Tribology and Mechanical Behavior of Coatings and Engineered Surfaces

Room San Diego - Session E1-2

Friction, Wear, Lubrication Effects, and Modeling

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

1:30pm **E1-2-1 Surface Engineering for Increasing Performance of Injection Molding Tools**, ***Lars Pleth Nielsen***, Danish Technological Institute, Denmark; *S Hengsberger,* Institute of Applied Plastics Research at Engineering College Fribourg, Switzerland; *K Pagh Almtoft, B Hold Christensen,* Danish Technological Institute, Denmark **INVITED**

Injection moulding of high-precision plastic components with high output volumes, using low cycle times without compromising on a high product quality is extremely important in order to increase both the productivity and keeping a competitive edge. At the same time, many moulds are becoming more and more complicated and costly. Hence, it is necessary to increase the lifetime, the wear resistance, minimize the diesel effect, improve the slip properties (ejection force) and the performance of the applied moulds.

The ejection force was quantified in situ during the injection moulding process by incorporating a force sensor. The developed method was found to be so reliable that it was possible to measure a difference between the as machined moulds implying that it was necessary to use each mould as its own reference.

The impact on the ejection force when adding different surface pretreatments to the moulds (as machined, grinded, blasted or laser textured) have been analyzed in combination with different PVD coatings (CrN, HiPIMS CrN, low-temperature pulsed TiAlN) combined with post treatments involving different doses of high-current nitrogen implantation.

The ejection forces were measured for four industrial relevant plastic types (PP, POM, ABS and TPU) before and after adding the wear-resistant coating as well as after ion implantation. The results revealed that the ejection force could be lowered by close to 70% for some of the plastic types by adding a combination of wear-resistant coating and ion implantation. The best performing surfaces were found to be HiPIMS CrN followed by nitrogen ion implantation.

Corrosion and the risk of diesel effect was minimized by Cr ion implantation. The Cr ion implantation was observed to lead to a new phase in the top most 50 nm. The improved corrosion resistance was quantified by cyclic voltammetry.

Thin film characterization of the applied coatings have be addressed based on nanoindentation, SEM and RBS.

The findings will be compared with empirical results from industrial-scale injection moulding.

2:10pm **E1-2-3 Increasing the Lifespan of High Pressure Die Cast Molds Subjected to Severe Wear**, *F Silva,* ***Vitor Nunes***, *M Andrade,* ISEP - School of Engineering, Polytechnic of Porto, Portugal; *R Alexandre,* TeandM - Technology, Engineering and Materials, S.A., Portugal; *A Baptista,* INEGI - – Instituto de Ciência e Inovação em Eng. Mecânica e Eng. Industrial, Portugal

Despite the increasingly incorporation of composite materials on vehicle components, high pressure die casting still remains one of the most useful manufacturing techniques to obtain automotive parts with complex shape in a cost effective way. It is well known that automotive industry requires high production cadency as well as high products quality. Thus, systematic approaches are permanently being done leading to optimize all the production and management aspects.

The aluminum alloys commonly used in automotive parts such as fuel pumps bodies, throttle bodies, EGR valves, support brackets and so on usually contain Silicon which presents high abrasively. The aluminum flow at high temperature and high speed into the mold induces severe wear, sometimes due to a combination of abrasion and erosion effects.

In this study, two molds with typical severe wear problems were selected and the wear mechanisms involved were deeply studied. After that, a careful selection of the best coating for this purpose was done and some of the most critical parts of the mold were coated in order to test possible effective advantages of the coating application, analyzing the wear resistance behavior and wear mechanisms involved. In parallel, tribological tests were also carried out in order to study if a correlation between laboratorial and industrial tests can be drawn. Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy were intensively used to characterize the coatings and the wear mechanisms observed. Laboratorial tribological tests have involved ball scattering and block-on-ring tests, trying to impose low and medium loads on the contact, respectively. Promising results were obtained allowing to conclude that certain coatings present a better behavior than other ones in this field of application.

Keywords: Wear, Abrasion, Erosion, High-pressure die casting, Mold wear, Wear mechanisms, Mold lifespan

2:30pm **E1-2-4 Effect of Cr Additions on the Structure,Oxidation, Tribological and Machining Performance of Multilayered TiAlN/CrAlN Films Deposited by Sputtering**, *F Fernandes,* Instituto Pedro Nunes, Portugal; *M Danek,* Czech Technical University, Czech Republic; *T Polcar,* University of Southampton, UK; ***Albano Cavaleiro***, University of Coimbra, Portugal

