## Surface Engineering - Applied Research and Industrial Applications
## Room Sunrise - 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, Ali Khatibi, Oerlikon Balzers, Oerlikon Surface Solutions AG

1:30pm **G3-1 Degradation Mechanisms of Protective Coatings in Precision Glass Molding**, ***Marcel Friedrichs**, O Dambon, F Klocke,* Fraunhofer Institute for Production Technology, Germany

Thermo-chemical and thermo-mechanical loads act on molding tools during several hundred cycles of Precision Glass Molding (PGM). Wear protective coatings are used on the molding tools in order to protect the optical surface of the molds against degradation. Therefore, the lifetime of molding tools and thus the process efficiency increase. Precious metal coatings such as platinum-iridium (PtIr) are the most versatile material class used for molding various glass types. Furthermore, diamond-like carbon (DLC) and ceramic coatings are employed in PGM as well.

The presented work investigates the degradation mechanisms of different protective coatings by PGM tests at a service lifetime test bench. Subsequent analyses of coated specimens were performed by white light interferometry, scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS), which proved different degradation mechanisms as diffusion, oxidation, corrosion, glass adhesion and flaking off. Summarizing these observations, a degradation model of the leading degradation mechanisms for different coating systems has been created, which is currently available for further coating development.

1:50pm **G3-2 Nanolayered Coatings for Advanced Fine Blanking Applications**, ***Marcus Morstein**, T Schär,* Platit Ag, Switzerland*; B Torp,* PLATIT, Inc., USA, Switzerland*; T Klünsner,* Materials Center Leoben Forschung GmbH (MCL), Austria

A combination of nano- and multilayer structures has proven to provide an optimum combination of wear- and mechanical impact resistance for physical vapor deposition (PVD) coatings used in metal cutting. One field of application where such ceramic coatings are particularly challenged is fine blanking, a versatile metal sheet cutting process able to produce high-quality parts for automotive and general engineering applications, in large quantities. In this process, high compressive and tensile shear forces interact with the coated tool surface, which is additionally challenged by mechanical shock, abrasion and work piece material adhesion.

This paper addresses how using structural design on the nano- and microscale, coatings based on AlCrN and AlCrTiN can be tailored to match the required compromise between wear resistance and toughness. The investigated coatings were produced on two different industrial coating units using lateral (LARC) and central (CERC) cylindrical rotating arc cathodes technology, or a combination of LARC and planar arc cathodes. The nanolayer structure was varied through selection of different target material combinations and different arc currents, and properties relevant to coating adhesion and toughness were measured. In particular, depth resolved internal stress profiles were collected using a modified side inclination XRD technique.

Since wire electrical discharge machining (EDM) is the typical production process for fine blanking punches and dies, pre-treatment methods for substrates made both from powder-metallurgical tool steel and from cemented carbide (WC/Co) were optimized in order to remove surface damage brought in by the manufacturing process and to ensure optimum coating adhesion. Furthermore, a strong coating post-treatment was applied and the beneficial effect of surface smoothness on suppressing workpiece material sticking was illustrated both on the lab scale and in practical fine blanking tests.

Long-term tests in production environment showed that by using the new nanolayered, toughness optimized coatings, controlled wear and thus higher productivity and process stability in fine blanking can be achieved.

2:10pm **G3-3 Growth of Low-defect-density $Ti_{1-x}Al_xN$ Thin Films by Cathodic Arc Evaporation under Industrial Conditions**, ***Marta Saraiva**, L Johnson,* Sandvik Coromant R&D, Sweden **INVITED**

The metal cutting industry is, nowadays, an extremely competitive market with numerous significant players. In order to stand out and be ahead of the competition, one needs to be proactive and offer products and solutions to customers before their need for them arises. Such achievement requires to carefully listening the market and continuous strive for improvement. Thus, it is crucial to maintain an R&D activity at the upmost level.

