Hard Coatings and Vapor Deposition Technologies
Room Town & Country D - Session B4-2-MoA

Properties and Characterization of Hard Coatings and Surfaces II

Moderators: Dr. Naureen Ghafoor, Linköping University, Sweden, **Dr. Marcus Günther**, Robert Bosch GmbH, Germany, **Dr. Fan-Yi Ouyang**, National Tsing Hua University, Taiwan

1:40pm **B4-2-MoA-1 Amorphous Carbon Coatings for Tribological Applications in Hydrogen and Natural Gas Environments***, **Thomas Gradt**,* Bundesanstalt für Materialforschung und -pruefung (BAM), Germany **INVITED**

For long distance land and overseas transport of large quantities natural gas is usually liquefied. Methane (CH_4), the main component of natural gas, has a boiling temperature of -161,5°C, which is much lower than the pour point of any liquid lubricant. Therefore, only dry running tribosystems can be employed in this temperature range, which is a challenge for frictionally stressed mechanical components.

Also for long distance transport of hydrogen liquefaction is an option. With a temperature of -253°C for liquefied hydrogen (LH_2) the conditions for tribosystems are even more severe. Furthermore, also for the utilization in gaseous form, in many cases purity requirements impede lubrication by oils or greases. Another requirement is that technical systems containing natural gas or hydrogen need to be inertized from time to time. Therefore, the function of the moving parts must be ensured not only in the reactive media, but also in inert environment.

It is well known that among the solid lubricants graphite and most amorphous carbon coatings show good lubricity in humid air and hydrogen environment, but the question arises if this is also true for methane and very low temperatures.

For identifying suitable carbon-based solid lubricant coatings, ball-on-disk model tests with several variants of a-C:H and ta-C were carried out in gaseous hydrogen, methane and nitrogen. Some coatings were also tested in liquid methane. The results show friction coefficients below 0.1, with lowest values of about 0.01 in CH_4 at room temperature. Also wear coefficients in the order of 10^{-8} $mm^3N^{-1}m^{-1}$ for most coatings indicate that amorphous carbon coatings are suitable for frictionally stressed components in hydrogen and natural gas environment.

2:20pm **B4-2-MoA-3 Effect of Bio-Lubricants on Wear and Friction of Borided Ti_6Al_4V Alloy***, A. Nieto-Sosa, G. Rodríguez-Castro, J. Escobar-Hernández, A. Meneses-Amador, **José Arciniega-Martínez**, H. Martínez-Gutierrez,* National Polytechnic Institute, Mexico

In this study, titanium borides were formed on the surface of Ti_6Al_4V alloy by powder pack boriding at 1100 °C during 5, 10 and 20 h. Under these treatment conditions, 3 thicknesses consisting of a Ti_2B outer phase and a TiB inner phase (whisker) were formed. The morphology and layer thickness were determined by scanning electron microscopy (SEM), while the identification of phases was carried out by X-ray diffraction. The maximum thickness of the Ti2B phase was measured in 10 µm. The hardness of the layers was determined by Vickers instrumented indentation exceeding 20 GPa. In addition, the instrumented indentation tests were used to calculate the fracture toughness and residual stresses of titanium boride layers. Linear reciprocating wear tests were carried out under dry and lubricated conditions To evaluate the effect of bio-lubricants, phosphate buffer saline, ringer's solution and sesame oil were used at different contact pressures. Wear mechanisms were identified by SEM. The behavior of the coefficient of friction and the wear rates were analyzed for each of the formed systems.

2:40pm **B4-2-MoA-4 Experimental and Numerical Evaluation of Multi-Pass Scratch on Borided Armco Iron***, **Jesús Vidal-Torres**,* SEPI ESIME Instituto Politécnico Nacional, Mexico*; A. Ocampo-Ramírez,* Universidad Veracruzana, Mexico*; G. Rodríguez-Castro, I. Campos-Silva, A. Meneses-Amador,* SEPI ESIME Instituto Politécnico Nacional, Mexico

Thermochemical treatments are used for increasing the surface mechanical properties of iron and steels. The wear on mechanical components caused by sliding contact is an important parameter in the field of tribology. In this study, the wear resistance of ARMCO pure iron hardened by the powder-pack boriding process was evaluated, using unidirectional sliding. The boriding treatment was carried out at temperatures of 1123 K for 1, 2 and 3 h of exposure time. Surface properties such as hardness and Young's modulus were obtained by the nanoindentation technique. Fracture toughness of the three layer/substrate systems were obtained by Vickers indentation.The wear test was performed by multi-pass scratch using an Al_2O_3 ball (6 mm diameter) as a counterpart under normal loads of 20 N. The sliding distances were 125, 250, 375 and 500 mm (25, 50, 75 and 100 passes). Archard´s model was used to obtain the wear coefficient. Finite element method applying mesh nonlinear adaptivity was used to evaluate the surface wear on the borided samples. It was found that wear resistance was mainly influenced by both the fracture toughness value and thickness of the boride layers.

