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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

MULTISCALE CONTACT MECHANICS FOR ROUGH SURFACES WITH APPLICATIONS TO RUBBER FRICTION, ADHESION AND THE LEAKAGE OF SEALS

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ABSTRACT

Surface roughness has a big influence on the dry or lubricated contact between solids in stationary or sliding contact. Surface roughness often occurs over many decades in length scale, e.g., from nm to the linear size of the objects. Thus the nature of the contact between two solids cannot be treated by exact numerical methods, e.g., molecular dynamics, without simplifications.

I have developed an analytical contact mechanics theory which can take into account all relevant length scales. The theory is very flexible and can be applied not only to homogeneous elastic solids but can include layering, plasticity and viscoelasticity (which is important for rubber-like materials).

Both dry and lubricated contact mechanics can be studied using this approach. The theory predicts the area of real contact, the distribution of contact stresses and the distribution of interfacial separations which is important for the leak-rate of seals or for microbial ingress during the shelf life of syringes. It also predicts the viscoelastic contribution to rubber friction and can be used to obtain the Stribeck curves for lubricated contacts.

In this presentation I will describe the theory in some detail and give some applications to rubber friction, adhesion and the leakage of rubber seals.

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CAPILLARY EFFECTS ON FRICTION: FROM NANOCONFINED IONIC LIQUIDS TO SKI FRICTION

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KEYWORDS

nanotribology; wetting and capillarity; phase-changing materials; capillary freezing

ABSTRACT

Capillarity and surface effects may dramatically affect friction. In humid environments, capillary bridges strongly increase adhesion and thus friction between solids in contact, with manifestation in terms of ageing behavior observed in solid friction, granular sandpiles [1] or crease opening [2]. Surface properties may indeed affect the thermodynamic phase properties of a confined material and this strongly affects dissipation and the tribological behavior. Reversly, shear may lead to phase change of a confined materials, thus strongly modifying friction and capillarity in a feedback mechanism.

In this talk I will consider two examples highlighting such intricate interplay between capillarity and friction, occuring at very different scales.

First I will discuss experimental results concerning the behavior of a nano-confined ionic liquid, obtained using a tuning-fork AFM setup. Our measurements demonstrate that below a threshold confinement - in the range of tens to hundred of nanometers-, the ionic liquid undergoes an abrupt phase change towards a solid phase, leading to a huge increase in dissipation. Quite unexpectedily, this threshold thickness is measured to be intimately related to the metallic nature of the confining materials, with more metallic surfaces facilitating freezing. This behavior is interpreted theoretically in terms of the shift of the freezing transition, taking into account the influence of the electronic screening on the wetting of the ionic liquid on the confining surfaces, as described by the simple Thomas-Fermi approach [3]

In a second part, I will explore the frictional behavior of snow and in particular of the role of hydrophobic waxes on decreasing friction. While it is usually accepted that a liquid film forms under shear heating (although this fact is not properly demonstrated experimentally), the reason why hydrophobic coatings decrease friction remains mysterious. It is however one of the key and highly sensitive ingredient for ski competitions. I will report recent experiments about snow friction and the effect of waxing, pointing to the subtle effects of capillarity on the friction process [4].

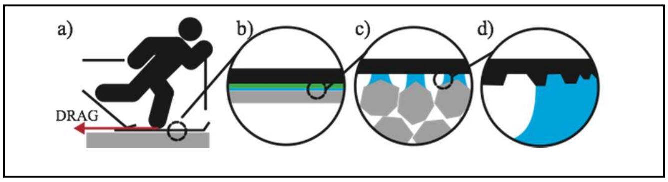

Fig.1 Ski friction and the effect of capillarity

ACKNOWLEDGMENTS

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LOCAL AND GLOBAL FRICTION PHENOMENA IN ROLLING AND SLIPPING TIRES

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ABSTRACT

The global dynamics of automotive tires under operating conditions can be described in the frame of a simple pulsed-driven rotator exposed to friction. Interestingly, the dynamical character of such systems can possibly switch (depending from the numerical value of an internal parameter) from a regular periodic to quasi-periodic or even chaotic behavior.

The presence of rolling losses as well as longitudinal and lateral forces of rolling and/or slipping tires are largely influenced by local frictional phenomena and due to dissipation within the inner bulk and/or near-interface bulk rubber materials. The hierarchy of different frictional phenomena will be discussed.

Introducing a physically motivated multiscale approach of polymer dynamics, I demonstrate how local friction in polymer networks under the presence of filler particles determines the visco-elastic behavior of the rubber from very low to very high deformation frequencies. Furthermore, it is shown how local (Rouse-like) network chain dynamics becomes non-linear for largely stretched network chain conformations which occur near tips of propagating cracks in rubber materials. These effects are discussed together with some specific features of the rubber fracture-mechanics and the failure behavior of rubber components.

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Tribology of Surfaces: A Study in Cartilaginous Tissue from Synovial Joints

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KEYWORDS

Biotribology; friction coefficient; cartilage; synovial joint.

ABSTRACT

Tribology applied to biology, or bio-tribology, studies the interaction of surfaces in these different biological systems. One of the main fields in biomedical industry nowadays, is orthopaedics; replacement of worn, damaged or destructed joints is, perhaps, one of the most important advances in medicine from last century. Natural surface interactions in joints occur between layers of cartilage that cover the portion of bone which participate in motion structures. Tribology in biological systems (or bio-tribology) embraces concepts in physics, chemistry, biology and material science [1]. Bio-tribology applications in biomedical engineering are from different nature; examples of this are: total joint replacements, footwear tribology, skin tribology, ocular and oral tribology, among others [2].

One of the main fields in biomedical industry nowadays, is orthopaedics. Replacement of worn, damaged or destructed joints is, perhaps, one of the most important advances in medicine from last century. Total joint replacement, principally total knee replacements and total hip replacements, was reported to have, only in 2010 in the U.S., over one million cases [3]. One of the main reasons for these surgeries to occur is osteoarthritis, which happens when cartilage from bone ends wears away [4].

This research work, aims to expand the knowledge on how surfaces, as part of human joints, behave. The main factor to be analysed in the experiments embraced on this work is friction coefficient. Friction coefficient becomes vital as it changes along an individual's life; it is directly connected to tear and wear of cartilage tissue due to aging but severely affected by diseases. In order to analyse friction coefficient in human joints, experiments were performed in samples obtained from animal models.

Friction, defined as the force exerted by a surface when an object moves across it [6] becomes vital as it changes along an individual's life; it is directly connected to tear and wear of cartilage tissue due to aging but severely affected by diseases.

The experiment consisted in the measurement of the friction coefficient of the samples harvested from plateau and condyle portions of bones from synovial joints. Measurement of the friction coefficient in the samples using a tribometer equipped with a Peltier hood for precise temperature control; controlled temperature was set to be 24ºC as the usual environmental temperature, and also, 37ºC as the average body temperature. Setup used in the test was a ball-on-three-plates. Comparison between two different lubrication means was also performed: one, distilled water and, a second one, a salty solution replicating human body's interstitial fluid. These experiments were partially reproduced from the techniques and experiments carried out in [45, 46]. Two lubrication configurations were set for the experiments: a salty solution replicating human body's interstitial fluid and artificial synovial fluid.

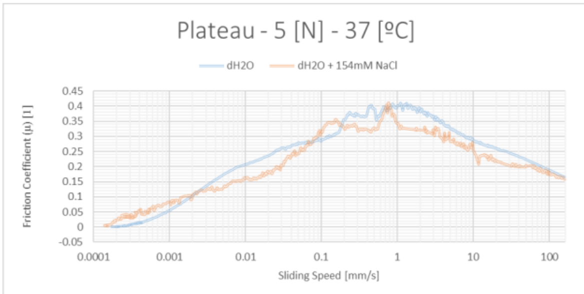

Figure 1. Compiled result for different lubricants interacting with Plateau samples with a 5 [N] normal force.

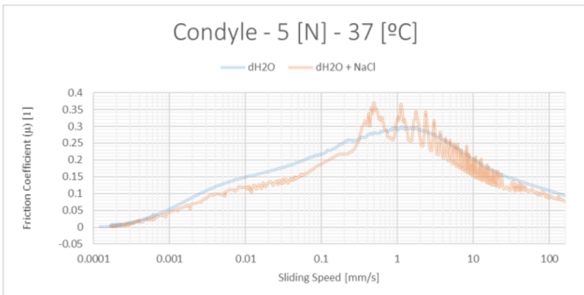

Figure 2. Compiled result for different lubricants interacting with Condyle samples with a 10 [N] normal force.

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ASSESSMENT OF THE PERFORMANCE OF AGENTS USED TO INCREASE GRIP IN ROCK CLIMBING

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ABSTRACT

A finger friction test wasdeveloped to test the performance of chalk and liquidchalk in dry conditions and conditions simulatingsweaty hands. This wascomparedwith data obtainedwithout the use of friction modifiers. These friction modifierswerechalk and liquidchalk. Theyweretested on four different rock samples and at four different forces (5, 10, 15 and 20N). Thesewerelimestone, fine grainedsandstone, coarsegrainedsandstone and gritstone (all commonlyfound in the Peak District near Sheffield whereclimbingisextremelypopular). A smallamount of testingwasalsodone on the effect of a range of skin moisturelevels in the testingfinger.

It wasfound in dry conditions the addition of chalk and liquidchalkhad no negativeeffect on the coefficient of friction, with a possible slightimprovement at forces higherthan 10N. This wasalsoseen at forces of 10N and below on rock sampleswithhigherroughness. At low force and roughnesschalkwasshown to have anegativeeffect on the coefficient of friction. In tests withmoisturelevelssimulatingsweaty hands chalk and liquidchalkimproved the coefficient of friction at all forces and rock types tested. There was no cleardifferencebetween the performance of chalk and liquidchalk in terms of affecting coefficient of friction. Theseresults support the use of chalk and liquidchalk in rock climbing. A moisturecurvewasobtainedthatsuggestsaslight addition of moisturewouldimprove the coefficient of friction but resultsalsosuggestthiswouldbedifficult to obtain and maintainwithcurrent friction modifiers.

BIOTRIBOLOGICAL AND MECHANICAL ANALYSIS OF TOTAL HIP ARTHROPLASTIY FAILURE:

How to "break the code"

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Keywords: hip arthroplasty failure, biomechanics, instabilities, vibrations, non linear system.

ABSTRACT:

Total hip arthroplasty (THA) has been a successful intervention for 50 years. In spite of the excellent long term results the challenge remains with failure and revision operations especially with younger and active patients. [3]

The reasons of failure are multi factorial. Today we know of many factors: bad surgical technique (bad positioning of components) poor implant design and industrial process material factors. Biomechanical factors are the third cause of failure and probably the most important to understand. [2]

Aseptic loosening and osteolysis are the limiting factors of lifetime with polyethylene on hard bearing (metal or ceramic head). Metal on metal bearings failure depends on material, size and gender. Ceramic on ceramic hip bearings are a cause of concern because of squeaking and implant breakage but there is not a biological reaction. In almost every failure the mechanochemistries factors of friction, lubrication, and wear are the first step.

We propose an inverse method created by understanding these complicated mechanisms. This method defines a global mechanical system where we include the main bearing as well as connections because they are also cause of friction. We have to associate the biological system with its close environment (bone, fluid, tissues...) and the general body reactions (cells and immunological

system). The most relevant factors are mechanical instabilities and 40-80 higher mechanical stresses than in standard conditions.

INTRODUCTION:

570 000 THA were performed in Europe (population 446 .2 million) for the year 2009 and 500 000 in the U.S. Choice of insert bearings: Polyethylene 48%, Ceramic insert 17% and Metal insert 5% with: Metallic head 68%, Ceramic head 32%.

There is a life time incidence of 18% for revision and is projected to double in the next 10 years.

The causes of revision are aseptic loosening 45%, bone lysis 15%, pain27%, dislocation/ subluxation17%, infection 13%. [1]

The reasons of failure are multi factorial. It is by understanding the mechanisms that we can improve our long term THA.

MECHANICAL ANALYSIS:

1/The tribological triplet: mechanism, first bodies, third body (fluid and particles debris) and the tribological flow are the framework of every contact analysis [4].

2/Contact instability and friction: In standard conditions close to equilibrium system there are few problems and wear. But friction of THA is not a long steady state. Fluoroscopy (dynamical X-ray) shows eccentric loading then a new centered position that changes the contact and sliding. Sometimes the mechanical stress is 40 to 80 higher than in standard conditions (contact test with micro- separation 2 mm).The consequences are energy diffusion(thermal energy) with surface transformation and deformation (polyethylene and metal) wear, chemistry change and oscillation-wave diffusion. A stick-slip phenomenon especially occurs with ceramic on ceramic bearing and sometimes associated with squeaking and breakage because toughness is low without deformation except at the nano scale. Instability, oscillation, wave and energy diffusion are fundamental in understanding the sliding of THA [6] [7] [8] [9].

3/ <u>THA is a global system</u>: Main hip bearings are connected with a metal back (insert-metal back). The head is connected to the femoral stem and sometimes to a modular neck [10]. THA itself is linked to the bone. Mechanism of the triplet depends on the THA positioning. Head size, neck and height size can be responsible for contact, impingement and dislocation-subluxation. THA and muscle can create a particular friction between the biological structure and the metal

BIOLOGICAL REACTIONS:

Firstly, the body has to adapt to an arthroplasty and its different mechanical properties compared to natural bone, cartilage, fluid and tissue: The whole triplet changes! We need a primary stability between the bone and the arthroplasty otherwise it is a failure. Secondly, over time wear debris appears and a biological reaction [11]. Our living body can tolerate a huge material like an arthroplasty but tiny particle debris triggers immunologic reactions except ceramic debris (inertness of ceramic). This reaction depends on age, gender, volume and size of debris.

SUMMARY

When we choose a THA we have to define a mechanical threshold and a biological threshold adapted to a patient in their personal and professional life. The most important factor is the mechanical contact instability and energy diffusion in a global system because others factors are a consequence of this one.

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ON THE DEPENDENCY OF FRICTION ON LOAD: THEORY AND EXPERIMENT

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KEYWORDS
interface structure; roughness

ABSTRACT
In rubber friction studies it is often observed that the kinetic friction coefficient depends on the nominal contact pressure. This is usually due to frictional heating, which softens the rubber, increases the area of contact, and (in most cases) reduces the viscoelastic contribution to the friction. We present experimental results showing that the rubber friction also depends on the nominal contact pressure at such low sliding speed that frictional heating is negligible. We attribute this effect to the viscoelastic coupling between the macroasperity contact regions (see Fig. 1), and present a simple earthquakelike model and numerical simulations supporting this picture.

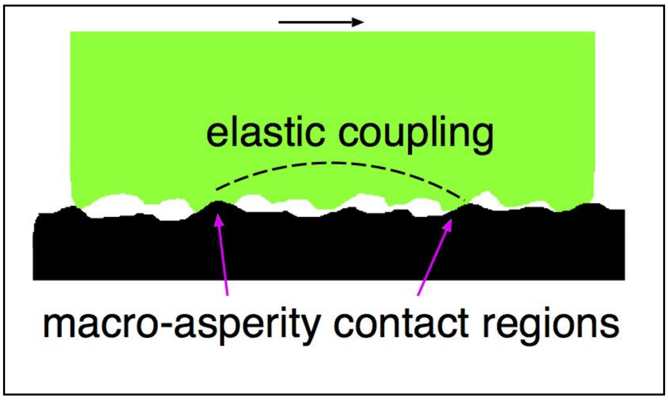

Fig.1 An elastic block (e.g., rubber) sliding on a substrate. For a randomly rough surface the concentration of macro-asperity contact regions increases proportional to the normal force. This will affect the lateral elastic coupling between the macro-asperity contact regions, and results in a friction force which depends non-linearly on the load.

Experiment. We have studied rubber friction for tread rubber compounds sliding against concrete and asphalt road surfaces. The measurements were performed using the Leonardo da Vinci set-up [1]. The slider consists of two rubber blocks glued to a wood plate. We have found that close to the first maximum (as a function of increasing sliding speed v) of the $\mu(v)$ friction curve (the first maximum is due to the adhesive interaction between the rubber and the road surface in the area of real contact), the friction coefficient decreases slightly with increasing nominal contact pressure. At the same time the friction coefficient for lower velocities is the same in all cases within the accuracy of the measurements.

Simulation. The experimental results were explained qualitative with the help of a quasi-1D model in Ref. [1]. Now we present a full 3D-model. Our model is similar to the Burridge and Knopoff spring-block model. In the model the top block (the slider) is coupled with the bottom block (the substrate), assumed to be rigid and fixed, by a set of frictional contacts. The sliding block is decomposed (or discretized) into N mass points, which are connected by viscoelastic springs. A fraction θ of the mass points at the bottom surface of the sliding block are connected by frictional coupling to the substrate. The upper surface of the sliding block is connected to a rigid surface with viscoelastic springs, and the rigid surface moves with a velocity v parallel to the substrate. The parameter θ is proportional to the normal load.

The model shows that the lateral coupling between the macroasperity contact regions can enhance the stick-slip of the contact regions. This effect has important implications for rubber sliding dynamics, e.g., in the context of the tire-road grip.

ACKNOWLEDGMENTS
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On stickiness criteria for nominally flat rough contacts

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Abstract

Recent numerical investigation on self-affine Gaussian surfaces by Pastewka & Robbins have led to a criterion for "stickiness" based on when the slope of the (repulsive) area-load relationship seems to become vertical in numerical simulations. However, a simple check of the results in terms of pull-off, shows that Pastewka & Robbins have many more data which fail their criterion than the ones who satisfy it, and this is evident even in their own Figures, so it could not be due to our misinterpretation of their data or criterion. It is noted that the criterion gives the same order of error of classical asperity model based one. For practical uses, a proposal to modify the criterion to better fit their data is put forward. However, the general conclusion that stickiness should depend only on slopes and curvature, and not on rms amplitude, may still be unwarranted. The PR criterion would imply that for fractal dimension $D \simeq 2.4$, stickiness should be relatively stable with resolution, but in general the problem of truncation of the spectrum seems ill-defined.

Key words:
Roughness, Adhesion, DMT adhesion, Pastewka and Robbins's theory, Fuller and Tabor's theory

1. Conclusions

We have shown that the pull-off data shown by Pastewka and Robbins are inconsistent with their stickiness criterion, and we have proposed a simple modification may be more realistic — which requires a corrective factor of

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the order 5, similar to what is needed to correct the Fuller-Tabor predicted threshold for stickiness with their data.

As the real limit behaviour at large reduction from theoretical strength is unclear from the Pastewka-Robbins data, the criterion is simply indicating an arbitrary level of reduction of pull-off.

However, PR data are too limited to draw any general conclusion about stickiness, and in particular that stickiness should depend only on slopes and curvature (let alone giving the exact multiplicative factors), seems not a certain conclusion. Incidentally, this would also define an ill-posed problem, because stickiness would be defined by the very fine scale, if not the atomic limit, unless the fractal dimension is $D = 2.4$.

