Tribology and Mechanical Behavior of Coatings and Engineered Surfaces
Room San Diego - Session E1-3
Friction, Wear, Lubrication Effects, and Modeling

Moderators: Albano Cavaleiro, University of Coimbra, Carsten Gachot, Vienna University of Technology, Giovanni Ramirez, Argonne National Laboratory, USA

8:00am **E1-3-1 Comparing of Adhesion Properties of TiNbVN Coatings Deposited on Different Substrates**, ***Ihsan Efeoglu***, *Y Totik,* Atatürk University, Turkey*; O Baran,* Erzincan University, Turkey*; H Cicek,* Erzurum Technical University, Turkey*; A Keles,* Ataturk University, Turkey

Adhesion properties of hard thin coatings were strong l y affected from used substra t e material. In this study, TiNbVN coa t ings were d e posited on 2024 A l -alloy, M2 and H13 steels substrates using react iv e magnetron sputtering method. Structural and m e chanical properties of the coat i ngs were anal y zed by SEM, EDS, XRD, and nanohardness. Adhesion properties of the coatings were deter m ined via scratch test under progressive load. It was observed that critical load (Lc) values of TiNbVN coa t ings varied in each substra t e. The coati n g m icrostruc tu re is dense a nd the fi l m thickness is about 440n m . The nanohardness values were taken under 1mN load and affec t ed by the substr a tes hardness due to l o ad c arr y ing capacit y . While the softest Al- alloy substrate hardness 1.25GPa, the coating hardness was measu re d 12GPa. On the other hand, the highest coa t ing hardness (39 G Pa) value taken fr o m the hardest M 2 substrate h a rdness (5.7GPa). The results of all the adh e sion tests s h ow a linear relationship between the hardness of th e base mater i al and the adhesion values. While adhesion value fr o m the co ated M2 w a s Lc≈65N, as function of the substrate eff e ct, the measured adhesion values are Lc≈15N and Lc≈50N from 20 2 4 Al-alloy and H13 st e el respectively.

8:20am **E1-3-2 Buckling of Ductile Thin Films on Rigid Substrate**, ***Nadia Ben Dahmane***, *G Parry, R Estevez,* SIMaP, University of Grenoble Alpes, CNRS, France*; C Coupeau,* Institut P', Université de Poitiers-UPR 3346 CNRS-ENSMA, France

The process of deposition of thin films can induce large compressive stresses (up to a few GPa) that combined with the low adhesion of the film to the substrate may result in simultaneous buckling and delamination of the film, leading experimentally to a large variety of buckled structures including straight-sided buckles, telephone cords or circular blisters. The mechanism of nucleation and propagation of elastic blisters has been widely investigated and described, either with analytical [1,2] or numerical methods [3]. In particular, the relationship between the mode mixity dependent interfacial toughness on the morphology of the wavy buckles has been highlighted [3]. The response of ductile thin films deposited on rigid substrates remains an open issue. For instance, it has been evidenced experimentally [4] that circular blisters exhibit folding angles at their base larger to that estimated from an elastic model (figure s1). In addition, recent experimental observations of 400nm gold films deposited on silicon wafers showed straight buckles with higher deflections compared to elastic predictions (figure 2). These differences in morphology are thought to originate from the elastic-plastic response of the film but the governing features need to be clarified. This is the purpose of the present study.

In this context, we carry out Finite Element simulations with a model that accounts for isotropic yielding and the non-linearity of the film. This approach aims at identifying the elastic-plastic constitutive model that is able to capture the experimental observations. A mode mixity dependent cohesive zone model is used to describe the thin film/substrate interface, that enables us to study the effect of plasticity on the stability and growth of straight and circular blisters.

[1] Hutchinson et al., Adv. in Appl. Mech. 29 (1992) 63.

[2] Hutchinson et al. Acta Metallurgica Materialia, 40 (1992) 295

[3] Faou et al., J. Mech. Phys. Sol., 75 (2015) 93.

[4] Coupeau et al., Thin Solid Films 469 (2004) 221.

