Surface Engineering - Applied Research and Industrial Applications
Room Palm 1-2 - Session IA3-ThM

Innovative Surface Engineering for Advanced Cutting and Forming Tool Applications

Moderators: Markus Esselbach, Oerlikon Balzer, Liechtenstein, **Fan-Yi Ouyang**, National Tsing Hua University, Taiwan

8:20am **IA3-ThM-2 Tool–Embedded Piezoresistive Thin–Film Sensors for Guide–Pad Normal Force Measurement in Deep Hole Drilling**, ***Martin Rekowski [martin.rekowski@ist.fraunhofer.de]***, Fraunhofer IST, Germany; *Lucas Brause, Sebastian Michel,* TU Dortmund University ISF, Germany; *Anna Schott, Christoph Herrmann,* Fraunhofer IST, Germany; *Dirk Biermann,* TU Dortmund University ISF, Germany

Deep hole drilling is essential for producing long, high-quality bores in safety–critical components such as hydraulic cylinders, turbine shafts, and fuel injectors. Its asymmetrical tool design and guide pad support enable excellent straightness and surface finish, but the contact zone experiences severe thermo–mechanical loads and steep temperature gradients followed by rapid oil quenching. These conditions can induce residual stresses and micro-structural alterations (e.g., white etching layers), directly affecting surface integrity and fatigue performance. Because the contact zone is inaccessible, workpiece-side measurements are limited and often require post-process analysis. Miniaturized thin-film sensors integrated directly into the tool's guide pad offer a robust and space-saving way to measure temperature, normal force, and wear in the force flow in real time. This paper details the design, fabrication, and characterization of a tool–embedded piezoresistive thin–film sensor system for measuring guide pad normal force with integrated temperature compensation. A 6 µm hydrogenated carbon DiaForce® (DLC) layer is deposited on a polished and hardened high-speed steel substrate (Rz = 0.1 µm) using plasma enhanced chemical vapor deposition (PECVD) process. Electrodes and conductive tracks are applied in a 0.2 µm thick chromium layer, which is deposited using physical vapor deposition (PVD) and patterned with photolithography and wet chemical etching. The stack is insulated and protected with SICON® layers. Three sensor structures (F1–F3) are positioned in the force flow to resolve normal loads, while additional unloaded DiaForce® electrodes act as temperature references to decouple thermoresistive drift from the force signals. Two overlapping thin steel washers (t = 150 µm) ensure uniform electrode loading. The overlap and thus the area of the loaded surface was determined in preliminary tests and can be adapted to the respective measurement conditions. Shielded leads were soldered to the base body and provide connectivity to a telemetry system. Calibration is done by recording resistance changes versus temperature and pressure. The DiaForce® reference electrodes show a decreasing exponential temperature dependency modeled by the Steinhart–Hart equation, enabling real–time compensation of the force signal, while pressure sensitivity is linear to quadratic over the investigated range. Servo–press experiments confirm stable signal deflection under combined mechanical loading and dynamic thermal transients. The thin-film sensor system is applied to both single–lip drilling (SLD) and BTA deep hole drilling

8:40am **IA3-ThM-3 Development of in-Situ Cleaning Processes and Customized Coatings on Numismatic Coinage Dies for Minting Industry**, *João Coroa, Alexander Gorupp, Parnia Navabpour, Giuseppe Sanzone,* ***Hailin Sun [hailin.sun@teercoatings.co.uk]***, Teer Coatings, UK **INVITED**

The minting industry is responsible for the design, production, and distribution of coins and medals both for national currencies and for commemorative purposes. The design and fabrication of coin dies combine expert craftsmanship with state-of-the-art technology which preserves value and celebrates heritage by producing coins of beauty and enduring worth.

The coin dies typically comprise of both highly-polished and frosted areas to create distinct visual contrasts and intricate images. The surface of dies needs to be coated with hard, wear resistant coatings for the die to withstand the force and repeated impact exerted on it during coin production. Physical vapour deposition (PVD) is an environmentally-friendly method used for the deposition of coatings on dies. Some of the processes, such as laser engraving, used in the minting industry during the production of dies have created new challenges for the PVD coatings.