2. Acknowledgements

A.P. is thankful to the DFG (German Research Foundation) for funding the project HO 3852/11-1.

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EFFECTS OF DYNAMIC FRICTION ON OBLIQUE IMPACT BEHAVIOR OF GOLF BALLS

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KEYWORDS

Energy and friction in sport and leisure activities, oblique impact, golf ball, dynamic friction, sliding velocity, contact area

ABSTRACT

A previous study [1] investigated oblique impacts of a golf ball of mass m (46 g) and radius r (21.3 mm) with a rigid target inclined at an angle θ_i (30°) (Fig. 1a) and demonstrated the following: (i) the contact force N and area A rose in the early phases of the impact and then reduced in the later phases (Figs. 1b and c); and (ii) the angular velocity ω can depend on A and the ball centre velocity u_b. However, the dynamic friction F_d causes the shear deformation of the ball, and consequently the discrepancy between u_b and the contact centre velocity u_c. This study used the analytical model proposed for the dynamic sliding friction on lubricated and non-lubricated inclines [2,3]. The contact area A and the velocity u_c were used to describe the dynamic friction force $F_d = \lambda A u_c$, where λ is a parameter related to the wear of the ball surface [4]. This study proposed an elastic sphere model to understand the mechanism of shear deformation during oblique impacts.

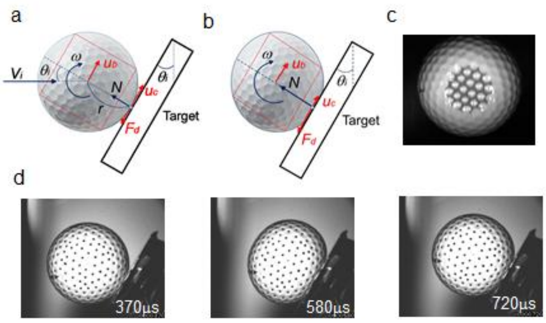

Figure 1. Impact behaviour of a golf ball. a, The rotating and sliding motion of the ball at impact. b, The compression and shear deformation of the ball during impact. c, High-speed image of the ball hitting a transparent PMMA target at an impact velocity $V_i = 32$ m s^{-1}. The image was photographed from the reverse side of the target. d, High-speed images of the ball hitting a steel target at $V_i = 37$ m s^{-1}. Markings were made on the dimples to enable ball surface measurement.

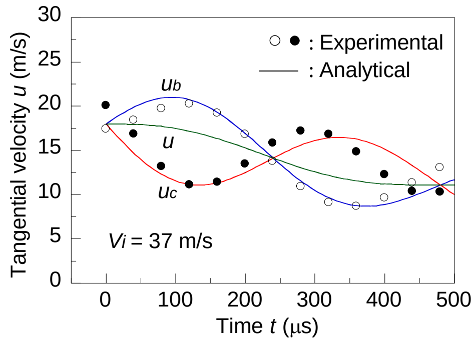

Figure 2. Tangential ball centre velocity u_b and contact centre velocity u_c for $V_i = 37$ m s^{-1}. u_c reduced in the initial phases of the impact, rose in the intermediate phases, and then reduced again in the final phases, whereas u_b showed the opposite trend.

Figure 2 shows the tangential ball centre velocity u_b and contact centre velocity u_c versus time t, where the experimental results were indicated with symbols; those derived from the proposed analytical model are indicated using solid curves. u_c showed three phases of noticeable velocity reduction, rise, and reduction once again. u_b showed the opposite velocity changes. The analytical velocities u_b and u_c are shown in Fig. 2. Although the analysis yielded discrepancies from the experimental results, the model represented all of the important qualitative features of the velocity changes at the ball centre and contact centre.

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

HOW ROUGHNESS AFFECTS ADHESION, OR, WHY DOES FOOD WRAP CLING AGAIN?

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KEYWORDS
Contact mechanics; adhesion; computer simulation

ABSTRACT

Thin elastic layers, such as food wrap or Gecko feet, easily stick to most rough counterfaces, while semi-infinite solids usually don't. One potential explanation for this phenomenon is that the large compliancy of thin structures automatically leads to a large, real contact area when being squeezed against a counterface. However, true contact between adhesionless solids is determined by the pressure, the elastic properties, and the roughness at the smallest wavelengths, i.e., that on nanometer scales or below. This is a thousand times smaller than the thickness of common plastic foil. In other words, even thin structures are essentially semi-infinite relative to those scales that determine the true contact area of adhesionless solids. Yet, every-day experience tells us that thin objects stick much better to counterfaces than thick ones made up of the same material. Computer simulations based on the Green's function molecular dynamics method [1] helped us to reveal why this is so.

As shown in Fig. 1, reducing the thickness of an elastomer below the roll-off wavelength of the height profile of its randomly rough counterface leads to the phenomenon of contact splitting [2], whereby mesoscale contact patches break up into smaller patches of similar contact area but with much increased contact line length. These are the zones where adhesion predominantly acts once it is "switched on". Results can also be rationalized in terms of Persson's contact mechanics theory for adhesive bodies [3].

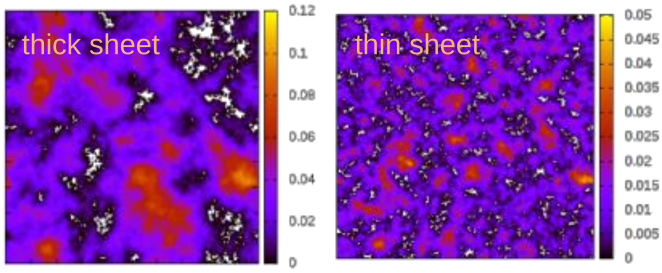

Fig.1 Gap topography of a thick sheet (left) and a thin sheet (right) that is pressed against a randomly rough substrate. White marks the area of contact, where the gap is zero, while colors indicate the gap height, expressed in microns. The gap is smallest for dark colors.

ACKNOWLEDGMENTS
We thank the DFG for financial support.

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THE EFFECT OF ROUGHNESS ON TRACTION BETWEEN CONTACTING BODIES

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KEYWORDS
adhesion; rough surface; Lennard-Jones law

ABSTRACT

We develop a model, based on a perturbation of the Lennard-Jones law, to estimate the effect of surface roughness on the relation between mean gap and mean traction.

INTRODUCTION

The traction-gap relation between two parallel plane surfaces is often characterized by the Lennard-Jones [LJ] law. However, if the surfaces are rough, the mean traction-mean gap relation is modified, generally resulting in a reduction in the pull-off traction and in the effective interface energy.

In a previous paper [1], we addressed this question by tracking the evolution of the probability density function [PDF] for the gap as roughness is added incrementally from coarse to fine scale. This is a modified version of Persson's model [2] in that the LJ law is used instead of classical non-adhesive contact mechanics. We found that the gap PDF converged at large wavenumbers, in contrast to non-adhesive contact theories, which typically require arbitrary truncation of the roughness spectrum [PSD].

This method can only be applied to fine-scale roughness, since long wavelength sinusoids exhibit a contact instability associated with the maximum negative slope of the LJ law. Here we develop a method which can circumvent this difficulty.

METHOD

In [1] we suggested that the fine scale roughness could be characterized by a modified [reduced] interface energy, which could then be used in a JKR formulation of the remaining [macroscopic] contact features. However, if instead we use the method to determine the entire modified traction law, we can then use this to replace the LJ law in determining the effect of the next lower tranche of the PSD. Since the maximum negative slope of the modified law is lower than that of the LJ law, this permits the method to be extended to longer wavelength features of the roughness. This approach can then be applied iteratively to describe the effect of an extended roughness spectrum.

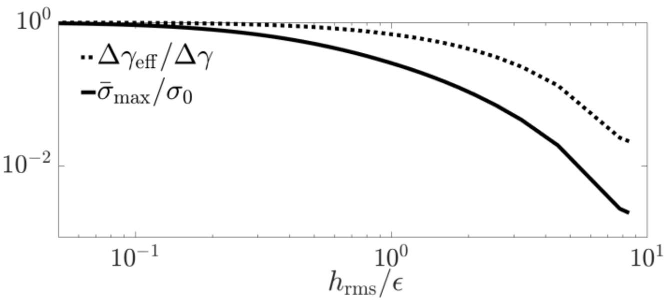

Fig. 1 Effect of surface roughness on $\bar{\sigma}_{max}$ and $\Delta\gamma_{eff}$, both normalized by the corresponding LJ values for a smooth plane surface.

RESULTS AND DISCUSSION

We define the dimensionless PSD as $\tilde{P}_S(\tilde{q})=P_S(q)/(\varepsilon\chi)^2$, where $\tilde{q}=\chi q$, $\chi=3\varepsilon^2E^*q/16\Delta\gamma$, ε is the equilibrium spacing in the Lennard-Jones law and E^* is the composite elastic contact modulus. Figure 1 shows the mean pull-off traction $\bar{\sigma}_{max}$ and effective interface energy $\Delta\gamma_{eff}$ for a surface PSD $\tilde{P}_S(\tilde{q})=0.0122\tilde{q}^{-3.6}$, $\tilde{q}_1 < \tilde{q} < 0.736$. The lower cut-off $\tilde{q}_1$ was varied resulting in a corresponding change in the RMS roughness h_{rms}. The results show that $\bar{\sigma}_{max}$ falls more rapidly than does $\Delta\gamma_{eff}$ as the roughness amplitude increases.

Although the new method extends the range of permissible wavenumbers $\tilde{q}$, instability is still predicted at very low $\tilde{q}$. However, in this [long wavelength] range it will generally be appropriate to describe the macroscopic geometry explicitly and use the JKR formalism with the appropriate value of $\Delta\gamma_{eff}$.

CONCLUSION

By applying the method of [1] iteratively, we are able to circumvent difficulties over elastic instabilities and hence predict the effect of broad spectrum roughness on mean adhesive tractions. The results show that pull-off tractions and effective interface energy correlate quite well with the RMS surface roughness.

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STUDY ON EHL OIL FILM BEHAVIOR OF TEXTURED SURFACE BY THREE-WAVELENGTH INTERFEROMETRY METHOD

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ABSTRACT

The three-wavelength interferometry method [1] is sucessfully applied for the high presicion, wide range and one shot EHL oil film thickness measurement method on the textured surface under the rolling contact. The effect of textured surface on the distribution of ultrathin EHL oil film thickness and the behavor is observed under the fully flooded lubrication condition and the starved lubrication condition.

INTRODUCTION

It is effective to reduce the quantity of lubricant to decrease the agitating resistance and the rolling viscosity resistance of rolling bearing. However, the reduction of lubricant quantity decrease the EHL oil film thickness. The break of EHL oil film causes the short life of rolling bearing. In order to improve the lubrication condition of rolling bearings, the effect of textured surface is studied under the fully flooded condition and the starved conditon. In this paper, the EHL oil film distribution and the EHL oil film behavior on the textured surface are observed by the three-wavelength interferometry method.

EXPERIMENTAL METHOD

The test rig is shown in Fig. 1. The intensity of each reflected light of RGB is different in oil film thickness, therefore the film thickness is measured by the three-wavelength interferometry method. It is possible to measure a minute oil film change in the textured surface with to use this method and an intermittent light by xenon flash lamp.

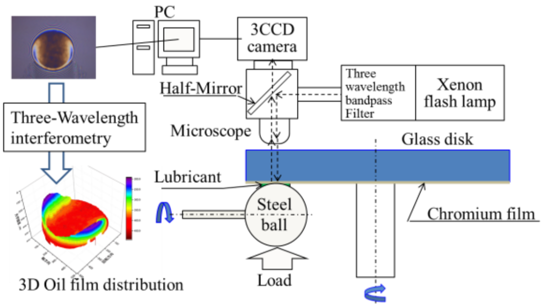

Fig.1 Schematic of test rig

RESULTS AND DISCUSSION

The cross-hatching type surface texture is processed on the part of steel ball for the rolling bearing. The shape of surface texture is shown in Fig. 2 and Fig. 3.

Under the fully flooded condition, the EHL oil film thickness is decreased around the groove (Fig. 4). The decrease of EHL oil film thickness is caused by the oil leak from the groove [2].

On the other hand, the starved condition is induced by the control of initial lubricant quantity to only 5μL. Under the starved condition, the oil flow from inlet side is small [3]. The EHL oil film thickness is not decreased because of the lubricating oil is held in the groove (Fig. 5).

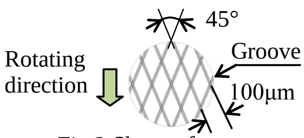

Fig.2 Shape of texture

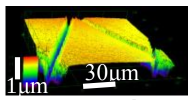

Fig.3 Microscope observation result of textured surface

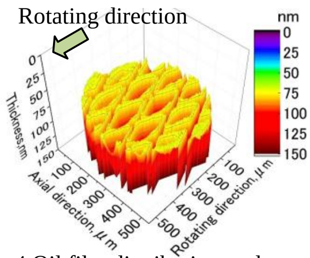

Fig.4 Oil film distribution under the fully flooded condition

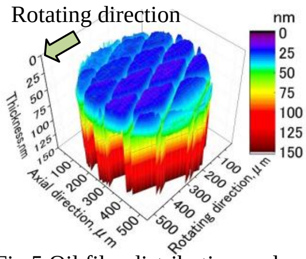

Fig.5 Oil film distribution under the starved condition

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

MOLECULARLY-ASSISTED TUNING OF THE FRICTION LAWS IN A MULTI-ASPERITY TRIBOCONTACT

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KEYWORDS: *Nanotribology ; Friction laws ; Self-assembled Monolayers ; MEMS*

ABSTRACT

The design and control of materials at the nanoscale are the foundation of many new strategies for energy generation, storage and efficiency. Besides, friction is an important limitation of energy efficiency performances in MEMS/NEMS [1]. Multi-asperity nanotribology studies are needed to develop a fundamental understanding of interfacial phenomena where frictional behaviour is controlled by interactions between nano-asperities [2]. Controlling these interactions is clearly the first *step* for designing *triboactive* surfaces – *ie,* surfaces whose frictional behavior can be controlled in *real time* by means of external stimuli [2]. A promising way consists to apply a suitable stimulus – *eg.* IR [2] or UV beam [3] – on grafted self-assembled monolayers (SAMs) in order to change their dissipated behavior in real time. However, the *real* friction laws occurring on the asperity's scale – especially their evolutions over time and over multiple asperities – need to be known to control friction when stimulus is applied. This complicated assessment is often ignored by assuming that the friction is uniformly shared on the whole *nanoasperities* which constitutes the so-called *real contact area*. Hence, the friction law is frequently supposed constant over time and well-described by various relationships – *ie*, Coulomb's dry friction, Stokes' viscous friction or Mindlin's partial slip.

However, it is also well-known – from the pioneered LFM/FFM's works – that the elemental friction law at the asperity's scale is intrinsically connected to the size of the asperity itself and especially to the ratio between the sliding amplitude and the asperity's contact radius. This is why the classical law often breaks down at the asperity's scale.

Hence, it clearly appears that friction law can *locally* changes from an asperity to another in a multi-asperity contact [4]. This is especially true for grafted self-assembled monolayers because their frictional behavior is mainly controlled by the entropy variations [5].

In this work, evolution of friction laws of alkanethiol self-assembled monolayers is studied at the nanoscale as a function of sliding amplitude and velocity by using a grafted AT-cut quartz crystal resonator (QCR, 6 MHz) which is in contact with a rough bare alumina ball (4 mm) at constant normal load (500 µN).

The surface displacement amplitudes of the AT-cut QCR – *ie,* the sliding amplitude – is controlled by means of a Vector Network Analyzer (*R&S ZNC 3*) [4, 6]. In order to study the interaction between the QCR and ball's asperities, experiments were performed over a wide amplitude range – from 40 pm to 40 nm – by changing the drive level provided by the network analyzer [6]. Thus, induced sliding velocity lies from $mm.s^{-1}$ to $m.s^{-1}$ which is actually in the range of actual MEMS one.

When the rough ball is applied at constant normal load on the QCR, the network analyzer sweeps the frequency across the resonance and measures the resonator's electrical admittance [6]. At the resonance frequency, the real part of the latter forms the well-known resonance curve which is characterized by its quality factor Q. Hence, any variations of resonance frequency (dF) and dissipation factor ($dD = dQ^{-1}$) can be studied over time as function of the sliding amplitude or sliding velocity [7]. The frictional behavior can be accurately studied – for strong bonding conditions – by fitting the evolution of *slip-time (ie. dD/dF) vs.* amplitude by power-laws [8].

As a main result, the power-law exponent continuously changes *vs.* amplitude. Since this evolution is equivalent to those of friction force *vs.* velocity [8], friction laws in a multi-asperity contact can be accurately tuned by specially designed or tailored molecules.

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Application of DLCs to engine valve train systems: Effects of coating both the cam and follower

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KEYWORDS; Friction; DLC coatings; Cam followers systems and Lubrication

1. Abstract

In this study, the tribological properties of two commercial diamond like carbon (DLC) coatings of taC-H and A-carbon were investigated on a single cam rig. The uncoated tribopair was used as a reference while the cam/follower was tested with both surface treatment conditions. A-carbon and taC-H had hardness of 20±4GPa and 35±7GPa respectively. All materials had a centerline average surface roughness (R_a) of 0.02-0.03 µm. XPS and SEM/EDX was used to evaluation the tribochemical films which was formed on the surfaces. It was observed that the interaction of the coating with the oil has been significantly reduced as zinc does not absorb to the surface of the DLC.

2. Introduction

DLC coatings are widely used in automotive valve train subcomponents such as valves, collets, spring retainers, inserts, buckets and even on camlobes. This is due to their excellent tribological properties of lower coefficient of friction, high wear resistance and unique running-in properties[1]. For high performance engines such as formula 1, they are becoming a necessary requirement due to the high pressure variation and temperature experienced in the cam-follower system.

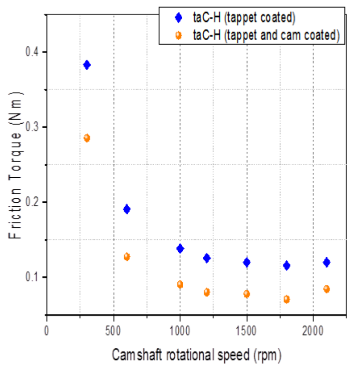
This paper characterizes the potential advantages of coating the cam, leaving it uncoated, as well as evaluating the cam and follower in an uncoated stated.

3. Material and Methods

The substrate material (follower) for all test was a 16MnCr5 (Steel) which was coated with 2µm A-Carbon and 1.5µm taC-H respectively. Both coatings had similar roughness with the cam. For the cam, this was achieved by micro-mechanical polishing to R_a of 0.02 µm. Lubricant used for this setup is a 5W30 fully formulated oil here after referred to as FFB.

