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Tribology is concerned with the influence of mechanically applied forces on interfacial phenomena that accompany and control sliding, including frictional dissipation, wear and tribochemical reactions. A wide range of models have been developed to describe these phenomena.

In this talk it is shown that most of these apparently disparate models are based on the same fundamental concept; that an externally applied force accelerates the rate of thermal transition of atoms or molecules across energy barriers present in solid and liquid materials, thereby promoting flow, slip or bond cleavage. This concept was developed independently and in different forms by Prandtl in 1928 to describe crystal plasticity [1] and Eyring in 1936 to model liquid viscosity [2]. These two works have underpinned subsequent theories of dry friction, boundary lubrication, EHD rheology, tribochemistry and nanoscale wear.

This paper first reviews the historical development of the stress-assisted, thermal activation concept, focussing in particular on the models of Prandtl and Eyring and showing how these have subsequently been adapted and used by others.

The two approaches are then compared and contrasted, noting that although superficially similar, they contain quite different assumptions and constraints. Prandtl’s model is developed from an essentially mechanics viewpoint while Eyring’s is based on a chemical thermodynamics approach. These very different origins lead to important differences between the models which are only now being fully understood.

It will be shown that the overall principle of stress-assisted, thermal activation lies at the heart of our understanding of tribological processes and provide a key link between observed macro-scale tribological phenomena reactions and their atomic and molecular origins.
In order to formulate high performance lubricants base fluids with outstanding properties have to be used. The following fluids are available: new developed mineral oils, synthetic oils, environmentally acceptable oils and fire resistant oils. Of course additive packages have to be incorporated into the base fluids to fulfil the requirements of the specific application. The most important base oils are based on mineral and synthetic stocks.

In the field of mineral oils tremendous advantages during the last years or even decades could be achieved. In the field of paraffinic oils sulphur content cold be decreased and VI could be increased. Also the properties of naphthenic oils now allow more application fields as in the past. An important step forward could be achieved realizing new refining processes for mineral oils using new base stocks. Besides the hydrocrack oils, based on crude oils, gas-to-liquid (GTL)-, coal to liquid (CTL)- and biomass to liquid (BTL)-oils complete the list of base oils for high performance applications.

Despite these tremendous improvements in the field of mineral oils the application depending requirements in some fields characterized by low and high temperature behaviour, oxidation stability, viscosity index and other properties can exceed the possibilities of mineral oils. Especial the excellent general properties of polyalphaolefins, some esters and polyglycol types allow the formulation of lubricants for applications where service times, extreme low and high temperature suitability or compatibility with certain materials are required. In these cases e.g. silicon oils, polyphenylethers or polybutens can be used to formulate high performance lubricants.

In principle it can be stated that synthetic oils will be used if mineral oils with additives cannot cover the requirements of the frictional contacts or the specific applications.
CFD Modeling of Elastohydrodynamic Lubrication Using Reduced FE-Models

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Typically, simulations of elastohydrodynamic lubrication (EHL) are based on the Reynolds equation derived by Osborne Reynolds more than 100 years ago. This equation is a simplification of the full Navier-Stokes equations and can be derived by neglecting inertia and gravity terms and assuming velocity gradients along the contact length to be small compared to the gradients across the fluid film. Additionally, pressure changes across the fluid film are not considered and hence, a constant pressure in this direction is assumed. By using a CFD (computational fluid dynamics) approach, the full Navier-Stokes equations can be solved and the previously mentioned limitations can be overcome. As a result, the computational domain can be extended to include inlet and outlet regions of the contact. Furthermore, the implementation of complex rheological models is straightforward as fluid parameters are fully resolved within the lubricant.

In the last years, several authors have presented CFD simulations of elastohydrodynamic contacts. In those models, the deformation of the solid is either determined by means of the elastic half-space [1, 2, 3] or by a coupled simulation of both the fluid and the solid domain, known as fluid-structure-interaction (FSI) [4]. The former approach is limited to simple geometries but very fast and efficient. In FSI simulations, the solid can have any arbitrary shape. However, the necessary calculation time is significantly higher.

Therefore, a method to reduce complex geometries, usually applied in multi body simulations, is adopted. This way, the elastic behavior of complex solids can be represented, while keeping the simulation time within reasonable limits.

In this contribution, funded by the Excellence Initiative of the German federal and state governments, the Guyan reduction method is described and applied to an elastohydrodynamic line contact. The governing equations of the CFD model developed in the freely available package OpenFOAM Extend are presented, including cavitation as well as shear-thinning and pressure dependent viscosity behavior of the compressible fluid. Special attention is given to the implementation of the reduced FE-models and the deformation of the computational fluid mesh in both serial and parallel simulation runs. Comparisons are made between simulation results of models using the classical theory based on the elastic half-space and models employing the reduced FE-model in order to verify the implementation.

TITLE
Dimensionless parameter groups and lubricant property models for EHL simulation

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ABSTRACT
Formulas generalizing EHL contact performance are typically expressed terms of dimensionless parameter (DP) groups, e.g. Hamrock and Dowson, or Moes. They are derived under the assumption of a Newtonian, isothermal, incompressible, and Barus-piezoviscous lubricant. These DP groups are less applicable under other circumstances and considerations as is demonstrated for a compressible lubricant with Roelands-type viscosity. Modern interest in traction force simulation requires TEHL analysis with additional knowledge of non-Newtonian rheology and the temperature-pressure dependent viscosity. These property data are lacking for a wide range of conditions realized in tribological contacts, implying that their extrapolations applied in EHL simulations are open to interpretation. Without accurate knowledge of the lubricant property data and appropriate models thereof, derivation of more widely applicable DP groups will not be attainable; further quantitative assessments are needed.
FLEXIBLE MULTI-BODY SIMULATION INCLUDING NON-CONFORMAL CONTACT SIMULATION BASED ON ELASTOHYDRODYNAMIC LUBRICATION THEORY

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Abstract:

The evaluation of lubricated contacts is an essential step in modern engine simulation to estimate runtime behavior and wear. The prediction of contact pressure and oil film height poses a complex task, especially in non-conformal conjunctions such as between a cam and a follower. A deep investigation of the occurring thin oil films is important to estimate friction and wear. Elastohydrodynamic Lubrication (EHL) theory investigates these contacts with high pressure and thin oil films.

In previous decades efficient algorithms and relaxation strategies have been introduced to solve the line contact problem in EHL. The algorithms analyze the underlying equations in detail and solve the resulting equation system efficiently.

One key feature of a tool for multi-body simulation is a versatile yet consistent modeling of the fundamental equations. Different demands on the model result in the need for variable modeling depth (e.g. consideration of cavitation and/or friction) and discretization techniques. An EHL solver needs to adapt to the changing conditions and requirements without customizing the implementation. Additionally, consistent run time behavior and results need to be guaranteed.

This paper shows an embedding of a generic EHL module in a flexible multi-body dynamic tool. The module will be used to simulate the oil film lubricated coupling of cam and follower contacts in an internal combustion engine. A four cylinder engine with eight valves and a cam shaft will be used to outline the effects of hydrodynamic conjunctions in valve train simulation.

The resulting body motions will be compared to a simpler contact model. The simpler model disregards hydrodynamic influences and uses a penalty formulation to calculate the resulting contact forces.

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CFD Modeling of Cavitation Flow in Journal Bearing Lubrication

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1. Introduction

According to Richardson [1], Mechanical friction takes away 4-15% of total energy from a fired engine of which 40-55% is due to the losses in the pistons, rings and connection rod bearings. The rod bearings are responsible for around 0.3 to 2.7% of total energy loss in an engine. Therefore, in order to reduce power loss and improve engine performance, it is important for tribologists to have a deep understanding of lubrication phenomena at the connection rod bearings.

2. Governing Equations and Simulation Method

A schematic of the big end bearing used in the IC engines is shown in Figure 1.

![Figure 1: An elliptic big end bearing configuration](image)

The contact is divided into two distinct regions: (i) full film, (ii) film rupture and cavitation (Figure 2). To describe the physics of fluid flow in the cavitated region, in which two state phases of lubricant co-exist at the same time, a suitable two-phase flow model needs to be employed alongside with the Navier-Stokes equations.

![Figure 2: Fluid flow through cavitation zone](image)

The fluid flow is governed by the 3D compressible Navier–Stokes equations:

\[
\rho \frac{D\mathbf{V}}{Dt} = -\nabla p + \nabla \cdot (\tau_{ij}) + \mathbf{F}
\]

(2)

where \( \frac{D}{Dt} \) is the covariant derivative operator, \( \rho \) is the lubricant density, \( p \) is the pressure, \( \tau_{ij} \) is the viscous stress tensor and \( \mathbf{F} \) is the body force field vector. In addition, \( \mathbf{V} = U\hat{i} + V\hat{j} + W\hat{k} \) is the velocity vector in which \( U \) is the component of velocity in the direction of axial lubricant flow entrainment, \( V \) is an axial velocity and \( W \) is the squeeze film velocity, \( \partial h/\partial t \). The viscous stress tensor is:

\[
\tau_{ij} = \eta \left( \frac{\partial U_i}{\partial x_j} + \frac{\partial U_j}{\partial x_i} - \frac{2}{3} \frac{\partial V}{\partial x} V_{ij} \right)
\]

(3)

where \( \eta \) is the effective lubricant dynamic viscosity, \( \delta_{ij} \) is the Kronecker delta and it is defined as:

\[
\delta_{ij} = \begin{cases} 0 & \text{if } i \neq j \\ 1 & \text{if } i = j \end{cases}
\]

(4)

To better understand the flow behaviour through the connection rod bearing, a detailed CFD based simulation of the two-phase flow for the 3D geometry is performed, using the commercial CFD software ANSYS Fluent.

3. Results

The pressure profile through the circumferential centre line is illustrated in figure 3. The positions of high pressure and cavitation zones as well as lubricant film rupture and film reformation points can be seen from figure 3.

![Figure 3. Pressure distribution in the centre plane at crank angle 180°](image)

References

The challenge of the erosive wear evaluation of thermally sprayed coatings

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To simulate the erosion wear events subjected to water and wind turbine blades, solid particle erosion tests, with and without water have been, respectively, performed on two thermally sprayed coatings. 30° and 90° erosion impingement angles have been used to evaluate the tribological behavior of these coatings. We used a mask to obtain an effective and well-determined eroded surface. The solid particle erosion test at the impingement angles 30° and 90° implies: i) different amount of erosive particles that are striking the surface, as well as, ii) different eroded surfaces. Therefore, we corrected the wear values by considering these previous factors. The volume loss per particle impact has been considered as the wear rate.

In solid particle dry conditions, both thermally sprayed coatings, surprisingly, showed a brittle behavior, whereas, in the wet erosion conditions, the coatings showed a ductile behavior, the wear mechanisms have been investigated in order to understand this paradoxical tribological behavior. As a result, we found, the severity of the thermodynamic parameters, and consequently, the resulted wear mechanisms, are the most important factors that determine the tribological responses when the coatings were subjected to high local stresses by erosion. Furthermore, by using a semi-empirical physical model to predicate the wear rate, the scatter found between the predicted wear value and the experimental one was estimated to be up to 3 factors, this scatter was mainly due to the microstructural features of the coating, as well as to the model assumption, e.g. erosive particle size, geometry, density, speed, etc.

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Experimental and Theoretical Study on the Effect of Nitriding on the Running-In Behavior of Lubricated Sliding Contact

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Abstract

Running-in is the early stage of the operation of a mechanical element in which asperities experience elastic and plastic contact. The operating conditions of this stage largely affect the steady-state performance of the tribo-system. In this research, friction and wear of nitrided and un-nitrided disks are experimentally and numerically studied. The experiments are conducted using pin on disk test rig on samples made from 4140 steel. A numerical model based on the load-sharing concept has been developed to predict the friction coefficient, surfaces' temperature, film thickness, and wear rate. The lubricant temperature along with the friction coefficient is used to predict the wear volume using the fractional film defect theory. The results for un-nitrided disks indicate that increasing the speed results in a higher lubricant film thickness and thus the wear volume decreases. Increasing the applied load, on the other hand, results in a decrease in the film thickness and as a result the wear volume increases. In the nitrided case, the wear volume is a function of load only and does not depend on the speed. The diagrams of wear volume versus sliding distance show a running-in period approximately before 1500 m after which the wear rate stabilizes. Friction coefficient and wear volume results are shown to be in an acceptable agreement with the simulation results.

Keywords: Running-in, Nitrided disks, Friction coefficient, Wear prediction, load-sharing.
Evaluation of tribological performance of novel multilayer tin-based overlays for plain bearing applications

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Abstract

Ever increasing demand for lower NOx levels in exhaust emissions and higher fuel efficiency of internal combustion engines is raising the firing loads above the capability of many current overlay materials for the plain bearing applications [1]. Electroplated tin based overlays are known to be highly effective owing to their excellent sliding properties, high corrosion resistance and reasonable mechanical strength [1, 2]. Recent development of the novel multilayer Tin-Copper (Sn-Cu) overlays for plain bearings by the authors is a major advancement in fatigue, wear and seizure resistance capabilities [1, 2]. This improved performance is owing to the introduction of a Tin-Nickel intermetallic sublayer in the multilayer system of Sn-Cu overlay alongside reducing the thickness of sublayers. Figure 1 shows the structure of multilayer Sn-Cu overlay compared with a commercial monolayer Sn-Cu overlay. In this article, authors present the further experimental evaluation of tribological performance of this newly developed multilayer Sn-Cu overlay.

Table 1: Structure of multilayer and monolayer Sn-Cu overlay [1, 3]

<table>
<thead>
<tr>
<th>Layer</th>
<th>Monolayer</th>
<th>Multilayer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st layer, Top</td>
<td>Sn-Cu (3 wt%)</td>
<td>Sn-Cu (3 wt%)</td>
</tr>
<tr>
<td>Materials</td>
<td>Sn-Cu (3 wt%)</td>
<td>Sn-Cu (3 wt%)</td>
</tr>
<tr>
<td>Thickness</td>
<td>8 µm</td>
<td>8 µm</td>
</tr>
<tr>
<td>2nd layer, Middle</td>
<td>n/a</td>
<td>Sn-Ni (27 wt%)</td>
</tr>
<tr>
<td>Materials</td>
<td>n/a</td>
<td>Sn-Ni (27 wt%)</td>
</tr>
<tr>
<td>Thickness</td>
<td>n/a</td>
<td>4 µm</td>
</tr>
<tr>
<td>3rd layer, Bottom</td>
<td>n/a</td>
<td>Sn-Cu (3 wt%)</td>
</tr>
<tr>
<td>Materials</td>
<td>n/a</td>
<td>Sn-Cu (3 wt%)</td>
</tr>
<tr>
<td>Thickness</td>
<td>n/a</td>
<td>8 µm</td>
</tr>
</tbody>
</table>

Unidirectional multi-pass scratch tests using Bruker UTM scratch tester were performed on multilayer Sn-Cu overlays plated on different lining materials. Comparison of friction coefficient and wear scar characteristics was made with different Sn-based overlays developed in past by Daido Metal. Each test involved a ball probe (Material = 100Cr6; Diameter = 6.35 mm) sliding across the length of circumferential section cut from half bearing samples plated with a specified overlay. Constant load of 60 N and speed of 10 mm/min were maintained during 60 sec of sliding after which probe returns to initial position, and the same process is repeated for 40 and 50 times. 0.014mL of high temperature lubricant (ROCOL LX544/175/2) was applied onto test surface maintained at 130°C. Wear characterisation of scratches was performed by surface profiling, micro cross-sectional analysis and optical imaging. Results revealed multilayer Sn-Cu overlays with superior anti-friction and anti-wear performances compared to the other overlays.

References:

Boron-doping effect on crystal structures and tribological properties of CVD diamond films

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Keywords: Diamond, Boron doping, CVD, Friction, Water.

Chemical vapor deposition (CVD) diamond film is well known for its outstanding physical and chemical properties. In order to enhance their properties, effects of dopants such as boron, nitrogen, phosphorous and sulfur in CVD diamond films have been widely investigated [1]. Liang et al. reported that the boron-doped diamond (BDD) film is superior to non-doped films in terms of enhancing mechanical strength and oxidation resistance [2]. Therefore, the BDD films show a lot of promise in improving friction and wear properties. However, tribological characteristics of the BDD films have not been sufficiently clarified for application as sliding materials. In this study, we examined the effects of boron doping on the tribological properties of the CVD diamond films under lubrication with water. The BDD films of different composition ratio of boron to carbon (B/C ratio) were prepared. The B/C ratios were defined as the flow ratio of Trimethoxyborane to Methane in CVD process to estimate the doping amount of boron in the diamond films. Friction and wear tests of the BDD films was carried out by using a ring-on-ring sliding tester, which was designed to simulate the sliding condition of mechanical seals and thrust bearings in a water pump.

Figure 1 shows SEM micrographs of the non-doped and the BDD films before the sliding test. The well-faceted diamond crystals were confirmed at a B/C ratio of 1100 ppm. In contrast, small crystal defects were confirmed at a B/C ratio of 2200 ppm and the well-faceted diamond crystals were not observed at a B/C ratio of 3800 ppm. Figure 2 shows the friction coefficients of the BDD films. The BDD film at a B/C ratio of 1100 ppm showed low friction coefficient of 0.04 which is equivalent to that of the non-doped diamond initially. However, in a case of the non-doped diamond film, an increment of friction coefficient was observed. On the other hand, the friction of the BDD film at a B/C ratio of 1100 ppm was decreased with the sliding distance.


Fig. 1 SEM micrographs of BDD films
(a) B/C = 0 ppm  (b) B/C = 1100 ppm
(c) B/C = 2200 ppm  (d) B/C = 3800 ppm

Fig. 2 Friction coefficient of BDD films under lubrication with water
Tribological performance and adhesion studies of high performance polymeric coating.

