Tribology and Mechanical Behavior of Coatings and Engineered Surfaces
Room On Demand - Session E3

Tribology of Coatings for Automotive and Aerospace Applications

E3-1 Coating Properties and Wear Resistance of ta-C Deposited by Arc Ion Plating (AIP) Technique*, **Yoshiyuki Isomura (isomura.yoshiyuki@kobelco.com)**, T. Takahashi, J. Fujita,* Kobe Steel, Ltd., Japan*; S. Kujime,* Kobe Steel Ltd., Japan

Hydrogen free DLC, also referred to as ta-C (tetrahedral amorphous carbon), attracts a large practical interest particularly in the automotive industry because of its unique characteristics of high hardness, low friction, and wear resistance. While ta-C exhibits those excellent properties, further improvement and assurance of adhesion in sliding parts under high contact pressure in severe operating condition is a challenge. Practical requirement and evaluation of adhesion performance is sometimes even beyond the level of basic adhesion investigation such as Rockwell indentation test or scratch test.

In this study, ta-C was deposited using an industrial arc ion plating coating system equipped with a round-bar type arc evaporation source, which is specially designed and optimized for ta-C coating process. ta-C samples with controlled adhesion was intentionally deposited on the sliding test piece with controlled process parameters. Adhesion performance evaluated by the basic test was found to be not always consistent to the results of sliding test. In addition, different frictional wear characteristics were detected among samples with different adhesion performance. In order to understand the relation of sliding properties to adhesion performance more in detail, the intrinsic coating properties were also analyzed more thoroughly in terms of mechanical hardness by nanoindentation, surface roughness/macro-particle density, chemical bonding characteristics of sp2/sp3 fraction and hydrogen concentration. We aim to combine this knowledge of material science with a practical aspect of sliding and adhesion towards improvement of performance in application of ta-C coating.

E3-2 Numerical Study of Cracking in Thin Hard Coating Layers Using a Cohesive Phase-Field Model and Experimental Validation*, **Ali Rajaei Harandi (ali.harandi@ifam.rwth-aachen.de)**,* RWTH Aachen, Germany*; S. Rezaei,* Technical University of Darmstadt, Germany*; S. Karimi Aghda, T. Brepols, J. Schneider, S. Reese,* RWTH Aachen University, Germany

Prediction of damage and cracking patterns in hard protective coatings play a vital role in the optimal design of these coating layers. Experimentally, in [1], it is shown that a micro-scale tensile test of a hard coating deposited on ductile substrates is a fast-tracking tool for determining the fracture parameters of such systems. This experimental approach is specifically valid when the first fracture mode is more dominant. On the numerical side, phase-field damage models are utilized, which have attracted much attention among several available methodologies. These models benefit from a robust response and the capability of modeling cracks without introducing any initial crack path. However, the damage field tends to widen based on the internal length-scale parameter. It could be problematic when it comes to simulations on a small-scale and create some boundary effects. To this end, a cohesive phase-field damage model is used. The relevant fracture parameters such as fracture toughness and maximum tensile strength are included in this model, for which the internal length-scale is considered as a purely numerical parameter. Furthermore, due to the specified morphology of the grains in the coating layers, as well as the evolution of damage based on multiple possible damage procedures, it is inevitable to use anisotropic damage models, [2,3]. To include them, a novel orientation-dependent fracture energy function is applied, based on the later reference. Finally, the numerical results considering the crack patterns and the crack density value is compared to the micro-scale tensile test of cubic metastable $V_{0.25}Al_{0.26}N_{0.49}$ coating deposited on the Cu substrate. It is shown in this study, how fracture characteristic parameters such as fracture toughness and maximum tensile strength, as well as the substrate elastic or elastoplastic behavior, will influence the overall damage behavior of the hard coating layer.

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E3-3 Duplex TiN and TiAlN Coatings on Ti-6Al-4V Alloy Formed by a Combination of Plasma Nitriding and Cathodic Arc Evaporation*, V. Pankov,* ***Qi Yang (qi.yang@nrc-cnrc.gc.ca)****,* National Research Council of Canada

A duplex coating concept has been investigated as a mean for protecting Ti-6Al-4V aerospace components against high impacts and high localized loads. The duplex coating consisted of the first layer formed by low-pressure plasma nitriding using a high-density plasma source and the second layer deposited on the nitrided surface by cathodic arc evaporation. Substrate temperature, substrate bias, and process duration were selected as the nitriding process parameters. The substrate temperature during Ti-6Al-4V nitriding was maintained below 800°C to avoid α-to-β phase transformation. TiN and TiAlN coatings were used for the second layer. The microstructure, elemental composition, phase content, and hardness of the nitrided layer were analyzed by scanning electron microscopy, energy dispersive spectroscopy, X-ray diffraction, and nanoindentation, respectively. Adhesion between the duplex coating layers was measured by scratch adhesion testing. The fabricated duplex coatings were evaluated for their wear and impact resistance using pin-on-disk and drop weight impact testing. The obtained results were used to identify optimum process parameters for producing protective coatings with duplex design characterized by high impact resistance and high load-bearing capacity.

E3-4 Determination of Method for Tribological Experiment on Ultra-Hard Coatings in Low-Viscosity Fuels*, **Kelly Jacques (kellyjacques@my.unt.edu)**,* University of North Texas, USA*; S. Berkebile, N. Murthy, J. Mogonye,* Army Research Laboratories, USA*; S. Dixit,* Plasma Technology Inc., USA*; D. Berman, T. Scharf,* University of North Texas, USA

In order to expand fuel operation capability of fuel systems to multiple fuels, fuel pump materials must resist scuffing and wear when lubricated with low viscosity, low lubricity hydrocarbons and alcohols under conditions of dynamic fluid pressure and flow. In this work, a high-frequency reciprocating tribometer was used to determine a set of tribological experimental parameters that emulate conditions within a fuel pump system, instigate material scuffing, and yield reliable and repeatable results. The ASTM D6079 standard for evaluating lubricity of diesel fuels by the high-frequency reciprocating rig was used as a basis for the development of new experimental parameters, of which the grinding lay orientation, temperature, counter body, substrate, contact load, and stroke length were altered. These experimental parameters were used to determine the onset of scuffing and wear of through-hardened 52100 steel substrates and various ultra-hard material coatings, including iron boride and tungsten carbides, possible candidates for steel protection. These materials were lubricated with F-24 (JP-8) and ethanol. Scanning electron microscopy, energy dispersive spectroscopy, white light interferometry, and optical microscopy were used to characterize the extent of wear and corrosion of the materials and counter bodies during the experiments. Overall, it was found that the ultra-hard coatings experience less wear and are more resistant to scuffing at low loads than the 52100 steel.

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