4. Results

During 50hrs testing, where the camlobes were uncoated, the taC-H coating showed significant friction improvements in the boundary/mixed regime for the speed range tested. No significant friction benefits were achieved in the EHL lubrication regime, as expected, since both surfaces were separated by a lubricant film and friction in controlled by the viscosity of the lubricant. The wear results showed that harder coatings on the camlobes do not provide the required wear resistance because ta-C:H had significant delamination due to edge loading. This was not observed for a softer a-C-H coatings. The results also show that the hard coating has an adverse effect on the uncoated camlobe and wear is higher on the rising edge of the cam and to the best of the knowledge of the authors, this has not been reported in previous cam follower research works.



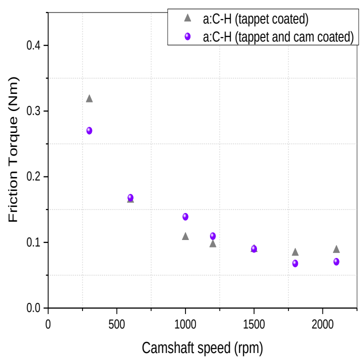


Figure 1Effects of DLC Coating of inserts in a single cam rig

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EFFECTS OF SURFACE ROUGHNESS ON LOCAL FRICTION AND TEMPERATURE DISTRIBUTIONS IN FRETTING CONTACTS

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KEYWORDS
surface roughness; friction; temperature; fretting wear; finite element method

ABSTRACT

Friction will result in power dissipation in fretting process and then induce temperature rise in fretting contacts which is known to affect the fretting wear behaviour of metals [1]. It has been found that initial surface roughness has significant influences on friction [2] and flash temperature rise in contact [3], which are believed to be very difficult to be measured by experiments.

In this paper, the dynamic local contact friction force and temperature distributions in fretting contacts during the fretting process are investigated by finite element (FE) method taking into account the initial surface roughness. The roughness of contact surfaces is characterized as fractal surfaces by the Weierstrass-Mandelbrot (W-M) function [4], and the finite element model including the contacting bodies with rough surfaces is developed according to a cylinder-on-flat configuration, see Fig. 1, which was used in the fretting wear experiment. An example of surface roughness characterization using the W-M function is shown in Fig. 2. The FE analyses were carried and the simulated results obtained can be used to identify the possible variations of local contact friction and local temperature rise due to varying surface roughness of the specimens.

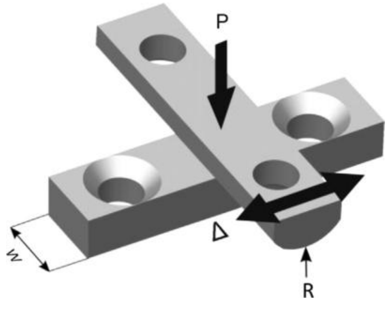

Fig.1 Cylinder-on-flat configuration for fretting test

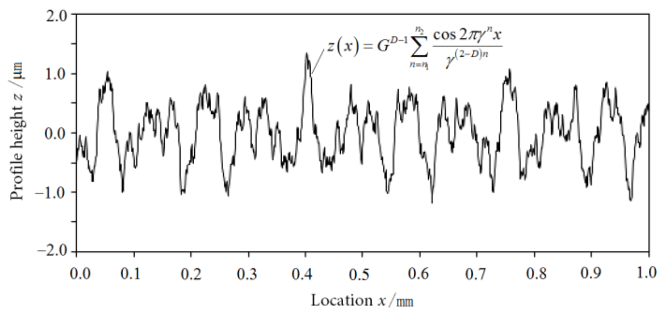

Fig. 2 Surface roughness characterization

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ELECTRICAL IMPEDANCE METHOD FOR MEASURING OIL FILM THICKNESS AND METALLIC CONTACT RATIO IN EHD CONTACTS

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KEYWORDS

Elastohydrodynamic lubrication (EHL); Oil film thickness; Metallic contact ratio

INTRODUCTION

To measure oil film thickness in EHD (elastohydrodynamic) contacts, optical interferometry methods have been used for a long time. However, it is difficult to apply them to measurements for practical bearings because visible lights cannot be transmitted through metal bodies. In this study, a novel method for measuring oil film thickness in EHD contacts has been developed by improving an electrical impedance method [1], which has a possibility to be applied to practical bearings.

EXPERIMENTAL DETAILS

A ball-on-disc-type apparatus was used for measuring oil film thickness in EHD contacts. A poly-α-olefin (viscosity: 30 mm^2/s at 40 °C) was used as a test lubricant. The ball (diameter: 25.4 mm) was made of 52100 steel. The disc (diameter: 100 mm, thickness: 10 mm) was made of BK7 glass. A Cr film and an ITO (indium tin oxide) film were coated on the disc surface as the semi-reflective layer and the spacer layer, respectively.

The central oil film thickness was measured using an optical method (i.e., ultrathin film interferometry [2]) and the developed electrical method (i.e., electrical impedance method) simultaneously. For the latter method, a sinusoidal voltage (RMS amplitude: 1 V and frequency: 1 MHz) was applied between the ball and the ITO film. The accuracy of the developed method was evaluated by comparing it with the optical method and the Hamrock-Dowson theory. Besides, the metallic contact ratio was obtained from the developed method.

RESULTS AND DISCUSSION

Figure 1 shows the measured central oil film thickness (h) as a function of the entrainment speed (U) at a normal load of 9 N. It was found that the h values measured by the electrical method agreed well with those by the optical method, which were located around the broken line predicted by the Hamrock-Dowson theory. The metallic contact ratio (α), which was simultaneously measured using the electrical method, was increased with decrease in U, which means that the experiments at lower speeds (e.g., less than 0.1 m/s) were conducted in the mixed lubrication regime.

CONCLUSION

From the above, we can conclude that the developed electrical impedance method can measure oil film thickness in EHD contacts with a high accuracy. Besides, by using it, metallic contact ratio can be quantified simultaneously. It is hoped that this method will be applied to practical bearings, to understand the invisible behaviors of oil films.

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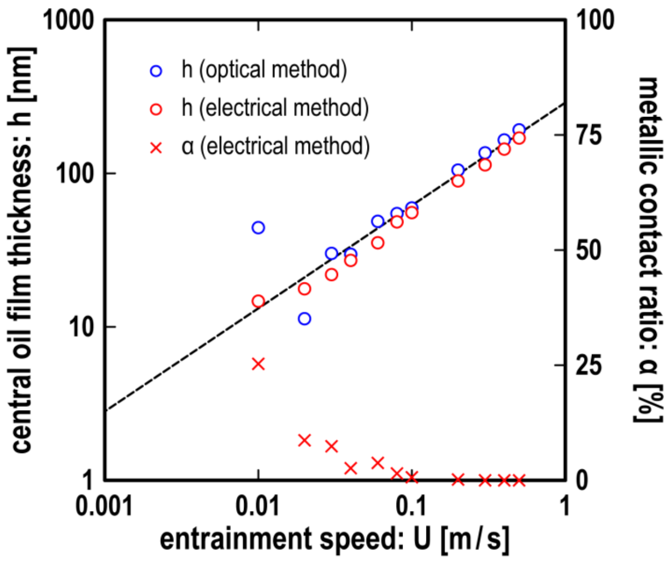

Fig. 1 Measured central oil film thickness h and metallic contact ratio α in EHD contacts; broken line: theory by Hamrock-Dowson.

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IDENTIFICATION OF MICRO TRIBOLOGICAL PHENOMENA ON METAL SURFACES BY SPM-AE IN SITU MEASUREMENT

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KEYWORDS
in situ; acoustic emission; wear mode; micro tribology; SPM

ABSTRACT

In situ measurement of acoustic emission (AE) signals of two metals being rubbed on each other on a scanning probe microscope (SPM) was performed in order to examine the relationship between the waveform analysis of the collected AE signals and the microscopic tribological phenomena.

In this study, AE signals from rubbing silicon probe or metal colloid probe and pure iron or copper metal using an SPM on friction force microscope mode were measured similarly like in our previous report [1]. A broadband-type AE sensor was mounted to a metal block specimen. The probe was slid back and forth on a metal specimen only once with a sliding distance of 10 µm and a sliding velocity of 12.5 mm/s. The AE amplification factor was 90dB. And, a band pass filter from 0.5 to 3.0 MHz was used to eliminate noise signals. All experiments were performed under dry conditions at room temperature (20ºC) in air (40% humidity).

Short-time Fourier transform (STFT) is an analysis technique that could transform a short time wave into spectrum that allows us to look into the changes of AE frequency in more detail. The AE signal waveforms detected by friction and wear of Si/Cu, Cu/Cu, Si/Fe and Fe/Fe experiments were analyzed using this method. Figure 1 shows the STFT analysis of the AE signal waveforms detected at rubbing of (a) silicon on copper and (b) copper on copper. STFT was done at every 100 microseconds (frictional distance of 625 nm). Features of the frequency spectrum of the AE signals corresponding to microscopic tribological phenomena are as follows: abrasive friction caused by silicon probe, a low frequency peak at around 0.5 MHz; and adhesive friction caused by metal colloid probe, a high frequency peak at around 1 MHz. Similar to the macroscopic experiments [2], the mode of wear namely abrasive wear and adhesive wear could be identified by looking at the AE frequency. The number of wear elements related to adhesive wear can be evaluated by counting the number of AE frequency peaks from the STFT. Thus, allowing us to understand the elementary process of wear.

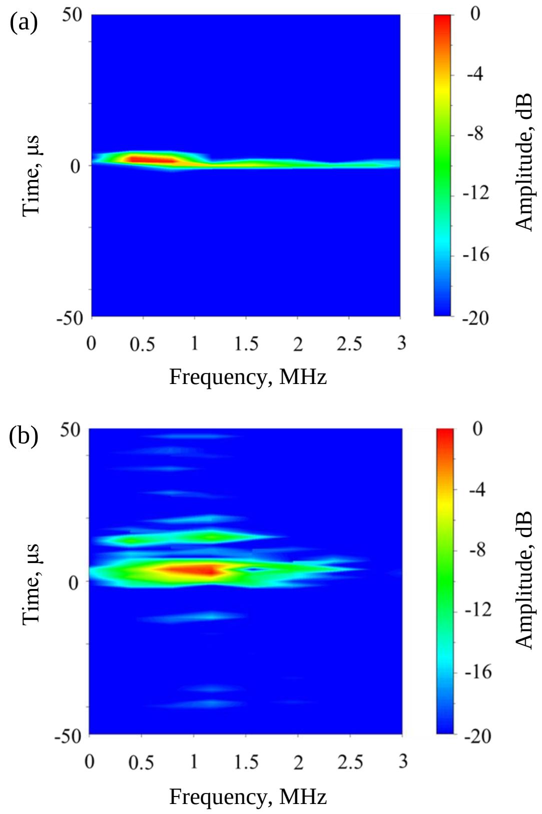

Fig. 1 STFT analysis of the AE signal waveforms detected at rubbing of (a) Si/Cu and (b) Cu/Cu

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LOW FRICTION MECHANISM OF CHLORINE-CONTAINING AMORPHOUS CARBON FILMS AGAINST ALUMINIUM ALLOY

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KEYWORDS

Diamond-like carbon films; Amorphous carbon films; Coating; Self-lubrication; Different element doping

INTRODUCTION

In our previous study, the effect of chlorine doping on tribological properties of amorphous carbon films against aluminium alloy were surveyed. As a result of friction test in non-lubricated conditions, the reduction of friction and improvement of wear properties of chlorine-containing amorphous carbon films could be observed. On the other hand, low friction mechanism was not clarified. The aim of this paper is to reveal the low friction mechanism of chlorine-containing amorphous carbon film in friction with aluminium alloy counterpart in non-lubricated condition.

EXPERIMENTAL SET UP & RESULTS

The hydrogenated amorphous carbon films and the chlorine-containing amorphous carbon films were deposited via the plasma based ion implantation and deposition (PBII&D) using $C_6H_5CH_3$ gas and C_2Cl_4 gas respectively. Friction test was performed under non-lubricated condition, and opposite material was φ6mm aluminium alloy (ISO-AlMg1SiCu) ball. As shown in Figure 1, friction coefficient of chlorine-containing amorphous carbon films indiceted lower friction coefficient compared with hydrogenated amorphous carbon films. This result means chlorine doping make it possible to improve friction properties of films. Figure 2 shows result of surface analysis using time-of-flight secondary ion mass spectroscopy (TOF-SIMS) on the wear track of chlorine-containing amorphous carbon films after the friction test. According to this result, several kinds of fragment ions, such as H_2OCl, H_2O_2Al, HAlCl, HOAlCl, H_2OAlCl could be detected from the wear track. It is possible to consider that there is some sort of hydrate composed of aluminium and chlorine at the sliding interface. This compound is thought to be tribofilms formed through tribochemical reaction between chlorine-containing amorphous carbon films and aluminium alloy. From the point of view about the tribofilm, we are going to report detail information about low friction mechanism of chlorine-containing amorphous carbon films

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant number JP15K17964.

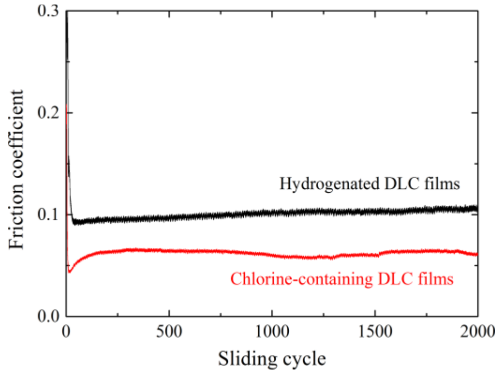

Figure.1 Comparison of friction coefficient

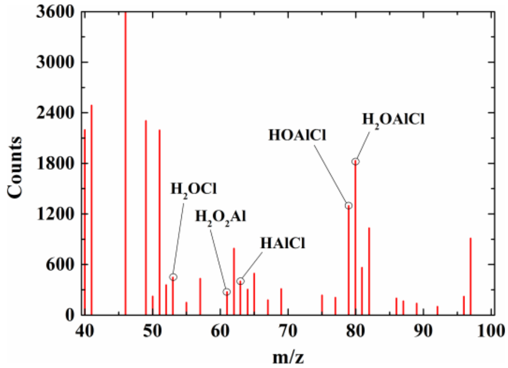

Figure.2 TOF-SIM analysis on the wear track of chlorin-containing amorphous carbon films

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TEMPERATURE RISE OF NITROGENATED DIAMOND-LIKE CARBON DURING SLIDING: CONSIDERATION OF REAL CONTACT AREA

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KEYWORDS

real contact area; height distribution; diamond-like carbon

ABSTRACT

The real contact area of the nitrogenated diamond-like carbon [1] against the alumina ball during sliding was evaluated in order to obtain precise data for the temperature rise model at the interface. The temperature distribution at the interface is a crucial parameter, as the mechanical properties of DLCs will be degraded above 400℃ due to the structural changes [2]. Yamamoto et al. estimated that the temperature at the steel/DLC interface can rise up to 560 ℃ using the numerical model [3] based on the frictional energy approach[4]. The numerical model also showed dependence of the interface temperature on the real contact area. Hence, it is important to evaluate the real contact area during sliding process, so that more precise temperature profile is obtained by the simulation [5]. However, most of the real contact area mechanisms have been discussed using static condition [6-7]. In this work, The 3D surface profiles of the wear tracks after ball-on-disk test (RHESCA FPR-2100) were obtained by the laser microscope (OLS4000 OLYMPUS). The overall height distribution of the surfaces asperities was obtained before (Fig. 1a) and after (Fig. 1b) the tribo test. The evolution of the average and the standard distribution of asperities has been evaluated, and used in the improved numerical model using frictional energy approach.

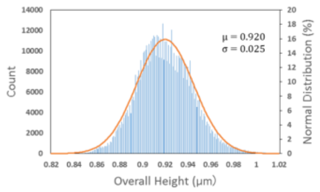

Fig. 1 (a) Overall height distribution before tribo-test: Nitrogenated DLC

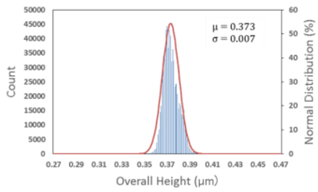

Fig. 1 (b) Overall height distribution after tribo-test: Nitrogenated DLC

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The author wishes to thank Dr. Chitoshi Masuda (retired Waseda University), Dr. Ichimura, and Mr. Egashira (retired National Institute for Materials Science) for helpful discussions of this work.

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SUPPRESSION OF FRICTION-INDUCED VIBRATIONS BY DAMPING FROM IN-PLANE ANGULAR MISALIGNMENT

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KEYWORDS

friction-induced vibration; stick-slip; instability; numerical simulation; eigenvalue analysis

ABSTRACT

Recently, it has been theoretically and experimentally shown that the in-plane angular misalignment (i.e., yaw angle misalignment (YAM)) can generate a damping to suppress friction-induced vibrations (FIVs) in a 1DOF sliding system with velocity-weakening friction [1,2]. This paper describes a subsequent study aiming to extend this YAM theory from 1DOF to 2DOF. The stability conditions of a 2DOF sliding system were investigated via numerical simulations and eigenvalue analysis.

Figure 1 shows the analytical model of the 2DOF sliding system. A "ball" with a mass m is in contact with a "plate" parallel to the xy plane at a constant normal load W. The ball is supported elastically (i.e., with no dampers) in the xy plane by two springs. The stiffnesses of the system in the x and y directions are denoted by k_x and k_y, respectively. They represent the anisotropic stiffness of the system (i.e., $k_x \neq k_y$), where the x and y axes are the principal axes. The plate is driven at a constant velocity V in the xy plane. The direction of V is represented by the in-plane angular misalignment φ ($0° < \varphi < 90°$) from the x-axis.

The dynamic behaviors of the system were simulated by solving the equations of motion (EOMs) numerically using the Runge-Kutta method for various conditions. For example, FIVs occurred when φ was small (e.g., 0.1°) due to the velocity-weakening friction. The FIVs were suppressed when φ = 45°. However, FIVs occurred again when φ was large (i.e., 89.9°).

The EOMs were linearized around the equilibrium point. By introducing five dimensionless parameters, the dimensionless linearized EOMs were derived. Then, eigenvalue analysis was conducted for the dimensionless linearized EOMs to find the stability conditions. As the results, the following four important conclusions were obtained to suppress the FIV using the damping generated by YAM:

(1) Lower and upper limits exist for the YAM to suppress the FIV, being smaller and larger than 45°, respectively, meaning that the YAM of φ = 45° is a promising setting.

(2) Decreasing λ is effective to suppress the FIV, where λ is a dimensionless parameter composed of m, k_x, V, W, and parameters determining the velocity-weakening friction characteristics.

(3) The stiffness of the system must be anisotropic (i.e., $k_x \neq k_y$) to suppress the FIV. Increasing k_x is effective to suppress the FIV when $k_x > k_y$. Inversely, increasing k_y is effective when $k_x < k_y$.