8:40am **E1-3-3 Study of Multi-cracking of Brittle Thin Films and Brittle/ductile Multilayers on Compliant Substrate**, ***Ilhem Ben Cheikh***, CNRS, Université de Grenoble-Alpes, France*; G Parry,* Laboratoire de Science et Ingénierie des Matériaux et Procédés (SIMaP), Université de Grenoble-Alpes, France*; D Dalmas,* CNRS, Laboratoire de Tribologie et Dynamique des Système (LTDS), Ecole centrale de Lyon, France*; R Estevez,* Laboratoire de Science et Ingénierie des Matériaux et Procédés (SIMaP), Université de Grenoble Alpes, France

Thin films coatings are used in many high technology applications particularly in microelectronics devices. Using flexible polymers as a substrate on which thin films (metal, oxides or organic) are bonded can give rise to new industrial applications such as OLED, flexible electronics or flexible photovoltaics devices. The mechanical stability and failure behavior of multilayer structures deposited on flexible substrate has been extensively studied both experimentally and theoretically [1-3]. Several relaxation mechanisms in thin films have been identified such as channel cracks, debonding or buckle delamination.

The objective of this study is to understand the multi-cracking of the silver and/or zinc oxide layers of various thicknesses coated on elastoplastic substrates (ETFE). In the process of cracking many parameters should be taken into account such as the elastic modulus mismatch between the film and the substrate, the plasticity of the substrate and the ductile or brittle nature of the film.

In the literature several experimental and analytical studies can be found. In [4], after experimental investigations, the existence of three different fracture stages was confirmed, the third one being a saturation stage of the cracks density at high strain with large opening of the existing cracks. Conventional models in literature such as Xia & Hutchinson model [3] and the "Shear lag" formalism [1,2] do not account for those experimental observations. We show that taking into account the plasticity in the substrate allows for capturing the crack density at the saturation regime.

To further validate this new model and the experimental observations, we present a numerical study which uses a cohesive zone model for the interface and to simulate the cracking of the film. This model also takes into account the plastic behavior of the substrate (Fig1). The different stages of cracking observed experimentally, including the nucleation stage were simulated (Fig2). A relationship between the properties of the film toughness, the saturation stress level in the film and the saturation distance between the cracks under deformation has been evidenced.

9:00am **E1-3-4 Tribological Behaviors of UHMWPE Composites with Different Counter Surface Morphologies**, ***Yanzhen Wang***, *Z Yin, H Li, G Gao,* Shanghai Jiaotong University, China

The influence of counter surface morphologies on hybrid glass fiber (GF) and carbon fiber (GF) filled ultrahigh molecular weight polyethylene (UHMWPE) were studied under various contact pressure and sliding speed against GCr15 steel in dry condition. The goals were to investigate the tribological behavior of GF/GF/UHMWPE composite as a kind of water lubricated journal bearing material. The friction and wear behavior of composites were examined using a pin-on-disc tribometer. The morphologies of the worn surface were examined by scanning electron microscopy (SEM) and laser 3D micro-imaging and profile measurement. The results demonstrated that the counter surface morphologies have significant influence on the tribological behavior of GF/GF/UHMWPE composite. Generally, the wear rate and friction coefficient of composites increase as the increment of counter surface roughness. Also, the sliding speed and contact pressure have important effect on the tribological behavior of GF/GF/UHMWPE composite. The friction coefficient increases as the increment of sliding speed, while decrease as the increment of contact pressure.

9:20am **E1-3-5 Evaluation of Friction and Wear Characteristics of Electrostatic Solid Lubricant at Different Sliding Conditions**, ***Rakesh Kumar Gunda***, BITS Pilani Hyderabad campus, India*; S Narala,* BITS Pilani Hyderabad Campus, India

