Surface Engineering - Applied Research and Industrial Applications

Room Palm 1-2 - Session IA3-TuA

Innovative Surface Engineering for Advanced Cutting and Forming Tool Applications

Moderators: Alessandro Bertè, Lafer SpA, Italy, **Markus Esselbach**, Oerlikon Balzer, Liechtenstein

1:40pm **IA3-TuA-1 Natural Rock Star: PVD-Functionalizing of Nature-Derived Materials for Cutting Applications**, *Wolfgang Tillmann, **Dominic Graf [dominic.graf@tu-dortmund.de]**, Nelson Filipe Lopes Dias,* TU Dortmund University, Germany*; Bernd Breidenstein, Berend Denkena, Benjamin Bergmann, Hilke Petersen,* Leibniz Universität Hannover, Germany

The manufacturing process of traditional cutting materials such as cemented carbide involves significant energy consumption and costly raw materials that are often linked to environmental harm during extraction. To address these concerns, there is a growing demand for developing sustainable cutting materials. In this context, natural materials are both environmentally friendly and abundant. Natural rocks, in particular, are promising due to their hardness, which typically ranges from 8 to 16 GPa depending on the rock type. The suitability of these natural materials for machining can be enhanced via functionalization of the surface properties by applying a protective thin film using physical vapor deposition (PVD) technology.

Preliminary studies show the suitability of various rock types as cutting material. Cutting inserts are crafted from these natural rocks and subsequently ground. A TiN thin film is deposited onto the various natural rock inserts using a magnetron sputtering process. The resulting TiN thin films crystallize in a cubic structure on all rock types. The obtained hardness values are comparable to TiN thin films grown on tool steel. In contrast to a polished surface, a ground surface of the natural rocks promotes good adhesion of the TiN thin films. To assess the cutting performance and wear characteristics of PVD-coated natural rocks, turning tests are conducted using the aluminum alloy Al7075. The TiN thin film significantly enhances wear resistance, thus extending the service life of the cutting inserts. Additionally, it is observed that the distinct material properties of the natural rocks significantly affect the wear behavior. Rock types with a more homogeneous structure demonstrate improved wear resistance over extended cutting lengths.

To analyze the effect of the substrate on the TiN thin film adhesion three different glass substrates were chosen as surrogates for natural rocks. Glasses are particularly suitable as surrogates because of their similar SiO_2 content. The investigations reveal a strong influence of the stress state on the adhesion, as TiN on window glass shows weaker adhesion due to high compressive residual stresses. The possible adaptation of thin film design strategies developed for glass onto natural rock surfaces is evaluated. The utilization of a PVD-coated natural rock emerges as a promising concept for broadening the spectrum of cutting materials and promoting sustainability in their manufacturing. A tailored adjustment of the grinding process for cutting inserts with an adapted thin film design is anticipated to further elevate the cutting performance of natural rock inserts.

2:00pm **IA3-TuA-2 Effect of Si Alloying on CrN Coatings Deposited by S3p Technology for Plastic Processing Applications**, ***Alessandro Togni [alessandro.togni@oerlikon.com]**, Denis Kurapov, Thomas Vermland,* Oerlikon Surface Solutions AG, Liechtenstein

In the plastic processing industry, molds and tooling components are frequently exposed to chemically aggressive environments, particularly when handling plastics containing halogenated and phosphorus-based flame retardants. While CrN coatings generally offer good corrosion resistance, their wear resistance may fall short when processing plastic formulations containing highly abrasive additives such as glass fibers or hard polymers like polycarbonate. In addition, achieving an ultra-smooth surface finish is essential for producing mirror-polished plastic components, requiring deposition techniques that enhance surface quality while ensuring precise control over coating thickness to meet stringent dimensional tolerances.

To address these challenges, we developed Si-alloyed CrN coatings using Oerlikon Balzers' Scalable Pulsed Power Plasma (S3p) technology. Si-doped Cr targets with varying Si concentrations were employed to systematically investigate the effect of Si content on the microstructure and mechanical properties of the coatings.

Our findings revealed that all coatings exhibited a cubic CrN phase and a columnar growth morphology. Increasing the Si content progressively refined the grain structure and induced higher compressive residual stress levels, thus improving mechanical performance. Notably, the hardness of the coatings increased by up to 50% at approximately 5 at.% Si while maintaining a consistent elastic modulus, resulting in a higher H/E ratio—a key indicator of wear resistance. These results highlight the potential of Si-alloyed CrN coatings as a promising solution for extending the lifespan of molds and tooling components in demanding plastic processing environments.