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Abstract:

Advent of high performance have led to increased interest in polymeric coating and its adhesion to the substrate are required for demanding applications such as electrical insulation, corrosion protection, tribological coatings for friction and wear resistance etc. Literature shows the scratch deformation does depend on various parameters such as indenter geometry and its hardness, apart from material.

In the present work, the scratch behavior of two polymers viz. poly ether ketone (PEK) and polyamide-imide (PAI) of three different melt flow indices (MFI) were studied for coating performance. The coating was carried out using electrostatic powder coating technique on a stainless steel substrate.

The scratch tests were carried out under constant force for analyzing the wear behavior and progressively increasing load to find out the critical failure load for coating. The role of MFI on scratch resistance was analyzed using Rockwell diamond indenter (conical shape, radius 120°). For both the polymers the lower melt flow grades showed higher scratch resistance. The coefficient of friction of coating was found to be in the range of 0.08-0.1. PAI showed higher adhesivity and scratch resistance compared to PEEK. Few more composite coatings containing hard fillers in different amounts such as Silicon carbide (SiC) and Boron carbide (B₄C) were also developed and evaluated. The inclusion of fillers proved beneficial adhesivity and scratch resistance point of view. Scanning electron microscopy and electron dispersive X-ray spectroscopy was used to understand the type of failure viz. adhesive or cohesive.
Evaluation of wear mechanisms on polymer composite surfaces by chemical mapping with Raman microscopy

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The friction and wear properties of polymers and polymer composites are determined by physicochemical reactions in the sliding interface as a combination of mechanical processes and frictional heating. The latter mechanisms cause changes in the morphology and structure of the polymer composite surface. For polymer matrices, different mechanisms such as polymerization, softening, melting, molecular chain orientation or thermal degradation concurrently occur. For polymer composites, filler-related mechanisms (e.g., preferential deposition of solid lubricants) or fiber-related mechanisms (e.g., debonding, delamination, fiber fracture) dominate the tribological performance. The latter phenomena are traditionally examined by different microscopic techniques, which rather offer an objective description of the composite wear mechanisms. By means of Raman microscopy, the changes on worn polymer surfaces can be described more quantitatively and certain surface patterns for specific wear mechanisms can be recognized. In this work, the strength of Raman microscopy will be illustrated based on the evaluation of various thermoplast and thermoset composite surfaces worn under mild and severe conditions. After cylinder-on-plate tribological tests of various polymers against steel under normal loads of 50 to 200 N and sliding velocities 0.3 to 1.2 m/s, the degraded surfaces were evaluated with a dispersive Raman microscope (laser 785 nm, Perkin Elmer Raman flex 400) over a surface area of 2 x 8 mm².

For worn polyoxymethylene surfaces, local variations in Raman maps have been detected as intensity differences in the ether stretching and oxymethylene deformation bands caused by polymerization and chain scission effects, respectively. For polyethylene terephthalate, the formation of an oriented amorphous phase under sliding has been detected. Moreover, the increase in normal loads during sliding progressively increases the average Raman intensity and modified surface area. The surface maps of composites with polytetrafluoroethylene powder added as internal solid lubricant clearly indicate that the lubricant is effectively liberated in different amounts depending on the normal load and sliding velocity, while it protects the polymer composite against severe wear under high normal loads. Finally, the Raman maps of thermoset polyester composite surfaces show that wear mechanisms are located near the fibers along 0° direction (fibers parallel to sliding direction), while they are mainly located in the matrix with fibers oriented perpendicular to the sliding plane.
Role of thermally conducting graphite in polymer composites for enhancing tribo-performance in severe operating conditions

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In the case of a tribo-couple such as polymer/composite sliding over a metal/ceramic/polymeric counterface in dry condition, frictional heat generated at the tribo-contact is the main culprit to deteriorate the tribological performance of a selected polymer. The PV limit in the case of polymers is hence very low restricting its utility for demanding operating conditions such as high load or speed. Selection of a polymer with higher and higher thermal stability along with very good mechanical properties is one of the remedies to increase the utility of polymer for severe operating conditions. Another remedy is to select the fillers or fibers which will be multifunctional and will help to increase the thermal conductivity (TC) apart from other functions such as reducing friction and wear. Amongst very popular solid lubricants viz. PTFE, graphite, hexaboron nitride (hBN), graphite is mostly favored since it enhances TC also.

Recently a novel type of graphite C-THERM™011 (TG) has been introduced by Imerys Graphite & Carbon Switzerland Ltd which is characterized by high specific surface area as an indication of high aspect ratio of particles along with higher TC. The particles have exfoliated structure. It was of interest to examine if inclusion of this graphite in a polymer composite offers any special advantage. Hence two composites were developed based on high performance Polyarylether ketone (PEK) (50% by wt) containing 30% short glass fibers and hBN 10% apart from 10% graphite. First composite designated as N contained 10% natural graphite while other designated as T contained 10% thermo-graphite (TG). These were processed by identical method (twin screw extrusion followed by injection molding). The tribological performance was evaluated in a pin on disc (mild steel) configuration under very high loads and speeds. It was observed that both the composites exhibited almost similar excellent tribo-performance. During evaluation for investigating PV limit values it was found that the composite N (96.6 MPa-m/s) was decisively superior to composite T (91 MPa-m/s). Composite N could sustain higher speed (3.45 m/s) than the composite T (3.25 m/s) under 900 N in spite of slightly lower TC. It was concluded that during special treatment (patented by the company) TG has slightly distorted layer-lattice structure as compared to natural graphite which could be responsible for transferring less beneficial film under severe operating conditions. SEM and EDAX studies were conducted to understand wear mechanisms.
The Wear and Thermal Mechanical contact Behaviour of Polymer Gears

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- Preference of presentation: oral
- Indication of presenting author: Dr. Ken Mao
- Keywords: wear, polymer gear, specific wear rate.

The present paper will concentrate on the extensive investigation of polymer composite gear wear and thermal mechanical contact behaviour. A test method for polymer composite gear wear has been proposed in the current paper and extensive investigations on polymer composite gear wear have been carried out.

It has been found from the tests that the polymer gear wear rate will be increased dramatically when the load reaches a critical value for a specific geometry. The gear surface will wear slowly with a low specific wear rate if the gear is loaded below the critical one. The possible reason of the sudden increase in wear rate is due to the gear operating temperature reaching the material melting point under the critical load condition. Gear surface temperature has been then investigated in detail through three components: ambient, bulk and flash temperatures. Through extensive experimental investigations and modelling on gear surface temperature variations, a general relation has been built up between gear surface temperature and gear load capacity. The method has been related to test results under different operating ambient temperature and gear geometries. Good agreement has been achieved between the proposed method predictions and experimental test results.
Surface Texturing to Improve Tribological Properties of C/C Composite Materials

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Keywords: Tribology, Texturing, C/C composites, Wear debris.

C/C (Carbon fiber-reinforced Carbon matrix) composite is widely used as the sliding materials because of the exceptional mechanical properties. However, there are some reports that the C/C composite causes drastically increase in the friction coefficient from 0.1 to 0.4, which is called “the friction transition”. H.Kasem et al. suggested that the wear debris affects the frictional properties of C/C composite [1]. It is known that surface texturing is an effective way to reduce the influence of wear debris. In this research, the effect of surface texturing was discussed in order to improve the tribological properties of C/C composite with the influence mechanism of wear debris on the sliding surface.

To investigate tribological properties of the C/C composite, the sliding tests were carried out by using a thrust cylinder type tribo-tester. The rotor and stator specimens were made of C/C composite. Two rotor specimens of “Flat” and “Slits” were prepared to evaluate the effect of surface texturing on the tribological behavior. Figure 1 shows schematic of two-types of the rotor specimens. The Slits specimen had 32 radial slits with 1 mm width and 2mm depth on the sliding surface. The sliding tests were conducted under dry sliding condition at a load of 300 N, rotation speed of 500 rpm, sliding time of 10 min, running- in period of 30 s. Wear debris were collected before the test, after 1 min, 5 min and after the test, to observe using a scanning electron microscope (SEM).

Figure 2 shows the friction behavior of Flat and Slits specimens. In the Flat specimen, the friction transition was observed with the increase of friction coefficient from 0.1 to 0.5 at 460 s. The wear debris of Flat specimens agglomerated with the sliding time. The morphology of wear debris on the sliding surface changed clearly after the friction transition. On the other hand, the friction transition did not occur in the Slits specimen. The wear debris of Slits specimen fragmented through the sliding tests. These results suggested that the agglomeration of wear debris arised the increase of the adhesion force and the friction transition. It is considered that the adhesion force increases caused by the agglomeration of wear debris. The addition of slits on the sliding surface suppressed the friction transition by ejecting the wear debris. Surface texturing is one of the effective solutions to improve tribological properties of the C/C composite.

Reference
Abstract

Role of Aramid fibers and amount on performance of NAO brake-pad materials

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Replacement of asbestos in organic friction materials was the most difficult challenge faced by the friction industry till today. Aramid fiber/pulp (Ar) is one of the most important ingredients, of non-asbestos organic (NAO) friction materials (FMs). In spite of its highest cost it is invariably added in good quality FMs. It improves the wear resistance and processibility of FMs. It seems that the amount used in industrial formulations is around 3 %. In spite of the fact that it will affect all other performance properties including wear resistance and processability, not adequate research efforts are placed to investigate an optimum amount of the pulp for the best combination of performance properties.

Keeping this in view Realistic multi-ingredient FMs (series of six composites containing Ar in increasing amount- 0, 2, 4, 6, 8 and 10 wt % and designated as C0, C2, C4, C6, C8 and C10) were developed as NAO brake-pads and characterized for physical, mechanical, chemical and tribological performance. Composites were tribo-evaluated on full scale brake inertia dynamometer following Japanese Automobile Standards (JASO C 406) procedure. Various performance parameters such as performance μ, fade μ, recovery μ; fade ratio, recovery ratio, wear etc. were used to evaluate the role of amount of Ar in FMs.

It was concluded that increase in aramid amount plays important role in improving wear performance. 10 % aramid content in the FMs showed best overall performance while composite without aramid fiber proved poorest. Worn surface analysis and wear mechanism were studied using SEM and EDAX technique.

Keywords:- Non-asbestos organic (NAO) friction materials, aramid fiber, friction, wear.
Tribocorrosion is a wear mechanism involving the material deterioration/transformation by the combined action of wear and corrosion of tribo-systems, mostly consisting of passive metals, exposed to corrosive environments. The degradation of materials used in tribology situations has been typically discussed in terms of mechanical strength versus loading and lubrication conditions. Little attention has been paid to chemical processes such as corrosion (dissolution of metal into an electrolyte, build up of surface oxide films, and adsorption of molecules on the metal surface) and their influence on the overall material degradation. The reason for that is the inherent complexity of tribocorrosion interactions and the lack of robust experimental and theoretical investigation tools.

A typical solution to solve wear damage of materials is the use of coatings and surface modifications. The selection and design of new surfaces for materials used in tribo-systems leads to the need of a better understanding of surface degradation processes especially when tribological components are operating in corrosive environments. Recently, significant progress in understanding tribocorrosion of passive metals (i.e. stainless steel, titanium, CoCrMo and Ni-alloys, that form spontaneously a thin oxide layer when immersed in aqueous media) has been made and mechanistic models have been developed and verified on laboratory scale systems. Under tribocorrosion conditions, the electrode potential plays an important role triggering wear thus designing surfaces with constant wear rates independently on the potential is the goal for succeeding in tribocorrosion situations.
Friction and wear of any sliding surfaces depend on interactions between the contacting materials, where a very thin (usually nanoscopic) boundary layers determine the efficiency and durability of such contacts. Therefore, there has been a great effort in tribology to be able to detect and analyze such boundary layers. This is especially true for the lubricated contacts, where the efficiency of the oils and additives is associated to their ability of forming appropriate boundary layers. Since such layers are formed at the solid-liquid or solid-solid interface, their detection is usually very difficult. Namely, most of the surface analytical techniques require removal of the excessive lubricant, which may disrupt the delicate surface layers and cause misinterpretation.

To be able to detect and analyze any existing interaction layers directly at the solid-liquid interface of the engineering surfaces, we have employed neutron reflectometry (NR) technique. Neutrons can penetrate deep into the material and enable the analyses of adsorbed layers directly at the solid-liquid interface, which eliminates the need for sample cleaning. Moreover, the NR technique allows sub-nanometer resolution when determining the average layer thickness and allows the estimation of the layer density.

We have used NR to confirm the existence of the adsorption layers on diamond-like carbon (DLC) coatings, which are known for their low friction and good anti-wear properties. In contrast to conventional metal surfaces DLCs have proven to be relatively non-reactive with limited ability to form protective layers from the oil additives, which would further protect the coatings from wear and remain their low friction properties at the same time. Besides, the investigation of the DLC-lubricant interactions can sometimes be difficult due to the carbonaceous structure of the DLC, which limits the use of certain spectroscopic methods.

We have analyzed the ability of various DLC coating to interact with organic friction modifiers like alcohols, fatty acid and esters as well as with the conventional anti-wear additive, the ZDDP. We showed that polar organic additives can adsorb on certain DLC coatings and thus form nanometer-thick adsorption layers. We also showed that ZDDP can form adsorption layers on DLC coatings as well, which is especially true at the elevated temperature of 120°C. Moreover, we showed a good correlation between NR data and tribological behavior of the DLC surfaces. These results proved the existence of adsorbed layers on certain DLC coatings and suggest that organic friction modifiers could be successfully used in combination with DLC coatings, which represents more environmentally friendly lubrication compared to the conventional additive/metal combinations.

Key Words: DLC, adsorption, neutron reflectometry, tribology.
Investigation of Chemical Reactivity of ZDDP in mineral oil on Different DLC Coatings by ATR-FTIR

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Abstract

In this paper we used attenuated total reflection Fourier transform infrared spectroscopy (ATR-FTIR) for the first time to study the adsorption of 1, 5 and 20 wt.% of ZDDP additive in mineral oil onto two different diamond-like carbon coatings (DLC, Si-DLC) at different temperatures. Steel surface was used as a reference. It has to be noted that the characterisation of tribofilms between ZDDP and DLC surfaces using FTIR is still greatly missing in the available literature. Our results clearly show that chemical reaction of the ZDDP and DLC happens only at 150 °C, where the adsorbed layers consist of the same chemical products irrespective of the ZDDP concentration used. The ATR-FTIR spectra showed a complete modification of the ZDDP molecule on the surfaces during thermal tests, where different organic phosphorous and S=O compounds were produced on the surfaces with high dependency on the type of the surface.

Keywords: zinc dialkyl dithiophosphosphate (ZDDP), mineral oil, attenuated total reflection-Fourier transform infrared spectroscopy (ATR-FTIR), diamond-like carbon (DLC) coating, and silicon-doped diamond like-carbon (Si-DLC).
E. Oblak, M. Kalin,

Nanoscale mechanical and topographic characteristics of boundary films and their relation to macroscopic friction

Properties of the tribochemical films play an important or even key role for friction in boundary lubrication. While their chemical behavior is already broadly studied, the mechanical properties are much less known. However, their nano-scale mechanical properties and behavior may reveal important correlation to macroscopic friction behavior, which was studied in this work. Steel and DLC contacts lubricated with fully formulated low-SAPS and high-SAPS commercial oils were studied, and compared to well-known ZDDP tribofilms. Tribofilms were characterized with atomic force microscope (AFM) with 6 different parameters: namely, topography, nano roughness, adhesion, film thickness, nanoscale friction (LFM) and film stiffness through force modulation (FMM). Results confirmed that film formation and its nano-scale properties are both, surface and additive dependent. Moreover, correlation between macro friction results and various tribofilm nano properties was found, which is discussed in this work.

Key words: DLC, AFM, LFM, FMM, tribofilm, SAPS, ZDDP
Application of 3D printing technology for development of novel tribo-system

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Keywords: Tribology, Surface texturing, 3D printer, Boundary lubrication, Dimple network

Excessive friction and wear on sliding components are the main causes of breakdown or increase of fuel consumption. Surface texturing, which is one of solution to reduce the friction and wear, creates various precise geometries such as micro-grooves and micro-dimples on sliding surfaces. Particularly, several studies reported that dimple textures improve frictional properties since the textures work as a lubricant reservoir and wear debris trap [1,2]. Such dimples are usually produced by machining, ion-beam texturing, etching, and laser texturing.

In this research, we focused on 3-D printing as a means of surface texturing. Figure 1 shows the schematic diagrams of disk specimens. By using a 3-D printer (Cube X Duo, 3D Systems, US), specimens with a new surface texturing structure (denoted as “dimple network”) were fabricated (Fig. 1 (b)). The surface texture’s role as a reservoir of lubricant could be improved by connecting adjacent dimples. This study aims to evaluate an advantage of the “dimple networks” against the conventional dimples (Fig. 1 (a)) in the frictional property under boundary lubrication. Sliding tests were conducted with a cylinder-on-disk friction tester. The disk specimens (ϕ 24 mm × t 8 mm) were made of PLA (Polylactic acid), the cylinder (ϕ 15 mm × l 22 mm) was made of AISI52100, and the lubricant used was PAO4 (Poly-Alpha-Olefin, VG4). Disk specimens were textured with 3 patterns (Non-textured, conventional dimple, and “dimple network”).

Figure 2 shows the friction coefficients of each specimen. The specimen with “dimple network” demonstrated a lower friction coefficient than the other specimens. The main finding of this study was that the application of "dimple network" made the lubricant to flow through the canals to adjacent dimples on contact areas. The present results suggested that "dimple network" improves frictional properties by facilitating lubricant flow. In this presentation, lubrication mechanism of "dimple network" will be discussed with the experimental results.

