Tribology and Mechanics of Coatings and Surfaces
Room Palm 5-6 - Session MC2-2-WeM

Mechanical Properties and Adhesion II

Moderator: Chia-Lin Li, Ming Chi University of Technology, Taiwan

8:00am **MC2-2-WeM-1 Adhesion, Delamination and Cracking of Thermal Spray Coatings: Understanding Critical Phenomena During Processing and Service***, Sanjay Sampath [sanjay.sampath@stonybrook.edu],* Stony Brook University, USA **INVITED**

The efficacy of coatings in engineering applications rely on their ability to be well bonded to the underlying substrate. Many factors govern this adhesion including deposition materials, substrate materials, substrate attributes, surface chemistry, processing conditions, thickness, build rate, mismatch between the coating and substrate etc. Methods to measure adhesion in present day is largely phenomenological with "go/no-go" agenda. Of importance is that today's measures of adhesion strength may not be appropriate for coatings which are largely brittle, where cracking is a predominant mode of failure representing a toughness problem rather than strength consideration. Furthermore, even well bonded coatings can delaminate during service where compounding effects of service load can superpose to accentuate the interfacial stresses. Thus, understanding these phenomena is critical. The debonding of the interface is driven by energy dissipation. In situation where bonding is strong, an alternative energy release mechanism is cracking of the coating. When harnessed they provide a pathway to build strain-tolerant vertically cracked coating with implications for novel design and manufacturing of thermo-structural coatings. In many instances, the factors of cracking and delamination compete. This is dependent on adhesion and microstructure. In this presentation, the above attributes are critically discussed through phenomenological and quantitative strategies.

8:40am **MC2-2-WeM-3 A Study on the Surface Morphology and Tribological Behavior of Hydrided Zircaloy***, Jun Xian Lin [linst214200@gmail.com], Kuan-Che Lan,* National Tsing Hua University, Taiwan

The integrity of used nuclear fuel claddings is one of the keys to assess the safety margin during interim dry storage. Nuclear fuel claddings made of zirconium alloys have been widely applied in commercial nuclear reactors such as boiling and pressurized water reactors. The accumulation of hydrogen in the form of zirconium hydride which could deteriorate the integrity of used nuclear fuel claddings during interim dry storage is one of critical concerns intrinsically. Besides, existence of hydride in zirconium alloys could weaken the tribological resistance of the cladding materials during the loading and transportation procedures of used fuel prior to a long-term dry storage and hurt the integrity externally. A thoroughly understanding of about the microstructure and tribological behavior of zirconium alloy with hydrides will improve the reliability of evaluation on the integrity of used fuel cladding during interim dry storage. The objective is to study the influence of zirconium hydride on the tribological resistance. Scratch tests were conducted on as-hydrided Zircaloy-4 plate using a scratch tester to determine the minimum load causing cracks and to analyze the morphology of surface cracks. Additionally, a pin-on-disc test was conducted to assess the wear resistance, followed by SEM analysis over the damaged surface to observe the effect of hydrogen permeation on the tribological behavior of the Zircaloy-4.

9:00am **MC2-2-WeM-4 Effects of Stored Elastic Energy and Stress Gradients on the Tribological Behavior of TiN Coatings on D2 Steel***, I-Sheng Ting [gary820902@yahoo.com.tw], Jia-Hong Huang,* National Tsing Hua University, Taiwan

Residual stress is one of the most pivotal issues in protective hard coatings deposited by physical vapor deposition methods. It is generally acknowledged that low residual stress is beneficial for prolonging the lifespan of hard coatings. In our previous studies [1,2], a Ti interlayer was added to alleviate the residual stress of TiZrN coating on D2 steel, thereby improving its wear resistance. An energy-based hypothesis was proposed to explain the enhancement in wear resistance [2], where by lowering the stored elastic energy (Gs) in the TiZrN coating, the margin for reaching the fracture toughness (G_C) was extended, indicating that the coating could endure more external loading. However, the energy-based perspective neglected the effect of stress gradient that significantly affects the propagation of cracks in coatings. This study aimed to measure the stored elastic energy and energy gradients of TiN coating on D2 steel and evaluate the effect of gradients on the tribological behavior. TiN coatings were deposited on D2 steel and Si substrates using DC unbalanced magnetron sputtering, where the stress gradient of TiN coating was controlled by adjusting the working pressure during deposition. The average stress of the TiN coating was determined using the average X-ray strain (AXS) combined with nanoindentation methods [3-5], and the stress gradient was acquired by changing the X-ray incident grazing angles. The adhesion and wear resistance of the TiN coatings on D2 steel were respectively evaluated using scratch test and pin-on-disk wear test. Through the adjustment of working pressure during deposition, it is feasible to control the tribological behavior of a hard coating by tuning the distribution of stored elastic energy and stress gradients.