(4) Increasing V is effective to suppress the FIV. In addition, the suppression effect becomes strong when V is far from V_f, where V_f is the velocity constant determining the velocity-weakening friction characteristics.

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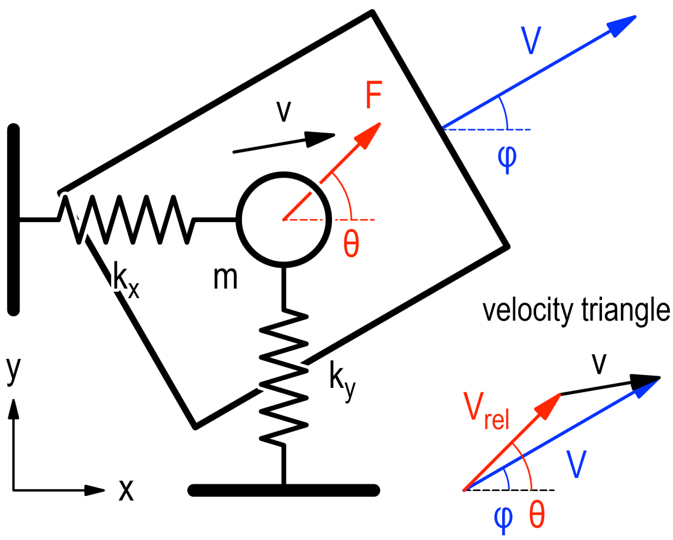

Fig. 1 Analytical model of 2DOF sliding system with in-plane anisotropic stiffness (i.e., $k_x \neq k_y$) and in-plane angular misalignment (i.e., $\varphi \neq 0°$).

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COLLAPSE BEHAVIOUR OF SOLIDIFIED FILM IN ELASTOHYDRODYNAMIC LUBRICATIUON CONDITIONS

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KEYWORDS
EHL; solidification; film shape; slippage

ABSTRACT

The film thickness is one of most important factors to estimate the severity and efficiency of lubricated contacts. The fluid film in elastohydrodynamic lubrication (EHL) conditions, found in gears, rolling bearings, and cam-tappet systems, is formed under high pressure of the giga-pascal order. The significant high pressure causes large elastic deformations of bounding surfaces and an increase in viscosity. The pressurized lubricant behaves in the non-Newtonian manner as the response to shear motion. During the last decade, anomalous film shapes have been found under high sliding conditions when fatty alcohols are used as lubricant [1-3].

In the current study, the authors investigates precisely the film formation of a solidified film in EHL conditions. A fatty alcohols of 1-dodecanol is used as lubricant, which has low viscosity and a clear melting point of 24 ºC. A circular contact is produced between a rotating transparent disc and a rotating steel ball, which are independently driven by AC servo motors. Optical interferograms formed between the disc surface and ball surface are captured by a digital camera attached to a microscope. A Xenon flashing light is used as a light source to produce optical interferograms between the bounding surfaces.

Figure 1 shows a representative result of optical interferograms of EHL films at different slide-to-roll ratios defined as $S = (u_b - u_d) / u_m$. In pure rolling conditions, the shape of film is the typical EHL shape, having a flat part at the centre and a constriction at the exit. As the slide-to-roll ratio increases with faster speeds of the steel ball surface, the inhomogeneous colour of optical interferograms appears around the centre. As the high slide-to-roll ratio increases furthermore, inhomogeneous film collapses gradually around the centre and exit. In the current study, the trend of the collapse behavior of the solidified EHL film is investigated.

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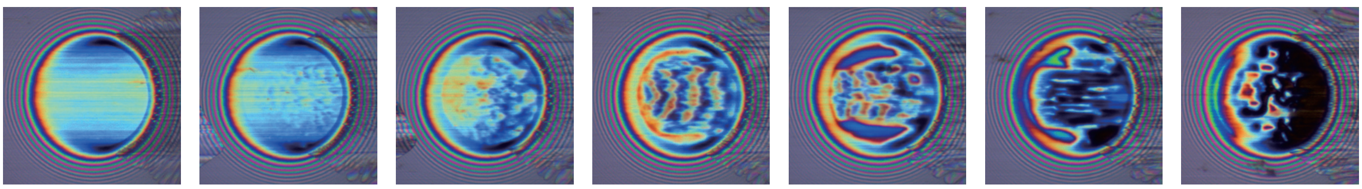

$S = 0$ $S = 0.3$ $S = 0.6$ $S = 0.9$ $S = 1.2$ $S = 1.5$ $S = 1.8$

Fig. 1 Collapse behaviour of EHL film at different slide-to-roll ratios (u_m = 1.8 m/s, p_{hmax} = 0.57 GPa, T = 30ºC)

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UNDERSTANDING ACTION MECHANISMS OF AMINE-BASED FRICTION MODIFIERS THROUGH MOLECULAR SIMULATIONS

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KEYWORDS

Organic friction modifiers, amines, iron-based surfaces, Molecular Dynamics

ABSTRACT

Friction-modifier (FM) additives of thermal engine lubricants have been beneficial in reducing friction between contacting surfaces [1]. In particular, organic nitrogen-containing compounds such as fatty amines seem to be promising additives. Besides their tribological performance, they are compatible with exhaust aftertreatment systems due their sulfur- and phosphorus-free chemical composition.

In this computational study, we have investigated the mechanisms of action of amine-based FM using electronic structure and Molecular Dynamics calculations. An α-iron oxide Fe_2O_3 surface was used as rubbing substrate model. The aim was to better understand the impact of the chemical structure of these additives on the thermal film formation and eventually on their tribological behavior.

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WEAR PERFORMANCE AND MECHANICAL CHARACTERIZATION OF NEWLY DESIGNED UHMWPE/HYDROGEL COMPOSITES FOR APPLICATION IN ARTIFICIAL JOINTS

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KEYWORDS
Wear; UHMWPE; Hydrogel; lubrication

ABSTRACT
Since life expectancy of people is increasing and more artificial joint (AJ) implants are required for people at an earlier age, it is important to improve the life-span of these AJs. Ultra high molecular weight polyethylene (UHMWPE) is the most commonly used material for AJs and the life-span of UHMWPE made implants largely depends on the wear performance, which is extensively related to their mechanical and physical properties, such as hardness, surface finish [1]. This work is to design new composite structures to further improve the wear performance and achieve a longer life-span by improving the load distribution and incorporating a self-lubricating function.

The proposed new structure has three layers – GUR 1020 UHMWPE as a top layer, a middle layer of a high molecular weight poly(vinyl alcohol) (HMW-PVA) hydrogel, and UHMWPE as the bottom layer. This design utilises the excellent mechanical properties of the UHMWPE on the top surface where wear takes place whilst an improvement on the lubricating is expected because of the biphasic characteristic of the hydrogel and its high water content [2].

In addition to this new structure, a surface texturing approach is considered. On the top layer, holes were made with specific diameters (1.0 and 1.5 mm) and distribution (20% surface density), and the middle layer, made of the hydrogel, was connected to the top surface through the holes for improving lubrication and shear stress. The ultimate tensile stress and Young's modulus of the hydrogel were tested, and they are 3.03 MPa and 2.49 MPa, respectively. The obtained mechanical properties of the hydrogel are similar to the one of human cartilage [3, 4], suggesting that the hydrogel can supply the minimum mechanical properties required in AJs. Wear tests were performed on the composites and their wear performance was compared to that of neat UHMWPE samples. A significant improvement on the wear performance was observed with a reduction in the wear rate and friction coefficient of 70% and 48% respectively (Figure 1).

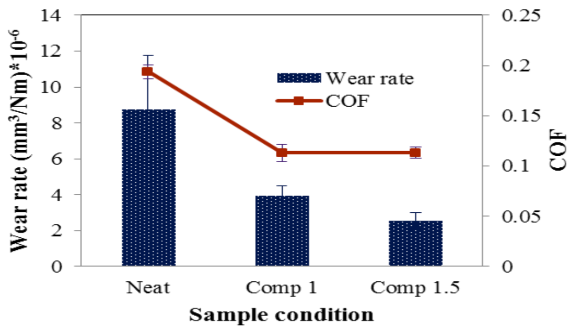

Fig. 1 Wear rate and COF of the Neat UHMWPE and the UHMWPE/HYDROGEL Composites with two different diameter holes (1.0 and 1.5 mm) and 20% surface density

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RESEARCH ON MAGNETIC MEMORY TESTING TECHOLOGY IN EVALUATING WEAR PHENOMENA AND WEAR MECHANISM

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ABSTRACT

The 40CrMo block specimen and the 316L pin specimen which constituted a pin–on–block friction pair were used for the friction magnetic memory test in the geomagnetic field. The relationship between the surface magnetic memory signals in the process of friction and wear phenomena, wear mechanism was investigated. The results showed that according to the changes of the magnetic memory signals tribo-magnetization was a four-stage process and wear phenomena and wear mechanism were also transformed at the demarcation points of these four stages.

friction and wear test; magnetic memory signals; wear phenomena; wear mechanism

INTRODUCTION

Metal magnetic memory testing technology (MMM) as a new nondestructive testing technology has widely been paid attention. Numerous experiments are carried out to study MMM under different stress conditions such as tension, pressure, bending, torsion and shock. However, studies about using MMM to evaluate wear phenomenon and wear mechanism are very limited[1]. This paper was devoted to research on the tangential magnetic memory signals in the friction process and the relationship between the magnetic memory signals and wear phenomenon and wear mechanism.

EXPERIMENTAL METHOD

The experiments were performed under dry sliding condition at a room temperature in the geomagnetic field. The friction and wear test was carried out with a normal load of 60 N and a mean velocity of 1 Hz until the reciprocating movement was repeated 10000 times. The tangential magnetic memory signals of the specimens were measured by a giant magnetoresistance-type magnetic sensor which had a higher sensitivity.

EXPERIMENTAL RESULTS AND DISCUSSION

Fig.1 shows the curves of the average of the tangential magnetic memory signals under the different sliding circles. It can be seen from the Fig.1 that wear phenomenon transforms at the three transition points (G-point, H-point, I-point) of the magnetic memory signals. At the G-point, the magnetic memory signals started to increase rapidly and wear scar was generated. To the H-point, the magnetic memory signals began to increase slowly and the area of wear scar reached the maximum. After the I-point, the magnetic memory signals remained constant and the depth of wear scar kept unchanged.

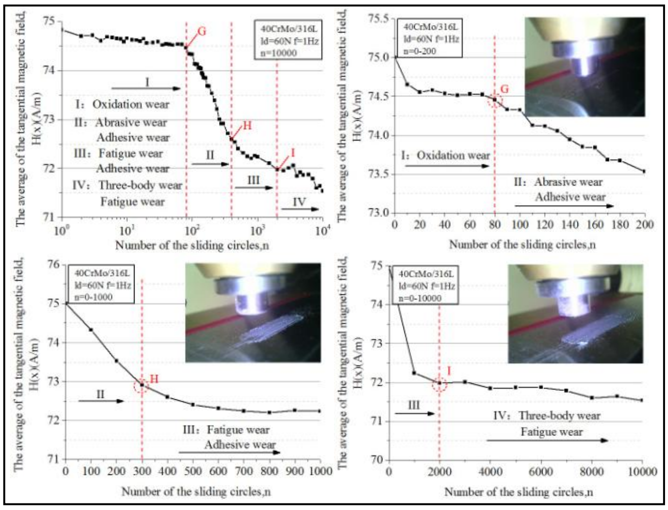

Fig.1 The average of the tangential magnetic memory signals under the different sliding circles

ACKNOWLEDGMENTS

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THE SELF-REPAIR BEHAVIOR OF CELL OVERLAY INDUCED BY THE SURFACE TEXTURE ON CO-CR-MO ALLOY

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KEYWORDS
Surface texture; Self-repair; cell overlay

ABSTRACT

The surface texturing technique has been increasingly applied in various engineering [1]. In the field of biomedical engineering, surface texturing is one of the effective strategies to improve the bioactivity of implantable materials [2]. In the study, the cell overlay was formed in an organized way when the template of the textured surface was used in the vitro culture. The following cellular activities, such as the adhesion, migration, signal transmission and physiological responses were investigated under simulated conditions. Using a micro/nano indentation system, the mechanical properties of the overlay, hardness and elasticity modulus, were investigated. The home-made tribometer was used to evaluate the anti-deformation of the cell overlay. It shows that the adhesion, growth and differentiation of cells were influenced by microstructure of the surface texture. A cell overlay was formed according to distribution of the texture. Compared to the smooth substrate, the cell overlay on the textured surface was more compact and had a better anti-damage ability. After the wound experiment, the recovery ratio of the cell overlay on the textured surface was achieved to 90 %, nearly 1.4 folds compared with that of non-textured surface. The mechanism of the surface texture on the self-repair ability of the cell overlay was discussed. Results indicated the formation of textured structure on the surface can improve the biological performance, suggesting its potential application in orthopedic implants.

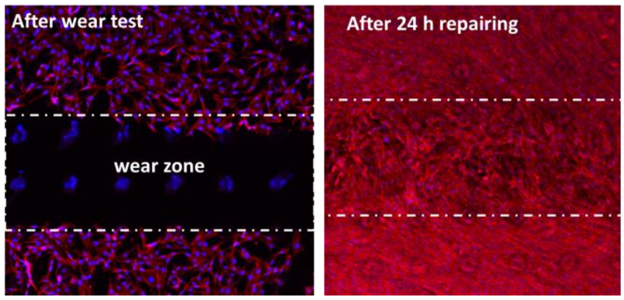

Fig.1 The repair ability of the cell overlay

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THERMO-HYDRODYNAMIC FE-ANALYSIS OF JOURNAL BEARINGS: EFFICIENT COUPLING OF THE REYNOLDS AND NAVIER-STOKES EQUATIONS

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KEYWORDS
Journal bearing; thermo-hydrodynamic model; Reynolds equation; Navier-Stokes equations

ABSTRACT

This paper deals with the fluid flow characteristics and the thermal behavior of a hydrodynamic journal bearing with a single oil supply groove. For this purpose, a thermo-hydrodynamic model has been developed, which represents the physical properties and interactions of the lubricant, the journal and the bush.

The pressure distribution in the fluid film region between the journal and the bush is described by the generalized Reynolds equation according to Dowson [1]. The determination of the velocity field and the pressure distribution within the groove requires the numerical solution of the Navier-Stokes equations and the continuity equation. The formulation of appropriate energy equations serves to obtain the temperature distribution in all bearing domains. The rapture and reformation of the fluid film in the cavitation region is modelled by a mass-conserving cavitation approach.

The physical domains of the bearing model –journal, bush, lubricant- are connected by using appropriate coupling conditions. Assuming that the temperature gradient in the axial direction is negligible, the energy equations as well as the Navier-Stokes equations are solved within the bearing mid plane. This simplification provides a reduction of computational effort and improves the convergence. The mathematical description yields a system of coupled nonlinear integro-differential equations, which are discretized by finite elements.

The predicted temperature and pressure profiles agree fairly well with the experimental data presented in [2]. The velocity field in the upper part of the bearing groove, see Fig.1, is dominated by two vortices, which cause the temperature to homogenize in this region. In the lower part, i.e. in the vicinity of the journal, a velocity boundary layer and a significant change of the lubricant temperature profile in radial direction is observed. Within this groove region, it can also be seen that the radial temperature profile remains almost constant along the circumferential direction.

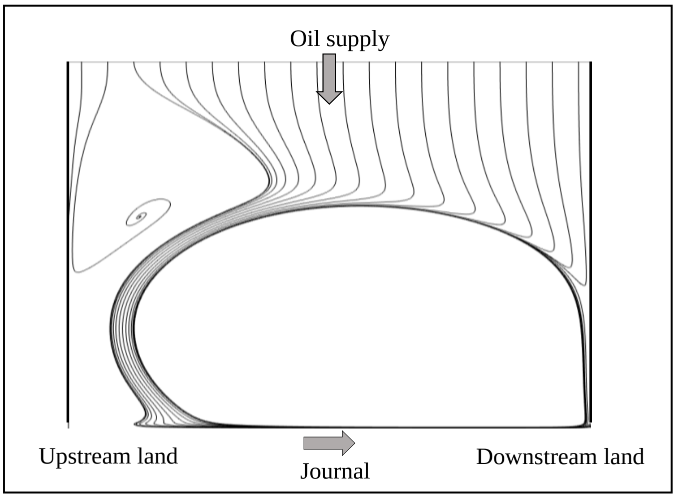

Fig.1 Streamlines of the velocity field in the upper part of the bearing groove

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TRIBO-CHEMISTRY OF DIAMOND (111) IN CONTACT WITH WATER

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KEYWORDS
Diamond Coatings; Humid Environments; Quantum-Mechanical Molecular Dynamics

ABSTRACT
Ultralow friction of diamond in humid environments is of both scientific and industrial interest [1]. Experimental groups suggested that the surface passivation by H and OH groups plays an important role in ultralow friction of diamond [2]. Zilibotti *et al.* [3] showed that water molecules undergo chemical reactions with a diamond (001) surface under a high normal pressure by Car-Parrinello molecular dynamics (MD). However, due to their high computational cost, the accessible time scale is still limited to a few picoseconds. Since running-in processes and related phase transitions occur on larger time scales, little is known about the steady-state atomic-scale friction mechanisms of water-lubricated diamond surfaces.

We here present the mechanism underlying the ultralow friction of a diamond (111) surface in contact with water molecules using the density-functional tight-binding (DFTB) MD method [4]. To understand the effects of the relative humidity on the friction of diamond, we perform sliding simulations of non-reconstructed diamond (111) surfaces interacting with different numbers n of water molecules. Simulations are carried out by rigidly moving the upper surfaces for 0.1 ns at a constant velocity of 100 ms^{-1} under an average normal pressure of 5 GPa. Figure 1a shows the friction coefficient as a function of n. The presence of a small amount of water initially induces cold welding and amorphization resulting in high friction. However, during running-in a tribo-induced Pandey reconstruction emerges preventing the diamond surfaces from cold welding, thus leading to ultralow friction (Fig. 1b). When the amount of water increases further, diamond surfaces are sufficiently passivated with H and OH groups. The surface passivation occurs via the two reaction mechanisms: (i) the dissociative chemisorption of a water molecule and (ii) Grotthuss-type proton transport [5]. The sliding of H/OH-passivated surfaces also leads to stable and ultralow friction (μ = 0.02). Our models provide microscopic insight into the kinetics at diamond/water interfaces and explain the experimentally observed ultralow friction of diamond at a wide range of relative humidity.

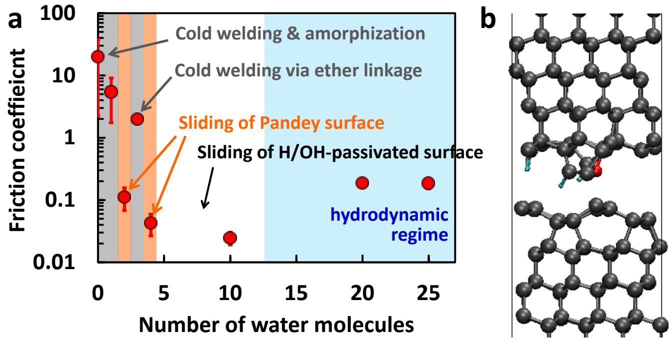

Fig. 1 (a) Friction coefficient as a function of the number of water molecules. (b) Representative example of the tribo-induced Pandey reconstruction.