References
Fiber surface modification to endorse fiber-matrix adhesion strength and tribological properties

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Abstract: Fiber - matrix adhesion in a composite is an important factor for efficient stress transfer from the matrix to the fiber. Carbon/graphite fibers due to their superior thermal and mechanical properties are best suited as reinforcement for specialty polymers. However, their non-polarity and surface smoothness lead to an inadequate fiber- matrix adhesion and hence feeble composites strength. The extent of fiber-matrix adhesion can be enhanced by employing various surface treatments to the fibers surface prior to their use for composite development. Multi-scale nano coatings applied on carbon fibers (CF) to fabricate fiber reinforced polymer composites. The studies were focused on the influence of nano additives (CNTs/other nano particles) treatment to carbon fibers. The physiochemical alterations at the fiber surface investigated using microscopic (scanning electron microscope - SEM, atomic force microscope - AFM); and spectroscopy (micro Raman spectroscopy - MRS) techniques. The optimization of nano additive attachment to CF done to control the fiber-matrix adhesion without affecting the single fiber strength properties. Composites developed using epoxy matrix showed improved interfacial strength and tribological properties in adhesives wear mode.
The tribological performance of scrapers in cleaning operation of conveyor belts

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1. Introduction

Large scale conveyor belt systems can be encountered in industry where huge amounts of bulk goods need to be transported ranging from a few meters to several kilometres. A conveyor belt tribosystem with scrapers in operation can be seen in Figure 1. Unfortunately a small fraction of the transported good strongly sticks to the belt and produces piles under the conveyor system when detaching later, entailing increased maintenance efforts and costs. Hence scrapers, or cleaners, are utilised to remove the sticking goods from the belt and keep the material in the production cycle. Additionally, about every third belt has to be replaced prematurely due to improperly adjusted scrapers [2], what demonstrates the need for understanding and troubleshooting of the belt-scraper tribosystem.

2. Experimental

Practically used scrapers were investigated after operation for failures by metallographic preparation techniques. Especially the interface between the WC/Co scraper element and the steel support, which was applied by brazing, was of interest.

To understand tribological interactions between scraper and belt, high speed camera investigations as well as thermal imaging were undertaken in order to understand the contact situation and frictional heating in field. With the knowledge from these investigations lab scale experiments on a modified pin-on-disc tribometer were carried out. Special focus was on the adjustment angle, investigating the effect of wrongly adjusted scrapers. Orthogonal mounting (0°) and adjustment angles of 5°, 10° and 15° were tested. Coefficient of friction and wear were monitored between WC/Co scraper elements and different qualities of commercially available rubber belts (e.g. natural rubber, styrene butadiene rubber and butyl rubber).

3. Results

The analysis of worn scrapers revealed that the main failure mechanism is not found in abrasion, but breaking of WC/Co scraper elements from the steel support takes place. The crack propagation occurred through the WC/Co scraper itself, so that fatigue may be the main source of failure. High speed video recording revealed continuous impacts on the scraper elements by the belt, leading to fatigue cracks and subsequent failure with increasing operation time. Thermal investigations determined temperatures between 40°C and 50°C, where the temperature distribution is highly depending on adjustment of the scrapers.

The pin-on-disc lab scale tests showed high coefficient of friction between 1 and 3 depending on the material pairing, i.e. the belt in use. On the other hand, wear and vibration are mainly dominated by the alignment angle. Most stable behaviour was recorded for orthogonal mounting of the scraper.

Acknowledgments

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4. References

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Miniaturization trends requiring ultra-thin protective coatings are an important area for science and technology. There are numerous examples that indicate these manufacturing complexities. As film thickness decreases, it becomes challenging to assess the mechanical and tribological properties such as modulus, hardness, adhesion, friction, etc. This is particularly true in cases where evaluation must be performed at the devices operating conditions. The characterization of thin films independent of the substrate properties is another challenge, especially for very thin films. Hysitron’s new Intrinsic Thin Film Mechanical Property Solution (iTF) allows for thin film characterization independent of the substrate properties in a straightforward, fast, and precise method. In addition, ultra-sensitive MEMS based xProbe transducer allow for direct and quantitative measurement of the mechanical properties of the ultra-thin films at the nanometer range. High sensitivity of the transducer allows for the topography imaging with the contact force at the range of few nN. In addition, capabilities of the direct lateral force measurements allow for the quantitative tribological estimation of the different components in the composite, or change of the properties related to the wear phenomena.

This presentation will summarize recent developments for the mechanical and tribological characterization of the ultra-thin films.
Nano-featured, coated surfaces for enhancing and optimizing friction and wear of sliding surfaces for bearings and seals in high endurance, high reliability applications.

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Abstract: Some of our most critical mechanical equipment operates under conditions of sliding friction. In particular bearing, wear ring surfaces and mechanical seal faces operate under high loads and conditions where critical faces slide against each other. Usually a fluid lubrication system is provided to ensure that a hydrodynamic layer is initiated between the two moving faces at all times. However this is not always possible at all times due to variable operating conditions; stop – start process conditions for example, where the lubrication fluid is either not present or where the equipment is not rotating fast enough to initiate a protective film. Many applications of mechanical seals for example need to be able to operate under a variety of conditions from humid conditions to ultra dry conditions in the presence of dry nitrogen. In mechanical seals, two rotating faces (often made of Sintered Silicon Carbide (SSiC) or tungsten carbide) rotate in close proximity to each other (2-3 microns). These materials have inherently high friction and therefore fail very quickly when they come into contact. Coatings can be used to enhance the lifetime under these conditions but are usually good for either wet (humid) conditions or dry conditions but not both. One potential way of overcoming this issue is to provide a composite solution where the properties of two coating solutions are combined to deal with the variable conditions. The paper presents a study seeking a solution to this using micro-structuring of a unique amorphous carbon diamond material closely allied to DLC (Diamond Like Carbon). Capitalizing on this PA-CVD (Plasma Assisted – Chemical Vapour Deposition) process’s ability to coat relatively thickly (8 microns) allows us to micro impregnate the surface with a material which provides low friction in dry lubrication conditions in order to solve this issue. Nanostructuring of DLC materials has been studied previously but never in this way. The study looks at the initial coating process, the nanostructuring of the subsequent coating and the impregnation of the structured surface. The components were then tested in dry (N2) and wet conditions under standardised conditions and the results compared to standard coated and uncoated faces.

Keywords: friction, geometry, features, coating, tribology, mechanical seals, laser etching, diamond, diamond-like-carbon, multilayer, reliability, dry running, nitrogen, chemical processing, pumps, nanotechnology, oil exploration, sealing, bearings

References:


A wear model for silicon nitride in sliding contact with nickel-base alloy

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The thermo-mechanical and chemical properties of silicon nitride ceramics allow their broad application in extreme wear conditions that include high mechanical load and high temperatures. A prominent example is the machining of nickel-based alloys using ceramic tools, where a combination of severe mechanical load and tribo-chemical interactions occur.

Apart from machining, high-temperature sliding contacts of silicon nitride against metals will be found more often in future applications, in which the ceramic’s wear resistance becomes clearly necessary.

In order to obtain a deeper understanding of the occurring wear mechanisms, dry sliding experiments were carried out covering a range of sliding speeds from 1 to 20 m/s (Fig. 1).

Fig. 1: Wear volume and coefficient of friction of Si₃N₄ vs. Inconel 718 plotted against sliding velocity

Based on the quantitative experimental results, a finite element wear model that considers the measured wear rates and friction coefficients was constructed. Thus, the stress and temperature in the contact zone becomes numerically accessible (Fig. 2).

The analysis of the worn surface of the ceramic specimens also provides information on the tribo-chemical processes as well as on the wear mechanisms (Fig. 3).

Combining analytical and numerical results enables the authors to present a schematic wear model, which will be quantified in further works.

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Abstract

In recent years, diamond-like carbon (DLC) thin films applied on relatively harder substrate materials have gained intensive attention for their use in tribological applications due to their excellent mechanical properties such as high hardness, low friction coefficient and high wear resistance, just to name a few. Furthermore, DLC-coatings may also represent an optimal solution for reducing the coefficient of friction when applied on elastomer seals, but due to the high elastic deformation and low hardness of such substrates, DLC-coatings have to be very flexible and exhibit a good adhesion to the underlying substrate material in order to develop their full advantages in reducing friction. Due to these special requirements on their mechanical properties, the suitability of DLC-coatings on elastomer seals may be significantly limited in terms of their tribological properties.

In this study, the suitability of such DLC-coatings on FKM elastomer O-ring seals with regard to the applied load (30 N / 75 N) and the test temperature (20°C / 80°C) and their effect on the coefficient of friction and wear rate have been investigated and compared to results obtained using conventional methods for reducing the coefficient of friction; namely anti-friction coatings and greases.

The results have shown that for a low load (30 N) combined with a low temperature (20°C), DLC-coatings on FKM elastomer O-ring seals may represent an interesting alternative to conventional methods for reducing the coefficient of friction. However, for a higher load (75 N) independently of the temperature or for a higher temperature (80°C) independently of the applied load, DLC-coatings exhibit high coefficient of friction combined with a very low wear resistance in comparison to other friction reducing methods. From these results, it may be concluded that the suitability of DLC-coatings on FKM elastomer O-ring seals is significantly reduced to applications having low loads and low temperatures only.
Characterization and Tribological Investigation of TiSixCy Wear Protective Coatings

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Ti-Si\textsubscript{x}-C\textsubscript{y} hard coatings have been deposited by magnetron sputtering from a composite target that was manufactured by powder technology. Other coatings were also obtained from a UBMS unit mounted with Ti and Si targets in partial acetylene atmosphere. The attained films are principally composed of TiC\textsubscript{x} nano-crystallites and amorphous phases. Although Ti\textsubscript{3}SiC\textsubscript{2} phase has not been detected, hard coating properties are yet interesting. Nanohardness values up to 1800 Hv could be obtained for coatings with friction values below 0.20 against steel in an unlubricating pin-on-disk setup. The main parameter, which conditions mechanical and tribological properties, is the negative bias voltage applied to the substrates during the deposition process. Application of a negative bias voltage results in significant variation between the target and thin film’s compositions. Material transfer, roughness reducing and tribo-chemical reactions between TiC\textsubscript{x} and environmental gases caused interesting tribological behavior of biased Ti-Si\textsubscript{x}-C\textsubscript{y} thin films. A strong dependence on the adhesion layer hardness and the film tribological endurance has been demonstrated. Measurements showed a thermal stability up to 400°C. Additionally, recent works enlightened Ti-Si\textsubscript{x}-C\textsubscript{y} could be also use as an adhesion layer for DLC coatings. Coatings have been tested in industrial applications and have been found encouraging because, in certain cases such as cold stamping and watch mechanisms, Ti-Si\textsubscript{x}-C\textsubscript{y} coatings can compete against those currently available on the market. Compared to some industrial processes, the benefit is no reactive gas is needed. Consequently, it has a long-term stability. This present document reports the investigation of the morphology, structure and tribological behavior of Ti-Si\textsubscript{x}-C\textsubscript{y} hard coatings deposited from a composite target.
1. Introduction

Sintering technologies such as the MIM technology are more and more often applied to save machining time and material cost. The latter is of major relevance especially for copper cased alloys. Consequently there is a need in industry to replace components which were conventionally produced by casting and hot forming production by e.g. metal injection moulding processes (MIM). As this production process lacks the option of grain refinement through mechanical deformation steps, the resulting grain sizes are often an order of magnitude larger or even more. The resulting tribological properties of components produced via MIM have therefore to be evaluated and the parameters guiding the tribotechnical performance have to be understood in order to enable engineers to tailor materials to their special functionality.

2. Experimental Set-up and Methods

The tribological behaviour of two commercially well-known copper alloys (CuSn8, CuNi9Sn6) was studied in a modified SRV test set up. Cylindrical samples were oscillated over a standard 100Cr6 steel disc with the sample axis perpendicular to the direction of motion. For lubrication a simple mineral base oil was used to avoid any alloy-additive specific reactions in the tribocontact. The coefficient of friction was evaluated over time and the wear volume was calculated after 2 h of testing time based on 3D topographic measurements of the wear track (assuming a perfectly cylindrical sample).

3. Results

The conventional production routes (Fig. 1a, c) involve casting and hot forming for both alloys and a defined heat treatment condition for the CuNi9Sn6 alloy. For comparison the MIM samples were studied in the as sintered condition for CuSn8 (Fig. 1b) and in a heat treated condition for CuNi9Sn6 (Fig. 1b) which ensures maximum tensile strength. The MIM samples show grain sizes of over 100 µm and very low hardness compared to the conventionally produced samples with grain sizes down to 20 µm. Often small grained materials are considered as generally beneficial due to higher strength and higher toughness properties but also to provide a good tribological performance with high wear resistance and low friction coefficients [1]. For the investigated MIM material the contrary proved to be true. The softer, large grained materials showed significantly lower friction coefficients (Fig. 2) than the small grained and highly deformed microstructure of the conventionally produced samples. This was true even for the steady state condition when all alloys are reduced to a much lower level than in the running-in phase. The reduction of the coefficient of friction was higher the larger the difference in grain size was due to the MIM technology. The same trend was confirmed by the wear volume measurements after 2 h test time.

4. Acknowledgement

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5. References

Effect of sliding velocity on wear of lead-containing brass

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Downsizing the mechanical system is a recent trend for reducing the energy consumption. In the meso region between nano and macro-scale, tribology is one of the key technologies to improve the machine performance. Mechanical watch belongs to this meso region of tribology. Lead-containing brass is generally used for the sliding parts of mechanical watch. However, there are some unclear points in the tribological properties of lead-containing brass especially under low load oil lubricated condition.

In this research, friction and wear behavior of lead-containing brass against ruby ball was evaluated for wide ranges of sliding speed and loads by using a ball-on-disk sliding tester under lubrication with oil.

Figure 1 shows relationship between the sliding speed and the wear rate of lead-containing brass. Wear rate increased with the increase of the sliding speed in each load condition. Friction coefficients in low sliding speed also showed lower values compared with those in high sliding speed. In addition, as shown in Figure 2, the worn surface in low sliding speed showed dark color (Fig. 2a) by contrast with the metallic surface (Fig. 2b) in high sliding velocity. The cross-sectional observation by FIB indicated the existence of discontinuous boundary layer on the worn surface in low sliding speed. We consider that under low sliding speed condition, the formation of such re-transfer layer protects the worn surface, reduces the friction coefficient and reduces the wear rate.

![Fig.1. Relationship between sliding speed and wear rate of lead-containing brass under lubrication with oil](image1)

![Fig.2. the worn surface: (a)in low sliding speed, (b)in high speed](image2)
Subsurface damage analysis in high loaded oscillating bearings

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The present work focuses on the degradation scenario of high loaded oscillating bearing. These bearings, needed to assure the relative oscillation between two members of the mechanical system (e.g. repetitive motions of assembling and manufacturing robots, ship helms, aircraft flaps, etc.), are subjected to extreme contact pressures at the ball-race contact surfaces with relative low rolling/sliding speed; the oscillations of the bearings provide a fatigue loading of the contact area due to the repetitive rotation of the balls between the races.

While a large literature can be found on rotating bearings and high-speed bearings, few works in the literature are addressed to high loaded oscillating bearings and their degradation scenarios under such extreme working conditions. Literature on rolling bearings and subsurface damage mechanisms highlights the appearance of subsurface plastic residual strain after the application of a shear-stress shear-strain loop.

In this paper both numerical and experimental analyses are presented to investigate the key factors for the rise and development of the bearing degradation. Numerical finite element analysis will be addressed to reproduce the degradation observed experimentally and investigate the role of key parameters such as coefficient of friction. The experimental tests, on a dedicated test bench, are addressed to the reproduction of the fatigue damage at different phases of the bearing life. The tribological observations, together with the numerical results, allow for highlighting the degradation scenario and its evolution. The role of the grease is addressed as well.
Tribological testing of dry-clutch facings: temperature measurement at sliding interface and influence on the engagement manoeuvre

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Abstract

Nowadays, passenger cars are equipped with effective electronic systems to increase vehicle dynamic performance, comfort and reduction of fuel consumption.

The systems whose purpose deals with the control of the vehicle dynamics, as the Anti-Lock Brake System (ABS), the Traction Control System (TCS) and the Electronic Stability Program (ESP), exhibit better performance when frictional behaviour of the clutch and brake systems have been extensively analysed and introduced through proper tables or maps in the control boards [1,2].

Moreover, the availability of such detailed frictional maps could provide a reduction of control engineers’ effort and time for the calibration of these systems. The inclusion in modern vehicle powertrain of Automated Manual Transmissions (AMTs) and Dual Clutch Transmissions (DCTs) is an affordable, robust and ecological engineering solution. On the other hand, the performances of dry-clutch based transmissions are deeply affected by the clutch frictional torque prediction operated in real-time by the control board coupled to these mechatronic system [3].

The tribological contact under sliding condition in the clutch facing surfaces during the engagement maneuver is strongly affected by heat transfer occurring in the system. The frictional forces acting on the contact surfaces produce mechanical energy losses which are converted in heat with ensuing temperature increase. The magnitude of temperature rise depends on the thermal properties of the clutch facings.

Unfortunately, only few literature works explore through experiments the influence of temperature and other influent variables on the frictional behavior of the clutch facing materials [4-6]. Evidence of temperature rise after repeated clutch engagements confirm peaks as high as 300 °C. Such high thermal level yields strong tribological effect whose substantiation is the sharp decline of the friction coefficient often related to the decomposition of the phenol resin of the facings.

This paper introduces original outcomes from an intensive experimental campaign carried out through original setup of the tribological tools with the purpose of achieving complete map of the dynamic friction coefficient over a broad range of interface temperature, sliding speed and average contact pressure values. Steep speed ramp allowed to capture frictional coefficient and temperature rise by means of reduced time response temperature sensing at facing/disk interface.

