UNIVERSITY OF CAMBRIDGE

2nd International Conference on Abrasive Processes - ICAP 2014

8 - 10 September 2014 | Cambridge UK

PROGRAMME & ABSTRACT BOOK

IOM3 The Institute of Materials, Minerals and Mining

Institution of MECHANICAL ENGINEERS

IOP Institute of Physics Tribology Group

Welcome from the Conference Chairman

It gives me great pleasure, on behalf of the Organizing Committee, to welcome you to Cambridge, to the University's Institute for Manufacturing and to the Second International Conference on Abrasive Processes: ICAP-2014.

The history of these conferences can be traced at least to the ELSI meetings – International Conferences on Erosion by Liquid and Solid Impact – which were held here in Cambridge in 1979, 1983, 1987 and 1994. By embracing abrasive wear as well as erosion, these morphed into the two ICEAW meetings of 1998 and 2003. Another name change in 2008 indicated the effort to bring together two communities who perhaps do not meet as often as they should: tribologists interested in wear by abrasive particles, and engineers and applied scientists specializing in abrasive and erosive processing. It is very much in this spirit that the organising committee embarked on ICAP 2014.

Presenters at ICAP are invited to submit manuscripts for publication, depending on subject matter and after the normal refereeing process, in regular issues of two journals: *Wear* and *Journal of Materials Processing Technology*.

John Williams
Conference Chairman
September 2014

Organising committee:
Anne Neville
Ian Hutchings
John Williams
Richard Wellman
Robert Wood

Programme

Monday 8 September

09.00 Registration and refreshments

10.00 Conference Welcome

10.10 - 10.50 Keynote – *Professor Jan Spelt, University of Toronto*
The mechanics and tribology of vibratory surface finishing

10.50 - 11.10 Refreshments

11.10 - 12.50 Session 1 – Abrasive processing I

11.10 **Surface wettability in abrasive manufacturing processes**
K J Kubiak[1,2] and T G Mathia[3]
[1]University of Liverpool, UK, [2]University of Huddersfield, UK, [3]CNRS, France

11.35 **Relocation profilometry for the assessment of abrasive wear**
M G Gee, J W Nunn and A J Gant
National Physical Laboratory, UK

12.00 **Numerical simulation and experimental observation of thermal damage in grinding of nitrided steel ball bearing races**
A Van Robaeys[1,2] , Nolwenn Imbert[1] and Hédi Hamdi[2]
[1]Airbus Helicopters, France, [2] University of Lyon, France

12.25 **Apparent and active areal topography of diamond abrasives surfaces**
Wojciech Kacalak[1], Katarzyna Tandecka[1], Dariusz Lipiński[1] and Thomas G Mathia[2]
[1]Technical University of Koszalin, Poland, [2]Ecole Centrale de Lyon, France

12.50 - 13.45 Lunch

13.45 - 14.25 Keynote – *Professor Margaret Stack, Strathclyde University*
Tribo-Corrosion maps: from marine renewable to bio-medical environments

14.35 - 15.50 Session 2 – Abrasion and erosion I

14.35 **The effects of tribological conditions and pH on wear-corrosion performance of WC-based multi-phase materials**
Mandar R Thakare[1], Julian A Wharton[2] and Robert JK Wood[2]
[1]Element Six Global Innovation Centre, UK, [2]University of Southampton, UK

15.00 **The role of the binder phase in control of the microstructure and abrasive wear behaviour of HVOF-sprayed WC based coatings**
P H Shipway and S M Nahvi
Nottingham University, UK

15.25 **Erosive wear resistance of CNT-epoxy based composites**
Jinhu Chen[1], Krzysztof K K Koziol[1], Ian M Hutchings[1], Tong Deng[2] and Michael S A Bradley[2]
[1]University of Cambridge, UK, [2]University of Greenwich, UK

15.50 - 16.10 Refreshments

16.10 - 17.25 Session 3 – Abrasion and erosion – II

16.10 **Effect of surface topography on the dynamics of the abrasive particles during micro-abrasion**
M A N Ardila, W S Labiapari, H L Costa and J D B De Mello
Universidade Federal de Uberlândia, Brazil

16.35 **In-situ imaging of the interfacial motion of individual diamond-like carbon (DLC) nanoparticles**
K Briston[1], J-M Martin[2] and B J Inkson[1,2]
[1]University of Sheffield, UK, [2]Ecole Centrale de Lyon, France

17.00 **The role of physical and mechanical properties in particle abrasivity**
K Budinski, Bud Labs, USA

17.25 Close

17.30 - 19.00 Poster session and drinks reception

Tuesday 9 September

09.10 - 09.50 Keynote – *Professor Eckart Uhlmann, Technical University of Berlin*
Manufacturing with abrasives - current research topics

10.00 - 11.15 Session 4 – Abrasive processing II

10.00 **Dry ice blasting – Investigation of particle impact**
E Uhlmann and R Hollan
Technical University Berlin, Germany

10.25 **A study of finite element analysis of materials removal characteristics in fluid jet polishing**
Zhongchen Cao and Chifai Cheung
The Hong Kong Polytechnic University, Hong Kong

10.50 **Experimental and numerical investigation of mass finishing processes**
F Grange[1], J Rech[1], A Texier[2] and G Kermouche[3]
[1]Université de Lyon, France, [2]SAFRAN-SNECMA, France, [3]Ecole des Mines de Saint-Etienne, France

11.15 - 11.35 Refreshments

11.35 - 12.50 Session 5 – Abrasion and erosion III

11.35 **Effect of abrasive particle size distribution on the wear rate and wear mode in micro-scale abrasive wear tests**
Victor A O Gomez[1], Marcelo C S de Macêdo[1], Roberto M Souza[2] and Cherlio Scandian[1]
[1]Federal University of Espirito Santo, Brazil, [2]Polytechnic School of the University of Sao Paulo, Brazil

12.00 **Wear mechanisms of elastomers in slurry transport**
Yongsong Xie, Jiaren (Jimmy) Jiang, Kidus Tufa and Sing Yick
National Research Council Canada, Canada

12.25 **Erosive wear behaviours of elastomeric materials in flowing slurry environments**
H H Tian and R J Visintainer
GIW Industries, USA

12.50 - 13.45 Lunch

13.45 - 14.35 Session 6 – Wear testing and measurement

13.45 **Simulating single particle impact and erosive wear with the nano-impact test**
Ben Beake
Micro Materials Ltd, UK

14.10 **The design, commissioning and proving trials of a new rotating arm liquid jet impingement erosion facility**
A J Gant, M G Gee, G Stammers, P Lovelock, N J McCormick and L P Orkney
National Physical Laboratory, UK

14.40 - 16.55 Session 7 – Scratch testing

14.40 **Evaluating the wear of polycrystalline diamond compact drill bit cutters using indentation and scratch tests**
Rafid Abbas, Ali Hassanpour, Colin Hare and Mojtaba Ghadiri
Leeds University, UK

15.05 **Recent progress in multiple-pass nano-scratch testing as a tool for abrasion simulation**
Ben Beake
Micro Materials Ltd, UK

15.30 **Energy considerations of single abrasion phenomena at elevated temperatures via scratch method**
M Varga, D Stenszky and E Badisch
AC^2T Research GmbH, Austria

15.55 Close and refreshments

18.00 Optional Cambridge Walking Tour

19.00 Conference dinner – Gonville and Caius College

Wednesday 10 September

09.10 - 09.50 Keynote 4 – *Professor John Nicholls, Cranfield University*
Volcanic ash: its role as an erodent in the aero gas turbine

10.00 - 10.50 Session 8 – Abrasion and erosion IV

10.00 **Wind turbine blade erosion and damage**
Hamish Macdonald, David Nash and Margaret Stack
University of Strathclyde, UK

10.25 **Three body abrasion of an organic polymer film on steel**
A C Kent[1,2], M J Adams[1], A T Ashcroft[2], S A Johnson[2] and N A Rowson[1]
[1]University of Birmingham, UK , [2]Unilever Research and Development, UK

10.50 **Abrasion resistance of Inconel 625 deposited by PTA**
Regina Paula Garcia[1], Henara Lillian Costa[1] and Temístocles Luz[2]
[1]Universidade Federal de Uberlandia, Brazil, [2]Universidade Federal do Espírito Santo, Brazil

11.15 - 11.35 Refreshments

11.35 - 12.50 Session 9 – Abrasion and erosion V

11.35 **Effect of fine third body on erosive wear of cermet, metallic, ceramic, plastic and rubber materials**
Maksim Antonov, Ahto Vallikivi, Juri Pirso, Irina Hussainova and Dmitri Goljandin
Tallinn University of Technology, Estonia

12.00 **Comparison of abrasive wear resistance of tool steels by pin-on-disc and ball cratering abrasion testing**
Mario Sonego and José Divo Bressan
University of Santa Catarina State - UDESC, Brazil

12.25 **A study of the erosive wear damage on a polymer matrix coating**
C A Márquez-Vera[1], K B Maldonado-Velázquez[1], I Hernández-Romero[1], V D Hernández-Melo[1], JR Laguna-Camacho[1] and H Martínez-Gutiérrez[2]
[1]Universidad Veracruzana, Mexico, [2]Unidad Profesional "Adolfo López Mateos", Mexico

12.50 - 13.00 Conference Close

13.00 Lunch (by arrangement)

Keynote Presentations

The mechanics and tribology of vibratory surface finishing

Vibratory finishing is a widely used industrial process to modify the surface properties and microtopography of metal, ceramic and plastic parts. Its applications are diverse, ranging from the polishing of coins, gears, and golf balls to smoothing the sharp edges of cast or stamped automotive parts, and from hardening and texturing the surfaces of electrical connectors to cleaning surfaces by removing rust and other contaminants. Current industrial practice relies on experience and experimentation to optimize the process for new parts and materials.

In a typical configuration, a vibrating container fluidizes a bed of granular media creating a circulating bulk flow. A workpiece entrained in this flow is subject to the impacts of the vibrating media. The impact velocity of the vibrating media will control the impact force and hence the degree of plastic deformation and erosion of the workpiece surface.

Our research is aimed at developing models to assist in the prediction of wear, hardening and residual stress as a function of the granular media and the motion of the vibratory finisher. The presentation will review our efforts to develop an understanding of the mechanics of vibratory finishing and its relation to erosive wear, hardening and residual stress. This includes the identification of media-workpiece impact characteristics under various conditions, and measurements of local impact velocities which provide a general means of quantifying the rate and extent of surface work regardless of workpiece-media compliance. These data have then been correlated with erosion rates and the rate and extent of plastic deformation occurring in Almen strips. Numerical models have been used to simulate edge chipping of brittle materials, and the motion of granular media as they flow past a workpiece and collide with its surface at the vibration frequency of the finisher.