Currently, Teer coatings PVD systems used in the minting Industry are capable of producing coatings for numismatic, proof or circulation coin dies using the PVD magnetron sputtering technique. To overcome the new challenges, an in-situ linear ion source device has been integrated in the coating equipment. It generates a wide, collimated plasma beam for treating large substrates. It is used to pre-clean surfaces by removing the surface oxides and hydrocarbons in order to improve the adhesion of the deposited thin films. At the same time, the process is tailored to ensure that the original features such as roughness, etc. are retained.

This study presents some of the developments which achieve the industrial demands, both through optimised coating design, and through equipment developments that enable the combination of different treatment and deposition technologies to improve the coating performance.

9:20am **IA3-ThM-5 Machining of Hardened Steels under Dry Conditions: Wear Mechanisms of AlTiSiN and AlTiXN-TiSiZN (X, Z= nonmetal elements) Coatings**, ***Rong Zhao [rong.zhao@eifeler-vacotec.com]***, *Simon Evertz, Alexander Fehr, Markus Schenkel,* voestalpine eifeler Vacotec GmbH, Germany

To obtain more environmentally friendly and cost efficient production processes, lubricants in milling applications are either removed completely or reduced to a minimum. Thereby, protective coatings for tools gain even more importance. Dry machining of hardened steels presents significant challenges due to elevated temperatures and the simultaneous occurrence of abrasive and adhesive wear. AlTiSiN based coating systems have been the state of the art for milling applications under these demanding conditions. In this study, milling tests were conducted to evaluate the performance of milling tools with different coatings. The coated tools exhibited varying degrees of wear and service life. Hence, understanding the underlying wear mechanisms is decisive for the development and selection of next-generation coatings, as wear is closely linked to tool longevity. Two types of coating systems were investigated: one AlTiSiN coating and one AlTiXN-TiSiZN coating. Wear was analyzed using confocal microscopy, scanning electron microscopy (SEM), and energy dispersive X-ray spectroscopy. Distinct wear patterns and mechanisms were identified for each of the coatings. The results demonstrate that the AlTiXN-TiSiZN coating exhibits superior wear resistance, which makes it particularly suitable for milling of hardened steels with a hardness higher than 55 HRC.

9:40am **IA3-ThM-6 Improving Injection Molding Process Performance of Recycled Plastics**, ***Yavor Sofronov [ysofronov@tu-sofia.bg]***, *Georgi Todorov, Milko Angelov, Boyan Dochev, Antonio Nikolov, Valentin Mishev, Krum Petrov, Rayna Dimitrova, Milko Yordanov,* Technical University of Sofia, Bulgaria; *Krassimir Marchev,* Technical University of Sofia, USA

The forthcoming European Union Packaging and Packaging Waste Regulation mandates that nearly all plastic packaging incorporate at least 30% post-consumer recycled (PCR) content, creating significant technological challenges for injection molding manufacturers. In particular, the use of recycled polyethylene terephthalate (rPET) is associated with pronounced adhesion to polished mold core surfaces and progressive polymer smearing, leading to frequent production interruptions for mold cleaning and reduced process stability. This study characterizes a functional Ti/TiN/(CrN/TiN)ml low-wettability coating deposited by unbalanced magnetron sputtering on injection mold cores from 1.2343 steel as a mitigation strategy. The coated surfaces exhibit reduced interfacial adhesion between rPET melt and metallic tooling, effectively suppressing polymer smearing and facilitating reliable part release. Peel strength according to ASTM D903 exhibits decreasement from 22.5N for uncoated core to 7.5N for coated which is 3 times reduction. As a result, the injection molding process demonstrates improved operational stability and a measurable increase in productivity. Industrial validation shows that the implementation of the proposed coating solution enables an increase in hourly production rate of approximately 20%, without altering processing parameters or material formulation. The results confirm that surface engineering of mold tooling represents a robust and industrially scalable approach to overcoming rPET-related processing limitations under emerging regulatory requirements.

11:00am **IA3-ThM-10 Over 30 Years of PVD Aluminium-Oxide Based Hard Coatings in Demanding Industrial Applications**, ***Philipp Immich [pimmich@hauzer.nl]***, *Louis Tegelaers, Julia Janowitz, Daniel Barnholt,* IHI Hauzer Techno Coating B.V., Netherlands; *Rolf Schäfer, Tobias Radny,* Robeko GmbH & Co. KG, Germany; *Thomas Schütte,* PLASUS GmbH, Germany

Over the past six decades, the requirements for hard coatings in protective applications have increased significantly. The progression from simple TiC monolayer coatings deposited via Chemical Vapor Deposition (CVD) in the 1960s to today's sophisticated multilayer systems has been driven by several key factors: enhanced reliability of industrial coating equipment, continuous optimization of substrate materials and new pre- and post-treatment processes.