The experimental results have been included in a virtual test bench based on a custom software environment to carry out dry-clutch engagement simulations managed by an open loop controller, which does not or poorly predict the thermal effects on the behaviour of the clutch facings and the actual torque transmitted by the clutch to the vehicle driveline. In a control strategy based on the throwout bearing position-control, by way of the driving of the actuator, the selection of a wrong position for the bearing could result in the switching off of the engine, in poor engagement with driveline oscillations, engine speed spikes, discomfort, etc.

Keywords: dry clutch, temperature influence, interface temperature sensing, open-loop engagement simulation.

References
In-depth tribological performance of functionally graded ductile iron for brake pads

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Tribological performance of functionally graded ductile iron brake pads were investigated on reciprocating sliding and model disc-brake machine. Ductile iron material we used consists of a strategic combination of ductile iron and functional gradient material (FGM) with a gradual composition, containing Cr, Mo, W and B. Due to the FGM and the in-depth hardness profile of the material, the friction coefficient and wear resistance were investigated at different depths. Results from tests on reciprocating sliding machine show that wear rate is significantly reduced when certain thickness of the material (compared to initial unworn surface) is removed. In addition to improved wear performance, more stable coefficient of friction, with faster running-in phase, is achieved. Braking tests performed on disc-brake machine further reveal that coefficient of friction is very stable, namely around 0.5, independently on the contact temperature and depth. Wear results show that with the removal of the material thickness the wear is in general lower and more stable, i.e. less influenced by the contact temperature.
Rubbing some Physics off Nanofriction Theory and Simulations

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Nanoscale probes are providing increasing experimental data about friction and dissipation processes at atomically controlled systems and interfaces. Theory and to some extent atomistic simulation offer some means to understand and predict the connection between the outcome of these experiments and the physical processes going on in the bulk substrate, including phase transitions, and at interfaces, including static friction as well as electrical control of lubrication. Of both, I will present and discuss some cases recently under study in our group.

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Noncontact dissipation reveals critical fluctuations and “central peak” of SrTiO$_3$

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Understanding friction or mechanism of energy dissipation is nowadays among few priorities in nanoscience. Bodies in relative motion separated by few nanometer gap experiences a tiny friction force, whose the nature is not yet fully understood [1]. This non contact form of friction can be successfully measured by highly sensitive cantilever oscillating like a tiny pendulum over the surface [2].

The idea of replacing passive substrate with “active” material hosting phase transition came from A. Benassi and co-workers [3]. According to their calculations friction coefficient is peaking when sliding body undergoes a phase transition. In relation to this study SrTiO$_3$ is a perfect candidate, because of the presence of structural phase transition ($T=110$K). Here we show that the critical fluctuations in a bulk crystal may affect the dissipation of mechanical probes even if completely external to the crystal surface. Here we show that noncontact force microscope dissipation bears clear evidence of a most classic bulk transition, that to the antiferrodistortive state of SrTiO$_3$. This transition is known to exhibit a unique critical neutron scattering peak whose extremely narrow width, less than 6 MHz, gave it the name of central peak. The noncontact dissipation directly reflects the central peak, showing that its amplitude is still nonzero at frequencies as low as 10 kHz, three orders of magnitude below the known limit. Tip – surface strain coupling explains this critical dissipation via linear response theory within the same model which accounts for the neutron scattering central peak.

Positive effects of artificial surface texturing in lubrication systems concerning load capacity, wear resistance, and friction properties have been investigated starting from the second half of the past century [1, 2]. The present work analyses the influence of surface micro-texturing on the hydrodynamic lubrication properties of two parallel sliding plates. A friction measurement device (see figure 1) [3] inspired the considered geometry model consisting of an upper stationary micro-textured surface with several rectangular cavities and a flat moving surface at the bottom. The influence of several geometric parameters, such as the cavity depth and width, on the drag force has been studied. A thorough analysis of the shear and pressure forces and of the velocity profiles inside the gap (see figure 2) is provided, showing how these quantities are influenced by the geometry of the surface micro-texturing. The analysis of the numerical results provides an explanation for the maximum drag reduction achievable with a single phase flow. Furthermore, the analysis of flow velocity profiles and pressure distributions highlights that three regions exist, depending on the dimple depth, in which a different flow dynamics occurs and the cavities have a different influence on the drag force. Finally, the analysis demonstrates that an "optimal" value of the dimple depth exists for which the pressure achieves a minimum value and the probability of cavitation is maximized.

References
INFLUENCE OF THE PROBE-SURFACE CONTACT AREA ON EXTREMELY SMALL NANO-PATTERNED SI SURFACES: AN AFM-BASED STUDY

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Keywords: nano-patterning, AFM, coefficient of friction, adhesion, contact area, hydrophobicity.

ABSTRACT

One of the most promising methods to control friction, wear and adhesion between sliding counterparts concerns the modification of surface morphology by means of patterning techniques. Depending on the load and the size of the surface features, different phenomena influence the tribological properties of surfaces. The effects of micrometric patterns on tribological parameters were extensively studied and it has been established that the contact area plays the dominant role in friction, adhesion and wettability [1-5]. In particular, many studies report on the effect of micro-patterning in increasing/decreasing the wettability in already hydrophilic/hydrophobic surfaces. At the nano-scale the tribological behaviour of patterned surfaces has not been completely understood. In fact, some studies showed that nano-patterning is able to induce a hydrophobic character to hydrophilic materials, such as Si [6,7] and Au [8]. The difficulty in studying the tribological behaviour of nano-patterns can be related to the instability of the contact area between the probe and the surface, which becomes very critical in case of very short and small nano-structures. In the case of AFM-based studies, the local contact area between the probe and the surface depends on many hardly controllable phenomena: wear of the probe, sticking of impurities, mounting of the cantilever, laser misalignment, etc. In this study we show how the variations of the local radius of curvature leads to different results in the tribological parameters of very small nano-patterns. Adhesion and coefficient of friction of ordered arrays of 1D linear protrusions of Si were studied by means of AFM, using a home-made Si rounded tip. The nano-patterns were fabricated by Focused Ion Beam working in very low-ion dose mode, taking advantage of the amorphization-related swelling effect. To limit the experimental errors, an ad-hoc measurement procedure and data analysis have been adopted. After the estimation of the local radius of curvature we were able to show that adhesion and friction are influenced by the contact area and by a hydrophobic effect induced by the nano-structures. Depending on the shape of the nano-features, one contribution dominates on the other: the contact area in the case 1D protrusions, the hydrophobic effect in the case of 1D grooves [7].

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Impact Dynamics of rough surfaces in the scale of minutiae

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This paper investigates the effect of surface parameters such as asperity tip radius and standard deviation of surface asperity heights ($\sigma$) as well as the existence of moisture on the impact behaviour of micro-scale mechanisms. This occurs because of surface forces such as adhesion and capillary action.

The small scale of Micro-Electro-Mechanical Systems (MEMS) makes the effect of surface forces become dominant. Therefore, in order to simulate the impact of dynamically loaded nano-scale contacts, the interactions between surface adhesion and repulsive forces should be taken into account.

Adhesion is usually undesirable. It may appear in the form of dry adhesion between asperity pairs or as capillary forces in the presence of moisture. These forces may lead to stiction, which can lead failure. Even without stiction, capillary and dry adhesion would consume some energy. This is also an undesired outcome.

In the case of MEMS dynamics, for example gears, adhesion may also mitigate errant dynamics. This is perceived in the form of damping, acting as an energy sink. Therefore, ideally a balance should be made between reduction of errant dynamics and undesirable effects adhesion as a source of excessive energy loss. In order to establish this optimum balance, a better understanding of the underlying physics of adhesion and capillary forces at nano-scale is required.

The current work comprises transient impact dynamic analysis of rough MEMS contacts. The effect of Hertzian forces as well as dry and wet adhesion is taken into account in a single degree-of-freedom system. All contacts are assumed as those occurring between an equivalent rough surface and a smooth flat counterface. A Gaussian distribution of asperity heights is also assumed. The DMT (Derjaguin- Muller- Toporov) model [1] is considered for the dry adhesion of asperities. As a new approach, numerically pre-calculated integral values of Gaussian distribution are developed in the form of polynomial representations. This simplifies the model and increases the speed of computational analysis. The effect of different surface statistical topographical parameters is included in the analysis, such as $\sigma$, the distribution density of the asperities and their average summit tip radius.

The results show that changes in the topographical parameters affect system dynamics as well as the consumed energy. This is also true of material composition of the counterfaces and the presence of moisture.

References

Solution drift control for friction models

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Abstract

Modeling, compensation and ability to control frictional behavior of dynamical systems play a vital role in modern investigation of frictional and tribological processes. Particularly, prediction and accurate reflection of physical processes is important for applications involving relatively small displacements and velocities. Recent research, proved that current single-state friction models exhibit a nonphysical solution drift. This phenomena originates from modeling presliding as a combination of elastic and plastic displacement. To control it, improvements to existing models have to be implemented. In this paper, we propose two alternative solutions, to eliminate drift phenomenon, while preserving realistic friction dynamic characteristic and deliver comparable match to experimental results. Investigation of a utilized friction model might be extended and though, might be treated as the blueprint for another friction models.
Investigation of the chemistry and tribological properties of thermal films formed by ZnDTP and by borate additives

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The investigation of the surface reactivity of ZnDTP and borate additives on iron oxide under purely thermal conditions is clearly of fundamental importance for the interpretation of the coefficient of friction values measured during tribological tests [1, 2]. Furthermore, tribological tests performed on thermal films allow the evaluation of their durability and of their anti-wear properties under conditions when the self-healing mechanism of these protective films is hindered by the lack of the additive in the oil.

While the reactivity of ZnDTP on steel surfaces under purely thermal conditions has been extensively investigated over the last few decades, the literature on the influence of this parameter in the case of borate additives is scarce. Furthermore, it has to be emphasized that most of the results reported on ZnDTP concern tests carried out at temperatures close or even higher than the decomposition temperature of ZnDTP in base oils, making it difficult to distinguish the relative roles of surface and bulk chemical reactions[3].

In order to understand and to compare the chemical mechanisms leading to the formation of ZnDTP and ZnDTP borate thermal films, a series of tests were performed at 140°C for 6 hours. Angle-resolved X-ray photoelectron spectroscopy (ARXPS) characterization was carried out to ascertain the elemental distribution within the thermal film and to determine the film thickness formed under these experimental conditions.

Moreover results of durability tests carried out using a ball-on-disc configuration at a pressure of 1.04GPa and of 0.7GPa and at a temperature of 100°C in base oil (Yubase 4) allow insights into the mechanical stability of the films grown under these purely thermal conditions and into the chemical changes occurring within the layers and induced by the sliding process.

The discussion will focus on the results obtained by characterization of the contact regions, on the steel ball and the steel disc following the tribological tests, by small-area XPS, time-of-flight secondary-ion mass spectroscopy (ToF-SIMS), optical microscopy, scanning electron microscopy (SEM) and atomic force microscopy (AFM).

Influence of in-situ formed tribolayers on abrasive wear behaviour

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1. Introduction

Resistance to high temperature (HT) wear is essential in industrial processes involving abrasive goods, as in steel making or power plants. The damage experienced by mechanical components has been found to increase significantly in HT environments. Additionally, the formation of mechanically mixed layers (MML) by embedding of abrasive particles may lead to improved wear resistance [1].

In particular, Fe-based cast materials seem promising due to their outstanding cost efficiency, but need to be evaluated under HT conditions before implementation in the real field application. The main goal of this study is the analysis of the wear behaviour of a wear resistant cast alloy under HT 3-body abrasive conditions. To this end, abrasion tests were performed in lab-scale, and the role of normal load and temperature on wear behaviour and tribolayer formation was studied in detail.

2. Experimental

A HT stainless cast steel grade was chosen for testing. Its microstructure featured a ferritic matrix with a coarse Cr-carbide network. Hot hardness testing (HHT) was performed as it has been reported to be a key parameter influencing HT abrasion resistance. Additionally, HT abrasion tests were carried out on a modified ASTM G65 tester [1], allowing the heating of samples. Standard Ottawa sand with grain size 212-300 µm was used as the abrasive. A rotating steel wheel was set as the counter body, entailing high stress conditions, as typical for industrial applications. Sample temperatures were chosen as room temperature (RT), 500 and 700°C, while the normal load was set to 10, 45 and 80 N, respectively. Wear rates were calculated by measuring the mass loss after testing, and subsequently normalised [mm³/m] dividing by the testing distance.

3. Results

HHT results showed a hardness drop from ~280 HV10 at RT to ~120 HV10 at 700°C. The observed material softening with increasing temperature was expected to enhance abrasive intermixing and thus MML formation at HT.

Calculated wear rates are displayed in Fig. 1. They were found to increase with temperature, achieving maximum values at 700°C. Temperature influence on wear rates was observed to be more pronounced at the 500 to 700°C interval. Additionally, an almost linear dependence with normal load was observed. Maximum wear rates thus corresponded to the highest chosen values of both load and temperature.

Characterisation of worn samples after testing showed the formation of a MML by embedding of abrasive particles in the deformed substrate (Fig. 2). Its surface coverage was found to increase with increasing temperature, a trend also observed for the penetration depth achieved by the abrasive in the sample substrate. It is suggested that thicker MMLs may decrease wear rates by impairing substrate removal. Also, abrasive particles embedded in the wear zone may work as artificial hard phases, contributing to increased HT wear resistance.

Figure 2: Cross section of the wear surface after testing at 700°C, as seen by optical microscopy

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4. References

SWCNH as additives to improve thermal and tribological properties of conventional lubricating oils for refrigerant and air conditioning applications

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At present, the refrigeration industry is working towards an equilibrium between environmental safeguard and energy saving, so the conventional working fluids in refrigerator compressors are being replaced by more ecological solutions. Among the natural refrigerants, CO₂ seems to be the most promising and it is being studied for possessing many useful features.

A critical component in all refrigeration and air-conditioning systems is the compressor, which contains both the lubricant and the coolant and operates at high contact pressure and temperature. In the last years, the tendency for high speeds, loads and efficiency is continuously raising, and the sliding conditions are becoming increasingly severe on moving components. The introduction of alternative refrigerants and lubricants changes the strictness of the tribological contacts, increasing operational failure probability for traditional designs. In this context, the tribology of critical couplings and the studies on new materials and surface solutions are under intense investigation.

Recent research has focused on developing wear resistant surface modifications and new more efficient lubrication systems. Variations of the applied refrigerants usually require the design of refrigeration apparatus to be adapted and lubricant to be re-selected, since the ability of the oil to provide adequate lubrication and its compatibility with the refrigerant affects the energy efficiency, reliability, and durability. Recently nanolubricants have been widely studied as alternative solutions to conventional lubricant oils, because of interesting improvements of friction decrease performances and load-carrying capability. Adding nano-objects to lubricating liquids can reduce friction and wear in surfaces that operate in sliding contact. Of particular interest are nanomaterials such as Single Walled Carbon Nanohorns (SWCNH).

In this work, a study on the tribological and thermal properties of nanolubricants for vane-on-roller systems is carried out, by testing suspensions containing different weight concentrations of SWCNH in oil. Poly-Alkylene Glycol (PAG) has been selected as the base fluid to prepare nanolubricants, and suspensions have been characterized both as regards the viscosity and the stability over time. Tribological and thermal behavior of produced nanolubricants is evaluated through wear tests and thermal diffusivity photo-acoustic measurements at different temperatures.

Nanolubricants containing up to 1%wt in PAG oil were prepared by a two-step method and tribologically characterized through rotational ball-on-disk wear tests. Experiments were carried out at 25°C and 70°C and wear tracks were analyzed by optical and electron microscopy and stylus profilometry. PAG based nanolubricants achieved improvements in coefficient of friction.

In fact, the coefficient of friction was significantly lower for nanofluids if compared with the values recorded for the base oil. The friction force reduction could be attributed to the mobility of the nano-objects in addition to the reduced contact area obtained from the presence of nanoparticles sited between sliding surfaces. Analyses carried out on wear tracks revealed that nanohorns played an important role in protecting surface against wear phenomena, as visible in Figure.

SWCNH in lubricant oils lower the wear amount compared to raw oil. Nanohorns could prevent the counter body surface to enter in direct contact with the sample surface and carry part of the applied load, thus reducing wear of the substrate through rolling and sliding activity. No exfoliation nor protective film formation was supposed, since no residuals of broken nanohorns nor carbon film were detected on wear tracks. Finally, Stribeck tests were performed on the most promising system, to evaluate benefits brought by SWCNH in all lubrication regimes. Thus, this study demonstrates the ability of SWCNH to reduce friction and wear phenomena under boundary lubrication conditions, which are the most severe for tribological couplings.
Surface modification of AISI 304 by atmospheric pressure low energy air plasma

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1. Introduction

For the production of smooth steel surfaces, especially high gloss surfaces, the final machining processes have tremendous influence on the characteristics of these surfaces. By achieving a smooth surface topography, properties of wettability or adhesion are change as well. AISI304 is a material used for such applications because of its advanced material properties, like high corrosion resistance and acid resistance. One of the most applied processes in order to achieve such a smooth surface, chemical mechanical polishing is applied. During and after this process step it was observed that the wettability is changing. Additionally, surface contamination takes place while the surface is exposed to air during drying and cleaning the steel surface. Plasma treatment is one of the most commonly used surface modification methods due to its favourable influence on wettability and adhesion properties of the material [1], [2]. In the actual work, the effect of low energy plasma on surface properties was investigated. Therefore, contact angle was measured to study the time dependent change of the wettability after plasma treatment. In addition, XPS analysis was carried out to obtain a deeper understanding of the chemical condition due to the plasma treatment.