Professor Jan Spelt, University of Toronto

Jan Spelt is Professor of Mechanics of Materials and Manufacturing Processes in the Department of Mechanical and Industrial Engineering at the University of Toronto. He has published widely in the areas of abrasive wear and impact erosion and the abrasive jet micro-machining of glass, silicon and polymers for microfluidic and opto-electronic applications.

Tribo-Corrosion maps: from marine renewable to bio-medical environments

Advances in the understanding of tribo-corrosion mechanisms in recent years have resulted in development of maps which chart the transition boundaries. Subsequently, such concepts have evolved further and, through models and experimentation, have been applied to a wide range of environments. From an initial "sketch" of the boundaries, there is now a body of mapping data available for various materials including pure metals, steels, thin films and composites and in a range of environments. This talk charts the historical development of the tribo-corrosion map, from the initial features of the erosion-corrosion map, for solid particle impact in aqueous and dry conditions, to the more recent maps developed for micro-abrasion-corrosion for dental, hip joint and marine conditions. The results from models in 2-D and 3-D spaces are appraised in the context of how such maps can be applied to complex shapes and processes. Future trajectories in the subject are explored in the context of emerging technologies in the bio-medical and renewable energy research areas.

Professor Margaret Stack, University of Strathclyde

Margaret Stack is Professor and Leader of the Graduate School in the Department of Mechanical Engineering at the University of Strathclyde. Her research interests include the interactions of solid particle erosion and wear of materials in corrosive environments, with specific emphasis on the development of mapping techniques for understanding the mechanisms of material loss.

Keynote Presentations

Manufacturing with abrasives - current research topics

Abrasives are widely used in manufacturing processes and a large variety of abrasives is available, both natural and synthetically produced. Predominately abrasives are applied in cutting with undefined edges and cleaning processes. In particular these processes include all forms of grinding, finishing, honing, lapping, blasting and abrasive water jet cutting. While similar abrasives might be used throughout all aforementioned processes, the fundamental working principles differ largely. This explains the wide variety of applications but also the complexity of research and development in this field. Good examples of this are current research topics such as abrasive water jet turning and speed stroke grinding of high performance ceramics. With abrasive water jet turning, high performance materials such as hypereutectic aluminum silicon alloys and titanium aluminides are machined and empirical models to predict material removal rates are currently being developed. The example of speed stroke grinding of high performance ceramics shows, how a brittle cutting mode can be employed to lower energy input into the work piece without introducing subsurface damage.

Prof Dr Ing Eckart Uhlmann, TU Berlin

Eckart Uhlmann is Director of the Fraunhofer Institute for Production Systems and Design Technology and Chair of Machine Tools and Manufacturing Technology at TU Berlin. He has published over 500 papers in journals and conference proceedings and has a particular interest in the development of manufacturing processing involving abrasion.

Volcanic ash: its role as an erodent in the aero gas turbine

J R Nicholls[1] and R G Wellman[2]
[1]Cranfield University, UK, [2]Rolls Royce Plc, UK

Following the eruption of the Eyjafjallajökull volcano in Iceland considerable disruption to the European air space occurred with many flights cancelled as the airline companies assessed the risk of flying through such dust ladened air space. This study examines the erosive role of volcanic ash as it is ingested in and passes through an aero-gas turbine engine. The study was initiated as part of a European collaborative programme to assess the impact of volcanic ash on aero-engine performance.

This presentation, first, considers the erosion of compressor components. Modelling work at Turbomeca was used to calculate particle flow patterns allowing prediction of leading edge compressor blade wear.

At Cranfield a comparative study of volcanic ash and silica was undertaken and will be presented. For volcanic ash, peak erosion rates occur at 30° impact, a ductile erosion mechanism, with only a small dependence on particle size. By way of comparison fine silica sand is more erosive than volcanic ash, while for coarse silica the relative performance depends on impact angle; less erosive at 30° impact but more erosive at 90° impact.

As volcanic ash passes through the combustor of the gas turbine it may melt and fuse. If it impacts the thermal barrier coating in the solid form, the erosion performance is similar to that of silica sand as has been previously published by the authors. However, if it melts it effuses into the thermal barrier coating structure and therefore stiffens the TBC and modifies its erosive response; increasing the erosion rate by factor of x4. This new damage mechanism for TBCs will be discussed.

Professor John Nicholls, Cranfield University
John Nicholls is Professor of Coating Technology and head of the Surface Engineering and Nanotechnology Institute, Cranfield University. He has extensive experience in high temperature surface engineering, oxidation, hot corrosion and high temperature tribology. His most recent work has been on the erosive wear and foreign object damage of thermal barrier coating systems.

Abstracts

Session 1 – Abrasive processing I

Surface wettability in abrasive manufacturing processes

K J Kubiak[1,2] and T G Mathia[3]
[1]University of Liverpool, UK, [2]University of Huddersfield, UK, [3]CNRS, France

In manufacturing processes many surfaces have to be functional and at the same time aesthetic. Therefore, abrasive processes like polishing, grinding, belt finishing, lapping, barrelling, and honing are often used in the final stages of a machining process. However, an abrasive process involves removal of material and creation of new and often very chemically and physically active surface. Freshly generated morphologically oriented surfaces can therefore be partially anisotropic.

During an abrasive process the lubricants are commonly used to control the process in order to obtain required surface properties, extend the tool lifetime and decrease frictional forces. Another important function of the fluid used in abrasive machining processes is cooling. Hear transfer coefficient become an important parameter in process control.

This newly created surface has to be wetted by the fluid to allow heat exchange to take place efficiently. Involved contact forces, flash temperatures and high cutting speed, makes the wetting process a very complex phenomenon.

In this paper a fundamental interaction of the fluid at the interface with solid material has been investigated. Wettability of the anisotropic surfaces are analysed experimentally and modelled numerically. The model of fluid-solid behaviour at those dynamic interfaces is for the first time proposed and discussed in details taking into consideration partial wettability and droplet heat transfer effect on anisotropic surfaces.

Relocation profilometry for the assessment of abrasive wear

M G Gee, J W Nunn and A J Gant
National Physical Laboratory, UK

As more materials with good resistance to abrasion are developed, the measurement of small wear volumes is becoming increasingly important. Relocation profilometry is a technique that can be used to accurately measure small wear volumes. In this study, abrasion, both single track and multiple track, was carried out with a micro-tribometer on a range of materials including ceramics, coatings and steels.

Scratch depths and volumes of a few 10s of nm could be measured accurately by the technique. A key part of the technique is to register the data sets and images that were obtained before and after damage was carried out to the sample. The registered datasets were then subtracted to form a good reference plane that could then be used as a basis for evaluation of damage. Accurate measurement of the damage to ground surfaces could also be carried out.

The quantitative evaluation of damage is discussed in the light of optical and SEM examination of the mechanisms of wear that took place. The role of friction is also discussed.

Numerical simulation and experimental observation of thermal damage in grinding of nitrided steel ball bearing races

A Van Robaeys[1,2], Nolwenn Imbert[1] and Hédi Hamdi[2]
[1]Airbus Helicopters, France, [2]University of Lyon, France

Nitrided steels are used today for gears and bearing races in order to answer high resistance and low wear demands in aeronautical applications. In order to give precise dimensions and a high quality surface finish to the parts as well as to eliminate the hard and brittle combination layer that appears during the nitriding process, a grinding operation is done on all functional surfaces. However, the grinding process has an important impact on the properties of the subsurface and therefore the definition of correct grinding parameters is essential. Improper grinding conditions can cancel out the beneficial effects of nitriding or even damage the surfaces.

To understand the mechanisms that lead to surface degradation, a thermomechanical finite element model for the grinding of nitrided ball bearing races has been developed in SYSWELD®. It gives the temperatures reached and the residual stress distribution in the workpiece after a grinding operation, considering an initial stress distribution obtained from nitriding. Comparisons between the model and experimental results from races generated with controlled damage show a good reproduction of the surface degradation and residual stress profiles.

Apparent and active areal topography of diamond abrasives surfaces

Wojciech Kacalak[1], Katarzyna Tandecka[1], Dariusz Lipiński[1] and Thomas G Mathia[2]
[1]Technical University of Koszalin, Poland, [2]Ecole Centrale de Lyon, France

The paper describes the methodology and results of research on the tribological characteristics of surface diamond abrasive films using stereometric analysis. The abrasive films are used in various finishing process of the surfaces with a very high smoothness and accuracy. The morphological analysis of surface summits in parallel plane to the film surface and perpendicular direction allowed an assessment of the distances between the particles by means of decomposition of the Voronoi cells.
Studying the formation of aggregates of diamond grains and the spaces between them can indicate the potential performances of the film abrasive machining and determine the recommended kinematic conditions of the film ensuring maximum utilization of this potential. Through the investigation of the morphology of diamond abrasive films, one can observe relevant characteristic of abrasive aggregates varying in term of size and shape depending on particle sizes. Units of elongated shape "cutting" have superior ability in relation to the spherical-shaped aggregates. One of significant proposed parameters describing the technological potential of the abrasive films is the ratio of length to width of the ridge crest diamond units. Different acting modes are discussed. Statistical analysis of observed dynamic of the abrasive interfaces allowed pertinent description of abrasive process taking into consideration of nominal and apparent as well as abrasively efficient morphologies.

Session 2 – Abrasion and erosion 1

The effects of tribological conditions and pH on wear-corrosion performance of WC-based multi-phase materials

Mandar R Thakare[1], Julian A Wharton[2] and Robert JK Wood[2]
[1]Element Six Global Innovation Centre, UK, [2]University of Southampton, UK

WC-based thermal-spray coatings and sintered compacts are extensively used in the oil and gas industry and are exposed to corrosive environments during operation often leading to premature failure. It is regularly observed that a material can exhibit very different failure mechanisms under different application conditions. As such, the influence of these individual parameters on the wear-corrosion performance of multi- phase materials needs to be fully understood to develop and tailor surface engineering. To achieve this, the present paper attempts to decouple the effects of contact conditions and corrosion by examining the wear-corrosion performance of thermal sprayed WC-10Co-4Cr coating and sintered WC-6Co using a micro-abrasion tester capable of in situ electrochemical measurements and a ASTM G65 rubber- wheel abrasion tester under neutral and alkaline test conditions using abrasive particles of same size (4.5 micron SiC). Electron microscopy and in situ electrochemical noise data has been used to compare behaviours of these materials in the different test and static environments. Effects of mechanisms such as micro- galvanic coupling on the overall attrition have been examined using X-ray photoelectron spectroscopy (XPS). Parameters such as severity of contact help in relating the overall wear rates to individual parameters of contact conditions and pH.

