Surface Engineering - Applied Research and Industrial Applications
Room Sunset - Session G3
Innovative Surface Engineering for Advanced Cutting and Forming Tool Applications

Moderators: Heidrun Klostermann, Fraunhofer FEP, Holger Gerdes, Fraunhofer Institute for Surface Engineering and Thin Films IST, Mirjam Arndt, OC Oerlikon Balzers AG, Liechtenstein

1:30pm **G3-1 On the Synergies Between Coating and Tool Material Substrate: A Strategy to Optimize Coated Tools Performance in Cold Forming**, *D Casellas,* Fundació CTM Centre Tecnològic, Spain*; A Mueller,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein*; **Giselle Ramirez**, M Vilaseca,* Fundació CTM Centre Tecnològic, Spain **INVITED**

In recent years hard coatings have acquired a significant importance in the microstructural and micromechanical design of tools and components. Among the wide range of surface modification techniques, PVD (Physical Vapour Deposition) is one of the most suitable routes to meet the demanding requirements of surface finish and dimensional tolerances that need some specific tools and components, such as those for the automotive sector. However, although thin films tend to reduce the wear mechanisms under service conditions, improved resistance against contact fatigue failure still remains a challenge. The latter has been emphasized in punching and forming processes, where the introduction of advanced materials (such as high strength steels, thick stainless steel strips, etc.) requires higher impact pressures than those used in conventional materials. In those cases, the load is mainly supported by the substrate. Thus, if any subsurface damage occurs in coated tools, then a premature detachment of the layer, or even more, chipping of material could be produced accelerating the wear damage mechanism.

Attempting to ensure the effective usage of coated steels under complex service conditions, where wear is accompanied by contact loads of cyclic nature, it is important to understand and document the interaction between coating and substrate of industrial components. Once the main mechanism of damage is identified on cold forming tools, the following step is the selection of the optimum configuration of coating, interface and steel. But the selection process is not trivial task, and a wrong decision can produce bad experience in the application of coating technology. Recent studies have demonstrated that topography and mechanical properties of the PVD coated surfaces is strongly dependent on the tool steel microstructure as a substrate. This was mainly attributed to a difference in sputtering rates of phases and the metal-matrix of steels during ion etching process, and also due to the size, morphology and structure type of primary carbides.

The main objective of this work is to address the interaction between tool steel and thin coating during cold forming and discern the most relevant microstructural and topographical aspects leading to high tool performance. Detailed microstructural analysis will be complemented with industrial tool behavior to properly understand the synergies between coating and tool material substrate.

2:10pm **G3-3 Deposition of ta-C Coating by Arc Ion Plating for Machining of Al Alloys**, ***Yoshiyuki Isomura**, T Takahashi, S Kujime,* Kobe Steel, Ltd., Japan

Al-alloy is soft metallic material and exhibits good machinability. However welding adhesion and building-up edge (BUE) tend to form easily at a surface of cutting tool due to its low melting point. To prevent the formation of BUE, dry cutting tool for Al-alloy requires high resistance against welding adhesion. For this purpose Diamond-Like Carbon, DLC, coating draws a great practical attention. DLC is known to exhibit low friction and high resistance to welding adhesion. Among various types of DLC coatings practically available in recent years, hydrogen free DLC, also referred to as ta-C, tetrahedral amorphous carbon, shows high sp3 content and hence high hardness as compared to conventional hydrogen containing DLC coatings.

In this study, we deposited ta-C coatings by cathodic arc process, also referred to as arc ion plating, in a middle sized industrial coating unit. The unit was equipped with a round-bar type cathode with a typical target diameter of 20 mm. Pure graphite was used as the target material. ta-C coatings were deposited at different bias voltage and film thickness. The sp3/sp2 fraction, hydrogen content, and film density were studied by XPS, RBS, and XRR method, respectively. These coatings were also deposited on cutting tools for machining of Al alloys. Correlation of the film properties to cutting performance is discussed.