2. Methods

The stainless steel surface was treated by low energy plasma (300 W) driven by compressed air. The steel samples have a dimension of 40 * 40 * 2 mm (h * w * t). The surfaces of the steel samples were already finished by chemical mechanical polishing (CMP) as they were delivered. To investigate the wettability after CMP the surface was polished for 2 minutes. To study the influence of plasma on the surface, plasma treatment with air plasma was done. Additionally, the distance between the plasma nozzle and the steel surface was set to 5 mm and 15 mm. AISI304 steel samples treated with the low energy plasma were compared to the polished ones. After treatment the wettability was tested by measuring the contact angle of distilled water. If the contact angle is low the wettability increases. In this case water drops show high hydrophilicity. To investigate the surface element composition in detail, XPS measurements were carried out.

3. Results

It was observed that the water contact angle of an untreated surface is at 77°. Contact angle measurements showed a time dependent effect after polishing AND plasma treatment (Fehler! Verweisquelle konnte nicht gefunden werden.). The water contact angle changes from 12° after plasma treatment at a distance of 5 mm and 30 mm/s back to 64° after 1 day. CMP of the steel surface show that the water contact angle can be reduced to 0°.

Figure 1: Contact angle of untreated, polished and plasma treated steel surface

XPS analysis (Figure 2) of an untreated and after plasma treated steel surface (distances of 5 mm an 15 mm) revealed a significant change in carbon and oxide content. Oxide content increases significantly with reducing nozzle-surface distance compared to an untreated surface while carbon content decreases dramatically. The increase of oxide can be referred to the activation of the surface by the plasma [3].

Figure 2: XPS analysis of carbon- and oxide content on an untreated and a plasma treated surface

4. References

Role of H₂O in lubrication science

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Water molecules interact with variety of surfaces to either reduce or increase the friction and wear in a system. Here, we have explored the opportunistic behavior of water – surface interaction related to salivary film lubrication, bacterial lubrication and grease lubrication. Several techniques like atomic force microscopy, pin on disc, tribochemist and four ball tester were used in this investigation. In biolubrication the ability of water binding within a salivary film is measured against the degree of glycosylation. Here, degree of glycosylation in salivary film was carefully controlled by physical adsorption of natural sugar molecules. Sugar molecules increased the glycosylation to enhance the water binding capability to the salivary film coated hydrophobic surface. Such a soft composite layer reduced the friction between PDMS pin and PDMS disc by almost 100 times under a physiological shearing condition. Apart from the naturally occurring brush like structures in salivary film the water molecules also interact with synthetic polymer brushes like polyethylene glycols (PEG). Water molecules are attracted towards hydrophilic part of the PEG (used as antibacterial coatings) to repel adhering bacteria. By varying the concentration of methoxy-PEG we were able to create polymer-brush coatings that were soft and rigid, on gold coated quartz crystal. Softness of the coatings was due to higher hydration content compared with rigid coatings. Interestingly, the friction between a bacterial cell and hydrated brush coatings was 4 times higher compared with brush coatings of low hydration. In another case, we investigated water interaction with calcium carbonate (CaCO₃) based grease. Increasing water content in grease contributed to chaotic friction profile resulting in an increase in the wear scar diameter. Here, increase in wear could be due to increase in the steric stability of CaCO₃ and overall, emulsion stability that prevents surface activity of CaCO₃ and an effective roll out of oil at the interface. In conclusion, we have demonstrated the benefits and drawbacks of water molecules interacting with the natural and artificial lubrication system.
Adhesion and friction mediated by host-guest bond rupture and rebinding

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Understanding the cooperative rupture and formation of bonds is crucial to unravel the tribological properties of biological systems and can be used as a means to tailor friction and adhesion in man-made mechanical devices. Recently J. Blass et al. investigated the behavior of friction and adhesion in presence of the supramolecular complex cyclodextrin-adamantane with atomic force microscopy. Motivated by the fresh data and by the new possibility disclosed by this technique, we set up a series of hybrid molecular dynamics/montecarlo simulations to understand the basic mechanisms leading to the measured mechanical response. Here we address in particular the role of the tip shape in the pull-off characteristics, the relation between the vertical manipulation hysteresis and the friction force and finally we discuss how the onset of cooperative multivalency might modify the velocity dependence of the frictional response.
Relationship between nano mechanical properties and tribological properties of tribo-films originated from phosphoric additives

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Extreme pressure (EP) additives provide the friction reduction and wear protection effects by forming the tribo-films on the sliding surfaces under boundary lubrication. Many researches have been tried to understand the relationship between the tribological properties and the chemical composition of tribo-films according to surface analytical results. However, it is considered that the mechanical properties such as viscoelasticity, adhesion, hardness, friction coefficient, and effective reduced modulus, of tribo-films on real contact area could be more dominant for tribological properties compared with the chemical composition [1]. There are few reports about quantitative mechanical properties of tribo-films because of the difficulty in measurement. In this study, we elucidate the correlation between the nano mechanical properties and the macro tribological properties of tribo-films.

Poly-alpha olefin (PAO, VG4) was used as the base fluid in this research. Three types of phosphates were added to the base fluid. The structure of each additive is shown in Table 1. Friction test was conducted by using a cylinder-on-disk type reciprocating sliding tester (SRV2, optimal, GE). The specimens were made of AISI52100. The nano mechanical properties of tribo-films were measured by using Atomic Force Microscopy (AFM, Nanonavi Real, SII, JP) and TriboIndenter (Ti-950 TriboIndenter, Hysitron, US). Figure 1 shows the frictional behavior of each lubricant in macro scale, while Fig. 2 shows the frictional force of each tribo-film measured by using AFM, in nano scale. In both cases, the tribo-film derived from DPP showed lower friction coefficient and frictional force than both TCP and TPP. The same tendency of friction properties in both nanoscale and macroscale suggests that the mechanical properties dominant their macro tribological properties. Relationships between various mechanical properties of tribo-films and their tribological properties will be discussed in the presentation.

References
Modelling normal contact of spherical asperity in Abaqus for determining the critical penetration depth corresponding to the onset of plasticity

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Abstract

We model a sphere-on-flat contact in Abaqus to determine the critical interference depth corresponding to the onset of plasticity. Due to the axisymmetric nature of the problem, only a quarter of a circle is used for modelling. We use quadratic quadrilateral elements to mesh the surface of the quarter circle. The quarter circle is divided into three regions to provide gradually increasing mesh density towards the contact patch. The results obtained from Abaqus for frictionless contact are compared with the Hertz solutions to verify the accuracy of our modelling. In this context, the effect of number of elements on the accuracy of the numerical results is also discussed briefly. We then obtain the stresses at the contact due to finite friction and infinite friction (full stick) conditions. The results obtained for infinite friction contact condition are also compared with some known analytical results. The critical penetration depths obtained using von Mises stress criteria are compared with analytical solutions available in the literature.
Tribological Properties of Textured Nanoporous Alumina Film

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Hard coating on a soft substrate is desirable to improve the wear resistance and to protect the soft surface [1]. Generally, hard coatings on soft substrate deforms by cracking and the cracks lead to the delamination. Hard nanoporous alumina coating on aluminum surface have high hardness [2]. The hardness of the nanoporous alumina surface depends on geometry and the distribution of the pores. We explore the possibility of using the nanoporous alumina film formed on an aluminium substrate as a tribological coating. Highly ordered nanoporous alumina has been created by controlling the anodisation process. By varying the anodisation parameters such as pH value of the solution, voltage and temperature of electrolyte, the diameter and pitch of the pores can be varied. As the anodisation time increases, the thickness of the porous alumina increases. The hardness of the coating is measured using nano-indentation and it is increased by increasing the coating thickness. The deformation mechanisms of the coating also depends on the coating thickness. During indentation, the cracks are observed at lower thickness and at higher thickness of the coating the pores get compacted. Since the alumina layer is much harder than the aluminium substrate, the area function method of determining hardness gave lower hardness values. Therefore the real area of the indent is obtained from the SEM images and calculated the hardness value. The results indicate that the mechanical properties like hardness can be improved by tuning the geometry of porous alumina and can be effectively used as a tribological coating. We measure the tribological property of the porous alumina surface by reciprocating a steel ball of 57 mm radius at different normal loads and found that it has good wear resistance property.

References

Mechanical systems with dry frictional contact interfaces are generally affected by friction-induced vibrations [1]; these vibrations are at the origin of a very wide family of phenomena from the sound emitted by a string chord to the annoying noise of an hip endoprosthesis [2].

In the study of friction-induced vibrations the strong coupling between the local and global dynamic behavior has been assumed to be one of the main mechanisms that governs this phenomena. The local behavior and the change of contact conditions (adherence, sliding or detachment) affect the global response of the system through the propagation of waves from the contact interface to the bulk of the system [3]. On the other hand the global dynamic behavior, material characteristics and boundary conditions, can affect the contact during friction-induced vibrations [4].

The investigation of these phenomena has been extended to a finite element model reproducing an experimental setup developed at the LaMCoS laboratory and allowing for reproducing friction-induced vibrations [5]. An energy balance has been formulated to distinguish between the energy dissipated locally at the contact interface and the energy re-introduced into the mechanical system by friction-induced vibrations and than dissipated into the bulk by means of the material damping, during the vibrations of the system [5, 6]. This analysis shows the strong interaction between the contact and global dynamics by an energy point of view. The evolution in time and space of these energy quantities is given for different operating conditions and different contact behaviors.

The investigation of the dissipation repartition between the bulk and the contact allows for quantify the mechanical energy that is actually dissipated at the contact. This energy and its temporal and spatial distribution are strictly related to wear during friction-induced vibrations.

On the dry-clutch torque kinetics: FE model for temperature field

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Abstract

The growing demand of automated manual transmissions in modern vehicles has led up to a rapid gain of market share of this type of transmission, especially respect to the manual transmissions. The Automated Manual Transmissions (AMTs) and Dual Clutch Transmissions (DCTs) represent an affordable, robust and ecological driveline solution. On the other hand, the performances of these transmissions types are deeply affected by the clutch frictional torque and its model implemented in the Transmission Control Unit (TCU) [1].

The tribological contact under sliding condition in the clutch facing surfaces during the engagement maneuver is strongly affected by heat transfer occurring in the system. The frictional forces acting on the contact surfaces produce mechanical energy losses which are converted in heat with ensuing temperature increase. The magnitude of temperature rise depends on the thermal properties of the clutch facings [2].

Reports about the temperature rise after repeated clutch engagements prove the occurrence of interface temperature peaks as high as 300 °C [3] and [4].

Unfortunately, only few papers address their focus toward experiments and their outcomes about the influence of temperature and the other operating parameters on the frictional behavior of the clutch facing materials [5].

In such works, the Authors mainly explored the frictional behavior modification for thermal level higher than 250-300 °C, whose effect is a sharp decline of the friction coefficient related to the decomposition of the phenol resin of the facings. Moreover, this phenomenon induces not expected transition from dry friction to mixed dry-lubricated friction which explains the reasons of the friction coefficient drop.

A Finite Element Analysis (FEA) analysis of the temperature effects on the cushion spring load-deflection characteristic and the ensuing transmitted clutch torque has been introduced in [6]. In [7] the FEA analysis has been proposed to predict the facing wear as function of the contact pressure.

In this paper an original frictional map has been implemented in FEA to predict the temperature field during typical clutch engagement start-up manoeuvre on the contact surfaces. In the proposed FE model the clutch facing material and the pressure plate have been modelled to get the heat generation due to the frictional forces by assigning the sliding angular speed and the pressure contact. The simulation results prove that after repeated clutch engagements the temperature field reaches values near the critical point of 300 °C.

In such a way, this paper aims at providing useful references to control engineers in order to improve the dry-clutch transmissions performances.

Keywords: dry clutch, friction coefficient, temperature, Finite Element Analysis, engagement driving.

References

Abstract

A numerical analysis of a reciprocating hydraulic rod seal, considering both flooded and starved boundary conditions, has been performed. It consists of coupled fluid mechanics, contact mechanics and load support analyses. The fluid mechanics analysis consists of a finite volume solution of the Reynolds equation. The static contact pressure is computed with a finite element analysis, while the contact of the seal asperities with the rod during rod motion utilizes the Greenwood-Williamson model. The fluid transport, friction force, film thickness distribution, contact pressure distribution and fluid pressure distribution in the sealing zone have been computed for a polyurethane U-cup seal. Starved conditions lead to a smaller region of pressurized fluid in the sealing zone, higher contact pressures and a higher friction force than with flooded conditions. It is shown that when the sealed pressure during the preceding outstroke is low, starvation will occur during the instroke. It is noted, however, that if the pressure during the preceding outstroke is high, flooded conditions can be approached.

**KEY WORDS:** seals, elastomeric seals, lip seals, reciprocating seals, rod seals, EHL, starvation
Modeling Friction in Nanoscopic Ionic Liquid Films.

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Room temperature ionic liquids refer to a class of salts with a relatively low freezing point, often consisting of a larger organic cation and an organic or inorganic anion. These materials recently attracted a lot of scientific attention as the flexibility in the choice of the cation/anion molecules allows the properties of the liquid to be fine-tuned. The behavior of ionic liquids in confined geometries is of great interest for different fields, ranging from biological systems to super-capacitors, micro/nano-fluidic, and lubrication. Ionic liquids form layered structures at surfaces, yet it is not clear how this nano-structure relates to their lubrication properties.

In this talk I will present results of our molecular dynamics simulations, which have been performed to study a relation between measured friction forces and structure of confined ionic liquids under shear. The focus of this research is on the effect of external electric field on frictional properties of ionic liquids. Simulations have been performed using simple models of ionic liquids, which have been shown to provide a good description of equilibrium properties of confined ionic liquids. The results of simulation exhibit chaotic stick-slip response in a wide range of system parameters. In agreement with experimental observations, the simulations show multiple friction-load regimes, each corresponding to a different number of ion layers in the film. In contrast to molecular liquids, the friction coefficients differ for each layer due to their varying composition. The simulations demonstrated that friction can be efficiently tuned by an electric field to either increase or decrease lubricity. Importantly, the response to an electrostatic potential change depends on the IL used. These findings open new pathways for lubricant design.
Highlights of the Wear Mechanism of Si(100)/Silica in the Presence of Various Ionic Liquids.

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Room-temperature ionic liquids (ILs) constitute a class of fluids generally exhibiting high thermal stability, negligible vapor pressure and non-flammability. These properties are highly desirable for lubrication and, consequently, the tribological performance of a large variety of materials lubricated with ILs has been extensively investigated during the last decade. However, knowledge of wear and friction mechanisms taking place when ILs are used as lubricants is still limited, particularly in the case of silicon-based materials. Lubrication of silicon is a topic of great interest in the light of the importance of wear prevention in MEMS systems, as silicon and silicon-based materials are still the materials of choice for their production.

In this work, an investigation of the tribological behavior of Si(100) vs fused silica surfaces lubricated with ionic liquids (ILs) is presented.

Two classes of 1-alkyl-3methyl imidazolium ILs were investigated: ethyl sulfate-based ILs (EtSO4) and tris(pentafluoroethyl)trifluorophosphate-based ILs (FAP). In order to assess the effect of environment on friction and wear, the tribological tests were carried out under two environmental conditions: in a nitrogen atmosphere and in humid air (45-55% RH).

The results of pin-on-disk tests showed that the differences in chemical composition among the tested ILs led to significantly different tribological behavior. In particular, it was found that wear was predominantly governed by brittle fracture in the case of EtSO4-based ILs, as evidenced by scanning-electron micrographs, which showed the generation of cracks and pits in the contact area. The presence of water was found to play a major role, mainly affecting the formation and aggregation of debris in the contact area and the composition of the resulting third body.

In contrast, no crack propagation was observed in the case of FAP-lubricated contacts and a much less severe form of wear was observed under these conditions. Chemical reactions induced by tribological stress are suggested to be playing a major role in this case. The environmental conditions were found to alter the composition of the tribological layer: this might explain the differences in wear and friction trends observed when using FAP-ILs as lubricants (1).

The presented tribological results are discussed in the light of the surface-chemical analysis carried out by X-ray photoelectron spectroscopy and the analysis of the structural changes of the surface and near-surface regions caused by the tribo-mechanical stresses.

Lubricity of Halogen-free Ionic Liquids

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Keywords: Tribology, Halogen-free ionic liquids, Sulfur element

Ionic liquids are expected to be used as new high-performance lubricants owing to their attractive characteristics such as high thermal stability, low vapor pressure, and conductive property. Most investigations have performed to find out the lubricating mechanism of halogen-containing ionic liquids [1, 2]. It was reported that the halogen in the ionic liquids cause the severe corrosion of metallic materials. To prevent the corrosion of metallic materials, we attempt to apply the halogen-free ionic liquids to lubricants. However, they show inferior lubricity to halogen-containing ionic liquids [1]. Thus, it is necessary to improve their lubricity.

In this study, the lubricity of the halogen-free ionic liquids on an AISI52100 surface were investigated by the ball-on-disk type friction tester. Figure 1 shows the molecular structures of used halogen-free ionic liquids (referred to as [EMIM][DCN], [EMIM][TCB], [EMIM][SCN], [EMIM][ESU]). [EMIM][SCN] and [EMIM][ESU] contain sulfur element, which can form reactant with the metallic materials. The sliding tests were performed at a normal load of 4.5N, sliding speed of 52.3 mm/sec., for 2 hour’s.

Figure 2 shows the average of friction coefficient of the last 5 minutes for each halogen-free ionic liquid. The friction coefficient of [EMIM][DCN] showed about 0.07. As for [EMIM][TCB], showed the highest friction coefficient. On the other hand, the friction coefficient of sulfur-containing ionic liquids showed the low value. About [EMIM][ESU] in particular, the friction coefficient showed very low value around 0.04.

These results suggested that the lubricity of halogen-free ionic liquids was improved by the containing sulfur in the molecular structure. As a reason for the low friction, sulfur element is considered to react with iron of ANSI 52100. In the presentation, reaction mechanism will be discussed with the analytical results by using XPS and Q-mass spectrometer.

