cu amorphous materials have been prepared by powder metallurgy methods such as atomization, mechanical alloying, and Spark Plasma Sintering (SPS). The various nanocomposite coatings could be prepared by using single alloying targets. The most important property is the composition of the target material could be transferred to the coating layers. The properties of as-prepared nanocomposite coatings will be summarized in this present including the coating's performance under conditions that simulate EV drivetrain environments.

9:40am **MC3-3-FrM-6 Enhancement of Tribological Properties of Graphene Oxide/MoS2 Composite Coatings Prepared on Textured Biomedical Implants by Electrophoretic Deposition Method**, *Madhusmita Mallick [mmallick@iitbbs.ac.in],* IIT Bhubaneswar, India

Graphene oxide exceptional solid lubrication properties, arising from its low shear strength and mechanical properties, make it an ideal material for tribological enhancement in biomedical implant surfaces. This study focusses on deposition of graphene oxide-molybdenum disulfide (MoS_2) composite coatings on laser-textured biomaterials such as commercially pure titanium and Nitinol substrates using the electrophoretic deposition (EPD) technique. Before EPD coating, substrates were treated with femtosecond laser texturing to produce both circular and bio-inspired micro-grooves morphologies, aimed at optimizing surface functionality. The tribological performance of the coated substrates were evaluated under dry sliding conditions using a ball-on-disc tribometer facility, while microstructural characterization were performed using SEM, EDS, XRD and Raman spectroscopy before and after wear testing. The results revealed that laser surface texturing significantly improved coating adhesion due to mechanical interlocking and enhanced tribological behavior, particularly in the case of bio-inspired patterns owing to better retention of graphene/MOS2 coating in the micro-grooves pattern. Additionally, EPD-prepared graphene oxide–MoS_2 composite coatings reduced the coefficient of friction to as low as 0.036 and markedly decreased wear rates compared to bare and EPD-coated GO/ MoS2 substrates. These findings demonstrate the strong potential of combining femtosecond laser texturing with graphene oxide -MoS_2 hybrid coatings to achieve ultra-low friction, high wear resistance, and durable biocompatible surfaces for advanced load-bearing biomedical implant applications.

Keywords: Biomedical Implants; Electrophoretic Deposition; Graphene oxide Nanoplatelets, MoS_2; Femtosecond laser texturing; Tribological property

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