SwissTribology

Online Symposium 2022

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28th of June 9 a.m. - 4.15 p.m. (CEST)

Dr. Nicholas Randall 09:15-09:45	Alemnis AG, *Recent innovation in Scanning Electron Microscope (SEM) in-situ extreme mechanics in extreme environments*
Charchit Kumar, PhD 09:45-10:15	University of Glasgow, *Contact Mechanics of Triboelectric Nanogenerator (TENG) for sustainable energy generation*
Noora Manninen, PhD 10:15-10:45	Oerlikon Balzers, *Tribological behavior of DLC coatings in oil lubricated conditions*
Dr. Balasubramaniam Vengudusamy 11:00-11:30	Klüber Lubrication München SE & Co. KG, *Grease behaviour in rolling-sliding contacts*
Vincent Hoffmann, M.Sc. 11:30-12:00	Tribo Technologies, *Tribo-X , Optimization of Gear Tooth Efficiency using Simulation*
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oerlikon balzers

Dr. Mousab Hadad — **Industrial Cooperation- Quality Management**

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Recent innovation in Scanning Electron Microscope (SEM) in-situ extreme mechanics in extreme environments

Nicholas Randall, Alemnis AG, Schorenstrasse 39, 3645 Thun, Switzerland

Nanomechanical tests are moving beyond the basic measurement of hardness and elastic modulus to encompass a host of different mechanical properties such as strain rate sensitivity, stress relaxation, creep, and fracture toughness by taking advantage of focused ion beam milled geometries. New developments, such as high cycle fatigue, are extending the range of properties which can be studied at the micro and nanoscale. However, such techniques are challenging due to low oscillation frequencies, long duration of tests and large thermal drift when attempted with standard indentation instruments. Novel piezo-based nanoindentation methods are now allowing access to extremely high strain rates (>104 s-1) and high oscillation frequencies (up to 10 kHz).

Until only recently, high strain rate testing of materials at strain rates from ~100/s – 10000/s has only been possible using macroscale techniques, such as split Hopkinson bar, Kolsky bars and plate impact testers. At the microscale, strain rates have typically been limited to ~ 0.1/s or less, owing to limitations in instrumentation, insufficient data acquisition rates and elastic wave propagation conflicts during testing.

This talk will focus on the most recent developments in instrumentation for in-situ extreme mechanics testing at the micro and nanoscales, with specific focus on a testing platform capable of strain rate testing over the range 0.0001/s up to 10’000/s (8 orders of magnitude) with simultaneous high speed actuation and sensing capabilities, with nanometer and micronewton resolution respectively.

The additional challenge of performing extreme mechanics in a wide range of extreme environments will include nuclear, cryogenic and high temperature tests covering the temperature envelope from -150 to 1000 °C. The challenges in variable temperature tests and the associated technological and protocol advances will be discussed along with select case studies. The inherent advantages of using small volumes of sample material, e.g., small ion beam milled pillars, will be discussed together with the associated instrumentation, technique development, data analysis methodology and experimental protocols. Some examples of test data will be presented where a wide range of strain rate has been combined with variable temperature in order to investigate rate effects as a function of temperature. Finally, future research directions in this sub-field of micromechanics will be discussed.

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Contact Mechanics of Triboelectric Nanogenerator (TENG) for Sustainable Energy Generation

Charchit Kumar, Jack Perris, Satyaranjan Bairagi, and Daniel M. Mulvihill
James Watt School of Engineering, University of Glasgow, Glasgow G12 8QQ, UK

Triboelectric nanogenerators (TENGs) are a newly developing technology to harness electrical power from mechanical energy, based on triboelectrification and electrostatic induction effects. In recent years, TENGs have gained a significant amount of interest from the tribology and electrical engineering communities, owing to their enormous potential to sustainably generate electricity in applications ranging from automobile tire or human movement (wearable textiles) to harnessing wave power.

Even though a significant amount of research has been done in the field of TENGs, the fundamental contact mechanics of TENGs is not very clear yet. Among others, material physicochemical properties, surface roughness, real contact area and frictional characteristics of contacting tribo-layers can strongly influence the energy output of TENGs. This research work focuses on a systematic and in-situ contact mechanics investigation of newly developed micro-textured TENGs to understand the role of contact interface at different scales.

Investigation results present an optimized framework to achieve a maximised power output and could offer important assistance to design better TENGs in future.