References
The effect of molecular structure on the tribological properties of ionic liquids against carbon coatings

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Ionic liquids (ILs) are organic salts consist of cations and anions in a liquid state at room temperature. They are expected to be used as new high performance lubricants under extreme environment such as high temperature and high vacuum conditions because of their low volatility, high thermal stability, and high oxidation stability. Tribological properties of ILs are generally determined by the tribochemical reaction films derived from the elements of anions.

We used two ILs; 1-Butyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide ([BMIM] [NTF]) and 1-Butyl-3-methylimidazolium trifluoromethanesulfonate ([BMIM] [OTF]) for the sliding test between the disks coated Hydrogen free DLC (H-free DLC) and 100Cr6 balls. These two ILs have the same elements, which generate tribochemical reaction film with steel easily, but showed the different friction behavior shown in Fig. 1. This result suggests that the friction properties of ILs do not depend on only the elements composing them. The H-free DLC surfaces lubricated with each IL were analyzed by X-ray photoelectron spectroscopy (XPS) to ascertain the difference of tribochemical films. Fig. 2 shows the XPS O1s spectra on the lubricated H-free DLC surface with each IL. The spectrum around 530eV indicates Fe₂O₃, which detected only from the surface lubricated by [BMIM] [NTF]. On the surface lubricated by [BMIM] [OTF], however, Fe₂O₃ was not detected and the presence of another compound whose binding energy was on 536eV was found. This result suggests that the molecular structures of anions affect the tribochemical reaction, which can decide the tribological properties of ILs.

In this research, we focused on the effect of molecular structures of anions against the tribological properties of friction between disks coated H-free DLC and 100Cr6 balls.

Fig.1 Friction behavior of each IL against H-free DLC disk with 100Cr6 ball

Fig.2 The XPS O1s spectra on the H-free DLC sliding surface with each IL
Nano and micro hBN in oil as anti-wear and antifriction additive
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Mineral oils are invariably used as lubricants for machineries. Performance of oils is enhanced manifold by adding a combination of additives such as anti-oxidant, anti-corrosion, detergent, anti-friction, anti-wear, extreme pressure, etc. Ever increasing demands on performance of oils calls for more and more efficient additives. Nano-Particles (NPs) appear to be the most efficient solution to this challenge which has changed the basic definition of additives. These NPs are not soluble in oils but exists in the form of nano-suspension. Because of the high surface area/volume ratio of NPs, the interaction with tribo contact points on metal surface increases significantly leading to very thin and uniform film which is beneficial from friction and wear point of view. A little is reported on such NPs such as Nano-PTFE, Nano-graphite but not on nano-hBN in details.

Hexagonal Boron nitride, hBN also called as white graphite is known as very efficient solid lubricant. A series of nano and micro-oils was developed based on dispersion of hBN (0.2 %) in group II mineral oil with the help of probe sonication. The oils were tested using ASTM D4172 and ASTM D5183 standards for wear scar and coefficient of friction, respectively on 4 ball tester. It was observed that inclusion of small amount of hBN (both in nano size- 70 nm and micro-sizes -0.2, 0.5, 1.5 and 5 micrometer) reduced the coefficient of friction from 0.08 to 0.04. The wear scar diameter also reduced up to 16 %. Extent of reduction depended on the size of particles. The biggest particles led to 10 % decrease. Nano- hBN was most effective in this case. The quality of film of hBN transferred on the balls was claimed to be responsible for the improved friction and wear performance as evident from SEM-EDAX studies.
Identification of oxidative degradation products of esters by joint use of mass spectrometry and isotope labelling

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1. Introduction
Besides stress conditions, the oxidative stability of lubricants, fuels and their components is heavily dependent on their chemical structure. Exemplarily, linear and unbranched hydrocarbons exhibit a higher oxidation stability compared to branched, aromatic and unsaturated hydrocarbons [1].

Numerous methods for the assessment of oxidation resistance exist that differ in temperatures, catalysts, pressure, and other parameters [2], e.g. CEC L-48-A00 for automotive transmission fluids, turbine oil oxidation stability test (TOST) for different oil types, thermo-oxidation engine oil simulation test (TEOST) for the prediction of high temperature deposit formation tendency, and rotary pressure vessel oxidation test (RPVOT) that is based on pressure drop upon oxidation.

Analytical methods mainly focus on routine methods, e.g. viscosimetry, infrared spectroscopy, titration for bases, and acids. However, none of these methods provide details on the chemical degradation. Mass spectrometry (MS) enables the structural elucidation of degradation products of lubricants. Though, in case of oxygen containing lubricants and components, e.g. ethers and esters, a differentiation of the oxygen origin in a degradation product, either from lubricant or via oxidation, is difficult to be determined. Therefore, isotope labelling is proposed.

2. Methodology
RPVOT was applied to monitor the oxidation via pressure decrease and to collect volatile degradation products. Artificial alteration was done according to a modified RPVOT method based on DIN EN 12205 [3]. A 2 wt% solution of linoleic acid methyl ester in dodecane was artificially altered at 95 °C with 16O as well as 18O labelled oxygen, respectively. For the oxidation (1 or 2 oxygen atoms) by comparison of cleavage and oxidative attack as well as degree of oxidation stability compared to branched, aromatic and linear and unbranched hydrocarbons exhibit a higher oxidation stability [1].

3. Results
MS analysis unambiguously revealed the sites of bond cleavage and oxidative attack as well as degree of oxidation (1 or 2 oxygen atoms) by comparison of spectra from samples altered under 16O atmosphere with spectra from oil aliquots altered with 18O. Spectra interpretation confirmed preferential cleavage in or next to a double bond with the formation of alcohols and mainly carboxylic acids. As another consequence of oxidation, the formation of water was observed.

4. Acknowledgements
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5. References
Silver sulfide as an antiwear additive for a biolubricant based on rice bran oil.

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Abstract:

Conventional energy sources are diminishing day by day and energy scarcity is one of the biggest problems which we are going to face in the next century. Lubrication is one of the main fields of science and engineering which reduces wear and tear and thus less energy loss due to transmission. It is necessary to improve the efficiency of lubricants and it should be biodegradable and less toxic. The mineral oils are found to be non biodegradable and harmful to earth and water reserves. Bio lubricant formulation from vegetable oils is getting more and more importance now a days due to its high biodegradability and non toxic nature. Vegetable oils has good thermal properties and lubricity but it has less oxidative stability and high wear characteristics are the main drawbacks. However the wear characteristics and oxidative stability of Rice bran oil shows better performance compared to the other vegetable oils. Rice bran oil is also one of the potential candidates for bio lubricant formulation since it has good thermal properties like flash point, fire point as well as thermal stability Therefore, rice bran oil is chosen to develop a new bio lubricant for industrial application.

In this paper tribological properties like viscosity, friction coefficient and wear of Rice bran oil have been evaluated and presented. To reduce wear silver sulfide is used as an anti wear additive in rice bran oil and the wear test has been conducted using a four ball tester. The SEM images have been taken for wear scar and is found that the silver sulfide fine particle has a good wear reducing property in rice bran oil. The coefficient of friction has been evaluated as per ASTM D 5183 – 05 with a speed of 600 rpm and wear scar diameter has been calculated as per ASTM D 4172-94 with a speed of 1200 rpm and 400N load. As silver sulfide as additive both coefficient of friction and wear are reduced in rice bran oil when those properties are compared with the commercially available mineral oil SAE20W40. The experimental results show that silver sulfide is a good antiwear additive for rice bran oil. The wear characteristics of 0.1% silver sulfide with rice bran oil has good compared with pure rice bran oil.
Surface characterization and contact mechanics

Simulative Investigations of a Close-to-Component Journal Bearing System and Comparison with Test Data

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Keywords: mixed friction, simulation, journal bearing, close-to-component test methodology

Abstract

Regulations for automotive industry aiming to reduce the CO₂ imply the use of low viscosity oils, light weight design, downsizing and hybridization. These performed actions have an impact on the tribological behaviour of hydrodynamic journal bearings of internal combustion engines (ICE) and increase their tribomechanical loading: widened mixed friction regime, high specific loads. Furthermore the upcoming Start/Stop technology leads to a significant part of lifetime in boundary/mixed friction regime and pushes these regimes of friction in to the focus of present research. Actual mixed friction models are composed of a contact model, e.g. according to Greenwood and Williamson [1], and the averaged Reynolds’ equation. In situations of small lubricant film thicknesses the micro topography influences the fluid’s flow and pressure build up, which is considered with help of flow factors [2].

With the current study the suitability of commonly used mixed friction models is investigated with help of comparison between performed tests and conducted simulations.

To evaluate the scope of commonly used models tests are conducted on a rotationary tribometer TE92HS by Phoenix Tribology in connection with a journal bearing adapter (JBA) [3]. The setup allows a sensitive acquisition of data which provides a deep in detail view of the system’s frictional behaviour. Thus, several influences on the tribological system can be visualized, see [4]. For the simulation part a model representing the JBA is set up in COMSOL and the conducted tests are simulated and compared with measured data.

The overall agreement between simulation and test is discussed with help of Strubeck curves allowing examining fluid and boundary/mixed friction regime in more detail. Furthermore specific aspects of the contact model and their influences on the simulation results are presented.

Literature


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An Experimental and Theoretical Study on Surface Distress Resistance of Hybrid Bearings

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Hybrid bearings, i.e. bearings with ceramic rolling elements and steel rings, are often used in applications with reduced (i.e. boundary or mixed) lubrication conditions. The reasons why hybrid bearings perform appreciably better than all-steel ones in these cases seem to be unclear so far [1], although experimental evidence shows that prominent performance benefits can be obtained with hybrid bearings under reduced lubrication (see e.g. [2-4]).

In the present work the surface distress resistance of hybrid rolling/sliding contacts in poor lubrication conditions is studied in detail by means of rolling bearing fatigue experiments and a previously developed surface distress model [5]. It is found that the large improvement in surface fatigue resistance of hybrid contacts cannot be explained solely on the basis of the unavoidable differences in some of the roughness parameters existing between the all-steel and the hybrid contacts (i.e. lower roughness r.m.s. and a more negative skewness of the latter). It is also necessary to take into account a considerable reduction in the effective boundary friction coefficient of the hybrid contact, in comparison with all-steel one, which has been observed in a number of dedicated tests. Understanding the mechanisms of the enhanced surface distress resistance of hybrid bearings under reduced lubrication conditions sheds a new light upon the operational tribology and performance capabilities of bearings with rolling elements made of silicon nitride ceramics.

Key words: Hybrid Bearings, Ceramics, Silicon Nitride, Surface Distress, Micropitting, Surface Fatigue.

References
Analysis of Dynamic Behavior of a Non-Nominal Five-Pad Tilting Pad Journal Bearing

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Abstract

Because tilting-pad journal bearings (TPJB) are more stable and efficient than conventional bearings, they have been commonly applied to many rotating machinery applications. Most of the studies about steady state and dynamic characteristics of TPJBs are usually evaluated by means of thermo hydrodynamic (THD) models assuming nominal dimensions for the bearing. However machining errors could lead to actual bearing geometry and dimensions different from the nominal ones. In particular for TPJB the asymmetry of the bearing geometry is the principal cause of unexpected behavior. In this paper a theoretical analysis on dynamic characteristics of a five-pad TPJB is investigated with non-nominal geometry, that is, different thickness for each pad. The dynamic coefficients of a five-pad TPJB with a nominal diameter of 100mm, length-to-diameter ratio (L/D) of 0.7 are evaluated versus rotor rotational speed, load direction and static load. Then, the analytical results of the non-nominal bearing are compared to those of the nominal one.

Keywords: Tilting–pad journal bearing, analytical model, non-nominal bearing, dynamic coefficients, five pads.

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WEAR PREDICTIONS FOR REVERSE TOTAL SHOULDER REPLACEMENTS

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Introduction
Reverse total shoulder arthroplasty (RTSA) has become the gold standard to treat rotator cuff tear arthropathy (Fig.1.a). RTSA is performed by substituting the humeral head and the glenoid cavity by a plastic cup in UHMWPE and a metallic head, respectively (Fig.1.b), in a geometrical reversed configuration with respect to the anatomical one. Major complications affect 27% of cases and mainly regard scapular notching due to cup-bone impingement and wear debris [1]. Unfortunately, wear in shoulder prosthesis has not been largely studied as for hip and knee implants. Indeed, no wear test standards or even shoulder simulators exist, also because of a limited knowledge on shoulder/RTSA dynamics. Additionally, only a few numerical wear models for RTSA can be found in the literature (e.g. [2,3]), mainly focused on the comparison between anatomical and reverse solutions, and which often simulates simplified conditions, such as planar unloaded motions [3] even neglecting fundamental aspects of wear process, i.e. cross-shearing (CS) [2].

The aim of the present study is to numerically investigate wear in RTSAs analysing the effect of: a) wear factor and wear law; a) implant geometry; b) inversion of bearing materials, i.e. plastic head + metallic cup, which should reduce the risks associated to scapular notching.

Methods
The wear model for hip implants described in [4] was adapted to shoulder replacements and modified in two main aspects: 1) addition of the relative translation between the head and cup centres in the expression of the sliding velocity; 2) adoption of Bartel’s approximated formulas [5] for solving contact analysis. Two wear laws were simulated: the Archard law and a new one for wear of UHMWPE [6]. In particular, different expressions of wear factor k were considered, also including the CS [4]. It is worth noting that the values adopted for k in numerical simulations were originally obtained for hip implants, since no specific k for RTSA is currently available in the literature. Numerical simulations were performed for different implant geometries \((r_c=18, 19.5, 21 \text{ mm}; c_{ls}=r_c-r_h=5, 50, 500 \text{ nm}; t_b=6 \text{ mm})\) and inverted bearing materials. As boundary conditions (BCs), high load levels and 3D kinematics, taken from [7] and depicted in Fig.2, were assumed.

Results and Discussion
The wear factor/law were demonstrated to affect significantly wear predictions, which is in agreement with [3,4]. Regardless the implant geometry, variations of volumetric/ linear wear rates higher than 50%, as well as different wear maps, were obtained (Fig.3).

The estimation and use of RTSA specific k is recommended in future researches because it might limit the model reliability, as suggested in [8].
Tribotesting of advanced materials for a lightweight brake disc concept

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The push to obtain lighter components and to improve energy efficiency, thus reducing harmful emissions of terrestrial vehicles, is at the base of the development of a car brake disc obtained by joining wear-resistant ceramic and MMC composite inserts to a lightweight aluminum alloy bulk material in the research project JOLIE. Tribological tests were carried out in the disc development process to evaluate the friction, wear and heat transfer performances both of the ceramic and composite materials and of the joined materials solutions: applied test methods and results are described in this paper.

First a screening of ceramic and ceramic-composite candidate materials was conducted by pin on disc tests using small scale disc specimens and counterpart “pins” extracted directly from in-production brake pad friction materials.

Best performing candidates were thus selected to be joined to Al alloy substrate and proper bonding technologies were tuned up.

Tribotests were then conducted with small scale Al-MMC joined specimens for a further assessment of the friction, wear and heat transfer behavior.

Afterwards the dimension of bonded samples was scaled up to a 110mm diameter disc to assess the brazed joint strength and a special tribotesting procedure was issued to simulate the operating conditions of the full-scale brake disc.

Finally a complete brake disc was assembled and preliminary tests on a dynamometer were conducted. The prototype brake disc offers a weight saving of 25% over the reference cast iron disc and a potential cost reduction in comparison with full ceramic composite disc.
WEAR DETECTION AND MEASUREMENT USING A 3D OPTICAL SCANNER: A CASE STUDY
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Abstract
Currently 3D optical scanners are more and more requested and used for a huge numbers of applications especially in industrial and manufacturing sectors. Examples of those applications include deformation, wear and geometry analysis or measurement, quality control, inspection, reverse engineering, industrial design, rapid prototyping and digitalization of existing components.
In this study, a handle 3D scanner for metrological applications has been used to perform wear volume measurements of two different steel blades for planetary concrete mixers. Scanned and CAD models have been compared by using mesh editing and 3D modelling software. To guarantee the consistence of the comparison, the two different blades have been tested with the same operating conditions (time-period, same mixture and mixer). The purpose of this paper is to show optical non-contact measurements of worn blades operating in a planetary concrete mixer and to demonstrate how a new proposed blade shape, previously presented in [1], allows longer durability than the actual one.
The scanner used in this work is Go!SCAN 20 by Creaform, a portable 3D scanner for metrology. Both resolution and accuracy are up to 0.1 mm and it works according to the principles of structured light imaging, by projecting white light patterns on the scene. This device allows real time coloured 3D reconstructions. Scanning procedures can be performed by using three different types of positioning references: physical targets, virtual targets provided by surface’s natural features and geometrical comparison frame by frame.
Performance optimization of a concrete mixer is an issue of great significance in many industrial technologies and wear is one of the main phenomena to be forecast and tested during the design and exercise of mechanical components. In all the concrete mixers types, blades suffer the wear more than other components.
The standard mixing blades have a ”T” shape, with vertical axial symmetry. Their main function is to unload the tank, while the main arms function is mixing the ingredients. The blade design has been studied to extend the blades’ life by considering the mixing phase after the water inlet.
In this study both the standard and the new designed blades have been measured using Go!SCAN 20 by Creaform, in order to get information about their consumption and wear and to investigate if the new designed blade is able to resists wear better than the standard one, allowing longer durability.
Only a few papers present researches about planetary concrete mixers. For instance [2], [3] show a calculation of blade forces but literature regarding mixer components’ wear is poor.
The novelties of this work are:
- Wear measurements used to validate the new improved blade design, based on the Bingham model and the kinematic analysis of blades.
- Wear volumes measured by means of an innovative optical 3D scanner
- Comparison of scanned and CAD models by dedicated software.