2:20pm **IA3-TuA-3 Tailoring PVD Coatings by Electro-Magnetic Fields Generated by Coil Systems for Cathodic Arc Evaporation**, ***Dominic Stangier [dominic.stangier@oerlikon.com]**,* Oerlikon Balzers Coating Germany GmbH, Germany

Cathodic arc evaporated (CAE) coatings are dominating the field of wear resistant PVD thin films for tools due to their excellent adhesion, high deposition rates and outstanding performance as well as service life in industrial scale applications. An established approach to control the movement of the arc spot on the cathode surface during the deposition process is the use of static magnetic fields, which are generated by a defined arrangement of permanent magnets placed close to the cathode material. However, this solution is strongly limited in its setting options and does not consider any dynamic effects such as an increasing magnetic field strength caused by changes of the erosion profile of the cathode material or adjusted evaporator currents. To overcome these challenges and limitations of CAE processes electro-magnetic fields generated by coil systems (CS) are a promising approach to precisely control and adjust the magnetic field design and strength and therefore enable the possibility of tailored and improved properties of PVD coatings. Due to this reason, a coil system consisting of an inner and outer independently controllable coil, which additionally allows switching of the polarity was used for an industrial scale arc source (APA evaporator) as well as in combination with permanent magnets. It was found, that besides the higher material utilization compared to permanent magnetic setups for cathodic arc materials, the adjustment of the magnetic field by APA CS enables the possibility of maintaining the desired fcc-structure for high Al-contents in Al-rich AlTiN coatings. Additionally, this dedicated setup can be used for challenging CAE processes for “hard to evaporate materials” in combination with a dynamically controlled magnetic field for steering the arc spot. A homogenous erosion profile of the cathode material was achieved for the deposition of carbon coatings with adjustable hardness profile.

2:40pm **IA3-TuA-4 Advanced Cyclic Load Resistance of AlXN Coatings for Metal Forming Applications**, ***Simon Evertz [simon.evertz@eifeler-vacotec.com]**, Stefan A. Glatz, Tobias Oellers, Markus Schenkel,* voestalpine eifeler Vacotec GmbH, Germany

Cyclic loading is critical for the industrial application of PVD coatings, especially in metal forming applications. With the increasing interest in using thin super-high-strength steel sheets for forming bodies/parts with reduced component weight, light-weight design and less fuel consumption could be achieved for example in automotive industry. Consequently, the loads become more demanding on molding dies and therewith protective coatings. These applications require coatings resistant to cyclic mechanical and/or thermal loading and fatigue. The specific structure of voestalpine eifeler’s Duplex-VARIANTIC® -1400-plus with its multiple hard material AlXN layers overcomes the very demanding requirements in terms of strength, hot-hardness, and load-bearing capacity in such metal forming applications and outperforms other commercially used hard nitride protective coatings. This property profile makes voestalpine eifeler’s Duplex-VARIANTIC®-1400-plus the optimal solution for metal forming high-strength and advanced high-strength steel sheets.

3:00pm **IA3-TuA-5 Bistability and Process Control in Electrolytic Plasma Processes**, ***Nicolas Laugel [nicolas.laugel@manchester.ac.uk]**, Aleksey Yerokhin, Allan Matthews,* The University of Manchester, UK

Electrolytic Plasma Processes (EPP) encompass a variety of surface modification techniques, leveraging high power densities in aqueous electrolytes to induce plasma-assisted reactions at material interfaces. These processes have diverse applications, including Electrolytic Plasma Polishing (EPPo), thermal diffusion-based hardening, Cathodic Plasma Discharge Electrolysis (CPDE) for surface cleaning or superficial inclusion of trace metallic dopants, and Plasma Electrolytic Oxidation for ceramic coatings on valve metals. Their relevance spans major manufacturing fields, particularly in the automotive, aerospace, tooling and medical sectors. Since EPP are independent of workpiece geometry and rely on harmless electrolytes, they are uniquely well-suited for finishing additively manufactured components. Yet despite their versatility, EPP development remains constrained by the complex interplay of electrochemical and physical effects. In particular, the emergence of a bistable regime - caused by the coupling between rapid electrochemical reactions and slower evolution of gas phases in the electrolyte - often renders a large portion of the electrical parameter space practically inaccessible.

We introduce a basic first-principle model able to capture the essential dynamics of bistability without distracting complexity. This model serves as a guide to predict the qualitative effects of varying key process parameters. We identify qualitative convergences as well as discrepancies between model-based predictions and experimental observations in industrially-relevant conditions, using ammonium sulfate-based electrolytes and stainless steel workpieces. The parameters explored include the polarity of EPP, electrolyte composition, temperature, and electric field distribution, manipulated via radius of curvature of the treated surface. Particular attention is given to the parameters impacting the boundary between stable and bistable regimes under these conditions.

Since industrial applications of EPP typically favor conservative approaches that prioritize process stability, improving the predictability of bistability regime boundaries is an immediately relevant opportunity for fine-tuning. This could lead to optimizations in energy efficiency, processing time, and uniformity. Furthermore, recognizing the role of transient states and harnessing them may inspire innovative surface engineering strategies, expanding the potential of EPP beyond current implementations.

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