The role of the binder phase in control of the microstructure and abrasive wear behaviour of HVOF-sprayed WC based coatings

P H Shipway and S M Nahvi
Nottingham University, UK

Three different WC-metal feedstock powders were deposited to form coatings by HVOF thermal spraying. The binder phases examined were the commonly used cobalt, and also NiMoCrFeCo and FeCrAl alloys. Characterisation of the coatings indicated substantial decomposition of WC during spray process for all the coating types. The differences in microstructures were related to the dissolution of WC into the molten binder during spraying, and to the precipitation of phases from that binder phase on cooling to form a coating. Coatings were characterized in terms of their phase make-up and their mechanical properties. Dry sand rubber wheel (DSRW) tests were performed with both silica and alumina abrasives. The coatings with the nickel and iron alloy binders exhibited low rates of wear whereas the coating with the cobalt binder exhibited much higher rates of wear, and this was primarily attributed to differences in the nature of the binder phase following spraying.

Erosive wear resistance of CNT-epoxy based composites

Jinhu Chen[1], Krzysztof K K Koziol[1], Ian M Hutchings[1], Tong Deng[2] and Michael S A Bradley[2]
[1]University of Cambridge, UK, [2]University of Greenwich, UK

Aligned carbon nanotube (CNT) polymer composites are envisioned as the next- generation composite materials for a wide range of applications. In this work, we investigate the erosive wear resistance of epoxy matrix composites reinforced with aligned CNT arrays and CNT films. Results have shown that the composite with vertically aligned CNT-arrays exhibits superior erosive wear resistance compared to any of the other types of composites, and the erosion rate (by mass loss) reaches a similar performance level to that of carbon steel at 20° impingement angle. The erosive wear mechanism of these composites, at various impingement angles, is studied by Scanning Electron Microscopy (SEM). In the case of aligned CNT arrays as the reinforcement material, the erosive wear performance shows strong dependence on the alignment geometries of CNTs (i.e., horizontally and vertically aligned) within the epoxy matrix under identical CNT loading fractions. However, the incorporation of multi-layered CNT films does not show significant improvement on erosion resistance which may be attributed to the relatively poor interaction between CNTs and matrix as well as porosity. Overall, this work demonstrates methods to fabricate CNT based polymer composites with high loading fractions of the filler, alignment control of nanotubes and optimized erosive wear properties.

Effect of surface topography on the dynamics of the abrasive particles during micro-abrasion
M A N Ardila, W S Labiapari, H L Costa and J D B De Mello
Universidade Federal de Uberlândia, Brazil

During abrasive wear, the prevailing wear mechanism has been shown to be associated with the movement of the active particles present at the wear interface. Two particle dynamics can occur: (i) rolling, which is evidenced by the presence of indentations on the worn surface, and (ii) sliding, which produces scratching and/or ploughing. The literature reports that the particle dynamics can vary with the tribological parameters such as different combinations of ball and specimen materials, applied load, slurry concentration, abrasive material, ball condition and equipment configuration (fixed or free-ball). In this work, the effect of surface topography of both the ball and the specimen on the dynamics of the abrasive particles and micro-abrasion wear is investigated for SiO2 abrasive particles. The effect of the ball surface topography was investigated using a fixed-ball rig, zirconia balls (Ra = 0.06, 0.34, and 0.54 µm) and stainless steel specimens (Ra 0.101 µm). When the roughness of the ball increased, the wear mechanism changed from sliding to mixed and then to rolling and the micro abrasion coefficient *kab* increased substantially, the difference between the values found for the smoothest and the roughest ball being around 175%. The effect of the specimen surface topography was investigated using a free-ball rig, AISI 52100 steel balls (Ra = 0.82 µm) and tool steel specimens (0.025 µm <Sq< 0.414 µm). The influence of the directionality of the specimen surface finish was also analysed by conducting tests parallel and perpendicular to the machining marks using three slurry concentrations. Although the test conditions used for the tests to investigate the topography of the specimens were very different from those used to investigate the effect of the ball topography, the calculated test severities were similar. The effect of the topography of the specimens on wear coefficients and mechanisms was much less pronounced than that found for the ball topography. For the highest slurry concentration (20%wt.), when the specimen surface roughness increased, *kab* reduced (around 23%) and a slight change in mechanism occurred from mixed (sliding in the centre and rolling at borders of craters), to sliding. This effect was less significant for lower concentrations: the reduction was 8% for a slurry concentration of 10%wt. and disappeared for a slurry concentration of 5%wt., with no change in mechanism. For the roughest specimens, a small reduction in *kab* was observed when the slurry concentration increased (around 12%), but no change in mechanism was observed. For the smoothest specimens, an increase of around 30% was observed when the slurry concentration increased and the mechanism changed from sliding to mixed. The influence of surface directionality on abrasive wear was negligible.

In-situ imaging of the interfacial motion of individual diamond-like carbon (DLC) nanoparticles
K Briston[1], J-M Martin[2] and B J Inkson[1,2]
[1]University of Sheffield, UK, [2]Ecole Centrale de Lyon, France

The interactions of hard particles with surfaces are dependent on many interlinked factors, including particle shape, mobility, mechanical properties and agglomeration. Dynamical mechanisms of abrasive wear by hard particles are typically interpreted from post-mortem examination of worn engineering surfaces and particle debris. Here the behaviour of hard nanoparticles between sliding surfaces are imaged directly in- situ between sliding surfaces, by using a novel NanoLAB triboprobe developed for TEM. The movement of individual nanoparticles can be tracked over thousands of reciprocating wear cycles, enabling motion and abrasion to be related to particle and surface properties. Here the dynamical behaviour of hard diamond-like carbon (DLC) nanoparticles between sliding surfaces will be presented. The nanoparticles are directly observed to move with sliding, rolling and spinning motions, with the nature of the counter surfaces strongly influence the types of motion observed.

The role of physical and mechanical properties in particle abrasivity

K Budinski
Bud Labs, USA

There is often a need to determine the abrasivity of potential work sites in agriculture, mining, tunnelling, and mineral extraction to assess tool costs. A rubber wheel test was developed to measure particle abrasivity. It is similar to the familiar ASTM G 65 dry sand rubber wheel test except in the abrasivity test, the particles of interest replace the sand and the test metric is relative wear volume on a stainless steel reference.

This test was used to rank particles from very different localities and their abrasivity varied significantly. Tests were then conducted to correlate the measured abrasivity results with particle size, particle strength, and surface roughness of the abraded reference steel. The abrasion wear volumes did not correlate with these factors. The only factor that seemed to correlate was the ability of indusial grains to scratch the reference material. This was called scratch severity. Overall, this study suggests that particle abrasivity mostly depends on particle" ruggedness", the angles, protrusion, facets, furrows, roughness etc. of particles assuming that the particles do not crush when they contact and move along a counterface.

Session 4 – Abrasive processing II

Dry ice blasting – Investigation of particle impact

E Uhlmann and R Hollan
Technical University Berlin, Germany

Cleaning technology is an important factor in the field of service and recycling as well as production technology. Mechanical acceleration of dry ice by rotational wheel blasting could offer higher energy efficiency compared to state of the art by compressed air, initial tests have proven feasibility.

The volatility of solid carbon dioxide at ambient conditions and the particle's transparency hinder the lab-based measurement of material data like hardness and modulus. This data is needed for further improvements. An investigation of the blasting process is more difficult because of the high impact velocity.

The mechanical and thermal effect of a particle's impact, usually used for cleaning, were investigated in detail because of the mechanical acceleration, a sequence of minor pellet impacts, results in early sublimation losses. First the air jet, hindering the measurement, was minimized right after the blasting nozzle. Thus, the impact impulse could be identified by a piezo element based force sensor while the particle's size and velocity were estimated by a high speed camera. A specific thermal element (TE) was used in a second series of experiments to investigate the thermal effect. According to the measured temperature difference the heat transfer could be evaluated by a fem simulation of the TE.

A study of finite element analysis of materials removal characteristics in fluid jet polishing

Zhongchen Cao and Chifai Cheung
The Hong Kong Polytechnic University, Hong Kong

With the broad application of structured surfaces in various areas, the fabrication of these complex surfaces with sub-micrometer form accuracy and nanometric surface finish has become more widespread. Ultra-precision Fluid Jet Polishing (UFJP) is an enable technology used in superfinishing freeform surfaces made of difficult-to- machine materials. Due to the complex machining mechanism, it is still difficult to model the material removal characteristics and simulate the surface generation for UFJP. In this paper, a framework of a theoretical model is presented which attempts to predict the material removal characteristics as follows: (1) impact information of particles in the slurry are calculated using the Computer Fluid Dynamics (CFD); (2) the particle spatial distribution and a erosion model are developed together with the data obtained from the CFD simulations; (3) some empirical constants involved in the erosion model should be determined by experiments. Then the structured surface generation is simulated based on the developed theoretical model and polishing path. A series of preliminary experiments are undertaken, and the experimental results are found to agree well with the predicted results of the form error and the pattern of the structured surfaces.

Experimental and numerical investigation of mass finishing processes

F Grange[1], J Rech[1], A Texier[2] and G Kermouche[3]
[1]Université de Lyon, France, [2]SAFRAN-SNECMA, France, [3]Ecole des Mines de Saint-Etienne, France

Mass finishing processes - barrel finishing, vibratory finishing or drag finishing – are more and more used to replace manual finishing operations … They makes possible to combine the ability of superfinishing processes to reach very low roughness level with the creation of a compressive residual stress field by burnishing or peening.

However the effects of the different process parameters (vibration, amplitude, finishing medium, additives) are not yet clearly understood because of the difficulties to take into account both microscale phenomena (grain/surface contact) and macroscale phenomena (finishing medium flow). For that purpose, we developed experimental devices dedicated to the investigation of the mass finishing of engineering surfaces submitted to continuous or oscillating finishing medium flows. Thanks to these set-ups, it is possible to investigate roughness change and residual stress creation for different polishing conditions and we show here that the size of the finishing media seems to be as important as its abrasive power. The ability of discrete element methods and finite element based methods to identify the local contact conditions and thus to correlate with the polishing power depending the process parameters is also discussed.

Session 5 – Abrasion and erosion III

Effect of abrasive particle size distribution on the wear rate and wear mode in micro-scale abrasive wear tests

Victor A O Gomez[1], Marcelo C S de Macêdo[1], Roberto M Souza[2] and Cherlio Scandian[1]
[1]Federal University of Espirito Santo, Brazil, [2]Polytechnic School of the University of Sao Paulo, Brazil

In this work, the particle size distribution of two powders was initially analyzed, indicating a normal (Gaussian) distribution with average particle size on the order of 2 microns in one case and 6 microns in the other. Both powders were composed of silicon carbide (SiC) particles. The two original powders were then mixed with different mass fractions, providing a series of SiC powders that were used in micro- scale abrasive tests with fixed-ball configuration. The wear tests were conducted on ASTM 1020 carbon steel and results were analyzed in terms of wear rate as well as wear mode (“rolling abrasion” or “grooving abrasion”). Results have indicated that the mass fraction of the original powders has a significant effect on the wear modes observed at the micro-scale level and that the wear rate does not follow a direct relationship with the mass fraction of the powder with larger average particle size.