The majority of cemented carbide tools used today are coated, with roughly 50% using a Physical Vapour Deposition (PVD) technique. The ability to deliver world class thin films to our products emanates from possessing adequate equipment and knowledge to tweak the process in order to obtain the desired thin film properties, which result in the best product performance for a specific application. Therefore, the control of microstructure is of high importance to tailor the functional performance characteristics of thin films, and in particular, for hard wear-resistant coatings such as TiAlN. Normally, the grain size of TiAlN is strongly correlated to the Al content, with Al as a grain refiner. Therefore it is of high interest to control the microstructure independently of the Al content. One such example is the recent work by Grezynski *et al.* [1], who demonstrated the growth of low-defect TiAlN by a hybrid DC/HiPIMS magnetron sputtering technique using synchronized bias pulsing under laboratory conditions. Here, we report the discovery of growth conditions for low-defect $Ti_{1-x}Al_xN$, deposited by cathodic arc evaporation using a full-scale industrial deposition system under production-ready conditions. By tuning the process parameters, it was possible to change the ordinary cathodic arc hard coating growth mode of defect-rich grains with featureless surfaces, to a mode of feature rich surfaces and low-defect-density.

[1] G. Greczynski *et al.,* Surf. Coat. Technol. 257 (2014) 15.

2:50pm **G3-5 A Contribution to Explain the Mechanisms of Adhesive Wear in the Plastics Processing by the Example of Polycarbonate**, *K Bobzin, T Brögelmann,* Surface Engineering Institute - RWTH Aachen University, Germany*; G Grundmeier, T de los Arcos, M Wiesing,* University Paderborn, Germany*; **NathanChristopher Kruppe**,* Surface Engineering Institute - RWTH Aachen University, Germany

In plastics industry, adhesive wear due to flowing hot melt is one of the main damage mechanisms of extrusion tools. Such damages strongly affect the economic efficiency and the product quality. Due to their beneficial properties, Cr-based nitride hard coatings deposited by physical vapor deposition (PVD) are applied as protective coatings. These coatings can prevent the formation of ferric oxides $Fe_xO_y$, which influence the adhesion and thus the degradation of plastic melt on the tool surface. In the present work, four different CrAl-based nitride and oxy-nitride monolayer coatings were synthesized on tool steel substrate AISI 420 (X42Cr13, 1.2083) by means of a hybrid direct current and high power pulsed magnetron sputtering (dcMS/HPPMS) process. At this, the chemical composition of the nitride and oxy-nitride coatings was varied in terms of the metal ratio Cr/Al. All coatings and one uncoated steel substrate were analyzed before and after long-term annealing in order to investigate it's influence on the chemical composition of the native passive film at the surface by using X-ray photoelectron spectroscopy (XPS). Furthermore, the influence on the wetting behavior of polycarbonate melt by means of high temperature contact angle measurements as well as on the degradation behavior of polycarbonate by fluorescence measurements using Raman spectroscopy were studied. It was shown that the annealing process leads to a significant higher increase of polycarbonate wetting on the uncoated steel compared to the coated samples. Additionally, the coatings with an increased Al content exihibit a significant lower wetting compared to the other coatings and the uncoated steel. The influence of the metal ratio Cr/Al within the nitride and oxy-nitride coatings on the degradation of polycarbonate was quantified and correlated to the high temperature contact angle measurements.

3:10pm **G3-6 Enhanced Replication Ratio of Injection Molded Plastics Parts by using an Innovative Combination of Laser-Structuring and PVD Coating***, K Bobzin,* Surface Engineering Institute - RWTH Aachen University, Germany*; C Hopmann,* Institute of Plastics Processing, RWTH Aachen University, Germany*; A Gillner,* Chair for Laser Technology, Aachen, Germany*; T Brögelmann, N Kruppe, **Mona Naderi**,* Surface Engineering Institute - RWTH Aachen University, Germany*; M Orth,* Institute of Plastics Processing, RWTH Aachen University, Germany*; M Steger,* Chair for Laser Technology, Aachen, Germany