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Tribological behavior of DLC coatings in oil lubricated conditions

Noora Manninen, Oerlikon Balzers, Liechtenstein

Diamond-like carbon (DLC) coatings have emerged as a promising coating solution able to combine high wear resistance and low friction coefficient. In fact DLC coatings comprise a family of different carbon based coatings which can show a broad range of properties based on the fraction of sp3/sp2 bonds and also on the amount of incorporated hydrogen or metal dopants.

In the present study different DLC coating variants were tested regarding their tribological performance, namely: a-C:H; a-C:H:W (WCC), a-C and ta-C. The coatings were tested in three pin-on-disc configuration under additive oil (ZDDP) lubricated conditions. Different pressure x velocity (P.V) conditions were tested during endurance tests in order to identify the coatings performance over a broad range of P.V conditions. The lubrication regimes were identified by Stribeck curves in order to determine the lubrication regimes for the different test parameters. The coatings were analyzed by scanning electron microscopy (SEM), profilometry and optical microscopy after the tribological tests, in order to evaluate the wear mechanisms.

The coatings were characterized regarding their topography and morphology (by means of SEM analysis), roughness (by profilometry analysis) and hardness (by nanoindentation).

The coatings chemical properties, roughness and hardness are strongly correlated with the tribological performance..

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Grease behaviour in rolling-sliding contacts

Balasubramaniam Vengudusamy, Klüber Lubrication München SE & Co. KG

A wide variety of greases varying in terms of base oil and thickener type, NLGI grade, oil separation properties, etc. are available in the market. Greases are widely used in rolling element bearings and their selection depend largely on many factors including application (e.g. wind turbine bearings, automotive hub units), operating condition (speed, load, temperature, bearing, horizontal or vertical mount, etc.) environment (humid, dust), etc.

Although greases have been in use for many years, they are much less investigated as compared to oils so much fewer general rules exist for greases. This partly is due to the involved complexity with greases. As greases hold a thickener/base oil two-phase structure, they generally exhibit properties of both. However, due to complex grease composition and limited rules, grease selection for a particular application has been mainly made based on base oil properties. This considerably ignores any potential benefits of thickener.

This talk will highlight some possible effects of thickener on film formation, friction and wear.

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Tribo Technologies, Tribo-X , Optimization of Gear Tooth Efficiency using Simulation

M.Sc. Vincent Hoffmann, Tribo Technologies

The further reduction of lubricant viscosity is a suitable measure to increase the efficiency through reduced splash and pump losses. However, the application of low viscosity lubricants can lead to increased operation of the gears in the mixed friction regime. One solution to counter the increase in wear generation can be the application of wear minimizing coatings on the gear teeth. Therefore, a good adjustment of coating and lubricant is of importance.

The potential of coatings for tooth flanks can be evaluated on the one hand by carrying out component tests and on the other hand by analyzing the gears with the help of simulation. Simulations offer the benefit of a good assessment of potential in an early development phase without having to manufacture costly prototypes.

Based on simulation results the influence of coating pinion and/or gear on the lubrication, temperature development, friction and efficiency is shown. Therefore, offering indications on how the coating could be optimized for one application.

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Performance of Bismuth Bronze Bimetal Bearing in Term of Load Capacity for Mixed and Boundary Regime

Natanael Dewobroto, Kugler Bimetal SA

Since June 2018, REACH regulation has classified lead as a SVHC (substance of very high concern) and has included it in the candidate list for authorization. This progress in banishing lead (Pb) use in industrial components gives pressure to machine and material producers to look for a new solution with comparable properties and performance than leaded parts. This paper presents the published results of experimental studies on the substitution of leaded bronze done by the Tampere University, in the context of the SLIBE project [1, 2]. The overall goal was to improve the sliding bearing performance in heavy operating conditions by using different leadfree alternatives bearing materials such as bimetal steel- bismuth bronze (Tokat 300) or advanced polymer liners in comparison with CuSn10Pb10 material as reference.

The characterization of tribological performance has been done through a special thrust bearing test device [1] and a journal-bearing test [2]. The special thrust bearing test device has been conceived to simulate the contact and severe working conditions of a mineral crushers. The thrust bearing test proceeds by an eccentric motion between the mating steel and the thrust bearing sample in boundary and mixed condition. The specific pressure applied to the thrust bearing was increased step by step after the running-in until a sudden rise in friction, which indicates bearing failure and risk of imminent seizure.