ACKNOWLEDGMENTS
T.K. acknowledges financial support by JSPS Overseas Research Fellowships. Simulations were carried out on the supercomputer JURECA at the Jülich Supercomputing Center.

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ADHESIVE CONTACT NEAR FULL CONTACT: GENERALIZED TABOR PARAMETER, LOADING AND UNLOADING FULL SOLUTION

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KEYWORDS
Adhesion;; round robin, tribology challenges

ABSTRACT

Recently (Ciavarella, 2015), the first author has obtained a model for adhesive contact near full contact under the JKR assumptions, extending the Xu et al (2014, 2017) model. The model shows, in the common case of low fractal dimensions, an `unbounded' adhesion enhancement when larger and larger upper "truncation wavenumber" is considered in the spectrum of roughness, i.e. when we increase "magnification". Here, using a more general Maugis-Dugdale model, we show that a generalized multiscale Tabor parameter can be defined which shows a transition to a non-hysteretic regime, dependent on the root-mean-square (rms) slope of the surface. The contact area returns in the "fractal limit" to the adhesionless one. Two examples of rough surfaces from the literature are considered to show the full dependence on magnification of the adhesive solution. The choice of the truncation of the spectrum remains fundamentally arbitrary. The full loading and unloading solution is provided, which is the first analytical solution to adhesive rough contact problem fully considering the difference between loading and unloading regimes in the best of the authors' knowledge.

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THE TRIBOLOGICAL PERFORMANCE OF GAS TURBINE LUBRICANTS

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KEYWORDS
Lubricant; Aviation; Traction; Wear; Film

ABSTRACT

The purpose of this project is to evaluate the performance of a number of novel and commercial oil candidates over the range of conditions seen within the oil system of Rolls-Royce gas turbines. This project will focus primarily on Rolls-Royce's future concept gas turbine, the UltraFan™ (Figure 1), which poses a new tribological challenge for the lubricant.

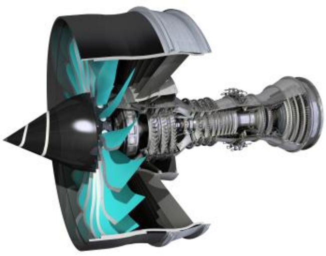

Figure 1 - Rolls-Royce's new future concept engine the UltraFan™.

It features a Power GearBox (PGB) between the intermediate pressure turbine (IPT) system and the corresponding fan that it is driving, the first of its kind in the large civil engine market. The PGB allows the fan blades to rotate slower than the IPT resulting in a large efficiency benefit. Therefore the lubrication system needs to be able to support the new PGB environment as well its other components such as ball and roller bearings, accessory gear boxes and splines etc.

Aviation lubricants are comprised of a base stock oil (~95% of the formulation and is generally a long chain ester) as well as a variety of different additives in order to enhance performance. Such additives may include anti-oxidants, anti-wear, corrosion inhibitors, and anti-foam additives [1]. Although the thermal properties of lubricants have been extensively investigated, there is a lack of understanding about their tribological performance under the high loads present in the PGB [2].

This research utilizes two tribology rigs to assess a range of lubricants under representative engine conditions. A Mini-Traction Machine (MTM) is being used to monitor traction coefficient (friction) of different lubricants over a range of speeds and therefore lubrication regimes.

The Spacer Layer IMaging (SLIM) is an extension to the MTM that uses optical interferometry to measure the thickness of boundary films. Lubricants with different amounts and amounts of boundary additives are being compared.

A MicroPitting Rig (MPR) is also being used to evaluate different lubricants ability to initiate the wear mechanism known as micropitting; a common type of wear seen in gears which usually propagates into a more severe failure mode.

The initial resulted will be presented along with an insight to the future work of the project.

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I would like to thank Rolls-Royce Plc for all their support especially the fluids team and also the CDT in Formulation Engineering at the University of Birmingham for all of their guidance too.

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TRIBOCHEMISTRY FOR SELF-FORMATION OF CARBONACEOUS TRIBO-LAYER IN SLIDING OF CARBON NITRIDE COATINGS

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KEYWORDS
tribochemistry; tribo-layer; carbon nitride coating; deuterium; mass spectrometry

ABSTRACT
Carbon nitride (denoted as CN_X) is an expected coating material which shows high hardness and relatively low friction under a nitrogen atmosphere [1]. Our previous paper [2] reported that carbon and hydrogen derived from coating transfer to opposite surface, which contributes the formation of low-frictional carbon tribo-layer. However, the process of transformation at the interface is not clarified in detail. Thus, with an effort to elucidate the tribochemical reactions of CN_X coatings during low friction, the gaseous tribochemical products are detected in vacuum during friction tests in this study.

The CN_X coating is produced on the surface of Si_3N_4 ball using an ion-beam-assisted deposition system at room temperature. The coating thickness is set at 400 nm. In addition, the deuterated-CN_X (CN_X:D) coating is produced on the surface of Si wafer by plasma-enhanced chemical vapor deposition using a mixture of deuterated-methane (CD_4) and N_2 gas with N_2/CD_4 flow ratio of 0.05 as precursor in this study. Due to introduction of the deuterium in CN_X coating, gaseous products derived from the coating can be distinguished from that derived from organic contaminants on the surface. The ball-on-disk friction tests are conducted in vacuum chamber with a quadrupole mass spectrometer [3]. The chamber is subsequently evacuated to a stable pressure of less than $5x10^{-4}$ Pa. The rotation speed and applied load are 60 rpm and 1.0 N, respectively.

Fig. 1 shows friction property of CN_X/CN_X:D in vacuum and the ion intensities of gaseous products (m/e=4 (D_2^+), 16 (CH_2D^+), 30 ($C_2D_3^+$ or $C_2H_4D^+$ or $C_2H_6^+$), 32 ($C_2H_2D_3^+$), 19 (NHD_2^+)) generated from the frictional interface. As is clear from Fig. 1, deuterium, deuterated-carbons, and deuterated-ammonia are generated when CN_X/CN_X:D shows relatively low friction coefficient. On the other hand, when the friction coefficient of CN_X/CN_X:D increases, the ion intensities of deuterium (m/e=4), deuterated-methane (m/e=16) and deuterated-ammonia (m/e=19) increase although the ion intensities of deuterated-ethane (m/e=30, 32) decrease. These data indicate that the deuterium inside the CN_X:D coating tribochemically reacts with carbon and nitrogen atoms, which desorb from the interface when they show relatively low friction.

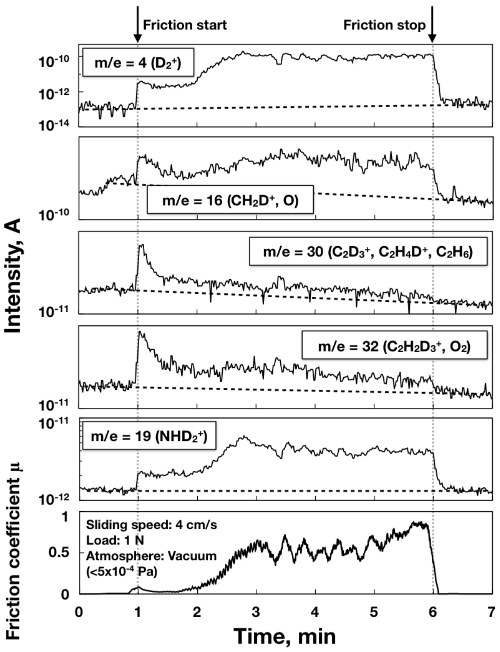

Fig.1. Friction property of CN_X/CN_X:D in vacuum and variation in the ion intensities of gaseous products

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This research was supported by CREST, JST.

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TOF-SIMS ANALYSIS OF DEUTERIUM DISSOLVED INTO BEARING STEEL DURING LUBRICATION TEST -EFFECT OF ADDITIVE-

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KEYWORDS
bearing ; steel; fatigue life; deuterium; TOF-SIMS

ABSTRACT

The effect of additives on a fatigue flaking life under EHL condition was investigated using a four ball tester[1] as shown in Fig. 1. The conditions of lubrication test were also shown in Fig.1. Fatigue flaking was accelerated by the effect of hydrogen in atmosphere. Lubrication tests were carried out with lubricant oil of PAO (poly-α-olefin, kinematic viscosity: 394 mm^2/s) under the atmosphere of deuterium gas which was used as a tracer for detection of D dissolved in steel by TOF-SIMS(Time of Flight-Secondary Ion Mass Spectrometry). A shorter fatigue life was observed under D_2 atmosphere. After lubrication tests deuterium was detected on the friction track of the lubricated upper-ball by TOF-SIMS[2]. It was found by TOF-SIMS analysis of the cross-section of the upper-steel ball that deuterium diffused into steel even at 300μm underneath of friction track, when lubricant oil without additive was used for the test.

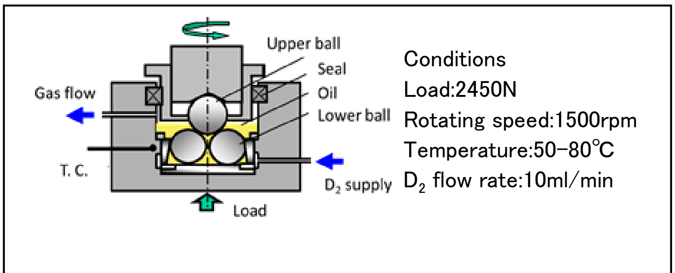

Fig.1 Four ball tester under D_2 atmosphere

Longer fatigue life was observed even under H_2 atmosphere when $NaNO_2$ was used as an additive[3]. TOF-SIMS analysis of the cross section of the tested ball with the lubricant containing $NaNO_2$ under D_2 atmosphere revealed that no deuterium was detected in steel. This suggests that $NaNO_2$ can prevent dissolution of deuterium into steel during the lubrication test even under D_2 atmosphere. It can be concluded that TOF-SIMS analysis with D_2 as a tracer can be a powerful method to investigate the effect of hydrogen and the effect of additives on fatigue life of steel.

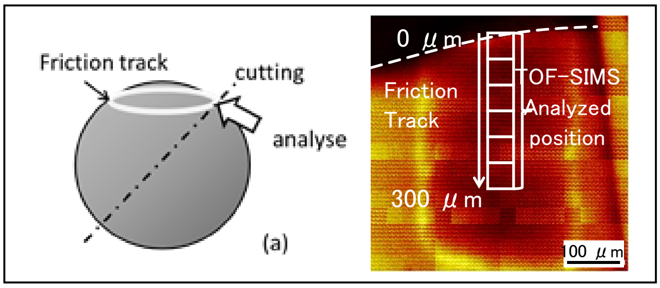

Fig.2 Sample preparation(a) and the analyzed position and region of TOF-SIMS analysis(b)

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ADSORBED FILM STRUCTURE OF AQUEOUS COPOLYMER LUBRICANTS CONFINED BETWEEN HYDRATED AND UNHYDRATED TiO_2 SURFACES

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KEYWORDS

Triblock copolymers; aqueous lubricants; thin film lubrication

ABSTRACT

Hydrocarbon based lubricants have demonstrated an impressive tribological performance in rolling. However, their surface cleanliness is poor due to lubricant residues remaining on the strip surface after rolling process. Aqueous copolymer lubricant has been a new potential lubricant that replaces oil emulsion. This lubricant has been used widely in metalworking operations as it satisfies the product surface quality, environmental and economic requirements. Many experimental studies have shown that the lubrication and antiwear properties could be significantly improved by introducing triblock copolymers to aqueous solution [1-3]. The adsorbed film structure on metal/metal oxide surface observed from experiment has driven an effort to study the behavior of triblock copolymers under confided condition.

Molecular dynamics (MD) simulation has been carried out to investigate the adsorbed film structure at atomic scale. The obtained theoretical results show that the PPO segments anchor onto T_iO_2 surface whilst the hydrophilic PEO segments extend away from the surface. The influence of surface property is also considered by including hydroxyl (OH) terminal group caped on T_iO_2 surface. The presence of OH group on the surface has resulted in a change in molecular structure of adsorbed film of copolymer in a manner that a weaker adsorption of PPO segments has been found. Additionally, at 2% of copolymer in aqueous solution, a buoy–anchor–buoy molecular structure has been observed for normal Pluronic (L62 and L64), whilst an anchor–buoy–anchor is found for reverse Pluronic (17R2, 17R4, and 25R2). At higher concentration (16%), a protective adsorbed film of copolymer has been observed on T_iO_2 surface, which is validated by experimental study by Lin et al. [1]. This adsorbed film has improved the tribological performance of tribo-system. Furthermore, the friction level is comparable with oil emulsion lubricants.

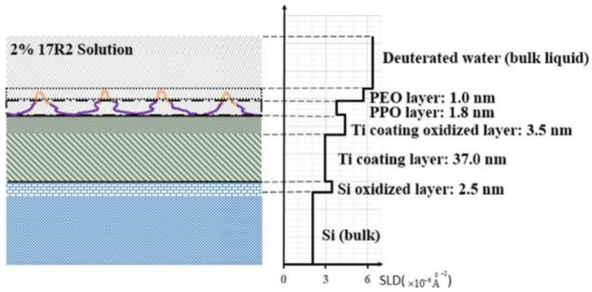

Figure 1 Adsorbed17R2 film thickness proposed adsorption model by Lin et al. [1].

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THE EFFECT OF MOLECULAR STRUCTURE ON FLOW IN AN ELASTOHYDRODYNAMIC CONTACT

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KEYWORDS
High-pressure rheology, elastohydrodynamic lubrication, lubricant flow, fluorescence spectroscopy

ABSTRACT
In non-conformal engineering contacts under high-pressure and high-shear, the rheological response of a thin film of lubricant may reveal non-Newtonian characteristics. Assumptions of a linear velocity profile and spatial homogeneity may be invalid [1]. An inaccurate description of the flow limits our understanding of lubricant behaviour, affecting our ability to theorize novel ways of controlling friction. The rheological behaviour will be dependent on the chemical makeup of the lubricant itself. It is therefore critical to gain an understanding of the rheology at a molecular level, considering the chemical structure of the lubricant.

In previous research, local through-thickness velocity profiles have been determined using molecular phosphorescence imaging velocimetry (mPIV) [2]. The technique exposes a lubricant doped with phosphorescence dye to a short laser pulse creating a tagged phosphorescence column. The spatiotemporal evolution of the phosphorescence emission is then captured using an intensified charge-coupled device. The experimental intensity distribution is simulated against an iterative numerical reconstructive scheme to determine the flow profile. The technique can predict shear localisation in elastohydrodynamic contacts to identify non-Newtonian phenomena such as shear banding. In the past, testing has been limited to high shear rates at slide to roll ratios above 50%. Therefore the resolution of the technique has been modified to test a broader range of conditions and limit any effect of shear heating on rheological measurements.

In this work rheological measurements of traction fluids under confinement are presented using mPIV. Comparisons will be made between different chemical structures of base stocks and their subsequent rheological response in high-shear environments.The effect of pressure on through-thickness velocity profiles will be investigated. Finally the frictional response is analysed as an overall goal to improve efficiency of mechanical systems.

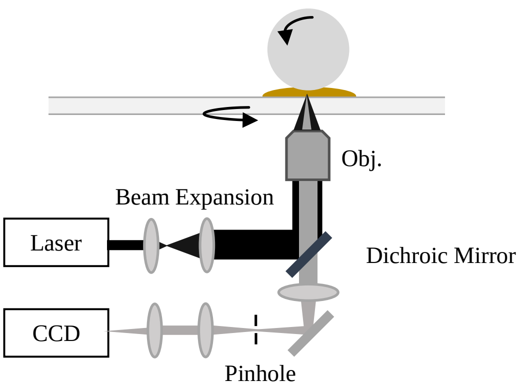

Figure 1- Schematic of mPIV technique

ACKNOWLEDGEMENTS
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IONIC LIQUIDS UNDER CONFINEMENT: THE ROLE OF ANISOTROPY ON FRICTIONAL PERFORMANCE

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KEYWORDS
Ionic Liquid; Confinement; Molecular Dynamics

ABSTRACT

Understanding the lubrication mechanisms in engineering systems is important for developing new concepts that can reduce friction. Such an interesting research topic is the use of Ionic Liquids (ILs) for lubrication, which has been shown to have a positive impact on friction loss reduction.

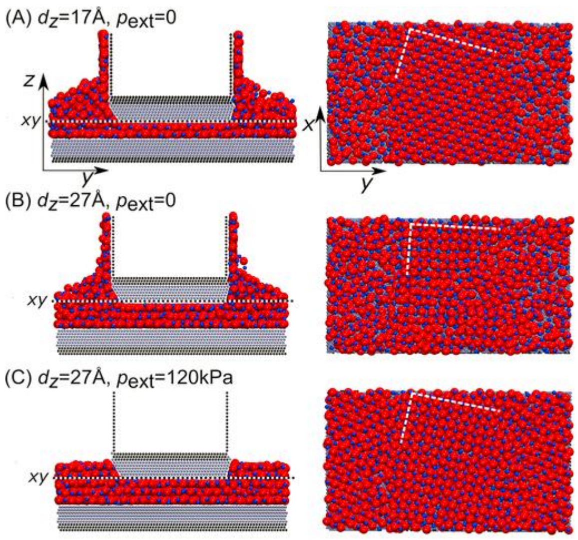

Fig.1 Side (yz) and top (xy) views of snapshots of MD simulations of IL under confined shearing.

Recent results from Molecular Dynamics simulations of IL lubrication [1] have shown the impact of confinement resulting in IL layering and solidification under high pressure. As shown in Fig. 1, layered ordering is observed in the transverse direction, while crystalline structures can be observed in the lateral direction, consistent with results known in literature [2, 3, 4].

In the current work we attempt to quantify the role of such anisotropy on the tribological properties of ILs. We employ equilibrium and non-equilibrium MD simulations of coarse grain IL molecules and correlate the ordering of bulk and confined liquids with their frictional behavior. The solidification of the liquid under isotropic and anisotropic loading is a topic of special interest and will be studied in detail.

We expect that the deep insight of such fundamental processes through the use of numerical methods, should result in more accurate description of the underlying physico-chemical mechanisms that control lubrication and guide us towards developing optimal engineering concepts.

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SLIPPING ZONES IN MICROSYSTEMS FOR IMPROVED LOAD SUPPORT

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KEYWORDS
Wall slip, Load carrying capacity, MEMS

ABSTRACT

Wall slip at surface-fluid interfaces is often quoted as a way to achieve better performance in micro- and nanoscale systems. Potential benefits involve improved fluid transport and reduced friction in nanochannels [1-3]. In addition, introducing slipping zones of the surfaces in tribological contacts can increase significantly the load carrying capacity [4,5]. This can reduce wear, which is a critical issue in MEMS. Here, slip can be created by modifying the roughness and chemistry of the surfaces [2,3], for instance through oleophobic coatings.