2:30pm **G3-4 Laser Structured High Performance PVD Coatings for Injection Molds**, *K Bobzin, T Brögelmann, N Kruppe, **Mona Naderi**,* Surface Engineering Institute - RWTH Aachen University, Germany

Structured plastic components, which are used for flow-optimization, self-cleaning surfaces and optical applications, are usually produced by injection molding using structured tools. A suitable technique for structuring is laser ablation, which offers a high level of accuracy and flexibility. Moreover, the dimension of structures fabricated by laser in the order of a few micro- and nano-meters can significantly change surface properties such as topography, mechanical properties and wetting. Specifically, adhesive and abrasive wear of the mold surface are important failure mechanisms in plastics processing. The key to overcome the aforementioned challenges is to modify the surface of the mold using innovative surface engineering such as physical vapor deposition (PVD). However, coating deposition on nanostructures leads to a decisive change in the surface topography and the surface functionality. For this reason a direct structuring of PVD coated tools is beneficial.

This work deals with the influence of laser structuring on the properties of nitride and oxinitride chromium-based coatings. For this purpose, three coatings with different chemical composition were synthesized on tool steel AISI 420 (X42Cr13, 1.2083) by means of high power pulsed magnetron sputtering process. The coatings were structured by means of ultra-short pulsed laser under variation of the parameters, such as pulse energy, repetition rate of laser and structuring speed. It could be observed that a decrease of the laser intensity results in a reduction in the structural depth observed with scanning electron microscopy. This, on the other hand, leads to a decrease of the surface roughness measured through confocal laser scanning microscopy. Structural changes at the surface of the coating as a result of thermal effects during laser structuring were characterized using Raman spectroscopy and in-situ high-temperature X-ray diffraction.

Based on the results of the laser-surface interaction one set of laser parameter was selected. With these parameters, the samples were structured over a large area for the tribological investigations. On these samples, friction behavior was measured by using a pin on disc tribometer in contact with polycarbonate and polymethyl methacrylate. Furthermore, the wetting behavior of plastics melts on the structured coatings was investigated by means of high temperature contact angle measurements. The shear energy while shearing the solidified plastics from the surface was determined. The results for the structured coatings are promising with regard to the production of optical plastics components.

2:50pm **G3-5 Effect of Layer Sequence on Wear Behavior of AlTiSiN Hard Coatings**, ***Joern Kohlscheen**, C Bareiss,* Kennametal GmbH, Germany*; C Charlton, D Banerjee,* Kennametal Inc., USA

The aim of this study is to understand the effect of different silicon contents and layer sequences on the resulting wear behavior of AlTiN based coatings. Deposition was done in an industrial scale PVD unit using cathodic arc evaporation of AlTi and TiSi materials. Silicon contents ranging from 3 to 15 at. % (metal fraction of the nitride compound) were adjusted. Monolithic and multilayers were deposited keeping the coating thickness between 3 to 4 micron. Coating hardness and elastic modulus were determined by nanoindentation. Adhesion and toughness were characterized by indentation with a diamond tip. Film structure and chemistry was determined using EDX and XRD. In some cases TEM images were prepared to clarify film structure in the nanometer range. Using fatigue testing at room temperature and T ~ 700 C it could be shown that multi-layers tend to be more wear resistant especially for moderate silicon contents below 10 at. %. In order to tailor the wear resistance in the contact zone of a cutting tool, we varied the silicon content and selectively removed the outer layer to obtain harder and tougher zones at the flank and rake face of carbide inserts (ISO K grade). Turning of high strength cast iron material was performed to show the beneficial effect of this method. The resulting wear patterns will be discussed.

3:10pm **G3-6 Structural, Mechanical, and Cutting Properties of AlCrN Coatings Deposited by Arc Ion Plating**, *N Ohba, T Takahashi, **Susumu Kujime**,* Kobe Steel, Ltd., Japan

High aluminum containing transition metal nitride such as AlCrN and AlTiN has widely been used for cutting tool application due to their high hardness and oxidation resistance at elevated temperatures. The intrinsic properties of the coatings, and hence cutting performance thereof is highly dependent on Al content and its crystallographic structure. It is of practically significance to increase Al content in the coating in a vacuum deposition process whereas the metastable cubic phase is preferred to be remained and the possible formation of AlN hexagonal phase should be suppressed during deposition as well as cutting operational condition.

In this study we investigate the correlation between deposition conditions, coating properties, and cutting performance. AlCrN coatings were deposited by cathodic arc, also referred to as arc ion plating. As for coating process we employed new industrial arc ion plating system having a reasonably compact batch volume for production, but yet high productivity. Al content x in $Al_xCr_{1-x}N$ was systematically varied by changing the target composition from 65 up to 73 at at.% Al. Bias voltage of 40, 70, and 150 V were applied at a given composition of Al. The structural, compositional, and mechanical properties of the coatings were studied by X-ray diffraction, SEM-EDX, as well as nanoindentation. Residual stress of the coating was also evaluated from curvature measurement of a plate sample. For cutting test evaluation the depositions were also performed on micro-endmills with a diameter of 1 mm. Cutting performance with respect to the coating properties will be discussed.