Among the most notable advancements are aluminium oxide (Al_2O_3) coatings, which have become a benchmark in modern cutting applications. Their unique phase structures offer performance benefits that are difficult to replicate with other coating systems. Alumina's high hardness, electrical insulation, chemical inertness, and thermal stability make it exceptionally well-suited for demanding environments.

Beyond cutting tools, aluminium oxide is widely used across various industrial sectors. Its mechanical strength and thermal resilience support its role in protective coatings, while its excellent insulating properties are essential for sensor technologies. Additionally, its optical transparency and chemical resistance make it ideal for advanced protective layers.

In cutting tool applications, CVD remains the established method for depositing aluminium oxide. However, over the past 30 years, Physical Vapor Deposition (PVD) has gained increasing relevance, because of the lower deposition temperatures compared to CVD —initially driven by high-temperature cutting applications and more recently expanding into low-temperature applications such as insulating coatings for sensors.

Despite its versatility, scaling the PVD deposition of alumina thin films for industrial use presents several challenges. RF sputtering from compound targets can produce stoichiometric, high-quality coatings, but its low deposition rate limits its practicality for mass production. PVD techniques—particularly dual magnetron sputtering (DMS) from metallic targets—offer significantly higher deposition rates and effectively address issues such as the disappearing anode.

In this presentation, we will highlight ongoing developments in PVD oxide coatings—including innovations in coating equipment and advanced deposition technologies—that are opening new possibilities for enhanced cutting performance and broader industrial applications. We will compare various regulation strategies, examine the properties of alumina films deposited at different temperatures, and discuss future technological improvements that could further optimize deposition processes.

11:20am **IA3-ThM-11 Sputtered CrN-based coating concepts for plastic injection molding***, **Alexander Fehr [alexander.fehr@eifeler-vacotec.com]**,* Voestalpine eifeler Vacotec, Germany

Typical demands in plastic processing are minimized material adhesions, better deformability as well as a certain gloss level of the produced plastic parts. Therefore, surfaces in plastic processing often require mirror-like polishing to produce very smooth plastic parts. Furthermore, there is a challenge with very complex structured plastic molds when it comes to the reproduction of textures on the plastic part. These applications do not only require a wear resistant but also a near net shape surface solution to guarantee a conservation of the gloss level as well as a persistent surface quality of the produced plastic parts. Since plastic injection mold steels typically have a low annealing temperature, a sputtered, low-temperature coating represents a well-suited approach. In this context, the CHROME-X coating solution from voestalpine eifeler Vacotec will be presented with regard on the application on textured surfaces. It will be shown why a sputtered Cr based coating delivers more advantages for PIM applications when compared to an arc Cr based film. Furthermore, the influence of the sputtered coating on the gloss level of the plastic part will be addressed.

11:40am **IA3-ThM-12 Study on Multilayer Thick ta-C Coating Process on Cutting Tools for CFRP Machining Using Filtered Cathodic Vacuum Arc Deposition***, **Jongkuk Kim [kjongk@kims.re.kr]**, Jae-Il Kim, Young-Jun Jang,* Korea Institute of Materials Science, Republic of Korea

Carbon fiber reinforced plastic (CFRP) is a composite material consisting of a polymer matrix and carbon fibers, which requires excellent mold release, low friction, and high wear resistance during cutting. To meet these demands, cutting tools are often coated with high-hardness carbon-based films. Among these, tetrahedral amorphous carbon (ta-C) coatings exhibit outstanding hardness and low friction while minimizing chipping and substrate damage due to their nanolayer structure. However, the high intrinsic stress of ta-C limits its achievable thickness, hindering its application as a thick, durable coating.