Wear mechanisms of elastomers in slurry transport

Yongsong Xie, Jiaren (Jimmy) Jiang, Kidus Tufa and Sing Yick
National Research Council Canada, Canada

Elastomers are an important class of materials which have the advantages of resilience, toughness, corrosion resistance, ease of fabrication, acoustic/vibration damping capabilities and light weight. Elastomers generally have better resistance to solid particle attack in wet condition than metallic materials thus are increasingly widely used in slurry transport for components such as slurry pipe liner, slurry pump side liner and casing liner. However, little studies were reported on the wear mechanisms of elastomers used in slurry transport. In this study, the wear mechanisms of three elastomers selected from three types of widely used elastomers - natural rubber, neoprene rubber and polyurethane - were studied. The worn surfaces of the three elastomers after slurry jet erosion and Coriolis scouring erosion tests were examined. Parallel overlapping scratch testing, in which the test samples were submerged in water, was conducted to simulate the wear of the three elastomers by slurry attack. The wear mechanisms of the three elastomers, as well as the relationships between their wear rates and mechanical properties, were discussed and presented.

Erosive wear behaviours of elastomeric materials in flowing slurry environments

H H Tian and R J Visintainer
GIW Industries, USA

Elastomeric materials play a significant role in engineering components such as pumps and pipelines dealing with flowing slurries in mining and many other applications. Sliding and low angle impact erosion is one of the predominant wear modes in such conditions. In the present research, experimental investigation was performed using Coriolis erosion testing approach on erosive wear behaviors of selected rubber and urethane materials. A few metallic alloys were also included in these tests for comparison. Wear surface of test samples were analyzed by means of microscopy. Results indicated that the resilience of elastomers is critical to promote the bouncing effect during the erosive wear process and a higher resilience generally leads to a lower wear rate. Properties such as tear strength of elastomeric materials are also important in determining final outcomes for particular wear conditions. The effect of solid particle size on erosive wear rate and mechanisms were also discussed.

Session 6 – Wear testing and measurement

Simulating single particle impact and erosive wear with the nano-impact test

Ben Beake
Micro Materials Ltd, UK

Nano-impact testing is a nanomechanical test technique that utilises high strain rate contact at strain rates orders of magnitude greater than in a normal quasi-static nanoindentation test. This high strain rate repetitive contact allows much closer simulation of the performance of coatings systems under highly loaded intermittent contact (such as interrupted cutting and erosive wear) and the evolution of wear under these conditions. The extent of correlation between results of nanoindentation and nano-impact and the performance of coated systems operating in extreme environments has been investigated.

Two situations are investigated in detail: (i) coatings for high speed machining of hard-to-cut aerospace materials and (ii) erosion of thermal barrier coatings for aero- engines. In both of these applications a direct correlation between the nano-impact results and the actual coating performance has been found. The reasons for the correlations, in particular the influence of mechanical properties and coating microstructure, are discussed. It is found that it is more reliable to use a nanomechanical test that more closely mimics the high strain rate and repetitive contact in the applications than rely solely on the results of nanoindentation.

The design, commissioning and proving trials of a new rotating arm liquid jet impingement erosion facility

A J Gant, M G Gee, G Stammers, P Lovelock, N J McCormick and L P Orkney
National Physical Laboratory, UK

A water droplet erosion rig, of the generic rotating arm type has been designed, assembled and commissioned at the National Physical Laboratory; the design brief being to have water droplets, in vacuo, of diameter 150 µm impinging on materials of interest at velocities of the order 500 ms-1. The concept is congruent with the precepts of ASTM G73, but due to inertial mass considerations, the rotor is 2.0 m diameter; considerably shorter than the example design detailed in the standard by way of illustration. During commissioning, component modifications were, of necessity, undertaken due to failure of bolt groups in the rotor and excessive temperatures. Once the latter were resolved, droplet (rather than continuous stream) impingement was verified by high speed flash photography. Thereafter a precipitation-hardening stainless steel and a cobalt alloy, being representative of a LP steam turbine blade and a blade overlay (insert) were used to validate the test method by means of long term erosion trials, monitored by pre-determined interval mass loss measurement and inspection by optical and electron microscopy.

Evaluating the wear of polycrystalline diamond compact drill bit cutters using indentation and scratch tests

Rafid Abbas, Ali Hassanpour, Colin Hare and Mojtaba Ghadiri
Leeds University, UK

Polycrystalline Diamond Compact (PDC) drill bits are widely used in oil and gas drilling. The wear of PDC cutters is a major issue during drilling that leads to severe time losses which affect the overall drilling operation cost. Therefore, it is essential to evaluate the wear tendency for these cutters using predictive approaches.

The present research is focused on studying the wear mechanisms of PDC cutters and the effect of their mechanical properties on the extent of wear. The volume of wear for the PDC cutters was determined experimentally using micro and nanoscratch tests on different layers of PDC cutters, i.e. the diamond layer and tungsten-carbide (substrate layer) by implementing a developed approach based on the geometry of the removed material after nanoscratch test.

The experimental wear was compared to the predicted wear based on current approaches in the literature. Various wear models are critically evaluated and compared to the experimental wear results for micro and nano scratch tests on both layers of the PDC samples (WC-Co) and (diamond). Details of the results will be presented.

This study in this paper is promising and could be extended for the evaluation of wear intensities of PDC cutters from various manufactures.

Recent progress in multiple-pass nano-scratch testing as a tool for abrasion simulation

Ben Beake
Micro Materials Ltd, UK

Multi-pass constant load nano-scratching is used as a model single-asperity system to simulate abrasive wear on monolithic materials and coated systems [1].

The observed frictional behaviour on repetitive sliding is explained by changes to the ploughing component of friction and smoothing of asperities, both of which alter the contact area and affect the measured friction force. The contact pressure and extent of scratch recovery decrease rapidly in the first few cycles as the asperities are smoothed out.

For hard and wear-resistant coating systems (TiN on M42 steel and DLC on silicon) extensive fracture and delamination can occur after several cycles at contact pressures and applied loads lower than those required for failure in a single-pass test. The technique provides valuable addition information regarding the durability of the coating systems not obtainable from single-pass scratch tests.

The location of the maximum in the von Mises stress in relation to the coating- substrate influence is shown to be a critical factor in determining the type of wear behaviour observed.

[1] This work has been carried out in the collaborative EU project “Nanoindent Plus” on the standardisation of the nano-scratch technique.

Energy considerations of single abrasion phenomena at elevated temperatures via scratch method

M Varga, D Stenszky and E Badisch
AC^{2}T Research GmbH, Austria

This work investigates initial wear mechanisms in abrasive contact. Thereto a novel tribometer is utilised which allows scratch and hardness testing at high temperatures under vacuum conditions. Scratch tests with loads of 1-100 N at temperatures from RT to 1000°C were done on two materials: I) austenitic stainless steel without hard phases, and II) white cast iron with primary Cr-carbide network. Wear scars were investigated with microscopic methods and cross sections were done, to determine wear mechanisms present at the different material phases. Scratch energy was calculated via measurement of tangential force and set into relation to the topography of the wear scar and hot hardness of the material.

The austenite shows low temperature influence, but strongly load depended scratch response and work hardening. On the white cast iron an interaction of carbides and matrix with ductile behaviour in the interface is observable, temperature reveals stronger influence, especially above 500°C.

Finally, it can be claimed that this newly designed High Temperature-Harsh Environment Tribometer (HT-HET) offers an enormous potential for deeper understanding of fundamental wear phenomena occurring at high temperature. Furthermore, the implementation of application's abrasives will be an important issue in the future.

Session 8 – Abrasion and erosion IV

Wind turbine blade erosion and damage

Hamish Macdonald, David Nash and Margaret Stack
University of Strathclyde, UK

Wind turbines are subject to a wide range of environmental conditions during a lifespan that can conceivably extend beyond 20 years. Hailstone impact is thought to be a key factor in the leading edge erosion and damage of wind turbine blades. Along with the size and density of the hailstone, the aggregated impact velocity components are crucial variables that characterise the kinetic energy associated with singular impact. These components include: the terminal velocity of the hailstone, the mean wind speed and the rotational speed of the turbine. Theorised values for the impact velocity may not truly reflect the conditions experienced by wind turbine blades. Using UK meteorological data, a greater representation of hail characteristics, occurrence probabilities and realistic impact component velocities is proposed, which will assist in the development of a realistic damage model for hailstone impact.

Three body abrasion of an organic polymer film on steel

A C Kent[1,2], M J Adams[1], A T Ashcroft[2], S A Johnson[2], and N A Rowson[1]
[1]University of Birmingham, UK , [2]Unilever Research and Development, UK

The formation of surface films may be deliberate, in the form of paints and other coatings, or accidental, in the form of fouling deposits. Whether the aim of abrasion is to remove such films or to enhance them by polishing, there are some common underlying principles. However, three-body thin film abrasion is a complex topic, often involving a number of mechanisms that depend on the materials and the wear environment that are poorly understood despite the numerous applications.
This project's current aim is to develop a more detailed understanding of the abrasive cleaning of a baked dehydrated castor oil deposit formed on stainless steel as a model kitchen deposit. The study focused on identifying the relative importance of the various factors that govern the performance of model abrasive cleaning fluids in film removal. A reciprocating linear tribometer was employed for this purpose with a spherical elastomeric probe sliding on a flat surface in order to achieve well defined contact mechanics. The factors investigated included the sliding speed, normal load, geometry of the particles and the rheological properties of the suspending fluid. The wear volume was measured by profilometry and the wear mechanisms were examined using optical microscopy.

Abrasion resistance of Inconel 625 deposited by PTA

Regina Paula Garcia[1], Henara Lillian Costa[1] and Temístocles Luz[2]
[1]Laboratory of Universidade Federal de Uberlandia, Brazil, [2]Universidade Federal do Espírito Santo, Brazil

Recent applications of Inconel 625 in pumping systems used in off-shore petroleum extraction can involve relative movement under the presence of abrasive sand particles.

Plasma Transferred Arc (PTA) deposition of metal powders allows high deposition rates and single layer deposits, with evident time savings, low dilution and fine microstructure and therefore has been seen as suited to deposit Inconel in such applications.

This work used PTA to deposit Inconel 625 on carbon steel substrates. The deposition parameters were current (three levels), welding speed (two levels) and feeding rate (two levels). Macrographic analysis of the deposits allowed the evaluation of dilution and the measurement of width, penetration and reinforcement of the beads.

Microhardness profiles and FEG-SEM analysis evaluated microstructural evolution of the deposits.
The abrasion resistance of both bulk samples and PTA deposits were evaluated via micro-abrasion wear tests. Maps of the micro-abrasion mechanisms were obtained as a function of the material of the sphere (hard martensitic steel and zirconia) and the concentration of the silica slurry (1, 10, 40 and 50%). Conditions that resulted in sliding of abrasives, rolling of abrasives and mixed regimes were identified. Welding energy affected the micro-abrasion resistance of the deposits and wear micromechanisms.