The journal bearing tests were performed in order to find the Stribeck curve and the running-in behavior. The results are analyzed using frictional energy and friction coefficient values.

In conclusion to their experimental research, bismuth bronze bimetal (Tokat 300) showed same level of tribological performance with continuously cast CuSn10Pb10 for both tests.
Sources

[1] Oksanen, V., Lehtovaara, A., Kallio, M. 2016. Load capacity of lubricated bismuth bronze bimetal bearing under elliptical sliding motion, Wear 388-389 (2017) 72-80
[2] Linjamaa, A., Lehtovaara, A., Kallio, M., Léger, A. 2018, Running-in effects on friction of journal bearings under slow sliding speeds, submitted

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How to use advanced nano-/micro-scale testing to deliver improved wear resistance of DLC coatings

Ben Beake, Micro Materials Ltd

Diamond like carbon (DLC) coatings can combine high hardness with low friction but they are often deposited with high levels of intrinsic stress and display low adhesion strength resulting in poor performance in demanding applications. A key challenge is to develop advanced DLC coatings capable of withstanding more demanding applications in the automotive, cutting tools, MEMS and oil and gas sectors. In highly loaded mechanical contact applications, a combination of load support and resistance to impact fatigue is often required. Longer lifetime of coated components may be achieved by designing the coating system to combine these properties rather than by solely aiming to maximise coating hardness as this may be accompanied by brittle fracture and higher wear!

In this presentation we show how data from a range of nanomechanical and tribological test techniques in the multifunctional NanoTest Vantage (nanoindentation, nano- and micro-scratch, nano- and micro-wear, nano- and micro-impact) can be used together, and with supporting simulation, to improve the design of DLC coating architectures for enhanced wear resistance in specific applications [1-3].

[1] Micro-scale impact testing - A new approach to studying fatigue resistance in hard carbon coatings, BD Beake, TW Liskiewicz, A Bird, X Shi, Tribol Int, 149 (2020) 105732.

[2] Probing fatigue resistance in multi-layer DLC coatings by micro- and nano-impact: Correlation to erosion tests, SJ McMaster, TW Liskiewicz, A Neville, BD Beake, Surf Coat Tech (2020) 126319.

[3] Influence of Si- and W- doping on micro-scale reciprocating wear and impact performance of DLC coatings on hardened steel, BD Beake, SJ McMaster, TW Liskiewicz, A Neville, Tribol Int 160 (2021) 107063.

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A Simplified Approach to Mixed/Boundary Friction Prediction Using S-Curves

Ian Taylor, University of Central Lancashire

A new equation for the prediction of the amount of mixed/boundary friction is proposed, based on recent experimental data. The equation can be used for un-additivated lubricants (base oils) and also for lubricants that contain anti-wear additives (ZDDP), provided the surface roughness of the ZDDP tribo-films is used in the calculation of the lambda ratio.

The new equation takes the form of an S-curve, and such curves generally arise naturally in growth/decay processes. In hindsight, it is not surprising that such curves appear when rough surfaces contact each other, since the real contact area, and the amount of mixed/boundary contact, grow as the load is increased.

A comparison of the new equation with well established (and well used) rough surface contact models has found that the Greenwood and Tripp model significantly underestimates the amount of mixed/boundary friction.

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Dr. Balasubramaniam Vengudusamy 11:00-11:30	Klüber Lubrication München SE & Co. KG, *Grease behaviour in rolling-sliding contacts*
Vincent Hoffmann, M.Sc. 11:30-12:00	Tribo Technologies, *Tribo-X , Optimization of Gear Tooth Efficiency using Simulation*
Dr. Natanael Dewobroto 12:00-12:30	Kugler Bimetal SA, *Performance of bismuth bronze bimetal bearing in in term of load capacity for mixed and boundary regime*
Ben Beake, Visiting Professor, PhD 13:30-14:00	Micro Materials Ltd., *How to use advanced nano-/micro-scale testing to deliver improved wear resistance of DLC coatings*
Ian Taylor, Visiting Professor, PhD 14:00-14:30	University of Central Lancashire Preston UK, *A Simplified Approach to Mixed/Boundary Friction Using S-Curves*
Jürgen Wranik, MBA 14:30-15:00	**Zeller+Gmelin GmbH, *Early stages in white etching crack formation induced by lubrication***
Dr. Julien Keraudy 15:00-15:30	Oerlikon Balzers, *Smooth and wear-resistant carbon coatings deposited by S3p™*
Prof. Dr.-Ing. Andreas Rosenkranz 15:30-16:00	University of Santiago de Chile, *MXenes, tunable mechanical and tribological properties*