In this study, a filtered cathodic vacuum arc (FCVA) system was employed to deposit thick ta-C coatings (>2.5 μm) on cutting tools. The effects of substrate bias voltage and process temperature on internal stress were investigated through multilayer film design. The deposition system consisted of an anode-layer ion source, a magnetron sputtering source, and a 90°-bent magnetic FCVA source. Stainless steel strips (100 μm) were used for stress analysis, and WC–Co inserts (15 × 15 mm) were used as substrates.

Prior to deposition, the substrate surface was cleaned using Ar ion etching at 2.5 kV and 400 mA, followed by deposition of a 500 nm Ti buffer layer via magnetron sputtering (6 A). The ta-C films were deposited using the FCVA source with alternating high-hardness (–70 V) and low-hardness (–200 to –500 V) layers, each 250 nm thick, yielding a total thickness of 2.5 μm. Additionally, the low-hardness layer (–500 V) was fixed at 100 nm, while the ratio between high- and low-hardness layers (1:2, 1:3, 1:4) was varied to optimize stress control.

The optimized multilayer structure (–500 V/–70 V, 1:3 ratio) produced a 63 GPa hardness and 4.5 GPa residual stress, enabling stable and uniform deposition even on the cutting edge of the inserts. These results demonstrate that proper stress control through multilayer engineering allows the formation of thick, high-hardness ta-C coatings suitable for CFRP machining applications, offering a promising route to improve tool performance and durability.

Keywords:

ta-C (tetrahedral amorphous carbon); Filtered Cathodic Vacuum Arc (FCVA); Cutting Tool; Hardness; DLC (Diamond-Like Carbon); Wear Resistance

12:00pm **IA3-ThM-13 Enhanced Fe and Ni bonded NbC Laser Surface Engineered Hardmetals: Alternative Cutter Materials for Electric Vehicle Applications***, Rodney Genga,* University of the Witwatersrand, South Africa*; Suzan Conze, Lutz-Michael Berger, Johanes Pötschke,* IKTS Fraunhofer Institute, Germany*; **Julien Witte [julien.witte@bam.de]**, Dirk Schroepfer,* BAM Berlin, Germany*; Adam Čermák, Pavel Zeman,* Czech Technical University in Prague, Czech Republic*; Sinoyolo Ngongo, Arno Janse van Vuuren,* Nelson Mandela University, South Africa

The substitution of tungsten carbide (WC) and cobalt (Co) in hardmetals has gained increased attention in recent years due to the reclassification of Co as a carcinogenic substance and the designation of both Co and W as critical raw materials by the European Union and under the U.S. National Toxicology Program. Thus, this study investigates the development and performance of advanced NbC-based hardmetals utilizing nickel (Ni) and iron (Fe)-based binders as sustainable alternatives for metal machining applications within the electric vehicle (EV) manufacturing sector.

The materials were developed using a Machining Property Led Tailored Design (MPLTD) approach, a reverse engineering strategy that leverages machining performance data to guide the optimization of microstructural, mechanical, and tribological properties. Four novel NbC-based hardmetals were synthesized, two with Ni-based binders and two with Fe-based binders. These were benchmarked against two reference materials: a standard WC-Co composition and a conventional NbC-12Ni grade. Comprehensive material characterization was conducted using field emission scanning electron microscopy (FE-SEM), annular dark-field scanning transmission electron microscopy (ADF-STEM), Vickers hardness testing, fracture toughness measurements, and elastic modulus evaluations.

Cutting tool inserts were manufactured from these hardmetals were further enhanced via femto-second laser surface engineering (Fs-LSE), which was employed to form laser induced chip breakers and modify cutting edge morphology. The microstructural effects of Fs-LSE were examined through ADF-STEM and selected area electron diffraction (SAED) analyses. The performance of both untreated (blank) and Fs-LSE-modified inserts was evaluated through interrupted face milling tests on AZ31 automotive grade magnesium alloy. As AZ31 is considerably lighter than both steel and aluminum, its use in EV components significantly improves power-to-weight ratios and operational efficiency. The laser enhanced Fe- and Ni-bonded NbC inserts demonstrated machining performance comparable to industrial WC-Co benchmark grades. Furthermore, the Fs-LSE process resulted in over 100% reductions in flank wear and up to 80% decreases in resultant cutting forces. The inserts' performance in this study provided valuable insights into the suitability of alternatives to WC and Fs-LSM for automotive industrial applications

Author Index

Bold page numbers indicate presenter