3:00pm **B4-2-MoA-5 Microstructure and Tribological Characteristics of Binary Refractory Metal Nitride Coatings***, **Yu-Hsien Liao**, S. Hsu, F. Wu,* Dept. of Materials Science and Engineering, National United University, Taiwan

This study focused on microstructure evolution and mechanical behavior of binary refractory metal nitride systems films, including (MoHf)N, (WHf)N and (MoW)N. The phase, adhesion, and wear behavior variations were discussed in terms of material selection. With a radio frequency, RF, magnetron dual gun co-sputtering system, the binary refractory metal nitride thin films were fabricated at a fixed Ar/N_2 inlet gas ratio of 12/8 sccm/sccm. The structure of (MoHf)N thin film exhibited MoN, Mo_2N, and MoN_2 phases, while the (WHf)N thin film possessed WN and Hf_4N_3 phases. As for the (MoW)N thin film multiple phases including WN, MoN, and Mo_2N were observed. The (MoW)N and (WHf)N possessed adhesion level of HF3 and HF4, respectively, indicating a poor adhesion due to the exist of tungsten element. On the other hand, (MoHf)N thin film showed an index of HF2. The wear results reflected a similar trend, For the (MoHf)N coating, the track maintained a smooth surface and the film kept intact after a wear length of 100m. On the contrary, the wear tracks of (MoW)N and (WHf)N coatings showed cracking and pealing after the wear test, indicated a weaker tribological behavior.

Keywords: Microstructure; Refractory metal nitride; Multiple phase; Adhesion; Wear.

3:20pm **B4-2-MoA-6 Hyper-Doping of Boron Carbide Ablators for Laser Fusion***, **Gregory Taylor**,* Lawrence Livermore National Lab, USA

Boron carbide (B4C) is a material with outstanding mechanical properties, chemical inertness, and low density. It is currently the leading candidate for use as the next generation amorphous ablator for inertial confinement fusion (ICF). Several approaches to deposit B4C ablators have been explored with promising recent results. However, the doping B4C for ICF applications has not been investigated. In this work, we investigate the feasibility of incorporating high concentrations of Si, Ge, and W dopants (i.e., hyper-doping) via combinatorial magnetron sputter deposition of ultrathick B4C films. We focus on the influence of the dopant type and concentration on film growth mode and major film properties of relevance to ICF, including residual stress, crystallinity, density and its uniformity, and chemical stability.

3:40pm **B4-2-MoA-7 Influence of Si Content on the Mechanical Properties, Microstructure and Tribological Behaviors of (AlCrNbSiTi)N Coatings***, **Yun-Chen Chan**, S. Hsu, P. Chen, J. Duh,* National Tsing Hua University, Taiwan

High-entropy alloy nitride coatings (HEANs) characterize superior mechanical strength, high oxidation resistance, thermal stability, corrosion resistance and wear resistance. As a result, it is a potential candidate in the protective hard coating field in recent years.

In this study, the (AlCrNbSiTi)N coatings were co-sputtered by radio-frequency magnetron sputtering. The power for the silicon target was varied from 0 watts to 120 watts and the silicon concentration of coatings varied from 0 (at. %) to 10.6 (at. %). As the silicon content in coatings increased to 4.4 (at. %), the coatings exhibited the maximum hardness of 31 (GPa) due to the mechanism of dislocation pile-up. However, as the silicon content in coatings exceeded 4.4 (at. %), the hardness of coatings started to decrease, which was attributed to the appreciable amounts of softer amorphous segregation. Furthermore, the incorporation of silicon interrupted the growth of the column structure due to the spinodal decomposition of amorphous SiN_x and (AlCrNbTi)N. Thus coating structure changes from a loose column structure to a dense featureless structure.

Last but not the least, the coating density was calculated from the data measured by XRR analysis. As the silicon content in the coating exceeded 4.4 (at. %), the lack of long-range ordering and free volume in amorphous structure lowered the packing density of the coatings, which led to the poor mechanical properties of the coatings. Nevertheless, the results exhibited that the coating characterized the highest packing density as the silicon content in coatings is 4.4 (at. %), exhibiting the optimal mechanical properties, which is strongly correlated to the crystallinity of the coatings.

4:00pm **B4-2-MoA-8 Effect of CrMoN Addition on the Thermal Stability and Tribological Property of TiVN Coatings***, Y. Chang,* ***He-Qian Feng****,* National Formosa University, Taiwan

The ternary nitride TiVN coatings can be regarded as a solid solution of TiN and VN, where V atoms infiltrate into the TiN lattice and replacing some Ti atoms. The addition of V atoms to TiN improves the mechanical and frictional properties. A further improvement of thermal stabilities and tribological performance of TiVN coatings can be achieved by a possible approach involving the replacement of monolayered coatings by multilayers. In this study, gradient-and-multilayered TiVN/CrMoN coatings were synthesized by cathodic-arc evaporation. During the coating process of TiVN/CrMoN, CrMoN was deposited as an interlayer to enhance adhesion strength between the coatings and substrates and improved thermal stabilities. An impact fatigue test using a cyclic loading device and ball-on-disc wear tests were conducted to evaluate the correlation between tribological properties and coating structures of the deposited coatings. Vacuum annealing and high temperature oxidation higher than 600 ^{o}C were conducted to evaluate the thermal stabilities of the coatings. Glancing angle X-ray diffraction was used to characterize the microstructure and phase identification of the films. The microstructure of the deposited coatings was investigated by field emission scanning electron microscope (FE-SEM) and field emission gun high resolution transmission electron microscope (FEG-HRTEM), equipped with an energy-dispersive X-ray analysis spectrometer (EDS). Hardness of the films were obtained using nanoindention measurement. The oxidation states of the oxidized coatings were identified using an X-ray photoelectron spectroscope. The addition of CrMoN into TiVN to form a multilayer architecture provides an alternative for a hard-and-lubricious coating. The design of gradient-and-multilayered TiVN/CrMoN coatings is anticipated to be advantageous in applications to enhance the thermal stability and tribological property of mechanical parts.

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