Interaction force measurement in case of quasi-instantaneous loadings: application to severe contacts in turbomachines

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In case of exceptional occurrences such as birds or ice ingestion during the running's aircraft engine severe contacts between the rotor blades and the casing or between fan blades and rotor slot may occur leading to possible damage and failure of main components. In order to improve performances, reliability and security specific coatings are used to prevent these events. The investigation of their thermomechanical behavior needs appropriate experimental means to reproduce quasi-instantaneous loadings where the sliding velocity can vary up to 300 m/s. For this purpose, two specific ballistic benches have been designed and developed to study extreme contacts between abradable coating and the blade tip or between the blade dovetail and the rotor slot. In both cases an impact of a projectile propelled by the sudden expansion of nitrogen (or air) against a specimen or a tool allows us to reproduce dry friction or cutting phenomena.

The force measurement is obtained thanks to customized dynamometer or tribometer devices. In this presentation both techniques are presented. Design, calibration and capability (samples size, velocity and normal pressure range) are detailed. The force signals of these dynamic events (process duration inferior to 2 ms) are explained and discussed. In the case of the highest interaction velocity a correction method, based on the principle of modal analysis, is applied to evaluate accurately the forces during the process. The comparison of raw, filtered and corrected signals highlights that such a correction is particularly well adapted to these extreme conditions. Being confident about experimental measurements, forces can be correlated to wear mechanisms observed by postmortem analysis or in-situ observations (by means of a high speed camera).

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KINETIC ENERGY REGENERATION IN FRICTION-INDUCED VIBRATION SYSTEM
BY USING PIEZOELECTRIC DEVICE

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Keywords: Friction-induced vibration, Negative friction-velocity slope, Piezoelectric power generation

Friction-induced vibration is a problem to be solved for realizing high performance and user-friendly sliding systems [1]. However, this vibration is a unique phenomenon in which kinetic energy is converted into vibration energy by the action of friction force within the sliding system. Using the friction induced vibration, kinetic energy regeneration is realized with a vibro-electric converter such as a piezoelectric device, and despite friction is a phenomenon which dissipates kinetic energy.

In this research, we propose a concept of electrical power generation by using friction-induced vibration with a piezoelectric device. In order to examine the feasibility of this concept experimentally, a ball-on-plate type friction-tester that embodied on 1 degree of freedom sliding system was developed. An AISI 52100 ball, which was supported by parallel leaf springs with a piezoelectric film, was slid on a SS300 plate lubricated with glycerin. The displacement of the ball and the generated voltage in the piezoelectric film were measured. Sliding tests were carried out on various normal loads and driving speeds.

Figure 1 shows temporal changes of displacement and voltage at normal load of 10 N and driving speed of 40 mm/s. The displacement change showed that the friction-induced vibration was generated with amplitude of approximately 0.3 mm. The voltage was generated by the temporal change of displacement. The generated electric power was calculated to 95 μW by integrating the temporal change of voltage. This result indicates that the friction-induced vibration is applicable as a means for the power generation of energy harvesting. Figure 2 shows the effect of driving speed and normal load on amount of power generation. It implies that the sliding condition of high load and/or high velocity is the preferred condition to obtain the practical power generation for the operation of the micro-power devices such as wireless node and sensors.

Reference
Tribometry in oscillation - a closer look at static friction

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1. Introduction
Critical aspects of tribological system like start-stop motions or stick-slip properties are characterized by mechanisms that take place both in static and dynamic friction.

Especially the properties in static friction are not easily measureable. Measurements at extremely low speeds are necessary to look at these phenomena in detail, to investigate the nature of the phenomena.

2. Approach
Rheometer measuring drives are optimized for controlling precise movements (min. deflection angles 0.1 µrad, resolution 10 nrad) and torques (min. torque: 10 nNm, resolution: 0.1 nNm) and for measuring the reaction movement or the reaction torque. This precision allows for the characterization of both static as well as dynamic friction.

In Rheology, the transition from static to dynamic conditions is determined by oscillatory measurements. In this work the approach is transferred to tribological measurements.

At a constant frequency, a sinusoidal force signal is induced in the tribo-contact and the resulting deflection is measured. From this moduli can be calculated that represent stored and dissipated energies. This allows for the characterization and differentiation of static friction properties of dry and lubricated tribo-systems.

3. Results
Extensive Information about the type of transfer from static to dynamic friction, as well as exact values for the static friction can be determined. Fig. 1 shows the dependence of the moduli and static friction value on material choice in a point-contact tribo-system.

Details of the method, its scope and limitations, will be discussed.

Figure 1: Moduli of metal-metal and metal-polymer tribo-systems in static friction at different excited states in oscillation
Practical aspects for the determination of the static and dynamic friction behavior using an oscillating tribometer

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Abstract

For a systematical evaluation of the friction and wear behavior of different material combinations and lubricants for specific applications, tribological model tests are often used. For these model tests, different measuring devices are used. However, the results of all these studies are meaningful and transferable into the practice, only if the measured signals are interpreted correctly.

In oscillating model tests it should always be specified how the coefficient of friction was determined. By default, the coefficient of friction determined by mostly all tribometers is the mean value of the peak values of the friction signal per period. This determination of the coefficient of friction over the peaks of the friction signal may conduct to a completely biased interpretation of the friction behavior. For example, the highest coefficient of friction may occur at turning points of the oscillating movement, where the velocity reaches zero. This coefficient of friction actually corresponds to the static friction. However, it cannot be traced back to the sliding friction and thus the coefficient of friction may be misinterpreted. On the other side, the maximum of the coefficient of friction may also occur in the region of highest sliding speeds, which can for example be attributed to the internal friction of a lubricant. In both cases, a detailed analysis of the friction signal over one or more movement periods can provide more information for an adequate evaluation of the friction behavior and, thus lead to a better understanding of the tribological interaction of a system.

Using examples, the present study will be focused on the practical aspects of a detailed friction signal analysis and the determination of the static friction of oscillating tribological model tests using a SRV4™ tribometer.
TRIBOMETRIC ASSESSMENT OF START STOP JOURNAL BEARING WEAR WITH THE AID OF A COMPONENT CLOSE TEST METHODOLOGY

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Keywords: Start/Stop operation, Bearing wear, Component near test methodology

1 INTRODUCTION

Journal bearings are commonly designed to transmit high loads and reaction forces with the aid of a load bearing fluid film. However, especially during start-up and shutdown of the engine the protective lubricant film collapses and direct contact of shaft and bearing material occurs. Within the scope of this study the start stop wear performances of various journal bearing systems have been investigated. Tribometeric tests were carried out on a rotational tribometer with a novel component near test configuration for journal bearing systems, wherein two 120° journal bearing shells were sliding against a shaft specimen [1]. The tests were performed with a lubricant similar to a fully formulated oil for heavy duty diesel engines containing ZDDP additives. Tribosurfaces have been analysed by light microscopy and SEM-EDX technique.

2 RESULTS

The used methodology proved its ability for component near testing of start stop operation of journal bearing systems. The results of this study emphasise on the difference in wear behaviour of various bearing materials under start stop conditions and their tribological functionalities under these operation conditions. Parts of the tribometric results are given in Figure 1, wherein the bearing wear of a polymer overlay, a casted Al based bearing material and an electroplated lead based overlay are compared.

![Figure 1.](image)

Figure 1.: Wear of selected bearing materials after 1800 start stop cycles

3 REFERENCES


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Quantification of barrel friction in small arms

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1. Introduction

Within the last decade, the friction-induced energy loss has been gaining a lot of attention in the development of modern firearms and ammunition-components. Besides the depression of muzzle energy, the reason for the interest in barrel friction lies in the persisting necessity for using either lead-free or lead-reduced ammunition in both civil and military applications. Beyond the well-known problems in the external and terminal ballistics of lead-free bullets, the friction-induced barrel fouling is also challenging when producing sustainable small arms ammunition.

To cope with these problems, first it is necessary to quantify the friction of a bullet travelling in a rifled barrel. One of the most common methods for this uses the force measurement of quasi-static push tests of bullets through small barrel segments [1]. It offers the possibility to record the friction force depending on the current bullet position, however, these tests are performed with completely different velocities in comparison to the real system, which results in different friction regimes.

Another, recently developed method for barrel friction determination under real sliding conditions is based on a relationship between powder charge weight and muzzle energy [2]. A considerable disadvantage of the latter method is that it assumes a linear relationship between powder weight and muzzle energy which is not always the case. Furthermore, one should also take into account that the resulting energy loss is a combination of several energies, i.e., it is not just a pure friction energy loss. Therefore, it is necessary to further develop the existing methodology, e.g., by a scheme which relies on energy considerations during the firing process of a small arm, in order to quantify the bullet barrel friction within a given weapon-ammunition combination [3].

2. Method

The proposed method is applied to the far-spread calibre .22lr (long rifle) used, for instance, in Olympic sport shooting competitions.

The energy balance in case of a shot is given by

\[ E_0 = E_n + E_a + E_{Gas} + E_{Gas} + E_{RS} + E_{Pat} + E_{kBarrel} + E_{kBullet} \]

where the total energy stored in the powder charge \( E_0 \) is obtained as the product of energy density and powder mass. Here, external ballistic measurements of the bullet velocity in combination with the simulation of internal and external ballistics provide the translational kinetic bullet energy \( E_n \), the rotational kinetic bullet energy \( E_{a} \), the kinetic gas energy \( E_{Gas} \), and the recoil energy \( E_{RS} \), respectively. By assuming an adiabatic expansion of the combustion products, the energy stored in the gas at the time of muzzle passage \( E_{Gas} \) can also be estimated. For the determination of the elastic and plastic deformation energies of the cartridge \( E_{Pat} \) and that of the bullet during engraving \( E_{kBarrel} \), mechanical material data of ammunition from various manufacturers are measured using nanoindentation of respective bullet lead and cartridge brass. Finally, the energy loss due to friction \( E_{kBullet} \) follows directly. Now, assuming there are no differences in compressive and tensile load for the projectile, the normal force on the bullet in the barrel can be obtained, which in turn leads immediately to a system-specific coefficient of friction.

3. Results

As described above, the proposed method offers the quantification of frictional losses in a given weapon-ammunition tribological system. The method also allows to investigate the impact of bore and ammunition tolerances as well as that of bullet coatings, if applicable. All calculations are shown for calibre .22lr, but the proposed method can be applied for arbitrary geometries and multi-base propellant powders, allowing the quantification of friction for the entire range of small arms.

4. Acknowledgements

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5. References

Characterisation of wear behaviour of bearing bush material for different lubrication conditions

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1. Introduction
The wear behaviour of tribological contacts depends on a variety of parameters such as material combinations, the type of lubricant and its additives and the loading conditions (temperature, normal load, sliding velocity, etc.). Furthermore, for a fundamental understanding of the wear behaviour of a system or specific tribocomponent, it is important to determine the lubrication regimes and the wear mechanisms in which the systems operates (depending on the loading conditions) [1] and to what extent they contribute to the overall wear behaviour [2] [3]. The goal of the present work is to investigate the influence of the loading parameters and the lubrication regime on the wear behaviour.

Therefore, the contact between the bearing bush and the bearing shaft was investigated. During real operation the bearing faces several lubrication regimes, usually pure hydrodynamic lubrication during normal operation mode and mixed and boundary lubrication at start or stop of sliding motion or during edge or shock loading.

2. Method
The wear behaviour of the tribological contact bearing bush versus bearing shaft was investigated on a test rig with unidirectional rotating movement. Tribological parameters such as normal load, sliding velocity and temperature were adjusted separately. The samples – CuZn25Al5 alloy bearing bush halves – were fixed in the tribometer as non-moving parts. The bearing shaft counterparts were made of 100Cr6 steel. The inner diameter of the bearing bush was 30 mm and the bush width (in axis direction) 20 mm. The shafts were specifically designed as pins for the purpose of the tribometer tests with a pin diameter of 29.5 mm. In order to avoid areas of high contact pressure at the edges of the contact (i.e. at the ends of the bearing bush), the pins were manufactured with a barrel shape with a 100 µm diameter difference between the middle and the end of the pin in axial direction over a length of 25 mm. The tribometer was equipped with continuous friction coefficient measurement. During pre-tests, the Stribeck curve was determined by changing the sliding velocity throughout the test. The parameters for the actual wear tests – and therefore the specification of the investigated lubrication conditions – were chosen based on the Stribeck curve observed in the pre-tests.

The wear of the bearing bush was measured continuously using the RIC wear measurement method based on radioactive isotopes [4] which allows distinguishing running-in and constant wear. The Cu element in the alloy was activated in a cyclotron by bombardment with protons, leading to the production of the gamma irradiation isotope $^{65}$Zn with a certain activity concentration in the first few micrometers near the surface.

In the test rig, an oil circuit is applied to support the contact with lubricant and to transport the wear particles to the detector for measuring the isotopes in the worn particles. The activity of the worn particles containing the $^{65}$Zn isotope was measured and then converted into a wear volume or depth removed from the specimen. All experiments were carried out at room temperature. The temperatures of the oil at inlet and outlet and on the specimen were monitored throughout the test. The outlet temperature of the oil is used to calculate its viscosity and therefore for calculation of the actual lubrication conditions. For the different lubrication regimes a calibration is achieved between the surface change of the bush (determined by confocal microscopy) and the wear rate of the bush (determined by RIC).

3. Results
The running-in and constant wear results obtained by RIC were used for evaluating the loading conditions and parameters describing the lubrication condition of related wear models. As the asperity contact of the surface roughness summits is assumed to be the main source for the wear of the material contact, for mixed lubrication conditions present in the contact it is necessary to separate between hydrodynamic and asperity contact. Therefore, numerical calculations were performed using EHD analysis. A simulation model of the tribometer was built and the mixed lubricated contact conditions were investigated for the different operating conditions.

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4. References
Investigating the effect of ultrasonic vibrations in friction force reduction between Die and Sample in ECAP Process

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Abstract: Researches show that friction forces between die and sample in Equal Channel Angular Pressing (ECAP, Fig. 1) constitute great part of the total forming forces. In several researches it is reported that the application of ultrasonic vibrations can reduce the friction rate. Recently, an application of ultrasonic vibrations has been introduced to reduce friction-forces in ECAP process. However, there is still need to do researches to overcome practical challenges of ultrasonic applications in ECAP process. This study discusses some theoretical and numerical aspects of ultrasonic assisted ECAP process. 3D finite element simulations of conventional and vibrated ECAP process are conducted for several ram speeds. The theory of friction reduction characteristics of ultrasonic vibrations in ECAP process has been discussed. The modified equation for theoretically calculation of friction coefficient is offered. The experimental results show that there is a minimum value for friction reduction rate by ultrasonic vibrations. It is found that by virtually increasing ram speed in FEM simulations (in order to raise the speed of simulation), the discrepancy between results of simulation and experimental data will be increased (Fig. 2). It is shown that by using theoretically calculated friction coefficient at the entrance channel of the die to the worth of removing ultrasonic vibrations, it is possible to get the similar results from simulation for ultrasonic assisted ECAP process.

Keywords: ECAP process, Ultrasonic vibrations, forming forces, friction

Fig. 1: Schematic representation of the ECAP design

Fig. 2: Shows that how virtually increasing ram speed in FEM simulation affects the final results
TRIBOLOGICAL MEASUREMENT TECHNIQUES

Development of a model experiment for friction analysis in forming processes

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Abstract

Tribological modelling of forming processes is very challenging to perform on standardized pin-on-disc tribometers due to the geometrical constraints and the limited possibility for ensuring of relevant process parameters such as plastic flow of the material, surface enlargement, high contact velocities, etc. Therefore, for modelling of forming processes customized test rigs are often used. While such test rigs offer a high level of comparability with the real system, they are usually very complex and focused on specific effects and sample geometries, which makes the interpretation of results in a wider context very difficult.

This study is focused on the development of a model tribological experiment for friction analysis in forming processes. On the basis of finite element simulation of the forming process and the model experiment, two different contact geometries were designed and compared. Experiments were performed on a pin-on-disc tribometer using different testing- and material preparation parameters and the results were correlated with the measurements performed in the real system.
Active Aerostatic Thrust Bearings with Piezo-actuator

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Abstract

An innovative active aerostatic bearing for very high precision applications is presented. This kind of systems is widely used in precision positioning and manufacturing applications in order to exploit the absence of losses and friction. However, aerostatic bearings are characterized by low stiffness due to the air compressibility and for this reason compensation methods are usually adopted.

The air pad presents a rectangular plant (the dimensions are 60 and 30 mm) with two grooves and orifices with a 0.8 mm diameter. It was designed to work with a 10 µm nominal air gap and a maximum load about 220 N (without active control). The active control was designed to increase the air bearing stiffness by reaching an infinite one. It is obtained by means of one stack piezoelectric actuator which allows the vertical dimension of the pad to be modified in order to compensate the air gap variation, so that infinite stiffness is accomplished. An opportune kinematic mechanism with flexure hinges is introduced to reduce the actuation force and thus favour the vertical dimension modification. The presentation will be focused on the mechanical kinematic design, by showing all the experimental and numerical results and the first preliminary tests of the active control system, describing the test bench configuration.
Grinding and Polishing on the Nanometric Scale Using Hard Abrasives –
An Atomistic Numerical Study

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1. Introduction

The current state of the art in the atomistic modelling of nanometric polishing and grinding focuses mainly on the interaction between a single abrasive particle and the work piece. The tool (= abrasive) usually removes a chip from a perfectly flat surface under controlled process conditions. What is ignored in most cases are the possible synergistic and antagonistic effects due to neighbouring abrasive particles in close proximity, the influence of nano-roughness on the finishing process, and the fact that polishing and grinding feature quite different kinematic constraints on the abrasive particles, where the three-body aspect of the particles’ motion is often neglected.

In this work we apply a recently proposed modelling, simulation, and analysis approach based on molecular dynamics (MD) simulations [1] which allows the consideration of multiple abrasive particles, rough surfaces with Gaussian topography distribution, and proper distinction between grinding and polishing kinematics. Although the model system is kept simple, much insight can be gained into the dependence of the final work piece topography on the process type and conditions such as the normal pressure or the finishing velocity.