One of the fast-growing segments of manufacturing is plastics processing. The properties of plastics products can be optimized by a suitable design of the component surface. One promising method is the usage of molding tools structured in the micrometer range for plastics processing by extrusion and injection molding. Such microstructured, optically functional plastics parts are commonly used in light-field photography, displays and security technology. However, the production of optical functional surfaces demands a high quality of replication from the tool insert. Due to the high density of structures and therefore increased surface area the filling rate during the injection molding is very challenging. The adhesion of the plastics melt on the mold surface during the processing can influence the product quality. One possible approach is the combination of physical vapor deposition (PVD) technology with laser based variothermal injection molding to improve the replication of microstructures. PVD hard coatings, such as ternary chromium based nitride (Cr,Al)N are used as protective coating due to the mechanical, chemical and tribological properties to reduce wear and wetting between mold and plastics. Within the scope of this paper, a laser microstructuring was carried out on an injection mold out of AISI 420. A nitride hard coating was deposited on microstructured mold by means of middle frequency pulsed magnetron sputtering (mfMS). Variothermal injection molding with an external laser beam was used to mold microstructured, coated and uncoated molds. The coating morphology and its chemical composition as well as the mechanical and tribological properties were characterized. Commercial plastics polycarbonate (PC) and two types of polymethyl methacrylate (PMMA) were considered for tribological investigations. Adhesion behavior of molten PC and PMMA on (Cr,Al)N hard coatings was analyzed by means of high temperature contact angle measurements. Wear tests were performed by using pin-on-disc-tribometer measurements at room temperature T = 23 °C and at half of the processing temperature T = 110 °C and T = 150 °C against solid PC and PMMA. The results exhibit a high potential of the investigated nitride coating to be used as protective coating against abrasive and adhesive wear during processing of polycarbonate and polymethyl methacrylate. A prosperous replication of microstructured and coated mold could be proofed at different molding temperatures. The replication ratio of optical microstructures is increased significantly up to 20-30 % by using mold coating in comparison to uncoated mold.

3:30pm **G3-7 Sophisticated Wear Resistant Coatings used in Cold Sheet Metal Forming of AHSS Sheet Metals***, **Ali Khatibi**, M Arndt,* Oerlikon Balzers, Oerlikon Surface Solutions AG, Liechtenstein

Engineering parts made out of high-strength-steel (HSS) sheets are widely used in the structural reinforcement of the car bodies especially where a high impact and crash resistance is required (e.g., passenger compartment, parts of side doors and bumpers). The increasing need for HSS parts in a typical car body (~40 % in 2007 to 75 % in 2015) on the one hand and development of advanced steel grades with very high strengths (>1000 MPa in UHSS) on the other hand demand the utilization of coatings which in combination with state-of-the-art surface treatments (eg nitriding) provide considerable resistance against a variety of failure mechanisms like adhesive and abrasive wear, galling, chipping, and spallation under severe forming loads.

Nitride based coatings like TiN, TiAlN, TiCrN, and AlCrN, which are also used in cutting tool applications have significantly increased the performance of these forming tool applications when compared to non-coated ones. But as the specific requirements in terms of resistance to abrasive and adhesive wear, fatigue, and in some cases corrosion are completely different for metal forming , there is an increasing demand for dedicated and in many cases complex coatings for an additional gain in efficiency.

The present work addresses the development of the wear and fatigue resistant coatings made by physical vapor deposition (PVD) technique to be used for high-scale industrial forming operations of advanced high strength steel (AHSS) and high strength low alloy (HSLA) sheets. Examples of successful implementation of the coatings in some highly challenging industrial forming applications are presented.