Session 9 – Abrasion and erosion V

Effect of fine third body on erosive wear of cermet, metallic, ceramic, plastic and rubber materials

Maksim Antonov, Ahto Vallikivi, Juri Pirso, Irina Hussainova and Dmitri Goljandin
Tallinn University of Technology, Estonia

The solid particle erosion of materials is characterised as wear caused by hard particles striking the surface (two-body process). However, it was observed that fine abrasive particles originating from abrasive mixture or being the residues of broken particles (appeared at speeds as low as 5 ms-1) may be retained on the surface of eroded material by electrostatic field. This results in the presence of the fine third body between attacking nominal abrasive and material surface during interaction.

Combination of particles of nominal and fine sizes leads to more localized stresses (with high stress concentrations). WC-Co hardmetal, alumina, zirconia, Hardox 400, AISI 316, MetaLine rubber and Delrin plastic were studied to assess the effect of fine third body on wear mechanism and wear rate of the materials under erosive conditions of impact velocities ranging from 10 to 80 ms-1. Four types of abrasive mixtures were prepared from naturally occurring silica sand and tested: (1) conventional (0-0.6 mm), (2) fine abrasive (0-0.1 mm), (2) coarse abrasive (0.6-1.0 mm) and (4) mixture of fine and coarse. SEM and optical images along with EDS results are given to support the conclusions.

Comparison of abrasive wear resistance of tool steels by pin-on-disc and ball cratering abrasion testing

Mario Sonego and José Divo Bressan
University of Santa Catarina State - UDESC, Brazil

Present work examines the abrasive wear resistance of four different tool steels evaluated by pin-on-disc and ball-cratering abrasion testing. Specimens of AISI H13, AISI A2, Bohler W360 Isobloc and Crucible CPM 9V tool steels heat treated were characterized and tested by ball-cratering microscale abrasive wear test, using abrasive slurry of silicon carbide hard particles with average size of 4.5 micron, SAE 52100 steel ball diameter of 25.4 mm, normal load of 2 N, ball rotation speed of 60 rpm and total sliding distance of 157 m. Also, pins of these four tool steels heat treated were tested by pin-on-disc apparatus, employing dry abrasion against a milling disc with silicon carbide of average grain size 200 micron, normal load of 5 N, sliding velocity of 0.45 m/s and total sliding distance of 3000 m. Experimental wear rate Q were obtained from graphs of measured lost volume versus sliding distance curves and experimental Vickers micro-hardness were performed. Comparison of wear resistance (R = 1/Q) and discussion were done amongst the tool steels and abrasion testing. Abrasion wear mechanisms inside the crater were observed and identified by scanning electron microscope. In conclusion, tool steel abrasion wear resistance depended on the wear testing and test operation conditions.

A study of the erosive wear damage on a polymer matrix coating

C A Márquez-Vera[1], K B Maldonado-Velázquez[1], I Hernández-Romero[1], V D Hernández-Melo[1], JR Laguna-Camacho[1] and H Martínez-Gutiérrez[2]
[1]Universidad Veracruzana, Mexico, [2]Unidad Profesional "Adolfo López Mateos", Mexico

In this work, erosion tests carried out to study the wear damage on a coating made of a polymeric matrix (crystal polystyrene) and clay (montmorillonite). The latter modified and purified with bromide quaternary salts (hexadecyltrimethyl ammonium chloride). The coating preparation was by liquid via dissolving 25% crystal polystyrene in a solution of 70% ethyl acetate and 30% acetone, after this, activated montmorillonite added and the coating application was by inverting the substrate (aluminum 6061) in the liquid phase polymer coating. The substrates coated with 5 layers of coating and the percentage of montmorillonite varied between 0.7%, 1% and 1.5%. An erosion rig similar to that shown in ASTM G76-95 used to perform the tests. The glass bead particles had a particle size between 200-240 µm. Tests carried out using impact angles, 30°, 45°, 60° and 90° with a velocity of 2.5 ± 0.5 m/s. The abrasive flow rate was 5.5 ± 0.5 g/min. The room temperature was between 35°C to 40°C. Chemical compositions of the particles and the coating obtained using energy dispersive X-ray analysis (EDS). In addition, SEM images used to identify the wear mechanisms. Finally, AFM used to compare the roughness of the surfaces before and after tests.

Poster Abstracts

Development of smart materials for marine renewable energy processes P1

Rafee Abdulmajeed Rafee Ahamed and Margaret Stack
University of Strathclyde and TriboS at Strathclyde, UK

In Tribology, there is an increasing interest in viewing mechanisms of materials with a multi-dimensional geometry such as structures in tidal and wave energy conversion environments. There have been many attempts to map these mechanisms under such conditions using a range of materials.

Progress in the understanding of Tribo-corrosion has led to the description of the erosion-corrosion process in terms of different regimes. These regimes under such conditions enable the deterioration to be classified. Such experimental analysis provides a means of generating Tribo-corrosion maps considering the particle velocity, applied potential, medium conditions and types of materials used.

In this project, the research work is being carried out on the Tribological and Tribo-Corrosion mechanisms of materials in tidal turbine conditions. This work is linked to an ESPRC-Supergen project (2013-2016) on materials for marine renewable energy capture processes. This research comprises of multiple phases, such as testing of materials in an impingement jet erosion rig, simulating the real world problems by using a multi-staged analysis and computational and physical modelling, and construction of Tribo-corrosion maps for the materials.

Improved centrifugal tribodevice for ranking the resistance to wear of materials for slurry transport system P2

Maksim Antonov[1], Arkadi Zikin[2] and Irina Hussainova[1]
[1]Tallinn University of Technology, Estonia, [2]NUTECH GmbH, Germany

The data on wear performance of materials in a wide range of conditions is important for selection of correct materials and working conditions providing guarantied lifetime of components in slurry transport systems (pipes, pumps, valves, etc). The new type of centrifugal slurry accelerator allows testing of up to 40 samples of materials simultaneously under identical conditions that enables precise comparative ranking of their resistance to wear. Device provides stable testing with abrasive particle concentrations in water slurry ranging from 0 to 60 % vol; the speed range is from 3 to 35 ms-1; temperature may be set from 20 to 100 °C. Stainless body allows making tests with low corrosive liquids. Several materials relevant to slurry transport system are tested (PE100, AISI316, commercial coatings with hard additives, HVOF and laser coatings). Discussion of results is accompanied by SEM and EDS observations.

Cavitation erosion-corrosion of ship propeller materials P3

Jahnabi Basumatary
Southampton University, UK

Cavitation has always been an issue with ships and their efficiencies. This research project looks at the cavitation erosion-corrosion mechanism of marine materials used in propellers and rudders. The first objective of this research will be to review physical mechanisms for cavitation erosion loads. The research will include the steady state mass loss of material using a ultrasonic vibratory probe on different types of ship propeller material samples, comparisons will be made before and after each experiment between the surface profilometry using Alicona, and the comparison between gravimetric and volumetric/optical loss measurements obtained using precision weighing machine and Alicona respectively. Then in-situ electrochemistry techniques will be applied to study the corrosion of the material sample during the experimental test. And finally, Computational Fluid Dynamics (CFD) will be carried out to predict the cavitation cloud formation. These all together would assist greatly in understanding the synergy between the cavitation wear and corrosion as a result.

Dynamical deformation of cerium oxide nanoclusters: an in-situ TEM study P4

U M Bhatta, A Lockwood, K J Briston, G Möbus and B J Inkson
University of Sheffield, UK

Cerium oxide is currently under extensive investigation in biomedical and energy sectors, due to its highly attractive mechanical and catalytic properties. Ceria is unusual due to its propensity to form agglomerates of highly oriented nanocrystals, and complex structural and chemical changes which can occur at the nanoscale under heavy stress and dynamical environments.

Here the mechanical behaviour of ceria clusters has been studied in-situ using a custom made TEM triboprobe. Individual nano to micro sized cerium oxide nanoparticles/clusters consisting of approximately 100 nm particles have been deformed inside an electron microscope, enabling the real-time dynamics of deformation at surfaces to be characterized. Real-time imaging of the deformation and fracture of a range of ceria nanoclusters during in-situ compression shows that clusters undergo local orientation changes followed by plastic deformation. Lateral shear completely changes the morphology, orientation and mechanical properties of the ceria clusters.

Erosive wear of polymer composite materials and its correlation with high strain rate mechanical properties P5

Lekshman Biju[1], Tong Deng[1], Michael S.A. Bradley[1], Michael Okereke[1] and Alistair McIlhagger[2]
[1]University of Greenwich, UK, [2]University of Ulster, Ireland

Erosive wear phenomena have been studied for more than half a century and it is well known that high-speed impacts generate very high strain rates. However the research work done so far used quasi-static data to correlate the erosive wear with material properties. It is believed that the localized compressive loading is more representative of erosive wear. In order to study relationship between erosive wear and high strain rate properties of materials, compressive tests on Split Hopkinson Bar (SPHB) were used to measure high strain rate properties of polymer composites in parallel with erosion tests.

In this paper the stress-strain rates curves of 3D Orthogonal Carbon Fibre Epoxy Composites, 3D Layer-to-Layer, BD Tufted and BD 090 composites were measured, and meantime erosive wear rates of the composites were obtained using a centrifugal erosion tester. Additionally mechanical properties of the composites like compressive strength, elastic modulus and fracture toughness at quasi-static loading were studied. Microstructures of tested samples show more details of the erosive behaviour of materials and damage at high strain rates. In this study, the correlation between the mechanical properties such as high strain rate and erosive behaviour of composite materials is tried to establish.

Why is it difficult to apply hardness of materials for erosive wear mechanisms and models P6

Lekshman Biju, Tong Deng and Michael S A Bradley
University of Greenwich, UK

Erosion is the surface degradation and material loss due to solid particle impacts, whereas hardness of a material is the resistance of a material to undergo plastic deformation. It is well known that the process of erosion at normal impacts is much similar to a hardness testing and therefore many attempts using hardness in simulation models have been made. However contradictions have been observed when using hardness to find correlation with erosion wear rate in many studies.

In order to explore the reasons of the contradictions, surface and sub-surface microstructures of some common ductile and brittle materials subjected to erosive wear testing and both dynamic and quasi-static hardness testing have been studied. The microstructures of indented and erosive wear tested surface and cross-sections show similarities and differences in damage pattern. This study demonstrates that conventional hardness testing is a quasi-static loading process, but impact erosion involves higher strain rates and the effect of indenter size and geometries. Also loading applied for hardness tests can be different in comparison to erosive wear process. This can be the reason why the hardness of materials cannot be directly used in explaining the erosive wear phenomena.