Machining of hard to cut materials, such as hardened steels or strong materials for high temperature aerospace applications, is nowadays a challenge of modern engineering. In past recent years, different types of coatings have been developed and applied on the protection of machining tools in order to improve their performance and lifetime. TiAlN has been the most widespread coating because of its sufficient thermal stability, up to 900°C, high hardness, oxidation resistance and adhesion resistance. The addition of Cr to this system has been extensively studied; however, at our knowledge the oxidation, high temperature tribology and in-service machining performance of multilayered TiAlN/CrAlN films is still rare. This work focused on the effect of Cr alloying on the structure, oxidation resistance, kinetics of ions diffusion at high temperature and in-service tribological behaviour of TiAlN/CrAlN films. The results were compared with a TiAlN film deposited as reference. The coatings were deposited in an industrial chamber by unbalanced close field magnetron sputtering, onto Si, FeCrAl alloy and WC substrates as well as onto tungsten carbide drills with 5.5 mm diameter. The crystal structure of the films was analyzed by X-ray diffraction. Oxidation of the films was assessed by thermogravimetric analysis (TGA). Tribological experiments were performed in a high temperature pin-on-disc tribometer at RT, 600 and 700 ºC, using Al2O3 balls as counterpart. The tribological experiments were then complemented with in-real machining tests by studying the lifetime of coated drills. The oxidation performance of coatings is improved with Cr additions due to the growth of a more protective Al-Cr-O rich layer in the interface film/oxide. Tribological behavior of Cr rich coatings at room temperature is similar to the one of reference TiAlN film, but at high temperature it is two to three times better. Coatings with high Cr content (Ti0.28Al0.31Cr0.51N) displayed the best oxidation, tribological and machining performance.

2:50pm **E1-2-5 Investigation on Tribological Behaviour of Boron Doped Diamond Coated Cemented Tungsten Carbide for Cutting Tool Applications**, ***Ramasubramanian Kannan***, *A Narayanaperumal, R Rao,* Indian Institute of Technology Madras, India

In this paper, tribological performance of boron doped microcrystalline diamond (BDD) films and boron doped graded layer diamond thin films (BDD/transition layer/NCD) was studied in detail. The widely used cemented tungsten carbide (WC-Co) was selected as a substrate material for diamond coating. Diamond films was deposited on WC-Co by Hot-filament CVD reactor (HFCVD) setup. Tribology experiment was conducted by using reciprocating tribometer with a normal load of 30 N and a sliding velocity of 10mm/second for a constant wear length of 3 mm. Silicon nitride (Si_3N_4) ball was used as a counter part to study the friction and wear behaviour of diamond films. The surface morphology, topography & roughness of the diamond films were analysed by scanning electron microscope and atomic force microscope respectively. The hardness of the thin diamond films was measured by using berkovich nano indentation test method. The test results found that BDD and boron doped graded layer shows a stable lowest friction coefficient values of 0.004 and 0.003 compared with conventional microcrystalline diamond films (0.007). On the other hand, the wear diameter of the silicon nitride ball for BDD and boron doped graded layer found to be 620 µm and 785 µm, relatively lower in comparison with microcrystalline diamond films (897 µm). The wear track width was measured by scanning electron microscope and shows that BDD and boron doped graded layer indicates lower wear track width 564 µm and 596 µm compared with microcrystalline diamond films (712 µm). Raman mapping was conducted on the wear track of the diamond films to

know about the phase pure diamond (sp^3) and partly graphite phases (sp^2) which in turn contributes for the distinct residual stresses in thin films. The obtained lower friction coefficient for boron doped diamond films on WC-Co cutting tool can be suitable for machining of aluminium based metal matrix composites effectively.

3:10pm **E1-2-6 Influence of Self-lubricating Non-metal Phase on the Erosion and Wear Behavior of Ni-based Abradable Coatings***, **Pantcho Stoyanov**, A Wusatowska-Sarnek,* Pratt & Whitney, USA

In this study, the influence of self-lubricating hexagonal boron nitride (hBN) on the erosion and abradability of Ni-based abradable coatings was investigated. Two coatings of same metallic content, one with and one without hBN, were deposited by means of plasma spray to different densities and consequently hardness values. Subsequently, the coatings were subjected to erosion and abradability testing at room temperature in order to evaluate their performance. In addition, to capture the characteristics of the wear process, a detailed chemical and structural analysis was performed within the near-surface region of the worn specimens (i.e. abradable and blade) by means of Scanning Electron Microscopy (SEM), Transmission Electron Microscopy, and micro-Raman spectrometry.