In modern industry, mechanical parts are subjected to friction and wear, leading to heat generation, which effect the reliability, life and power consumption of machinery. Solid lubricant additives have demonstrated better tribological performance in terms of reducing the machining zone temperature by creating friction without polluting the environment. With an appropriate application of solid lubricant additives in the sliding interface, the friction reduction and wear resistance properties of the lubricant have been successfully improved. Therefore, an attempt has been made in this research work with an investigation of using molybdenum

disulphide suspension to reduce the friction at machining zone. To achieve this, in the present work, Electrostatic charged spray lubricant (ECSL) system has been envisaged for effective supply of solid lubricant mixture at an extreme low flow rate to the sliding interface of WC pin and Ti-6Al-4V alloy as disk materials. Excessive tribological measurements with SAE 40 oil concentrated with 20wt% of MoS_2 with micron size particles showed friction coefficient as low as 0.001 and negligible wear. It is proposed that negatively charged sprayed MoS_2 solid lubricant mixture at nozzle tip has found remarkable influence on their tribological behavior.

9:40am **E1-3-6 Evaluation of Friction and Wear Properties of Al-TiC_p Metal Matrix Composite under Cryogenic Condition***, **Sravan Josyula,*** BITS-Pilani, Hyderabad Campus, India*; S Narala,* BITS Pilani Hyderabad Campus, India

Aluminium reinforced titanium carbide particulate (Al-TiCp) composites has gained attention for several engineering and structural applications due to its unrivaled properties, such as high specific strength to weight ratio, high thermal conductivity and excellent wear resistance. However application of Al-TiCp composites in sliding components creates larger friction and wear due to high abrasive nature of reinforcement particles in the soft matrix. It is well known that friction generates increase in contact temperatures can have an imperative impact on the tribological behaviour and failure of sliding components. Further, controlling of friction and wear behaviour enhances the wide application of Al-TiC metal matrix composites in various industrial applications. In this connection current research work try to improve the performance of Al-TiCp composite using cryogenic coolant. Sliding wear tests are performed in order to ascertain friction and wear properties of Al-TiCp metal matrix composites under cryogenic condition. To supply cryogenic coolant effectively to the sliding interface zone, a customized cryo-tribo setup has been developed by fastening cryogenic setup to pin-on-disc tribometer. Comparative studies have been carried out under cryogenic liquid (Liquid Nitrogen (LN_2)) and dry environment under different applied loading and sliding velocities The present analysis reveals that the weight loss of composite sample increases linearly with increase in normal load and sliding distance whereas decreases with increase in sliding velocity. Auxiliary observations revels that presence of cryogenic liquid in sliding contact offers significant reduction in friction and wear values when compared to dry condition through reduction in contact zone temperature and favorable change in pin and disc interface. Microscopic analysis has been carried out to understand the wear behavior of developed under cryogenic condition. The developed technology helps to improve the tribological properties (reduction in friction and wear) there by improving service life and durability of the component in various industrial applications.

10:00am **E1-3-7 Wear Mechanisms and Tribological Characterisation of Novel Nanocomposite Coated Cutting Tool Material for High Temperature Applications***, **Pavandatta Jadhav**, S Narala,* BITS Pilani Hyderabad campus, India

The parts which undergo dry sliding encounter high friction and wear which affects the durability. In recent years, there is a growing interest in the application of Nano-composite coating on the cutting tools to increase the wear resistance, high thermal stability, hardness and durability of the tool. The Nano-composite coatings have been found to have better practical performance capabilities. To reduce the friction and enhance the wear resistance, the hard Nano composites (ZrO_2 Y_2O_3, Ti, Si) N show high performance capabilities. This article attributes a specific study of the application of Nano-composite coating on the cutting tools which shows an impact on the increase in wear resistance, low friction, and increase durability of the tool. In this study, the (ZrO_2 Y_2O_3, Ti, Si) N hard nanocomposite coatings have been deposited on a carbide tool by electrostatic spray coating (ESC) technique. The coatings have been tested for wear and friction behaviour by using a pin-on-disc tribological tester designed according to ASTM G99 standards. The dry sliding wear test was performed on Titanium alloy (Ti6Al4V) disc and (ZrO_2 Y_2O_3, Ti, Si) N hard nanocomposite coated carbide tool (pin) at various speeds and loads at ambient atmosphere. The results revealed that electrostatic Nano-composite coated tools performed much better as compared with those uncoated tools.

Author Index

Bold page numbers indicate presenter