Influence of particle characteristics on abrasive wear resistance of multi-layered/gradient NCr-AlSi PVD coatings P7

W M da Silva[1], V C Teles[1], S Victor[2], C A S de Oliveira[2] and J D B de Mello[1]
[1]Universidade Federal de Uberlândia, Brazil, [2]Universidade Federal de Santa Catarina, Brazil

During stamping, sliding between sheet metal and forming tool damages their surfaces. Maintenance of stamping tools involves polishing the tool edge, or, in case of severe damage, replacement of the tool. Hard coatings have been used on stamping tools to minimize these costly and time consuming operations. Sliding wear tests of NCr-AlSi coatings applied by PVD onto SRV2W tool steel have evidenced the occurrence of abrasive mechanisms on the worn surfaces, apparently caused by wear debris. In this work, the abrasion wear resistance of these coatings was investigated, where the effect of substrate surface finish and coating architecture was analyzed.

Two different coating designs were used: Multilayered and Gradient Coatings. In both coating architectures, the initial composition at the interface with the substrate was kept constant and the surface composition (NCr-AlSi ratio) was varied. Free-ball microabrasion tests were carried out using SiC, Al2O3 and SiO2. The wear rates of the multilayered coatings were higher than those of the gradient coatings. Low severity abrasion tests (SiO2) were sensitive to substrate surface topography, where the rougher substrates presented the lowest wear rates. Severe abrasion tests (SiC) showed that coatings with higher concentration of AlSi near the surface presented the lowest wear rates.

Effect of WC grain size and content on low stress abrasive wear of manual arc welded hardfacings with low carbon or stainless steel matrix P8

Vytenis Jankauskas[1], Maksim Antonov[2], Valentinas Varnauskas[3] and Remigijus Skirkus[1]
[1]Aleksandras Stulginskis University, Lithuania, [2]Tallinn University of Technology, Estonia, [3]Vilnius Gediminas Technical University, Lithuania

The abrasive wear by hard soil particles is the main factor limiting the lifetime of soil- engaging tools that is especially important for agricultural sector (tillage and harvesting tools). Manual arc welding is the easiest, convenient and economically feasible methods suitable for coating of the metallic tools in small and medium scale farms. Coating may be applied by personnel with basic welding skills and even in the open field (with portable power generators). The aim of the current work was to develop electrodes for manual arc welding enabling significant reduction of wear in three-body abrasive conditions. Reinforcement by tungsten carbide powder was used due to possibility of production these powders through recycling of hardmetal scrap. The effect of binder material (low carbon or stainless steel), WC content and WC grain size on wear resistance of hardfacings was evaluated by ASTM G65 method (Procedure B). The reduction of wear rate down to 9 times was achieved. Discussion on the mechanism of material degradation is based on SEM and EDS observations.

Micro and nano - discontinuities of chips formations in diamond foils abrasive finishing process P9

Wojciech Kacalak[1], Katarzyna Tandecka[1], Dariusz Lipiński[1] and Thomas G Mathia[2]
[1]Technical University of Koszalin, Poland, [2]Ecole Centrale de Lyon, France

The chips formation becomes recently important in abrasive high precision finishing process and particularly in case of diamond foils due to tooling cost lower when the free spaces between the grains during the process are fully utilized. The morphology of micro-chips in term of shape and seize are essential for the degree of filling of that spaces without interferences with abrasive grains actions. Systematic investigations were carried out on building up of microchips using a scanning electron and confocal microscopy. To analyze the shape of chips the number of indicators have been applied and discussed. It was stated that the part of the chips formed by the action of abrasive grains of specific shapes reduce ability to fill the free space of abrasive dynamic interface. One of investigated solutions in order to increase the efficiency of the process is the oscillating movement which has been applied during the grinding process. The phenomenon of the micro chip formation and its frequency may be determined on the basis of their characteristic of a stepped building-up process and its proliferation. It was found that the thickness of the plates forming a staggered stacked chip is about 300 nm for investigated diamond foils, which allows the estimation of slip chips components. To assess the dynamics of micro smoothing process was also developed analysis of the valleys of the scratches along the direction by an elementary grain process for depth of cut approximately 500nm.

Morphological kinetics of stainless steel surfaces in abrasive water jet process P10

Grzegorz M Krolczyk[1], Sergej Hloch[2], Thomas G Mathia[3]
[1]Opole University of Technology, Poland, [2]Technical University of Kosice, Slovakia, [3]École Centrale de Lyon, France

Brief critical bibliographical analysis is showing that scientists of manufacturing industry have studied abrasive water jet process (AWJ) since a long time, but no consensus has been found yet in fundamental mechanisms of removing and displacement of material, therefore of resulting surface morphology. Moreover, from the results which have been published are often impossible to correlate process and morphology because of their relative rareness, the large number of test devices or surface "damages"/"modifications" characterization methods. Therefore for fundamental reasons specific experimental device and strategy have been designed in order to understand better the (AWJ) process. The stainless steels have been selected to reduce corrosion and oxidation processes interferences. The results from systematic investigations of austenitic stainless steel (AISI 309) surfaces morphology in correlation to simultaneously measured vibrations modes for different (AWJ) process conditions are elucidated and discussed. Surfaces observations and 3D morphological characterizations in terms of height, amplitude, spatial, and hybrid parameters (ISO 25178) are discussed. Finally partial conclusions are stated on invariants of morphological kinetics of (AWJ) process. Perspectives in monitoring of (AWJ) machining process as well as an Adaptive Control or Self-Tuning Control of Multivariable Controllers for Multivariable Processes are discussed.

A study of the erosive wear performance of AISI T1, AISI D2 and metal Babbitt P11

J R Laguna-Camacho[1], A Marquina-Chávez[1], J E Escalante-Martínez[1], A A Patiño-Valdez[1], I Hernández-Romero[1] and M Ortega-Avilés[2]
[1]Universidad Veracruzana, Mexico, [2]Unidad Profesional “Adolfo López Mateos”, Mexico

In this work, solid particle erosion tests conducted to evaluate the wear performance and resistance of three materials, AISI T1, AISI D2 and Metal Babbitt against silicon carbide particles. The first two steels chose because of their good corrosion resistance, high hardness, high toughness and fatigue strength, while metal Babbitt was due to its high ductility. An erosion test rig similar to that shown in ASTM G76-95 standard used to perform the tests. Particle size distribution analysis conducted and the silicon carbide particles had a particle size between 350-450 µm. Tests carried out using different impact angles, 30°, 45°, 60° and 90° with a particle velocity of 24 ± 2 m/s.

The abrasive flow rate was 0.7 ± 0.5 g/min and the room temperature during the tests was between 35°C to 40°C. Chemical composition of the abrasive particles and the materials obtained using energy dispersive X-ray analysis (EDS). In addition, SEM photographs used to identify the wear mechanisms and obtained cross-section images of the wear scars on metal Babbitt to measure their depth, it because this material exhibited the most pronounced wear damage on the surface. Finally, Atomic Force Microscopy (AFM) used to compare the roughness of the surfaces.

A study of the wear damage of backhoe bucket tips P12

JR Laguna-Camacho[1], A Marquina-Chávez[1], I Hernández-Romero[1], C A Márquez-Vera[1], J V Mendez-Mendez[2], I Arzate-Vázquez[2] and H Martínez-Gutiérrez[2]
[1]Universidad Veracruzana, Mexico, [2]Unidad Profesional “Adolfo López Mateos”, Mexico

In the present study, a wear damage analysis of backhoe bucket tips from a Caterpillar Model conducted. These mechanical components were subjected to hard working for about six months. Firstly, the backhoe tips sectioned in small segments from different wear zones, and then a tribological characterization carried out for obtaining the chemical composition of the backhoe tips, which were in operation, by using energy dispersive X-ray analysis (EDS). Atomic Force Microscopy (AFM) and Surface Profilometry used to measure the roughness and obtained the profiles to have a perspective of the degradation of the surfaces of the bucket tips after real service.

Hardness tests also conducted to determine the material employed to manufacture these mechanical components. Additionally, optical microscopy and scanning electron microscopy (SEM) used to identify the wear mechanisms on the surfaces. A digital image processing with an analysis program (Image J) conducted to interpret information contained within SEM images. This allowed obtaining a more complete failure analysis and the wear mechanisms identified were severe pitting action, large grooves similar to those observed in abrasive wear, high corrosion, scratches and ploughing and cutting action.

Solid particle erosion of AISI 420 using organic abrasive particles P13

J R Laguna-Camacho[1], A Marquina-Chávez[1], J E Escalante-Martínez[1], I Hernández-Romero[1], C A Márquez-Vera[1], J V Mendez-Mendez[2] and M Vite-Torres[3]
[1]Universidad Veracruzana, Mexico, [2]Centro de Nanociencias y Micro y Nanotecnologías, Mexico, [3]SEPI-ESIME-IPN, Mexico

In this work, erosion tests carried out to evaluate the performance of AISI 420 martensitic stainless steel against organic abrasive particles such as walnut shell, pistachio shell and a conventional abrasive as glass beads. An erosion test rig similar to that shown in ASTM G76-95 standard used to perform the tests. Particle size distribution analysis conducted and the walnut and pistachio shell particles had a similar particle size around 1000-2000 µm while glass beads were between 200-240 µm. Tests carried out using different impact angles, 30°, 45°, 60° and 90° with a particle velocity of 20 ± 2 m/s. The abrasive flow rates were 200 ± 0.5 g/min for walnut and pistachio shell and 60 g/min for glass beads. The room temperature during the tests was between 35°C to 40°C. Chemical composition of the abrasive particles and the material obtained using energy dispersive X-ray analysis (EDS). In addition, SEM images used to identify the wear mechanisms. In this case, high plastic deformation observed on the surface of AISI 420. A great amount of embedded particles on the surfaces observed as walnut and pistachio shell particles used. Finally, Atomic Force Microscopy (AFM) used to compare the roughness of the surfaces.

Influence of mechanical properties and blending of rubber conveyor belts on abrasive behaviour investigated under 2- and 3-body abrasion conditions P14

W Molnar[1], M Varga[1], P Braun[2], K Adam[3] and E Badisch[1]
[1]AC²T research GmbH, Austria, [2]Semperit Technische Produkte GmbH, Germany, [3] voestalpine Stahl GmbH, Austria

Although wear of polymers is a major subject in literature, detailed information about the wear of conveyor belts and comparison to specific application is scarce. Hence a detailed understanding of lab scale tests, the employed wear mechanisms and correlation of wear and mechanical properties of conveyor belts is necessary for subsequent lifetime prediction in real applications. This includes understanding of the effects of aging on the deterioration of mechanical properties and their influence on abrasion rates.

For this work we used a standard sample (A), which is used in the industry for its good cost-performance ratio and investigated it with the well established ISO 4649 2-body abrasion test and the ASTM G65 3-body abrasion test. After the tests the volume losses were determined, wear rates calculated and the wear patterns examined by optical microscopy. Along those investigations two additional samples were characterised with either high tear strength (B) or high tensile strength (C). Both of these samples featured higher wear resistance than the standard samples.