The erosion resistance of the coatings increased with increasing the density as well as with the addition of hBN, which correlated well with the hardness results. The abradability of the coatings without hBN showed a reverse correlation with erosion capability where the less erosion resistant coatings were more abradable as manifested by the lower blade wear. Similarly, the high density hBN content coatings caused higher blade wear compared to the lower density coatings with hBN. However, the coatings with hBN showed overall better abradability compared to the ones without, which correlated well with slightly lower interface temperatures (i.e. measured by means of thermocouples and IR thermometer) and was attributed to the difference in the particle pull-out mechanism.

3:30pm **E1-2-7 Tuning Run-in Friction Behavior of Carbon Film with Graphene Nanocrystallite Structure***, **Cheng Chen**, S Qiu, D Diao,* Shenzhen University, China

In general, amorphous carbon films always has a high friction stage, so-called “run-in” stage, before reaching low friction steady stage. The causes of the run-in stage have been attributed to removal of surface contaminants, oxide film formation, material transfer, and subsurface microstructure reorientation. Regarding to the low friction application, the run-in stage is undesired and necessary to be shortened or even avoided. However, few effective methods have been proposed for eliminating the run-in stage.

In this study, we demonstrated that the run-in stage of carbon film could be tuned with graphene nanocrystallite structure. Firstly, graphene nanocrystallite embedded carbon films were prepared with low-energy electron irradiation using an electron cyclotron resonance (ECR) plasma sputtering system. The structure of graphene nanocrystallite was varied with electron irradiation energy. Friction behaviors of the films were investigated with a Pin-on-Disk tribometer. Compared with amorphous carbon film, the films with graphene nanocrystallite showed shorter run-in stages. And the run-in stage nearly disappeared for the film with irradiation energy of 40 eV. The steady-stage friction coefficients of amorphous carbon film and graphene nanocrystallite embedded carbon films were all about 0.04. The wear rates of the carbon films in run-in stage were measured with a profilometer. The nanostructures of transfer films were investigated by a Raman spectroscopy. The short run-in stage mechanism was interpreted that graphene nanocrystallite was easier to be worn out than amorphous carbon, and it was beneficial for the formation of nanocrystallized transfer film. Secondly, two layer hybrid films were fabricated by depositing 1~10 nm graphene nanocrystallite layer on a thick amorphous carbon layer. The hybrid films showed short run-in stages and low friction behaviors. This study enables a convenient method to control the run-in stage of carbon film, which is significant for tribology application.

3:50pm **E1-2-8 Study of the Wear Mechanisms and Solutions Regarding Inserts used on Cork Grinders***, F Silva, **Thiago Oliveira**,* ISEP - School of Engineering, Polytechnic of Porto, Portugal*; R Alexandre,* TeandM - Technology, Engineering and Materials, S.A., Portugal*; A Baptista,* INEGI - – Instituto de Ciência e Inovação em Eng. Mecânica e Eng. Industrial, Portugal*; A Alves,* Amorim Cork Composites, S.A., Portugal

Cork was one of the main pillars in the Portuguese economy some decades ago, being nowadays one of the most important natural materials currently exported from Portugal to the entire world. Initially, wine bottle stoppers were almost exclusively the only product extracted from the cork oak hull. However, the high quality required by the bottle stoppers makes unviable the use of some cork hooves and the waste generated by the bottle stoppers extraction also is considerable. Moreover, the traditional Portuguese creativity allows bringing to the market a huge number of products based on cork aggregates as composites, due to the addition of bonding and other materials in order to improve the overall characteristics of those products. Nowadays, cork composites are used in products as distinct as sportive floors, wall memos, lady bags or shoes.

However, these composites need to be processed and one of the first steps to produce the cork granules is its grinding process. Despite the cork presenting a relatively low mechanical strength and hardness, the grade of abrasion generated by cork on grinder inserts during the grinding process is considerable. Companies devoted to cork composites have as main initial operation the cork wastes sorting, separating eventual metallic pieces coming to the process together with the cork. Posteriorly those wastes are driven to the grinders leading to the granules generation and further particle size selection. The inserts used in these grinders as main tools to proceed to the grinding process are severely affected by wear and the increasing competitiveness imposed by the market is forcing to face this concern with care.

This study intends to realize what kind of wear mechanisms are strongly influencing the premature end-of-life of the grinding inserts, which occurs due to reduced cutting efficiency and generation of out of specification cork granules, allowing to determine the best ways to extend their life cycle, improving the cost/benefit ratio and allowing to get a better equipment performance by the increase of the OEE (Overall Equipment Efficiency) of the machines related to this manufacturing operation. Results obtained led to understand the phenomena induced in the inserts and some promising alternative solutions using special materials and coatings were drawn and tested, allowing improve the inserts wear behavior thus making this operation more efficient and profitable.

Keywords: Cork, Cork grinders, Grinders inserts, Inserts wear, Wear mechanisms, Abrasion, Coatings

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