We consider nano- and microsystems, where a single slipping zone is placed between positions x_1 and x_2 in different contact geometries of length L and ratio h_1/h_2 between inlet and outlet film thicknesses (Figure 1a).

Of interest is the optimal positioning of the slipping zone to maximize load support. The standard Reynolds formulation with the addition of a slip length b on the upper surface is employed. This is similar to the methodology in [4], and is valid for nanometer-thin films [5]. An analytical solution based on a flow analysis is proposed to calculate the pressure distribution P and line load $W1$ form P_0 and $W1_0$ of the no-slip case. Parametric studies on the convergence ratio h_1/h_2 and slip length b are then performed. It is found that:

- For low surface slopes, the optimum slipping region starts from the trailing edge and extends approximately towards the middle of the convergent geometry (Figure 1b).
- For high surface slopes, the optimum patch must be moved towards the end of the contact. Placing the slipping zone at the inlet has a negative effect on the load carrying capacity.
- Increasing the slip length results in a slightly broader optimum slipping patch.
- The extent of the optimum slipping zone can be explained from the maximization of inlet flow and minimization of outlet flow. This leads to a simple model for quick estimation of the limits of the slipping region (Figure 1b).
- For large slip length (b/h_2>1), the maximum load carrying capacity is achieved with flat surfaces (Figure 1c). For small b/h_2 the surface should be slightly slanted, since the convergent geometry also plays a role on pressure generation in the contact.

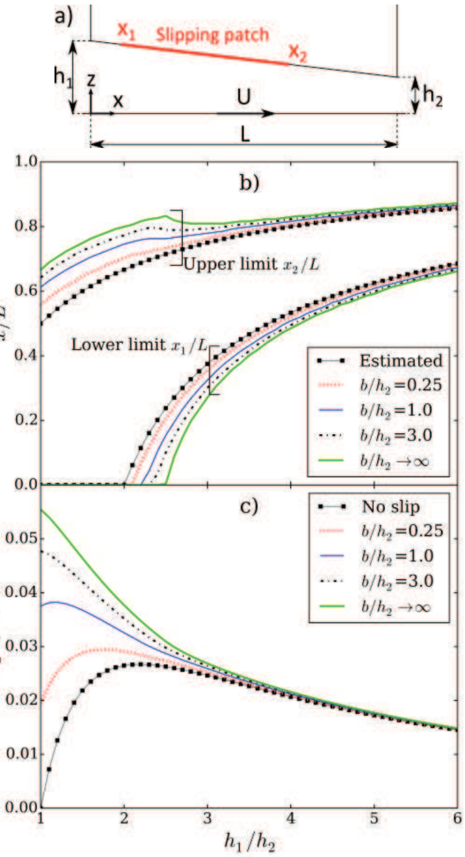

Fig.1 a) Slider of length L and convergence ratio h_1/h_2 with slip patch. b) Lower and upper bounds x_1, x_2 for the optimum zone with constant slip length b. c) Dimensionless line load.

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RATE- AND STATE-DEPENDENT FRICTION MODEL FOR RUBBER-METAL CONTACT BASED ON THE ELASTOPLASTIC FORMULATION

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KEYWORDS
Friction model; rate-dependency; pressure-dependency, rubber

ABSTRACT

It is widely known that a rubber friction shows not only a rate- and state-dependency but also a pressure-dependency, which is induced by surface roughness [1]. A friction model capable of properly describing above-mentioned dependency is an essential to conduct numerical simulations of frictional contact boundary value problems. One of authors has been proposed the rate- and state-dependent friction model based on the elastoplastic analogy formulation [2]. In addition, its validity was also verified by comparing with experiments [2]. In the formulation, however, Coulomb's frictional criterion, i.e. the constant friction coefficient, was adopted, and thus, the pressure-dependency cannot be described.

In this study, we propose the rate- and state-dependent friction model based on the elastoplastic formulation, in which the pressure-dependent frictional criterion is incorporated. In the formulation, we also prescribe evolution rules for microscopic sliding and rate-dependency. Furthermore, to demonstrate the validity of proposed model, we compare frictional responses with the experiment of sliding contact between rough rubber surface and rigid smooth plane [1].

In the formulation, we focus on only an adhesion friction. Then, we assume the isotropic sliding surface in traction space (frictional criterion) as follows:

$$\| \mathbf{f}_t \| = \tau S_r (\| \mathbf{f}_n \|, \| \bar{\mathbf{u}}^p \|, \phi), \tag{1}$$

where $\mathbf{f}_t$, τ and S_r are the tangential traction vector, the shear stress of adhesion and the ratio of real contact area to the apparent contact area, respectively. As shown in Eq.(1), S_r is the function of $\mathbf{f}_n$, $\bar{\mathbf{u}}^p$ and ϕ. Here, $\mathbf{f}_n$ is the normal traction vector, $\bar{\mathbf{u}}^p$ is the plastic (nonreversible) sliding displacement, and ϕ is the state variable (, which corresponds to time). To describe the microscopic sliding due to the change of traction inside the sliding surface, we adopt the concept of unconventional plasticity [2] and incorporate the subloading-sliding surface as follows:

$$\| \mathbf{f}_t \| = R \tau S_r (\| \mathbf{f}_n \|, \| \bar{\mathbf{u}}^p \|, \phi), \tag{2}$$

where $R\ (0 \le R \le 1)$ is called the normal-sliding ratio.

Figure 1 shows variation of friction force with elapsed time under several normal load conditions. It is confirmed that the pressure-dependency of friction can be described by the present model.

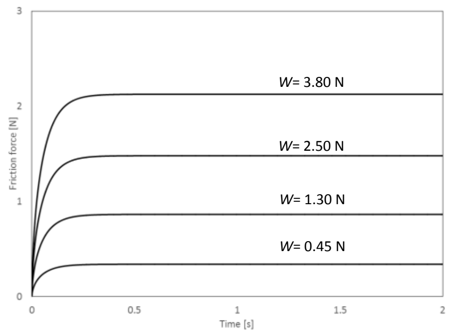

Fig.1 Time changes in friction force (pressure-dependency).

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TRIBOCHEMICAL REACTION OF SODIUM POLYPHOSPHATE ON IRON OXIDE SURFACE IN METAL FORMING

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KEYWORDS
Inorganic glass lubricant; tribochemistry; adaptive tribofilm;

ABSTRACT
An appropriate lubricant is necessary in a hot metal manufacturing process due to negative effects at elevated temperature such as enormous friction, considerable wear and severe oxidation. Currently, zinc diakyldithiophosphate (ZDDP) is the most successful lubricant additive which can form an antiwear polyphosphate film on the interface between metallic surface and lubricant. In the effort of designing a new lubricant which can withstand high pressure and elevated temperature for hot rolling of steel, the studies of alkali polyphosphate have been conducted. With good antiwear property, friction reduction in harsh condition and being an environmentally friendly lubricant, inorganic polyphosphate glass is considered to be a candidate to replace ZDDP for high-temperature tribological applications [1]. In previous studies, the polyphosphate film has been observed after tribological process with layered structure and gradient composition. The digestion of iron oxide into polyphosphate film which shortens the polymer chain has been proven[2, 3]. Even though the experiment studies show some interesting properties of alkali polyphosphate boundary film on elevated temperature interface, the detailed mechanism between them is still unknown due to limitation of analytical method in severe conditions. In this study, a theoretical method has been carried out to understand the behavior of lubricant and surface interaction in atomistic scale.The chemical reaction and adsorption of lubricant on iron oxide surface has been performed on quantum calculation package Dmol^3 with periodic boundaries and GGA PBE functional.The configurations and energies obtained from the simulation have been validated with the experimental and theoretical works of phosphate adsorption on iron oxide surface. Besides literature pre-mentioned Fe-O-P linkage, direct Fe-P bond has been observed in the simulation which achieved as stable energy as the bond through bridging oxygen. The interaction between lubricant and surface through phosphorus or oxygen has proved to be an effective contribution of successful tribological role of alkali polyphosphate in reducing friction and wear.

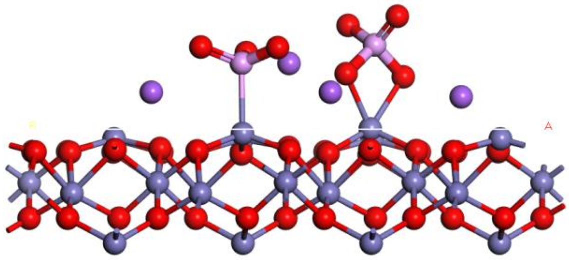

Fig.1 Fragments of tetrasodium pyrophosphate after P-O bond breaking adsorbed on iron oxide surface. The adopted color scheme is: P in pink, O in red, Fe in blue, and Na in purple.

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EFFECT OF SPECIMEN THICKNESS ON GROWTH OF REAL CONTACT AREA OF RUBBER WITH TWO-DIMENSIONAL REGULAR WAVY SURFACE

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ABSTRACT

The effect of the specimen thickness on the growth of the real contact area of silicone rubber with two-dimensional regular wavy surface is investigated. The experimental results indicate that the degree of influence of the specimen thickness is markedly affected by the shape of the valley of the wavy surface and environments under which the tests are conducted.

INTRODUCTION

Soft material like a rubber is easy to approach the complete contact. The authors [1] have shown from their study of the elastic contact of two-dimensional regular wavy surface with a flat surface that the formation of the percolation channels allowing the leakage of fluid and the dependence of the size of the real contact area on the load are markedly affected by the shape of the valley of the wavy surface. Furthermore the real contact area became the crucial factor for the friction force. In this study, the effect of the specimen thickness on the growth of the real contact is investigated form the first touch to the complete contact.

EXPERIMENTAL PROCEDURE

Four types of surface profiles A, B, C and D are formed on blocks of silicone rubber having a shape of quadrangular prism with a base 9 mm×9 mm. The pitch and the maximum height of asperities are 3 mm and 230 μm for specimen A and 1 mm and 75 μm for specimen B, respectively. Specimens C and D have surfaces with the reversed profiles of specimens A and B. The thicknesses of the block specimens are 0.5, 1, 3 and 5 mm. These surfaces of blocks are pressed into the bottom surface of a right angle prism. In order to elucidate the effect of fluid existing between the mated surfaces, the tests are conducted under two kinds of environments, that is, (a) vacuum condition; the test is conducted in decompression environments and (b) wet condition; the gap of two mated surfaces is filled with water before experiment.

RESULTS AND DISCUSSION

Figure 1 shows the relation between the real/apparent contact area A_r/A_0 and p of the mean pressure over the whole surface for the specimen D. In the case for the specimen thickness L = 5 mm, all asperities on the contact surface tend to be equally compressed with the load. On the other hand, in the case for L = 0.5 mm, the asperities are compressed from the center of the contact surface toward its periphery. In this case, the rate of increase in the real contact area shows sharp drop after the asperities in central part are flattened. When the gap of two mated surfaces is filled with water, the real contact area keeps almost the constant value after each contact spot touches the neighbors irrespective of the specimen thickness, as the coalescence of contact spots, which is resulting in the extinction of the percolation channels allowing the leakage of fluid, occurs before the influence of the specimen thickness appears in the contact area. The results of specimen C show almost the same aspect as those of specimen D.

On the other hand, in the cases of specimens A and B with V-shaped trough, the percolation channels could be hardly extinguished. In this case, not only the fluid between mated surfaces but also the specimen thickness has a little influence on the growth of the real contact area.

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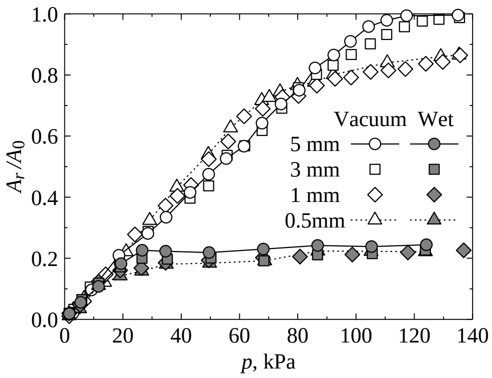

Fig. 1 Relation between A_r/A_0 and p for speimen D

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Tribological properties of Ni-based composite coatings containing silver vanadate at elevated temperatures

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KEYWORDS

Silver vanadate; Solid lubricant; Composite coating

ABSTRACT

The preparation method of Ni-based composite coatings containing silver vanadate and its tribological properties at room temperature to high temperature were studied.The silver vanadate particles were prepared by chemical method and were observed by scanning electron microscope (SEM). The silver-vanadate containing nickel-based composite coatings were prepared by thepulse electrodeposition process. The phase compositionswere analyzedby using X ray diffraction (XRD), energy dispersive spectroscopy (EDS) and Raman spectroscopy. The tribological properties of the coating were tested by HT-1000 high temperature friction tester at room temperature, 200℃ and 600℃. The effects of different content of silver vanadate additives and temperature on the tribological properties of the composite coatings were compared in order to obtain the best technological parameters of silver-vanadate containing nickel-based composite coating.The morphology of wear scars after friction were analyzed by using scanning electron microscopy (SEM) with silver vanadate as a self lubricating material feasibility..The results show that the friction coefficient of single Ni-based coating is about 0.75, while that of the composite coating is between 0.4-0.7. Especially at high

temperature, the antiwear effect is obvious. The results shows that the composite coating containing silver vanadate has better antiwear and lubrication effect than pure nickel base coating, and the friction reducing effect increases with the addition of silver vanadate within a certain content range.

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EVALUATION AND IMPROVEMENT OF CAVITATION EROSION BEHAVIOUR OF DIFFERENT STEELS IN SALTWATER USING ELECTROCHEMICAL METHODS

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KEYWORDS

Tribological performance evaluation and rating
cavitation erosion; wear-corrosion synergy; in-situ wear evolution; electrochemical calculation

ABSTRACT

Cavitation is caused by rapid movement of objects in a fluid. The resulting steam bubbles are entrained by the flowing fluid and collapse in a sudden manner with increasing static pressure [1]. This results in extreme pressure and temperature peaks, which leads to massive damage and removal of the so-called cavitation erosion on surfaces. This occurs, for example, frequently in rotors of centrifugal pumps, water turbines, as well as in control valves and in motors. Furthermore, cavitation can cause noise, vibration, and loss of energy efficiency. Due to the resulting enormous economic effects, an intensive examination of the cavitation erosion is necessary. Current research focusses on the examination of the synergetic mechanisms of mechanical damage and corrosion [2].

Therefore the aim of this thesis consists in the characterization of these synergetic damage mechanisms and the quantification of static and dynamic corrosion processes during cavitation erosion with different steels using electrochemical methods [3]. For this purpose the electrochemical behavior of the different steels was investigated and the cavitation wear was influenced by the use of electrochemical methods.

At the beginning of the work an electrically insulated 3-electrode cavitation test setup was constructed, manufactured and assembled. The static and dynamic corrosion mechanisms in seawater were determined by the measurement of electrochemical characteristics. The cavitation behavior was analyzed by means of indirect cavitation experiments using a sonotrode. On the one hand, by combining these experiments with electrochemical methods, the different damage mechanisms could be quantified and identified. On the other hand, it has been demonstrated that the removal of material by the application of externally induced cathodic potentials can be enormously reduced (Fig. 1). In addition, the damage mechanisms of the different steels were identified by various wear and surface analyzes.

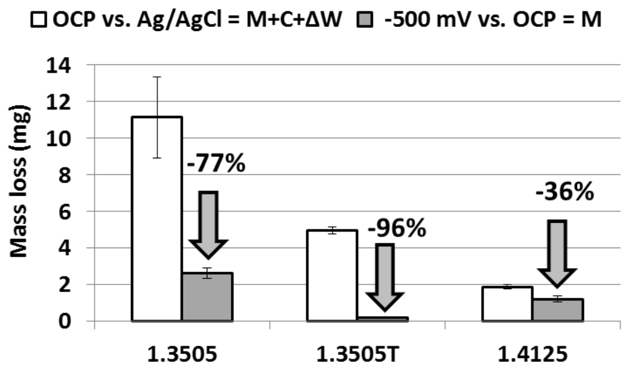

Fig.1 Comparison of material loss at open circuit potential (OCP) and at cathodic potential (-500 mV vs. OCP)

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EFFECT OF MATING MATERIAL ON FRICTION AND WEAR PROPERTIES OF a-C:H DLC IN BOUNDARY BASE OIL LUBRICATION

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KEYWORDS
DLC, Friction, Wear, Carbon diffusion, ToF SIMS, XPS

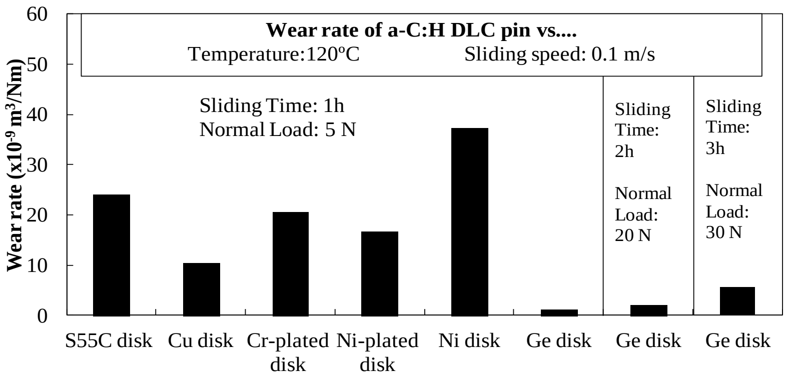
ABSTRACT

Increasing energy demand of the human society is a serious concern on sustainability of the Earth's ecology due to environment pollution and global warming. Diamond like carbon (DLC) hard coatings are being researched about extensively for decades now, as a solution for reducing energy consumption in modern industry, due to their mechanical and tribological properties, in order to understand those properties, and related mechanisms[2]. Literature broadly reported about ultra-low friction coefficient in boundary lubrication with DLC coatings, and also about a large number of wear mechanisms to occur in a DLC coating involved tribosystem. Broadly speaking, these mechanisms can be classified into physical and chemical processes, and the major ones are adhesive wear, abrasive wear, fatigue wear, corrosive wear, or diffusion wear. In most cases, and depending of involved material, several wear mechanisms occur simultaneously, and it is difficult to ascertain specific proportional contributions to wear from different mechanisms [1-3]. In light of the current state of research about DLC coatings, several questions remain unanswered:

Evaluate the FRICTION & WEAR behaviors of DLC coatings against different materials,

- How DLC coatings display different friction coefficient against different counterpart materials and what factors are related to the low friction mechanism.
- What factor characterize the low friction coefficient of DLC coatings in pure PAO oil or with additive.
- Wear mechanism and related factors of DLC coating
- Why does DLC coatings show lower wear rate against some mating materials than others
- Why does DLC coatings hardly wear against some mating materials than others
- What are the best mating materials for DLC coatings in boundary base oil lubrication.