To capitalise on the advantages, blends between A and the other two samples were made to minimize the cost-wear resistance ratio. The results showed, that even the addition of 25 % B or C reduced the wear rate by 10-20 % for the ASTM G65 and by up to 45 % for the ISO 4649 test.

Simulation of surface morphology evolution during cylinder liner plateau honing P15

Pawel Pawlus[1], Andrzej Dzierwa[1], Rafal Reizer[2], Michal Wieczorowski[3] and Thomas Mathia[4]
[1]Rzeszów University of Technology, Poland, [2]University of Rzeszów, Poland, [3]Poznań University of Technology, Poland, [4]Ecole Centrale de Lyon, France

The surface morphology of cylinder bores is one of the most substantial factors influencing the friction, wear and lubrication of co-acting surfaces within the engine. Plateau honing process is commonly applied to receive the specific surface texture.

In experiment, after boring, the plateau-honed cylinder bore surfaces, made from grey cast iron, were produced in a three-stage process. The first stage of the process, rough honing, using diamond stones, removed material to improve the cylindricity of the bore. Then cylinder liners were divided into two groups. Liners from the first group were coarse and then plateau honed by diamond stones, but liners from the second group by ceramic stones. After coarse honing, plateau honing was carried out for three different plateau honing times.

The plateau honing process was simulated by imposition of random two-directional surface, of Gaussian ordinate distribution, inclined to axial cylinder direction, on the base surface obtained after coarse honing. Then other two-directional surface of normal ordinate distribution was imposed on the computer created plateau honed texture. The imposition process was repeated, the number of iterations was related to plateau honing time. The matching accuracy of modeled and measured liner textures was assessed by set of surface morphology parameters.

Investigation of abrasive wear processes in electrical submersible pumps P16

M V Prozhega, N I Smirnov and N N Smirnov
Institute for Machine Science named after A.A.Blagonravov, Russia

An electrical submersible pump (ESP) for oil production is complex mechanical system, the reliability of which depends of details wear resistant. ESP consists of a large number of impellers and diffusors, the wear of mating surfaces which leads to a pressure decrease, as well as a vibration increase of the pump body and as a consequence of its destruction. The inner surfaces of diffusors and housing parts are destroyed under the action of the corrosive liquid containing abrasive particles. Also intermediate WC-Co hard alloy bearings wear in a liquid medium. The aim of present work is to develop of procedures and test machines for investigation abrasive wear in ESP. It was shown that the greatest resistance to wear have hard alloys with a higher stress intensity factor KIC. Hard alloy WC-Ni (92/8) has a higher wear resistance of 30...32% compared to the tested materials based on WC-Co. Test machine for the corrosion-erosion wear was developed.

Tribo-corrosion maps for titanium/titanium carbide composite coatings P17

G Rasool and Margaret Stack
University of Strathclyde, UK

Tribo-corrosion describes the combined action of wear and corrosion. It occurs in many conditions ranging from energy conversion environments to bio-medical conditions. Progress in the understanding of tribo-corrosion has led to the description of the wear-corrosion process in terms of regimes. These regimes enable the degradation to be classified in terms of wear or corrosion dominated behaviour. Such an analysis provides a means of generating tribo-corrosion maps of the overall regimes encountered.

Tribo-corrosion resistance can be increased by development and using the different methods and techniques of surface engineering. In this project, the research work was carried out on the tribo-corrosion behaviour of titanium and titanium carbide composite coatings produced by Tungsten Inert Gas (TIG) process in collaboration with IIUM Malaysia. The materials were tested on a pin-on-disk sliding wear testing rig. Tribo-corrosion maps constructed for these materials check the integrity of TiC composite coatings. Mild wear regime area expanded due to the presence of TiC coating towards higher sliding speed and normal load.

Bio-tribocorrosion in orthopaedic devices: mapping the micro-abrasion-corrosion behaviour of a simulated CoCrMo-UHMWPE hip replacement couple in calf serum solution P18

K Sadiq, Margaret Stack and R A Black
University of Strathclyde, UK

Load bearing prosthetic implants such as orthopaedic hip and knee replacements may be considered tribo-corrosion systems. The success of an implant depends on a number of factors, including patient age, body weight and activity levels. Pre-clinical testing is crucial in assessing and predicting the long-term performance of an implant, including safety, reliability and patient outcomes. This study investigates a CoCrMo-UHMWPE couple in a biological solution of 0.9% NaCl and 10% foetal calf serum (FCS) in order to simulate physiological conditions of a hip prosthesis metal-polymer couple in-vivo. The effects of applied loads and applied potentials were investigated to assess the wear mechanisms. Micro-abrasion-corrosion maps have been constructed as a result of this work. The maps identify zones of wear mechanisms, wastage rates and synergistic behaviours for the implant couple over the range of testing conditions.

Microscale investigation on grindability of a new high speed steel grade for cold work rolls using scratch tests with real grain P19

Haifa Sallem and Hedi Hamdi
University of Lyon, France

Grinding is an abrasive process, which involves various complicated tribological interactions between the material and the wheel. In order to study the grindability of a new high speed steel grade with particular microstructure used for cold work rolls, simulations by linear scratch tests using different type of abrasive grains, were proposed.

Firstly, different types of abrasive grains were tested in order to largely characterize the response of such grade when subjected to abrasive material removal. Beside classical abrasives (white alumina, brown alumina and Zirconium), specific indenters constituted of the super abrasive Cubic Boron Nitride (CBN) were considered in this study. The grain is dragged across a surface under a known load at a constant low speed. It was found, after characterization, that classical abrasive as well as zirconium are easily broken and worn facing to vanadium and chromium carbides. Specific energy has been determined from the removed material volume and friction load. It shows that the CBN is the most appropriate abrasive to grind the High Speed steel.

Secondly, the effect of attack angle and normal loading on the overall friction coefficient and deformation behavior was studied using conical CBN indenter. Analytical Tabor's model was used to determine the relationship between the adhesion friction coefficient and the plastic deformation friction coefficient. It was found that the adhesion effect is more influential at small attack angles.

Numerical and experimental analyses of scratch tests on two-phase microstructure of tool steels P20

Vanessa Seriacopi, Newton Kiyoshi Fukumasu, Erika Fernanda Prados, Cristiano Fernandes Lagatta, Roberto Martins de Souza and Izabel Fernanda Machado
Polytechnic School of the University of Sao Paulo, Brazil

Abrasive wear is one of the main damage mechanisms leading to tool steel failure during forming processes. The present study has investigated the effects of abrasion micromechanisms (micro-ploughing and micro-cutting) on the microstructure of a two-phase tool steel. Experimental scratch tests were conducted by sliding a diamond tip over a tool steel slab considering different values of normal load. The same procedure was simulated using the Finite Element Method, allowing the analysis of the interaction between the indenter tip and the microstructural components, as well as the analysis of the effect of precipitate distribution. The simulations considered elastic precipitates immersed on an elastic-perfectly plastic matrix. Results have indicated the importance of the ratio between the abrasive particle size and the size of the second phase particles, as well as the ratio between the hardness of the abrasive particles and that of the steel matrix.

Micro-Abrasion-Corrosion Mapping of 316L Stainless Steel in Artificial Saliva P21

Shayan Sharifi, Andrew Hayes and Margaret M Stack
University of Strathclyde, UK

The performance and longevity of foreign fixed materials in the oral cavity depend on many tribological interactions. AISI 316L stainless steel has been widely used for dental applications due to its resistance to corrosion, durability and low cost. The aim of this work is to investigate the tribological behaviour of SS316L under micro-abrasive-corrosive conditions in artificial saliva with (simulating food bolus) and without particles in order to have a closer simulation to the oral cavity mediums.

The test variables are applied load, applied potential and sliding distance. The results of this work show that the wear of the material is dominated mechanically; however, there is a form of proportionality between the abrasive and corrosive wear. Accordingly, changes of the applied potentials do not cause any significant effects on the material loss. Also, the presence of abrasive particles reduces the corrosion potentials for different loads whereas the applied load alterations in the absence of abrasive particles do not affect the corrosion potentials significantly and they vary within a relatively smaller amplitude. The results also show that the severity of wear decreases by increasing the applied load which can be due to the difficulties in particles rolling in higher loads.

Abrasion resistance of 17% Cr white cast irons P22

Jan Suchánek
Czech Technical University, Czechoslovakia

Abrasive wear is responsible for intensive degradation of machine parts or tools. This process starts as an interaction between hard, mostly mineral, particles and the working surface. Methods of increasing the lifetime are based on application of abrasion resistant materials or creation of hard, wear-resistant surface layers or coatings on the surfaces of machine parts or tools. High abrasion resistance have chromium ledeburitic steels, high-speed tool steels or chromium white cast irons. The microstructure of chromium white cast irons consists of tough matrix and very hard complex carbides. The matrix of the chromium white cast irons can be changed by heat treatment. The abrasion resistance of several 17% Cr white cast irons was tested at different parameters of heat treatment. Results of laboratory tests of 17% Cr white cast irons were compared with the results of tests of chromium white cast irons Cr27 and Cr15Mo2.

Abrasive slurry jet micro-machining of talc filled polypropylene co-polymer P23

N Tamannaee[1], JK Spelt[1] and M. Papini[2]
[1]University of Toronto, Canada, [2]Ryerson University, Canada

Abrasive slurry jet micro-machining (ASJM) is relatively new machining technique which is capable of creating micro-features in a variety of materials such as metals, glass and polymer. The jet diameter is often small enough to produce high-resolution features without the use of the erosion-resistant masks typically used with abrasive air jet micro-machining (AJM). The present research investigated the use of ASJM to micro-machine planar areas and the edges of a talc-filled thermoplastic olefin.

The erosion behavior and machinability of TPO (60% PP, 25% EP rubber and 15% Talc) was explored using fundamental erosion tests and the effect of talc filler content was measured. A ductile erosion response was observed, showing maximum erosion rate at 45°.

A superposition model was then developed to predict the cross-sectional shapes of small-scale flat-bottomed pockets and curved edges machined in TPO. The model was based on the distribution of the erosion measured during a shallow “first pass” channel at a specific angle. The model predictions were in close agreement with experimental measurements.

Abrasive wear of selected steels, cermets and hardfacings P24

R Tarbe, P Kulu, A Surzenkov and K Talviste
Tallinn University of Technology, Estonia

The main goal of the present work was to study the abrasive wear behaviour of different wear resistant steels, hardmetals/cermets and advanced hardmetal/cermet particle reinforced PTA-hardfacings.
The following wear resistant steels were under the study: (a) hardenable B-steel, (b) hardened SSAB steels from Hardox series and steel C45 as a reference material.

WC-Co hardmetals and TiC-NiMo cermets with different binder content were studied from the ceramic-metallic composites.