2. Computational Set-up and Methods

The work piece model consists of a monocrystalline bcc Fe block with lateral dimensions of 28.5x28.5 nm² and a periodic Gaussian surface roughness of $S_a = 0.6$ nm. The abrasives are implemented as 16 rigid (and hence wearless) randomly rotated cubes of edge length 4.2 nm, arranged in a staggered 4x4 grid. An equivalent model was set up replacing the cubes with rigid spheres of diameter 6.5 nm. When grinding, the abrasives are pressed against the work piece using constant average normal pressures ranging from 0.1–1.0 GPa and dragged across the surface at a slight angle with the simulation box edge to prevent that a given abrasive particle immediate re-works its own wear track due to the periodic boundary conditions which apply laterally. When polishing, which is only done with the spherical abrasives, each abrasive is allowed to rotate freely. It carries 1/16 of the total normal pressure and may adjust its movements perpendicular to the polishing direction according to the local conditions such as the topography. The sliding velocity is kept constant at 8 m/s, and the base of the work piece is thermostatted to 300 K.

The analysis methods include an identification procedure which can dynamically partition the work piece material into deformation zones such as substrate, shear zone, and wear particle, leading to a quantification of the wear volume. Furthermore, a grid-based topographic evaluation scheme allows the determination of roughness parameters and their tracking over time. Finally, an iterative clustering algorithm differentiates between the contributions of the individual abrasive particles to the contact area and the wear volume.

3. Results

We will compare the work piece topography before and after grinding/polishing, see Figure 1, in the context of the applied process conditions as well as the normal pressure, including a discussion of the time development of roughness parameters such as the levelling, the roughness and the topography skewness. Time-dependent wear maps will be presented which visualise topographic changes to the surface after the wear particles have been removed. Furthermore, we will show how the partitioning of the work piece asperity reduction volume into its components (pit fill-up, wear particles, shear zone, and sub-surface compression zone) varies greatly with the given process conditions and the load. We will finally give an outlook as to how the existing modelling scheme may be extended for more closely resembling realistic systems and surface finishing processes.

Figure 1: Work piece topography before (left) and after grinding at a normal pressure of 1.0 GPa for 10 ns with cubic abrasive particles (right). Colouring is according to height, where red is high and blue is low.

4. References

The role of the interaction between local contact behavior and structural response in frictional contact instability.

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Frictional vibrations arise in the system when two contact surfaces are in relative motion to each other. Moreover, in frictional systems the coupling between local contact behavior and the structural response can give rise to diverse forms (frequency spectrum and amplitude) of system vibrations, leading often to frictional contact instabilities [1]. Contact instability phenomena produce, as a function of system parameters (frictional interface, material damping, sliding velocity, contact pressure, material properties, etc.), strong vibrations in the system, discontinuous motion (stick-slip) [2] and fastidious noise emissions. Understanding the physical mechanisms that drive the onset and the evolution of the sliding and the consequent friction induced vibrations, between two media in contact, is of great importance to many research and industrial applications such as disk brake squeal, hip endoprosthesis vibrations, wheel-rail vibrations and noise emission, machining tool vibrations, earthquakes, tactile perception, etc.

In this context, contact frictional scenarios of similar materials (PMMA-PMMA) and dissimilar ones (PMMA-PC), have been investigated both experimentally and numerically. The newer dedicated experimental set-up, TRIBOWAVE, allowed for reproducing the relative motion under well-controlled values of the driving parameters (imposed driving velocity, normal contact force). On the other hand, the explicit finite element code PLASTD has been used to perform transient contact nonlinear simulations in order to analyze the interaction between the local contact dynamics and the structural response to the frictional excitation. Tests performed on the experimental set-up highlight the complex phenomena arising when two media are in frictional sliding. The same system with respect to different boundary conditions, such as imposed horizontal velocity, switches its macroscopic frictional behaviour from macro stick-slip instability up to stable continuous sliding with or without mode coupling instability. Experimental and numerical analysis allowed for drawing maps of the frictional contact scenario as a function of the key system parameters.

The numerical model, including the set-up tangential stiffness and dynamics, allowed for reproducing the same transition ranges from stable sliding to macroscopic stick-slip as a function of the key parameters. The numerical results show a quantitative agreement both in frequency and in time domain with the macroscopic frictional behaviours obtained by the experiments. The comparison, performed on the macroscopic response of the system (measured tangential and normal force, system acceleration and velocity), allows for validating the numerical simulations, which are useful for the investigation of the local contact dynamics and its coupling with the system response.


A pneumatic active control for air pads

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1. Introduction

Aerostatic bearings and air pads offer important advantages in precision linear guides due to their practically negligible friction, high positioning accuracy and long life. Air pads are applied in machine tools, coordinate measuring machines (CMM) and wafer-steppers; their design is addressed to meet the required load capacity, stiffness and air flow consumption.

The main drawback of air bearings is their relatively low stiffness. To increase significantly the stiffness of the air guides different control systems can be adopted, pure pneumatic or also electronic, all aimed to limit the displacement of the bearing due to the applied load [1] [2] [3]. Electronic control with piezo actuators give generally very good results, both static and dynamic, but are quite expensive. Pure pneumatic control is an interesting alternative solution in terms of performances and cost and can be successfully adopted to cheaper systems. In this work an active control with a pneumatic valve connected to a commercial air pad guide is presented. The realized valve and the preliminary tests of the passive and active pad are described.

2. The control valve and operation

Figure 1 illustrates the scheme of the control system. Supply air passes through the nozzle of diameter \( d \), facing at distance \( x \) from the deformable circular steel membrane of diameter 6 mm and thickness \( s \). \( P_s \) is the supply pressure, \( P_m \) the pressure in the control chamber sealed by the membrane. Nozzle distance \( x \) can be adjusted by a screw. The small dimensions of the valve allow to mount it directly on board of the pad. \( P_c \) is the pressure downstream the inlet holes of the pad, just before the flow goes through the viscous resistance of the gap and escapes to the ambient pressure \( P_a \). As the applied force to the pad increases, air gap became smaller and pressures \( P_c \) and \( P_m \) increase. Consequently the membrane deforms more until the pad reaches a new equilibrium position.

The behavior of the control system strongly depends on the geometry and number of the pad orifices. Interchangeable nozzles of diameter \( d =0.2, 0.5 \) and \( 1 \) mm were prepared in order to adapt the control to the load capacity and the air consumption of different pads. Before the operation nozzle distance \( x \) is regulated to obtain the required load capacity and consumption at the given air gap height. Three interchangeable membranes of thickness \( s = 50, 80 \) and \( 100 \) \( \mu m \) can be selected to define the desired displacement range of the valve.

3. Tests and conclusions

Static load capacity trials were carried out on a rectangular pad 60 mm×30 mm provided of four supply orifices of 0.17 mm diameter and 40 mm×20 mm rectangular groove. Tests were conducted at the relative supply pressure of 0.4 MPa firstly in passive operation and then in two active configurations, with different \( d \) and \( s \) values.

Results (Figure 2) show that the better load capacity of the controlled pad is obtained with the nozzle of diameter \( d = 1 \) mm. With a 7 micron air gap the stiffness of the controlled pad is increased of about 15% respect that of the passive pad. Technological limits caused difficulties in regulation of the distance nozzle-membrane and a limited mobility of the membrane. Future work will be addressed to further increase the active stiffness by improving the technology of the valve prototype.

4. References

Polyelectrolyte-Multilayer-Supported Polymer-Brush Coatings

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The confinement of synovial fluid within cartilage’s permeable soft structure is one of the main mechanisms underlying its excellent tribological properties. Similarly, well-designed polymer-brush structures can confine viscous fluids, enabling fluid-load support and lubrication of the migrating contact area.1 Specifically, poly(dodecyl methacrylate) (P12MA) brush-based coatings in combination with a good, viscous solvent provide low coefficients of friction and can even extend the mixed lubrication regime to lower Sommerfeld numbers.2 However, wear phenomena can pose limitations to the industrial and medical applicability of polymer-brush based coatings. In order to mitigate substrate roughness, and achieve a more gradual load transition from the soft polymer brush towards the stiff substrate, a mediating material is introduced in the form of a polyelectrolyte multilayer (PEM).

As proposed by Li et al., a mechanical gradient structure, going from gel to polymer-brush in the normal direction, could present such a solution.3 In this work, layer-by-layer (lbl) deposition of polyelectrolyte layers was chosen to produce a rigid transition thin-film to support a grafted-to, polymer-brush top coating. The lbl structure consisted of poly(ethyleneimine)-graft-perfluorophenyl azide (PEI-PFPA), as the positively charged polyelectrolyte, and alternated with negatively charged 70 kDa poly(styrene sulfonate) (PSS). The PEM structures were deposited by means of spray coating the polyelectrolytes from ethanol. As a final step, P12MA was spin-coated on top of the PEM structure. Crosslinking of the PEM, as well as covalent attachment of P12MA, was achieved by nitrene insertion reactions triggered by UV decomposition of the azides.4 Ellipsometry was used to characterize the individual layers and the final brush thickness. The coefficient of friction, as well as the wear properties of the coating, were studied via microtribometry.

P12MA grafted to a PEM supported PEI-PFPA layer showed a slight decrease in brush thickness compared to a single PEI-PFPA layer, indicating a lower P12MA density at the surface due to the underlying PEM structure. Probably in the case of the PEM, nitrene insertions of the final PEI-PFPA layer act towards both the PSS underlayer, as well as the P12MA top-layer, allowing for less anchor points in the case of a multilayer structure. A further indicator of reduced brush density was the earlier onset of wear upon increased normal load, indicating a loss of solvent-confinement ability. In order to further improve the confinement effect, an increased brush-density is targeted by modified grafting-to strategies. Ultimately, studies on micro-roughness gradients will provide more information on the ability of PEM-supported polymer-brush coatings to provide lubricating properties on different substrate material types and roughnesses.

References:
THEORETICAL MODELS FOR WEAR CAUSED BY OXIDATION OF WHEEL/RAIL CONTACT OF THE METRO SYSTEM

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KEYWORDS: Contact temperature, Oxidative wear, Frictional heating, and Wheel-rail contact.

ABSTRACT
Wheel, in the process of rolling, undergoes heat flows generated by friction with the rail. Oxidative wear presents interest as a form of corrosion, in particular for steel and cast iron, in normal operation mode of wheel-rail friction under dry or at limit regime. K. Dies's researches show that on the friction surface of steel, oxide of Fe2O3 is formed, protecting the surface against damage. Contact, WEAR, Vol. 253, 2002, pp. 498-508.

1. INTRODUCTION
In order to analyze the oxidative wear of metro vehicle wheels, Quinn model, presented by Kraghelsky (1970), Lim-Asby (1986) and Tudor (2002), is detailed and applied. In Quinn model, the wear process takes place in two phases: a) formation of the oxide film, while the roughness of one element of the coupling is not in contact with the roughness of the other element of the coupling. b) while roughness are in contact, continuous oxide layer formation, and when the thickness of the oxide layer has reached a critical value, layer breakage occurs at the separation level of metal-oxide.

2. OXIDATIVE WEAR IN MODERATE REGIME
In moderate oxidation regime for speeds of about 1 m/s, the instantaneous ("flash") temperatures occurring at these speeds are sufficient to oxidize iron, but the oxide layer is, for a certain time-period, "cold" and fragile. In relation to the parameter of rolling and sliding speed of wheel's surface roughness on rail, we can determine the instantaneous temperature on the roughness’s peaks at sufficient to oxidize iron, but the oxide layer is, for a certain time-period, "cold" and fragile. In relation to the parameter of rolling and sliding speed of wheel's surface roughness on rail, we can determine the instantaneous temperature on the roughness’s peaks at moderate regime. Formula 1 presents the dimensionless intensity of moderate oxidative wear (Iuzw).

\[ I_{uzw}(\theta_0, \theta, Pe, Bi, h_f, q_1, \epsilon_1, \xi, P_a) = \left( \frac{C_{ox} - A_{ox} \theta_0}{Z_c a} \right) \exp \left( \frac{-Q_O}{R_g T_w(\theta, 0, Pe, Bi, h_f, q_1, \epsilon_1)} \right) \frac{P_a}{Pe} \]  

(1)

3) OXIDATIVE WEAR IN SEVERE REGIME
In severe oxidation regime for speeds of about 10 m/s, the temperatures occurring at these speeds are sufficient to create oxidation and even local melting of the layer of oxide and its conversion into liquid. Until and during melting process, the heat generated by friction is transferred by conduction. It is considered that a fraction of the material melted and then resolidified, is lost as wear particles. Contact points are strong and completely oxidized as a result of the temperature generated by friction. Roughness peaks are melting and temperatures are limited by the melting temperature of the oxide \( \theta_m \). As a result of redistribution of heat, the material has an average temperature \( \theta_m \). Figure 1 presents the evolution of dimensionless intensity of severe oxidative wear (Iuxoxsw) in relation to specific elastic sliding (\( \xi \)) of the metro vagon wheel.

4) CONCLUSIONS
Products of the oxides contaminate the contact area and, as a result, the specific sliding increases. Both the intensity of wear by oxidation and the hertzian semi-axis contact increase along with the increase of the rolling wheel speed. Likewise, both the intensity of wear by oxidation and the specific elastic sliding (\( \xi \)) increase along with the increase of the rolling speed. As a result of the oxides deposited on the periphery of the wheel and the high local temperatures, adhesion on the rail-wheel contact decreases and the sliding speed increases. The load capacity in relation to the specific elastic sliding is influenced primarily by the contamination mode of the surface of the rail-wheel contact.

5) REFERENCES
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CONVENTIONAL POLYETHYLENE VS. HIGH-CROSSLINKED-PE WITH VITAMIN E USING A HIP JOINT SIMULATOR

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Abstract

Although hip arthroplasty is a consolidated procedure that relieves pain and improves functions, problems remain with wear and osteolysis. Highly cross-linked polyethylene and Vitamin-E-stabilized polyethylene were introduced in the last years to solve these problems.

In this study we compared the in vitro wear behaviour of cross-linked polyethylene (XLPE) versus Vitamin-E diffused XLPE (XLPE_VE) versus the so-called standard polyethylene (ST_PE) acetabular cups. The test was performed using a hip joint simulator run for two millions cycles under bovine calf serum as lubricant.

Weight loss was found to decrease along the series ST_PE > XLPE_VE > XLPE, although statistically significant differences were found only between the weight losses of XLPE and ST_PE at 1.2 and 2 million cycles. The weight loss data were explained in relation to the crystalline morphology of the control unworn cups, as investigated by non-destructive micro-Raman spectroscopy. This technique allowed to disclose a different wear behaviour of the ST_PE and cross-linked PE specimens; the vitamin E-blended specimens underwent the least significant micromorphological changes upon mechanical stress.
Abstract

Sliding lip seals are used in pneumatic cylinders to prevent leakage past the piston and rod. Though they guarantee excellent sealing, the friction forces at contact between lip and counterpart can be relatively high. This results in energy losses and problems with wear on components in relative motion, as well as difficulties in controlling actuator positioning. Standards for compressed air cleanliness restrict the use of greases and lubricants, especially in applications such as the food processing and pharmaceutical industries. A number of studies are thus under way in order to find effective alternatives to the use of common lubricants. These studies address both seal configuration [1-4], and the use of innovative materials [5-7]. Other approaches employ systems permitting small amounts of air leakage that operate as lubricated supports, variable-profile pistons [8], or rings with special micromachined surfaces [9-10]. Such solutions are not always economical, both because they require precision tolerances and geometries, and because they use special seals, often produced ad hoc.

This paper discusses the possibility of using commercial lip seals with a non-conventional mounting on the piston in order to obtain a simple controlled-leakage system that reduces friction forces in pneumatic cylinders economically and effectively. The non-conventional mounting consists of positioning the lip seal in the direction opposite to that used in a conventional installation, so that the contact pressure reduces as air pressure in the chamber rises. In this way, an air gap is created at the sliding interface which allows air in the pressurized chamber to escape past the seal lip, thus reducing the contact force on the barrel. The piston is provided with a hole which exhausts the leakage flow to the atmosphere.

To evaluate the validity of this approach, a number of preliminary tests were carried out in [11] to measure flow rate on a type of spring-loaded lip seal consisting of graphite-filled PTFE for barrel diameters of 50 mm. In particular, the tests determined air leakage behavior for different mounting tolerances.

This paper presents further tests conducted on the same samples examined in [11] and on another PTFE and graphite-filled PTFE configuration, measuring leakage flow rates and friction forces. Leakage flow rate measurements were carried out with single and double seal installations. The results obtained are discussed together with the advantages of the proposed solution compared to the conventional mountings in ordinary use.

References

In fluid power systems, higher working pressures gives reduction in oil flow rates for given system power, resulting in smaller pumps, bore pipes and components. It is well known that most hydraulic oils are refined from mineral oil, so its viscosity increases exponentially with pressure. The spools used in hydraulic control valve have several circumferential grooves to prevent the well-known hydraulic locking problems which result in high friction and excessive wear. In this study, a lubrication analysis between axially moving spool and sleeve in high pressure spool valve is carried out to design optimal balancing grooves. In order to consider the variation of viscosity with pressure and to solve effectively the nonlinear Reynolds equation, a pressure-viscosity parameter is introduced. Solving the modified one-dimensional Reynolds equation for the case that the multi-grooved spool has uniform eccentricity, analytic expressions for pressure distribution and leakage flow rate in the clearance are obtained. Numerical solutions of two-dimensional Reynolds equation are also presented to confirm the validity of the analytical results. There exist each groove positions for given number of grooves where the lateral force reduces to a minimum value. And the analytic solution of modified one-dimensional Reynolds equation shows better agreement with the numerical result of two-dimensional equation as the number of grooves increases. Therefore the analytic results presented in this paper can be used in optimal design of balancing grooves for spool type hydraulic machinery.

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