Contact Information

For participation, please send an email to: **rowena.crockett@empa.ch**
Please visit: **www.swisstribology.ch**
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Early stages in white etching crack formation induced by lubrication

Jürgen Wranik, Zeller+Gmelin GmbH & Co. KG

The reliability of rolling bearings is affected by white etching crack (WEC) or white structure flaking (WSF) failures causing tremendous commercial burdens for bearing manufacturers and operators. The research for the underlying failure mechanism has attracted interests from a large scientific community over decades. Despite the significant amount of efforts, a root cause of white etching cracking is still missing. Amongst other factors, lubricant chemistry is considered to be essential in WEC formation.

The here presented work aims to elucidate this key parameter by provoking white etching crack formation on a FE8 bearing test rig using a well-described set of chemicals in high and low reference lubricants. Scanning electron microscopy and energy dispersive X-ray analysis prove the presence of a patchy tribofilm on the surface of bearing washers leading most likely to a higher frictional torque at the early stages of operation when the low reference oil is used.

Secondary neutral mass spectrometry (SNMS) shows a hydrogen containing tribofilm in the shallow subsurface of about 30 nm depth, suggesting that hydrogen proliferates into bearing material may subsequently, facilitate crack propagation via dislocation pile-ups leading to premature bearing failure.

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28th of June   9 a.m. - 4.15 p.m. (CEST)

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Prof. Dr.-Ing. Andreas Rosenkranz 15:30-16:00	University of Santiago de Chile, *MXenes, tunable mechanical and tribological properties*

Smooth and wear-resistant carbon coatings deposited by S3p™

Julien Keraudy, Oerlikon Balzers, Liechtenstein

Diamond-like carbon (DLC) coatings, namely hydrogenated amorphous carbon (a-C:H) coatings deposited by a PECVD process emerged years ago as the ideal solution for applications where component parts are under high loads or subject to extreme friction, wear and contact pressures with other parts. However, there are nowadays many tribological systems, in which the abrasion resistance of a-C:H coatings is at the limit or even insufficient. With its higher hardness, tetrahedral amorphous carbon (ta-C) would provide more abrasion resistance, a longer lifetime and enable a better performance for the related components. However, the state-of-the-art arc-deposited ta-C coatings (filtered or not) are simply too rough for many applications. Possible solutions to improve surface quality are post-finishing methods such as brushing or polishing, which however have a significant impact on the processing costs.

Recently, high power impulse magnetron sputtering (HiPIMS) was reported to be a suitable method to deposit dense hydrogen-free amorphous carbon (a-C) coatings. In this work, we report on the coating growth and properties of smooth and hard carbon coatings produced by the S3p™ (Scalable Pulsed Power Plasma) method in an industrial deposition plant. S3p™ technology enables scalability of the pulse power density and pulse length in a wide range and expands significantly the choice of the deposition parameters and process stability as compared to conventional HiPIMS technology. Smooth and hard hydrogen-free carbon layers were produced using graphite targets in Ar ambient. The thermal stability of the coatings in air and their tribological behavior in dry and lubricated environments were investigated and compared to the results of standard a-C:H and ta-C coatings. Furthermore, the influence of adding a C_2H_2 precursor in an Ar ambient atmosphere on the film properties and S3p™ reactive process was investigated.

Finally, selected applications where carbon coatings deposited by S3p™ outperformed common DLC coatings will be presented.

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MXenes, tunable mechanical and tribological properties

Andreas Rosenkranz, University of Chile

MXenes, a new class of early transition metal carbide, nitrides and carbonitrides, have gained tremendous attention in the scientific community due to their interesting property combination.

Applied as solid lubricant coatings, MXenes have shown an outstanding performance resulting in an excellent durability and longevity (ultra-high wear resistance), which even outperformed state-of-the art solid lubricant including graphene and $MoS2$.

This contribution presents the latest findings regarding MXenes’ ability to form beneficial tribolayers depending on MXenes’ number of layers (few- versus multi-layer systems), coatings thickness (amount of lubricious material), applied load (thermomechanical) and sliding velocity (kinetics).