Different hardfacings like (a) experimental PTA-welded Ni- and Fe- based self- fluxing alloys reinforced with recycled cermet hard phases and (b) commercial composite wear plates were investigated.
Abrasive wear of investigated materials was evaluated by (a) abrasive rubber-wheel wear test based on ASTM standard G65, (b) abrasive erosion wear test according to GOST standard and (c) abrasive impact wear test developed in Tallinn University of Technology. Fracture characteristics were evaluated by Charpy impact test.

The dependence of wear resistance from hardness-toughness properties of steels, cermets and hardfacings was investigated, wear mechanisms were studied and wear maps composed. Recommendations for materials and coatings selection for realistic wear conditions and applications are proposed.

Experimental simulation of abrasive wear of hot sieves P25

M Varga[1], L Widder[1], R Kirchmayer[2], K Adam[3] and E Badisch[1]
[1]AC²T research GmbH, Austria, [2]Castolin GmbH, Austria, [3]voestalpine Stahl GmbH, Austria

Hot sieves are necessary for screening materials processed at high temperatures, such as sinter in the steel industry. The interaction of abrasives with the sieve openings causes wear, especially at the acute-angled top edges and leads to the widening of the sieve openings.

Currently a hypereutectic alloy with high amount of hard phases is used. The widening of the openings was documented over the life time of a sieve used in a field application. It was found that especially early wear at the edges leads to significant geometry changes and widening of the sieve openings, while later wear progress is slower. Hence the blunting resistance of the used material is essential for increasing the sieve’s lifetime.

In order to investigate the wear resistance, cyclic impact abrasion tests (CIAT) were performed with standard quartz sand abrasives, as well as with custom sinter material from the field application. It was found that the wear progress can be simulated with the test and early damaging mechanisms can be investigated in detail.

Based on the findings of this work future improvement of the blunting resistance of the high loaded edges will be applied, e.g. by using highly sophisticated high temperature wear resistant materials.

Shadowing in barrel finishing a new surface finish distribution characterised by areal surface metrology P26

K Walton, L Blunt and L Fleming
University of Huddersfield, UK

Mass finishing or barrelling, is amongst the most widely employed finishing processes in manufacturing, seen in a wealth of applications from deburring, edge radiusing, and burnishing. Processing objectives too are varied, ranging from the strictly cosmetic to the functionally critical. One such critical application is the polishing to a hydraulically smooth finish of jet engine component gas washed surfaces (compressor blades). Well known in the field is the phenomenon of shadowing, where, depending on component geometry surface finish may vary, for example at the base of an internal corner. Employing areal parametric analysis the spatial distribution and surface character of a new shadowing effect is described. It is shown that the square cut edge of a flat plate generates a shadowed region on the plate surface around its periphery. A mechanism is outlined for the process deficit caused by the plate edge which results in the observed shadow. Additionally a correlation is illustrated between the increased abrasion (radiusing) ubiquitous on the plate edge and the deficit adjacent to it as detailed here. In addition to the variation in surface finish, the findings here extend the understanding of shadowing, and the mechanics of the abrasive interactions seen in this process group.

Influence of the abrasive slurry concentration on the coefficient of friction of different thin films submitted to micro-abrasive wear

P27

Jorge Thiago de Sousa Lima Wilcken[1] and Ronaldo Câmara Cozza[1,2]
[1]University Center of FEI – Educational Foundation of Ignatius "Padre Sabóia de Medeiros", Brazil,
[2]CEETEPS – State Center of Technological Education "Paula Souza" Technology Faculty – FATEC, Brazil

The purpose of this work is to study the influence of the abrasive slurry concentration on the coefficient of friction of thin films submitted to micro-abrasive wear. Initially, a micro-abrasive wear testing by free rotative ball equipment was designed and constructed, able to measure the coefficient of friction on the tribo-system "thin-film– abrasive slurry – ball". After, experiments were conducted with thin films of TiN, TiC, CrN, TiAlN, HfN, ZrN, TiZrN, TiN/TiAl (multi-layer), TiHfC and TiHfCN, balls of AISI 52100 steel and abrasive slurries prepared with black silicon carbide (SiC) particles + glycerin. All tests were conducted without interruption, and the abrasive slurry was continuously agitated and fed between the ball and specimen. The tangential (T) and normal (N) forces were monitored throughout the tests and the coefficient of friction (u) was calculated by the equation u = T/N. The results obtained have shown that the concentration of abrasive slurry affected the actions of the abrasive wear modes (grooving abrasion or rolling abrasion) and, consequently, the magnitude of the coefficient of friction: high abrasive slurry concentration was related with low coefficient of friction.

Identifying process stiffness parameters through a single grinding process

P28

Chung-Yung Wu[1], Kuo-Hua Chen[1], Jiunn-Jyh J Wang[2] and Huang-Chuan Chang[3]
[1]China Steel Corporation, Taiwan, [2]National Cheng Kung University, Taiwan, [3]Chung-Hsin Electric and Machinery Manufacturing Corporation, Taiwan

Grinding process stiffness parameters, including the contact stiffness, wheel wear stiffness, and work grinding stiffness, play important role in designing an efficient, stable grinding process, but are difficult to quantify in an industrial setting, especially for a large work roll grinding process. The papers presents a method for identifying the major process stiffness parameters through a single grinding process. The grinding process is designed to carry out on a work roll in a spiral path. Although the width of the spiral path is defined by the grinding wheel width in the steady state operation, its width is a divergent one near the process entry point where the wheel starts engaging with the work roll. This transient, divergent area offers a variable grinding width with corresponding variation of grinding depth along the spiral path. By choosing two different width at this divergent regions and measuring their respective groove depth allows the three grinding process stiffness parameters to be calculated from their respective analytical algebraic formulas. These formulas are derived and expressed in explicit function of two pair of groove widths and depths, and grinding parameters including the nominal feed depth, wheel and work speed, machine stiffness and measured grinding ratio.

Microstructural characterization of 690 nickel based alloy induced by hand disc grinding process and SRHT

P29

S Youssef[1], O Calonne[2], Ph Gilles[2] and H Hamdi[3]
[1]National School of Mechanical Engineering and Microtechnology (ENSMM), France, [2]AREVA NP, France
[3]University of Lyon, France

The understanding of the microstructural modifications occurring during the final stage of manufacture of nuclear power components is important. This will contribute to the challenge to develop predictive models of the susceptibility of a component to stress corrosion cracking. A multi-scale characterization protocol based on several methodologies like the electron backscatter diffraction technique and X-Ray diffraction among others has been developed to identify the microstructural changes induced by hand grinding process and its evolution after a stress relief heat treatment (SRHT). Residual stress distribution and crystallographic information about the microstructure, the texture and the grains disorientations were analysed. A methodology based on EBSD measurements was developed to quantify the level of plastic strains induced by the hand-disc grinding process before and after the SRHT. The high level of the plastic strain quantified in the near ground surface, has enabled the emergence of the static recrystallization phenomenon after a SRHT at 610°C for 10 hours.

Residual stress computation induced by hand grinding process P30

S Youssef[1], O Calonne[2], Ph Gilles[2] and H Hamdi[3]
[1]National School of Mechanical Engineering and Microtechnology (ENSMM), France, [2]AREVA NP, France
[3]University of Lyon, France

Hand grinding process is a manual process often used to give specific surface characteristics for non-destructive controls or to level of welds. Several tools can be used such as disc-grinding wheel or cup-grinding wheel and so on. Recent investigations have shown that the residual stresses profiles on and below the ground surface hardly depend on the manufacturing procedure and the way operators act. Differences are visible in the applied load, the feed speed and the tilt angle of the tool and the surface. A high level of tensile stress is obtained in some cases. Integrity is strongly affected by those processes and consequently influences the surface behaviour in terms of resistance to corrosion, stress corrosion and crack initiation. This operation is difficult to master due to its manual nature.

The aim of the present study is to give new modelling approaches to compute residual stresses induced by hand-disc and hand-cup grinding. The moving heat source is well adapted for this kind of problem. The difficulties are to give the level of heat energy entering the Workpiece for those manual processes. Analytical formulation given the heat flux density versus the process parameters is performed in each case by a local analysis of the grinding contact area. Calibrations are done using an inverse FEM and experimental method using embedded thermocouples. The heat flux and its distribution in the grinding area are then entirely known and FE simulations are performed with SYSWELD.

Wear behaviour of doped WC-Ni based hardmetals P31

Der-Liang Yung, Maksim Antonov and Irina Hussainova
Tallinn University of Technology, Estonia

Cemented tungsten carbide systems have been widely used in machine tools, ammunition rounds, and sporting equipment, etc. as they possess the necessary combination of hardness and toughness to endure wear environments. In most applications, the abrasion phenomena has been identified as one of the sources of surface damage and material degradation. In this work, WC hardmetal is doped with zirconia, zirconium carbide, or titanium carbide to improve the abrasive wear resistance. Yttria stabilised tetragonal zirconia is known to induce phase transformation toughening by hindering crack growth, while TiC has been known to produce platelet grain structure meant for strengthening leading to abrasion enhancement. Tribological characteristics are obtained from dry abrasive paper sliding, slurry, and erosion tests. The erosive wear rate and abrasive wear resistance of our samples differ depending on which test is applied. Wear rate and mechanisms of wear are analysed by and discussed based on scanning electron microscopy and electronic dispersive x-ray spectroscopy studies.

General Information

Conference Venue
Institute for Manufacturing (IfM)
Alan Reece Building
University of Cambridge
Cambridge
CB3 0FS, UK

Tel: +44 1223 766141

The sessions will take place in the Lecture Theatre at the IfM.

Registration
Registration for the conference will take place in the main reception area at the IfM from 09.00 - 10.00 hrs on Monday 8 September.

Please go to Reception if you have any queries at any other time.

Informal Reception and Poster Session
This will take place on the evening of Monday 8 September at the IfM, providing an opportunity for discussions with the authors of poster presentations and informal networking.

Conference Dinner – Tuesday 9 September
The main social event takes place at Gonville and Caius College in the Dining Hall.

Pre-dinner drinks will be served in the Green Room at 19.00 hrs and dinner in the main Dining Hall at 19.30 hrs.

Refreshments and Lunch
Refreshments and lunch will be available at the times indicated in the programme. Please let us know if you have any dietary requirements.

Walking Tour
There will be an optional walking tour on Tuesday 9 September at 18.00 hrs around the city centre, with a tour guide. The tour will start at 18.00 hrs from adjacent to Queens College (maps will be provided on arrival at registration) and will finish at Gonville and Caius College at 19.00 hrs, in time for the dinner drinks reception.

Internet Access
Internet access is available at the IfM using eduroam. Alternatively you can access the guest network for which you will need to collect a login code from IfM Reception.

Conference Organisers
University of Cambridge
Department of Engineering
Trumpington Street
Cambridge CB2 1PZ
United Kingdom