Thus in our research we will try to give answers and explanations to above mentioned questions, by characterizing friction and wear behaviors of a-C:H DLC coating against various materials, in order to classify selected materials according to tribological behaviors that a-C:H DLC coating exhibit when they are involve with in a tribosystem. First results reveal that a-C:H DLC coating show surprisingly low wear rate against one of the chosen counterpart materials as we can observe in the following figure.



By further investigating, we will try elucidate the tribological behaviors of a-C:H DLC coatings form a material to another, especially against germanium (Ge) material, we will try to understand which properties of Ge induce such low wear rate of a-C:H DLC film. At the end, we will try to enlighten the scientific and industrial world about materials that are the best counterpart material against selected a-C:H DLC coating, in terms of low friction and wear resistance.

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THERMOMECANICAL STUDY OF HIGH SPEED ROLLING ELEMENT BEARING: A SIMPLIFIED APROACH

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KEYWORDS

Rolling element bearing, Thermal network, Power losses models

ABSTRACT

Rolling element bearing (REB) is an essential component in mechanical transmission because it reduces friction between two rotating parts. Two main approaches to evaluate power losses are proposed in literature: i) global engineering models using few input data[1], [2]; ii) local models which are more accurate but need much more information on REB geometry[3].

In this study, an intermediate model which uses a thermal network method is developed. The main idea is to obtain lumped information (temperature of REB's components and power losses) with a minimum of input data (external geometry only). The power losses are not calculated for each contact but by using global power losses models. Influences of geometrical estimation and power loss models used on the REB thermal behavior are studied. The research work is divided into parts:

In the **first part** the simplified thermal network[4] developed by Neurouth et al[5] is adapted for an angular contact ball bearing under oil-jet lubrication in high speed application. This thermal network allows an estimation of REB rings' temperatures. Figure 1 shows the power losses calculated in the thermal network. It underlines that Harris' model underestimates the power losses. Nevertheless, Harris' model combined with drag loss estimation provides accurate results. It can be noted that these values are calculated at the ring temperature estimated through the thermal network.

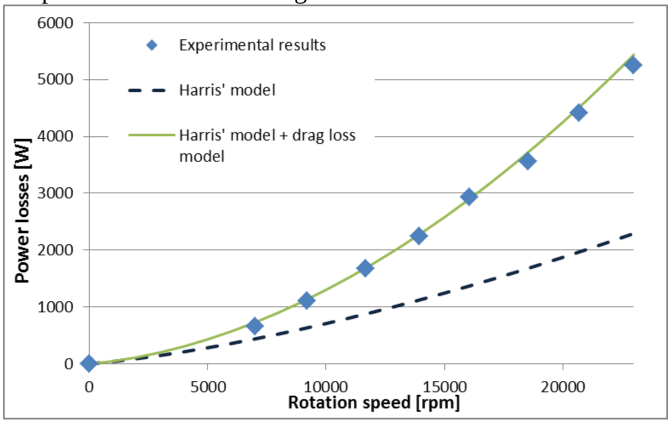

Figure 1: comparison between power losses models and experimental

In the second part, the thermal network developed in the first part is used with a limited input data. It means that the input parameters provide only from REB manufacturers' catalogues. Therefore the REB's internal geometry (ball diameter, Raceway groove curvature etc.) have to be estimated.

Internal geometry estimation leads to a slightly modification of temperatures calculated (Figure 2) and power losses.

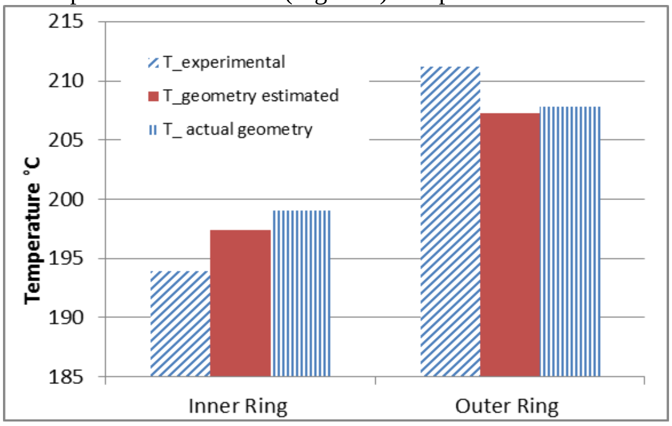

Figure 2: evolution of temperature depends on the geometrical estimation

To conclude, this new approach estimates the REB's thermomechanical behavior with a limited number of input data and by using global power losses models.

ACKNOWLEDGEMENT

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NUMERICAL AND EXPERIMENTAL INVESTIGATION OF SURFACE TEXURES

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INTRODUCTION

In recent years, surface texturing was found to have beneficial effects on the performances of lubricated surfaces[1]. However, under certain operating condition, surface texturing may also have a detrimental influence on the friction coefficient. The present work, which combines experimental and numerical approaches, aims at shedding light into the underlying physical mechanisms of friction variation with surface textures.

Surface textures; pattern orientation; Reynolds equation

EXPERIMENTAL SETUP

The experimental approach is based on a pin on disc configuration[2]. It reveals that surface patterns that might lead to a significant reduction of the friction coefficient in one case do not yield beneficial behavior under different operating conditions. Figure 1 shows one example where the optimal texture shape for a certain temperature becomes less effective when the operating conditions change.

NUMERICAL ANALYSIS

The numerical approach is based on the Reynolds equations. In a first step the validity of the Reynolds equations for the film flow over circular dimples as used in the experimental study is thoroughly analyzed in comparison to results of full Navier-Stockes simulations. Since this check reveals that the Reynolds equations in which nonlinear effect are taken into account through the model proposed by Arghir *et al.*[3] yields reasonable results, simulations that resemble the experimental pin-on-disc scenario are set up. The macroscopic pin geometry measured in the experiment reveals a non-uniform gap height between pin and flat surface. The numerical finite volume mesh is set up in such a way that the same dimple shapes and patterns are reproduced as in the experiment. Cavitation and compressibility effects will be subsequently considered[4].

RESULT AND CONCLUSION

The numerical results confirm the experimentally observed trend that an optimal dimple diameter appears to exist for different operating conditions. In addition, the experimentally observed trend that different sliding directions for non-symmetrical dimple arrangements yield different results in terms of the friction coefficient is also found numerically. The fact that the numerical model is able to capture the experimentally observed trends correctly suggests that the model can capture the underlying flow physics. Therefore, the conference presentation will focus on the analysis of the generated flow fields.

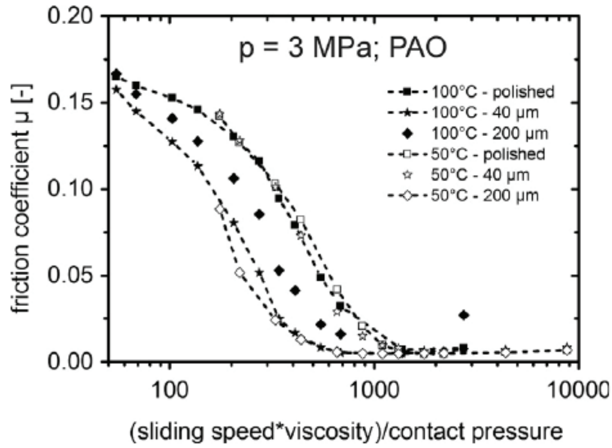

Fig.1 Friction coefficient plotted against the Stribeck parameter for a texture made by dimples with different diameters, from [2]).

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

GENERATION OF ACOUSTIC EMISSION FROM THE RUNNING-IN AND SUBSEQUENT WEAR OF A MIXED-ELASTOHYDRODYNAMIC CONTACT

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KEYWORDS
Acoustic Emission; Running-In; Wear; Mixed Lubrication

ABSTRACT
There is currently considerable interest in using Acoustic Emission (AE) to measure the contact conditions in the critical components of rotating machinery. Researchers [1] have shown that asperity interaction between their contacting surfaces is a source of AE. However there have been few attempts to describe the change in AE response as the surface changes.

The paper presents the AE response from the running-in and subsequent micro-pitting fatigue test of an elastohydrodynamic contact operating in the mixed lubrication regime, between two axially ground disks. The contact pressure, slide to roll ratio, rotational speed and oil supply temperature were kept constant throughout the experiment. The experiment was paused at various intervals so the surface roughness profiles could be measured. Figure 1 shows the AE results from the initial run-in of 3000 cycles (~3 min) and a subsequent 3000 cycles. At the start of the test the AE drops and then stabilises extremely rapidly. This is attributed to a decrease in surface roughness as a result of load induced plastic deformation of asperities. The AE results confirm the hypothesis that this type of surface modification occurs almost instantaneously upon first loading. After the first 3000 cycles the test was paused for a surface roughness measurement then restarted. The re-starting response, noticeably different from the first, is due to the reduced initial disk temperatures at restart and consequent increased viscosity and film thickness.

Figure 2 shows the AE results from the micro-pitting fatigue test which ran for 2.5 million cycles (~ 42 hrs). There is a significant, comparatively slow, decrease in AE over the duration of the test indicating continual but decreasing surface wear. Micro-pitting was observed after the first 100,000 cycles however there was no significant change in the surface roughness (R_q) over the test. It is hypothesised that the AE response is due to a self-limiting wear regime. In this, only a small proportion of prominent asperities interact and these generate the bulk of the AE signal. As they are worn by micro-wear mechanisms the contact pressure is redistributed more evenly and the AE reduces. The R_q value is unaffected as only a tiny proportion of the surface is being modified.

The results presented in this paper show that AE is extremely sensitive to modification of surface asperities and has great potential for use in monitoring running-in and wear regimes.

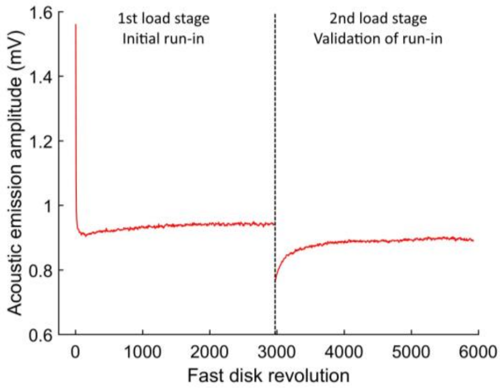

Figure 1. Initial running-in of disk set. Showing the mean Acoustic Emission band-passed between 150 - 300 kHz.

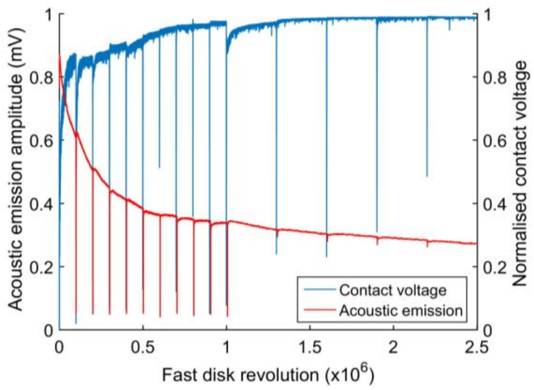

Figure 2. Micro-pitting fatigue test. Showing the mean Acoustic Emission band-passed between 150 - 300 kHz and the contact voltage for comparison. The spikes are transients due to pauses for surface measurement.

ACKNOWLEDGMENTS
EPSRC Grant references EP/L021757/1, and EP/K031635/1 supported this work in part.

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

LUBRICATION WITH HIGH-VISCOSITY LUBRICANTS: SIMULATIONS AND EXPERIMENTS.

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KEYWORDS
Molecular Dynamics; Hydrocarbons; Friction; Silicone oils; High viscosity

ABSTRACT

We have simulated the friction of hydrocarbons with lengths from 20 to 1400 carbon atoms by Molecular Dynamics [1-4].

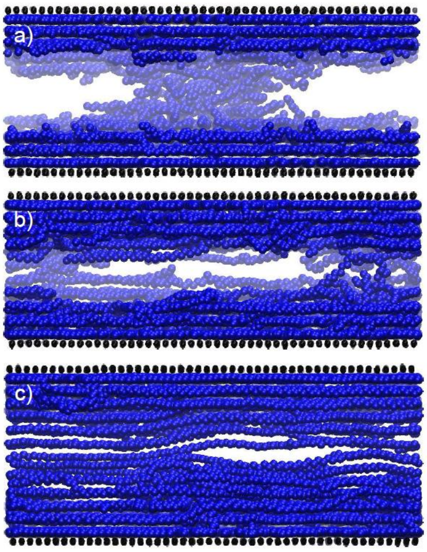

Fig.1. Snapshots of the films of a) $C_{20}H_{42}$, b) $C_{100}H_{202}$ and c) $C_{1400}H_{2802}$. The sliding velocities are 100 m/s and 1 m/s in the x and z directions respectively. The surfaces have been separated by about 2 nm. From [4].

We found that the shortest ones act as liquids forming capillary bridges. See figure 1 a). As the length of the molecules increases the interface in the polymer slab becomes more defined finishing by a distinct cut as indicated by figure 1 c). As the molecules become longer the friction also obeys the laws of Amontons [1] and Coulomb [2]. At the same time the equations describing the flow also show a decreased tendency of the polymers to melt as the length of the molecules increases (and so does the viscosity) [3]. The outcome of the simulations showed that the friction decreases with increasing polymer viscosity and the behavior becomes more Amontons-like. One of us (IMS) has conducted experiments using silicone oils with viscosities from 100 cSt to millions of cSt. They showed the same trend as the simulations where high-viscosity oils obeyed the laws of Amontons and Coulomb. The main result being a lower friction than the lower viscosity liquid-like oils. This indicates that it is possible to make a cheap low-friction coating of high-viscosity silicone oil that also migrates less because of the very long molecules.

ACKNOWLEDGMENTS

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NUMERICAL INVESTIGATION OF THE INTERACTION OF AN ULTRASONIC WAVE WITH A DISCOUNTINUOUS CONTACT INTERFACE

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KEYWORDS

Numerical modelling; wave propagation; ultrasound; rough contacts; contact stiffness

ABSTRACT

When two surfaces are brought into contact and slide against each other, junctions are formed at the interface. The dynamics of formation rupture and evolution of these junctions governs the tribological response of the macro-contact. Getting insight on the real-time behaviour of these junctions is a challenging task.

Ultrasonic wave propagation is a phenomenon that has been already widely used in non-destructive techniques or medical imaging. When an acoustic wave reaches some interface or other, it can be partially transmitted or partially reflected depending on the nature of this interface and the properties of the bodies in contact. An application in tribology appears promising as this technique may be used to investigate, in-situ and in real-time, the interaction between the surfaces in contact [1-3].

This work addresses the understanding of the wave propagation, reflection and transmission through the interface by means of a numerical model. Pulse echo method of a 9MHz ultrasonic pulse is followed on two aluminum bodies to record the transmitted through and reflected back signals from the contact interface. Reflection and transmission were both analyzed as a function of local interface parameters such as number, shape of asperities in contact, contact ratio etc.(Fig. 1).

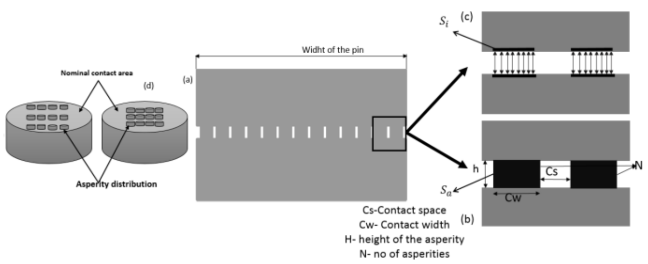

Fig.1 Asperity distribution with interfacial and asperity stiffness representation

Transmission coefficient is for example investigated depending on the contact ratio and number of asperities in contact as shown in Fig. 2. Results from the simulations are first compared to the extensive work performed by Kendall and Tabor [4] and connected to the stiffness relation in multiple contacts. Assumptions made by the authors are especially discussed. The numerical model is then used to investigate the interaction between the ultrasonic wave and the contact interface at the asperity scale. Interesting local diffraction phenomena are especially highlighted.

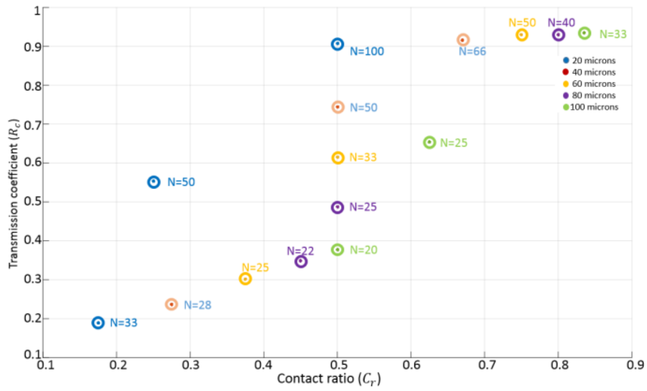

Fig.2 Evolution of the transmission coefficient (Rc) depending on the contact ratio (Cr)

ACKNOWLEDGMENTS

This work was supported by the LABEX MANUTECH-SISE (ANR-10-LABX-0075) of Université de Lyon, within the program "Investissements d'Avenir" (ANR-11-IDEX-0007) operated by the French National Research Agency (ANR).

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A COMPARATIVE STUDY OF THE TRIBOFILMS DERIVED FROM ZDDP AND THIADIAZOLE WITH FOCUS ON THE TRIBOFILM-MICROSTRUCTURE RELATIONSHIP AND ITS IMPACT ON ROUGHNESS

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KEYWORDS
Lubricant additives; Surface structure; Atomic force microscopy

ABSTRACT

Anti-wear (AW) lubricant additives are often used to provide wear protection for hard steels used in tribological applications. Some additives, especially zinc dialkyldithiophosphates (ZDDPs), are known to have a negative impact on the surface roughness due to formation of patchy tribofilms, which is also reflected by an increase in the coefficient of friction [1,2]. A recent study [3] shows that the morphology of ZDDP tribofilm is related to the microstructure of the underlying material. In this work a novel atomic force microscopy (AFM) procedure [4] has been employed to investigate the extent of this relationship on the roughness of the tribofilms and the resultant coefficient of friction. Tribofilms derived from two model lubricants, containing ZDDP and thiadiazole AW additives respectively, on four distinctive martensitic steel grades (100Cr6, 440C, M2 and 16MnCr5) have been examined in detail. The results prove that the tribofilm thickness and roughness are correlated for ZDDP tribofilms, but such correlation is not observed for thiadiazole tribofilms. Evidence shows that when the thickness-roughness relationship is accounted for, the ZDDP develops smoother, less fragmented tribofilms on more homogeneous steel grades (100Cr6 and 16MnCr5) than on the high alloyed steels (440C and M2), containing a significant volume fraction of residual carbides. Although the tribofilm-microstructure correlation has also been observed for thiadiazole tribofilms, it this case no measurable impact on the tribofilm roughness or the friction coefficient has been noted.