[1] Y.-W. Lin, J.-H. Huang, W.-J. Cheng, G.-P. Yu, Surf. Coat. Technol., 350 (2018) 745-754.

[2] Y.-W. Lin, P.-C. Chih, J.-H. Huang, Surf. Coat. Technol.,394 (2020) 125690.

[3] C.-H. Ma, J.-H. Huang, H. Chen, Thin Solid Films, 418 (2002) 73-78.

[4] A.-N. Wang, C.-P. Chuang, G.-P. Yu, J.-H. Huang, Surf. Coat. Technol., 262 (2015) 40-47.

[5] A.-N. Wang, J.-H. Huang, H.-W. Hsiao, G.-P. Yu, H. Chen, Surf. Coat. Technol., 280 (2015) 43-49.

9:20am **MC2-2-WeM-5 Adhesion at the Glass/Metal interface probed by Colored Picosecond Acoustics***, Arnaud Devos [arnaud.devos@iemn.fr],* IEMN, France

Glass is a common material already employed in everyday applications, which has gainedconsiderable interest for electronic components,due to its attractive electrical, physical, andchemical properties, as well as its prospects for a cost-efficient solution.Adhesion of thin metal film on glass is especially critical and bonding between glass and metal can broaden the applications of glass in many industrial areas.A large number of methods have been developed to characterize the adhesion of a thin film to a substrate. Acoustic waves and especially ultra-high frequency acoustic waves are also sensitive to adhesion defects as they affect the way acoustic waves are transmitted and reflected at the interface concerned. At a poor interface, acoustic waves are much more reflected than expected and therefore much less transmitted.In this work, we use picosecond acoustics for measuring the metal film thickness and the acoustic transmission coefficient at the interface with a glass substrate. Picosecond acoustics is a ultrafast laser technique that implements a nanoscale pulse-echo technique[1]. A femtosecond optical pulse excites a short acoustic pulse inside the sample and another optical pulse is used to monitor acoustic propagation and reflections. We show that we can take advantage of the laser tunability to improve the measurement of adhesion between metal and glass: by making picosecond acoustic measurements at different wavelengths (spectroscopy), we observe very sensitive changes in the photo-acoustic response which can be used to improve measurement accuracy.

References:[1] A. Devos, Ultrasonics 56, pp. 90-97 (2015) DOI 10.1016/j.ultras.2014.02.009

9:40am **MC2-2-WeM-6 The Mechanical and Tribological Performance of (V,Mo)N Coatings Deposited by Magnetron Sputtering***, Yuqun Feng, **Jia-Hong Huang [jhhuang@ess.nthu.edu.tw]**,* National Tsing Hua University, Taiwan

The wear resistance of transition metal nitrides (TMeNs) can be enhanced by introducing self-lubricating oxide forming alloy elements, such as V and Mo. However, TMeNs are usually brittle under dynamic loading conditions. (V,Mo)N is a recently developed material for wear-resistant coatings due to its high fracture toughness. The objective of this study was to evaluate the mechanical and tribological properties of single-phase (V,Mo)N coatings. (V,Mo)N coatings with different N/metal ratios were deposited on AISI D2 steel substrates using direct current unbalanced magnetron sputtering (dc-UBMS) and high power pulsed magnetron sputtering (HPPMS). The results showed that the coatings deposited on steel substrates have higher N/metal ratio and (200)-preferred orientation than those on Si substrates. This may be attributed to the higher electrical conductivity of the steel substrate, leading to more intense ion bombardment that delivers more energy in forming N-metal bonding and enhances the channeling effect. The hardness of the coatings increases with decreasing N/metal ratio. Additionally, the coatings deposited by HPPMS on steel substrates have lower residual stress than those by dc-UBMS. This may be due to the stress induced by the power cycle being relieved by plastic deformation of the steel substrate. All (V,Mo)N coatings show a very low wear rate ranging from 1.1×10^{-7} to 4.0×10^{-7} $mm^3N^{-1}m^{-1}$ at room temperature. As temperature increases to 500 ℃ and above, the wear resistance of the (V,Mo)N coatings significantly decreases, while low friction coefficients are maintained by the formation of self-lubricating V- and Mo-oxides. All coatings remain intact after 150k impact fatigue test, even when the deformation depth is larger than the coating thickness, implying the remarkable toughness of the (V,Mo)N coatings. In contrast, the coatings deposited using dc-UBMS have the worst impact fatigue resistance, which may be related to their lower fracture toughness.

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