3:50pm **G3-8 Performance Evaluation of HSS Cutting Tool Coated with Hafnium and Vanadium Nitride Multilayers, by Temperature Measurement and Surface Inspection, on Machining AISI 1020 Steel***, **John H. Navarro-Devia**, W Aperador,* Universidad Militar Nueva Granada, Colombia*; C Amaya,* CDT- ASTIN SENA, Colombia*; J Caicedo,* Universidad del Valle, Colombia

The application of hard coatings onto cutting tools improves lifetime, performance and also quality of workpiece, usually by increasing the wear resistant. Hafnium nitride and Vanadium nitride multilayer coating [HfN/VN]n has mechanical, tribological and physic-chemical properties that have been identified by other authors and are desirable for cutting tools. For the above physical vapor deposition (PVD) of hafnium nitride/vanadium nitride [HfN/VN]n multilayer coating, with 1, 50 and 80 bilayers, were carried out onto High-speed steel (HSS) cutting tools by the Multi-target Magnetron Sputtering technique , using toolbit ASSAB 17 3/8 X 3" as a substrate. Toolbits uncoated and coated with HfN/VN multilayers were used to machine AISI 1020 steel samples at the same turning parameters in a CNC machine.

Cutting efficiency, quality product, and tool wear are influenced by temperature, therefore as evaluation method the temperature of the tool, the steel and the chip were measured by means an infrared sensor, a data acquisition system and data analysis in MatLab to identify mean temperature and temperature rate for each tool. Also superficial roughness (*Ra*) of work pieces were evaluated using a roughness tester and Scanning Electron Microscopy (SEM). Tool rake wear were checked through Optical Microscopy and SEM.

In most of the parameters evaluated differences between the tools were identified, as the temperature at the chip increased, temperature at the tool and temperature rates decreased, the work piece roughness reduced up to 25%, and the wear reduces up to 50%, those were proportional to the bilayers number. Results reveals that on [HfN/VN]n coated tools, occurs less deterioration, due the proportionality between the energy transfer and wear resistance, also improves surface finish of the machined piece; all of them are reflected in changes in process temperatures.

**Highlights**: This novel method relates three fundamental aspects such as temperature of the components, work piece roughness and tool wear, in order to evaluate the performance of coated cutting tools at in situ tests.

The use of multilayer [HfN/VN]n coating on HSS cutting tools, improves superficial properties by reducing friction coefficient and heat transfer, could increase their lifetime, improve the quality of the workpiece, leading to reduce process time and cost, enhance uniformity of material removal and tool lifetime, getting a manufactured product with a better surface quality.

**Acknowledgment**: This work was supported by funds for internal calls for projects at Universidad Militar Nueva Granada, contract number ING-2100.

4:10pm **G3-9 High Temperature Oxidation and Cutting Performance of AlCrN, TiVN and Multulayered AlCrN/TiVN Hard Coatings***, **Shi-Yao Weng**, Y Chang,* National Formosa University, Taiwan

Transition metal nitrides, such as TiVN and AlCrN, have been used as protective hard coatings due to their excellent tribological properties. In this study, nanostructured AlCrN/TiVN multilayered coatings were deposited periodically by cathodic-arc evaporation (CAE). The AlCrN/TiVN multilayered coatings were post-treated by rapid thermal annealing (RTA). During the coating process of AlCrN/TiVN, TiN was deposited as an interlayer to enhance adhesion strength between the coatings and substrates. The cathode current of both TiV and AlCr alloy cathodes was controlled to produce hard nitride coatings. The microstructure of the thin films was characterized by using a field emission scanning electron microscope (FE-SEM) and transmission electron microscope (TEM), equipped with an energy-dispersive x-ray analysis spectrometer (EDS). Glancing angle X-ray diffraction (XRD) was used to characterize the microstructure and phase identification of the films. The chemical composition and bonding structures were also evaluated. The periodic thickness and alloy content of the deposited coating were correlated with the evaporation rate of cathode materials. A ball-on-disc wear test at room temperature was conducted to evaluate the tribological properties and lubricities of the deposited coatings. To evaluate the cutting performance, end milling tests of 7000 series Al alloys of the deposited tools were conducted at high rotational speed. The TiVN coated tool showed improved tool life as compared to CrAlN and AlCrN because the lubrication effect of TiVN. The design of multilayered AlCrN/TiVN hard coatings is anticipated to inhibit grain growth and improve toughness which expected to increase the mechanical, tribological and oxidation resistance performances of the coatings.

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