3:30pm **G3-7 Physical Properties and Cutting Performances Relation to Coating Conditions of AlCrN Coating Deposited by HiPIMS and Cathodic Arc***, **Keizo Tanaka**, S Imamura, M Setoyama, H Fukui,* Sumitomo Electric Hardmetal Corp., Japan

Recently Aluminum Chromium Nitride (AlCrN) coating is widely used in cutting tool industry. And HiPIMS technology has been seen as a probable alternative to the cathodic arc technology. In this study, physical properties and cutting performances was examined and the results explained in terms of coating conditions compared HiPIMS to cathodic arc technology.

HiPIMS coating showed valuable surface morphology, hardness ; 22.9 to 41.6GPa, compressive residual stress; 0.3 to 3.3GPa by bias voltage ; 30 to 100V, peak pulse power ; 30 to 60kW and nitrogen partial pressure.

HiPIMS coating showed higher hardness and more stable tool damage than cathodic arc by higher bias voltage or higher peak pulse power. These results were considered argon ion bombardment assist during film deposition. This consideration indicates further usability of HiPIMS technology in cutting tool industry.

4:50pm **G3-11 Nanoscale Multilayer PVD Coatings to Serve in Demanding Environments***, **Papken Hovsepian**, A Ehiasarian,* Sheffield Hallam University, UK **INVITED**

Superlattices were discovered in 1925 by Johansson and Linde as periodic structures of layers of two (or more) materials. In 1970 J.S. Koehler theoretically predicted that if these materials were selected to be with high and low elastic constants a super strong man made material could be produced. Various theories and models have been put forward to explain the super hardening and super toughening effects and a large variety of coatings have been explored both on laboratory and industrial scale. This work summarises results on the properties and performance of novel nanoscale multilayer structured coatings produced by High Power Impulse Magnetron Sputtering, (HIPIMS) dedicated to serve in demanding environments.

To protect Gamma-TiAl components used in automotive and aero engines against environmental attack dense oxide forming elements such as Cr and Al were combined to produce **CrAlYN/CrN** nanoscale multilayer coatings. Coatings with very low layer waviness and strongly improved density have been successfully grown by HIPIMS. These coatings provide excellent oxidation resistance up to 850°C and reduce the fatigue deficit of the aerospace turbine blade material to less than 9%.

TiAlCN/VCN represents a new class of superlatice coatings where enhanced performance is achieved by lateral segregation of small atom material (in this case Carbon) at the interfaces between the individual layers producing low shear strength interfaces. These coatings provide excellent tool protection against build-up edge formation during machining of Aluminium alloys, Titanium alloys and MMCs widely used in aerospace and automotive applications.

In **Me doped Carbon films** a unique nanoscale multilayer structure was produced by unconventional method of coating growth based on dynamic segregation driven by intensive ion irradiation. By varying the ion energy and ionisation degree, layered structures with bi-layer period of up to 25 nm were grown. With Cr/C and Mo-W doped Carbon nanoscale multilayer films enhanced tribological performance in boundary lubricated conditions at elevated temperatures, (up to 200°C) was achieved. Smart material selection allowed *in- situ* formation of lubricious phases at the asperity contacts due to tribochemical reactions between the dopants and the oil and improved the coatings high temperature stability.

CrN/NbN combining the electrochemically stable Nb with the wear resistant Cr was initially developed as a replacement of hard Cr, however its unique properties allowed the coating to be used in many other demanding applications described here.

CrN/NbN provided reliable protection against high pressure, (50 bar) , high temperature, (600°C) pure steam attack on P92 steel used in steam turbines and showed high resistance against water droplet erosion. Furthermore, the coating did not deteriorate the mechanical properties such as Ultimate Tensile, Low Cycle Fatigue and Creep Strength, which is of paramount importance in turbine blade applications.

The performance of medical implants was enhanced by the application of **CrN/NbN** coatings. Metal ion release studies showed a reduction in Co, Cr and Mo release at physiological and elevated temperatures to undetectable levels (<1 ppb). Thorough *in vitro* biological, cytotoxicity, genotoxicity and sensitisation testing proved the safety of the coating in biological environment.

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