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THEORETICAL AND EXPERIMENTAL INVESTIGATION OF LASER SURFACE TEXTURING FOR PISTON-RING FRICTION REDUCTION

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KEYWORDS

Friction; Piston Rings; Surface Texturing

ABSTRACT

Friction loss in an internal combustion engine (ICE) is an important factor in determining fuel economy and performance of the vehicle [1-4]. Laser surface texturing (LST) has emerged in recent years as a potential new technology to reduce friction in mechanical components. Surface texture may help improve some key physical characteristics of the hydraulic piston-cylinder interface, such as friction, heat transfer, and adhesion. A theoretical and experimental study is presented to evaluate the effect of laser surface texturing (LST) on friction reduction in piston rings. Several textures are designed, and the oil film pressure distribution and fluid force between the piston and cylinder are calculated. The effect of texture type, aspect ratio, depth to diameter ratio, position of placement, texture density, and distribution were investigated. A texture design optimization procedure for pistons with different geometries and subjected to a wide range of operating conditions are constructed and implemented.

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Friction loss in an internal combustion engine (ICE) is an important factor in determining fuel economy and performance of the vehicle [1-4]. Laser surface texturing (LST) has emerged in recent years as a potential new technology to reduce friction in mechanical components. Surface texture may help improve some key physical characteristics of the hydraulic piston-cylinder interface, such as friction, heat transfer, and adhesion. A theoretical and experimental study is presented to evaluate the effect of laser surface texturing (LST) on friction reduction in piston rings. Several textures are designed, and the oil film pressure distribution and fluid force between the piston and cylinder are calculated. The effect of texture type, aspect ratio, depth to diameter ratio, position of placement, texture density, and distribution were investigated. A texture design optimization procedure for pistons with different geometries and subjected to a wide range of operating conditions are constructed and implemented.

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TRIBOLOGICAL EFFECTS OF THE COMBUSTION CHAMBER PRESSURE ALONG AN EXTENDED ELROD-ADAMS MODEL

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KEYWORDS

Piston rings; combustion chamber pressure; Elrod-Adams model

ABSTRACT

The Piston Ring/Cylinder Liner (PRCL) is a tribological mechanism that have received great deal of attention during the last decades. The source of this attention becomes from the important amount of energy losses due to friction in the PRCL [1]. During the compression stroke, the combustion chamber pressure (CCP) achieves values as high as 100atm. The compression ring is in direct contact with the combustion chamber gas through the gap present between the piston and the cylinder. Thus, when simulating the PRCL including the CCP (which depends on time), the value of the CCP must be imposed as a Dirichlet condition for the pressure on the hydrodynamical model considered.

As mass-conservation is essential when considering the texturization of lubricated mechanisms [2], in this work we extend the Elrod-Adams cavitation model (which is already an extension of the Reynolds Equation) to accommodate non-homogeneous boundary conditions. This is, in the side of the ring in touch with the combustion gas, the boundary condition for pressure is the CCP value, while on the other side we impose 1 atm.

In this work, we compare the friction losses predicted by the proposed extension of the Elrod-Adams model, with those friction losses predicted by a non-mass conservative model, which represents the state-of-the-art when including the CCP as a boundary condition [3].

ACKNOWLEDGMENTS

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SUBSURFACE DYNAMIC RECRYSTALLIZATION DONINATED WEAR MECHANISM OF NANOSTRUCTURED COPPER IN LOW-AMPLITUDE OSCILLATING

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KEYWORDS
Nano-structure; Dynamic recrystallization; Low-amplitude oscillating

ABSTRACT

The increase in hardness of metals induced by grain refinement is of interest from a tribological point of view. Correspondence between the wear resistance of a material and its hardness has been proposed by Archard for a few decades, known as Archard wear equation [1]. This empirical relation suggested that the wear resistance is proportional to a material's hardness. Most of nanostructured metals show an enhanced wear resistance in comparison with their corresponding coarse-grained (CG) counterparts. However, nanostructured metals with high hardness do not always correspond to high wear resistance in some cases [2]. In fact, wear of materials involves many solid state processes, including plastic deformation and microstructure refinement, interactions with the environment, transfer and mechanical mixing, and fracture, etc. Identifying the key important process of wear from other concurrent solid state processes under a certain wear condition is crucial to quantify materials' wear resistance.

Nanostructured materials are structurally characterized by a large volume fraction of grain boundaries, the increased energy associated with increased grain boundary areas makes them have a low thermal stability at lower temperatures. The structural evolution beneath the sliding surface of nanostructured materials might be quite different from that of the CG counterparts. During the wear process, dynamic recrystallization (DRX) and grain growth under the worn surface plays an important role on the wear resistance, as investigated in nanostructured copper and Ni-W [3] when sliding and scratching at dry conditions.

In fact, the correlation between the wear resistance and the worn subsurface structure of nanostructured copper under dry sliding condition has been identified in our previous paper. However, it is well known that the wear resistance of a material is correlated with the wear conditions, such as oscillating amplitude and lubricated conditions. It is necessary to understand the related wear mechanism of nanostructured copper in low-amplitude oscillating process as a special wear mode. Therefore, the tribological behavior and the worn subsurface structure of nanostructured Cu prepared by dynamic plastic deformation (DPD) were investigated when oscillating at a low amplitude under both dry condition and oil lubrication.

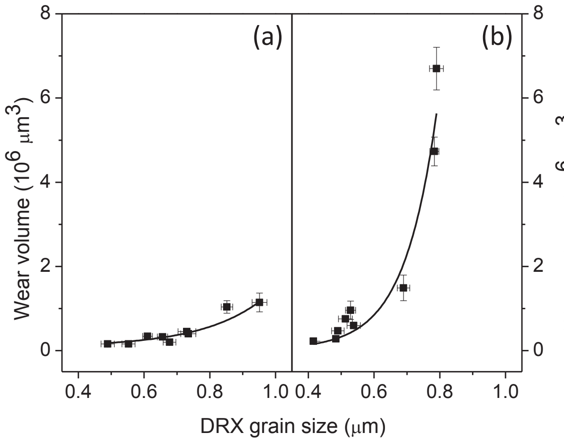

Fig.1 Correlation of the wear volume with the average grain size within DRX layer for DPD Cu sample under (a) oil lubricated and (b) dry conditions

In this investigation, the results indicate that nano-structured copper also exhibits a dynamic recrystallization dominated wear mechanism under both oil-lubricated and dry conditions in low-amplitude oscillating wear. A correlation is identified that wear volume increases obviously with an increasing grain size of DRX structure.

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FUNDAMENTAL TRIBOLOGICAL PROPERTIES OF THICK CPB

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KEYWORDS
Concentrated Polymer Brush; Ionic Liquid; Viscoelastic property

ABSTRACT
Concentrated Polymer Brush (CPB) is an assembly of polymer chains densely end-grafted to the surface. The CPB which swells in a good solvent shows excellent micro-tribological properties such as super lubrication with the extremely low friction coefficient (μ~10^{-4})[1][2]. However, there are few reports about the macro-tribological properties of CPB In this work, the macroscopic tribological properties of CPB of Poly(methyl methacrylate) (PMMA) immersed in the ionic liquid. As for the ionic liquid, *N*,*N*-diethyl-*N*-methyl-*N*-(2-methoxyethyl)ammonium bis (trifluoromethanesulfonyl) imide (DEME-TFSI) was used. DEME-TFSI is the good solvent for PMMA.

The macroscopic tribological properties of CPB on SUJ2 Disk were evaluated using cylinder-on-disk tester and viscoelastic property (tanδ) of CPB were investigated by nano indentation method. As a result of these tests, friction coefficient of CPB have dependence on normal load and sliding speed.

These results show that macroscopic frictional property of CPB have relation to its viscoelastic property.

Table 1 Friction test condition

Normal load	[N]	2, 3, 5, 10, 20
Sliding speed	[mm/s]	1, 2, 3, 4, 5, 10, 15
Sliding distance	[mm]	2000
Stroke	[mm]	5
Lubricant	[μL]	300
Temperature	[℃]	25

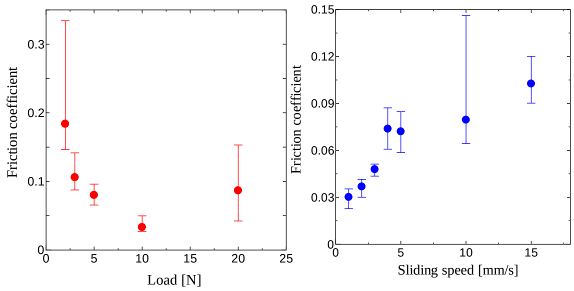

Fig.1 Relationship between friction coefficient and normal load, sliding speed

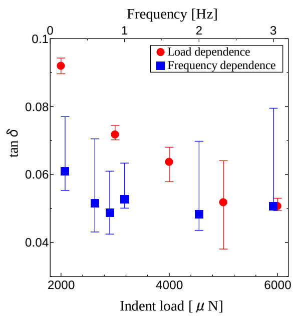

Fig.2 Relationship between tanδ and load, frequency

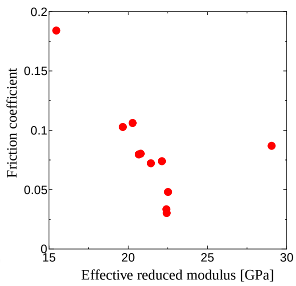

Fig.3 Relationship between friction coefficient and effective reduced modulus

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

Bifunctional tribofilms derived from inorganic borate on heated rubbing interface

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KEYWORDS

Inorganic borate, molten glass lubrication, high temperature tribology.

ABSTRACT

The extreme state of friction, wear and oxidation invariably occurs in the rolling process of steel components, especially at elevated temperatures (800^{o}C). The use of high temperature lubricants to mitigate the aforementioned difficulties will boost process productivity. Most conventional lubricants have failed to perform due to their poor thermal stability. On the other hand, glass lubricants are reportedly quite effective for anti-friction, anti-wear and anti-oxidation behaviors [1, 2].

In this study, tribological responses of alkaline metal borate are evaluated in hot friction testing of steel contact. The generated tribofilm induces a significant reduction in friction coefficient, material loss as well as oxidation. Under tribological exposure, the interaction between lubrication molecules and oxide scale results in the formation of *in-situ* tribo film which accounts for wear and oxidation inhibition. The tribofilm consists of two layers : (i) an upper viscous layer of borate which contributes predominantly to anti-friction function (ii) a lower layer which consists of iron, boron, alkaline and oxygen elements. The two tribochemically-yielded tribo-layers perform complementary functions that enhance the lubrication synergistically. The study indicates boundary/mixed-film regime for glass lubrication where an evolution mechanism of the layered films is also proposed. Multiple surface characterization techniques including AFM, XPS, SIMS and FIB/TEM were employed to provide insights into the structural nature of borate tribofilm.

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FRICTIONAL PROPERTY WITH 3D CAPILLARY STRUCTURED SURFACE BY SELECTIVE LASER MELTING

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KEYWORDS
capillary phenomenon; selective laser melting; seizure

ABSTRACT

In order to improve friction characteristic of sliding surface, it is important to prevent oil starvation. Surface texturing is one of the method to improve friction properties by maintaining lubricant on sliding surface [1]. However, effect of conventional surface texturing has limit to prevent oil starvation under severe condition [2]. In order to improve friction properties, self-oil circulating structure called the 3D capillary structure as shown in Fig. 1 was proposed. The 3D capillary structure can collect excessive lubricant from sliding surface and supply it again into sliding interface by utilizing capillary phenomenon. The 3D capillary structure was manufactured by selective laser melting, because of its complex microstructure.

The 3D capillary structure specimen was made from AISI S17400 powder by a metal 3D printer (ProX 300, 3D Systems USA). In this report, oil circulating function and sliding properties of the 3D capillary structure were investigated. To confirm oil circulating function, sliding test was observed by a video camera. Sliding tests were conducted by cylinder-on-plate type SRV4 sliding tester. The cylinder (ϕ 6 mm × l 8 mm) was made of AISI 52100. In this experiment, non-textured and conventional dimpled specimen's as shown in Fig. 2 anti-seizure property of the 3D capillary structure was assessed by comparing.

Experimented results showed that the 3D capillary structure exhibits oil circulating function and improves anti-seizure properties. It is suggested that the 3D capillary structure has a potential to improve anti-seizure property.

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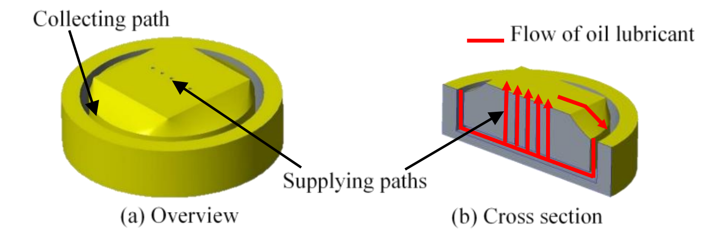

Fig. 1 Schematic diagram of the specimen with the 3D capillary structure

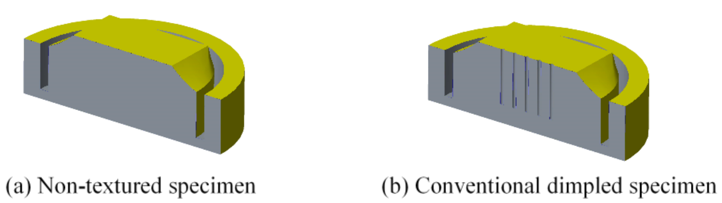

Fig. 2 Schematic diagram of test specimens

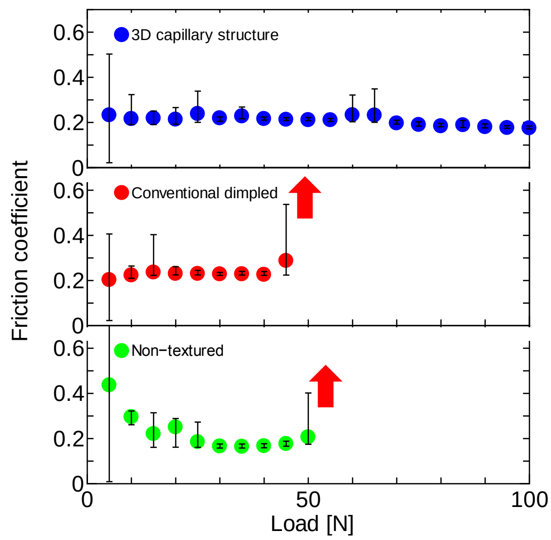

Fig. 3 Frictional behavior of textured specimens

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EFFECT OF SURFACE TEXTURE ON FRICTION ANISOTROPY UNDER BOUNDARY LUBRICAION

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KEYWORDS
CVT; surface texture; friction anisotropy

ABSTRACT

To further reduce fuel consumption and emission of vehicles, continuously variable transmission (CVT) is commonly used in automobile. CVT consists of a belt clamped between two pulleys, which enables continuous ratio change under load. Apart from seamless ratio change, CVT allows internal combustion engine to operate at much efficient engine rotational speed independently from vehicle speed, therefore reducing fuel consumption and emission [1]. However, efficiency of CVT itself can be improved [2]. Low friction can reduce loss when sliding belt in the radial direction of the pulley, but causes slip in the circumferential direction. In this study, relationship between surface texture and friction anisotropy was investigated to improve tribological properties of pulley surface.

To investigate the relationship of surface texture and friction anisotropy under boundary lubrication, cylinder-on-disk type sliding test was conducted. The sliding test was conducted in four different directions, parallel, thirty degrees, sixty degrees, and perpendicular to the direction of the surface texture.

The experimental results show that the friction anisotropy was generated under boundary lubrication. The results also suggest that different texture patterns, which increase or decrease contact area within sliding surface, have an effect on both generation of friction anisotropy and friction coefficient.

Table 1 Dimension properties of simulation

Normal Load	[N]	20
Stroke	[mm]	10
Speed	[mm/s]	20
Lubricant	[µL]	100
Temparature	[℃]	80
Cycle		500
Lubricating oil		CVTF NS-3

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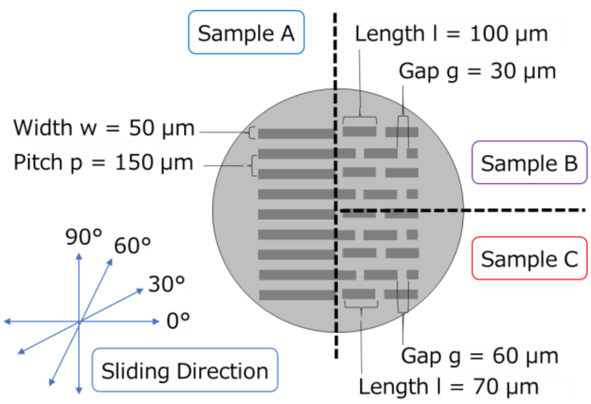

Fig. 1 Texture specimens

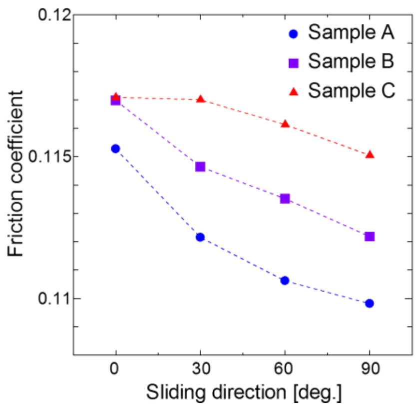

Fig. 3 Friction behavior

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IMPROVED CALCULATION OF LOAD-DEPENDENT GEAR LOSSES BY CONSIDERATION OF SO FAR DISREGARDED INFLUENCES

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KEYWORDS
Friction; Efficiency; Spur Gears; Helical Gears;

ABSTRACT

The topic of this study identifies potentials for improving the efficiency calculation of gearboxes. In drive technology, spur gears are frequently used for transformation of torque and speed. Power transmission always involves power losses.Particular interest has to be given to the load-dependent gear loss as it often accounts for a large share of the total loss.Hence, precise calculation proceduresfor the load-dependent gear loss are required for gear box design.

Systematic and comprehensive experimental investigations at the FZG efficiency test rig (Figure 1)have been carried out to investigate the load-dependent gear losses of spur and helical gears with and without flank corrections(Jurkschat et al. [1]). The experimental results have been incorporated into a calculation procedure, where a distinction is made between tribological(μ_{mz}) and geometrical (H_{VL}) influence factors.

$$P_{VZP} = \mu_{mz} \cdot H_{VL} \cdot P_A$$

Additional experiments have been conducted to improve the calculation of load-dependent gear losses by so far disregarded influences. On the one hand, the influence of the driving direction is investigated. Thereby, the considered driving and driven gears showed high differences of the specific sliding at tooth root and tooth tip. On the other hand, the influence of the change of contact ratio under load is investigated. Both influences show considerable influence on the load-dependent gear losses.

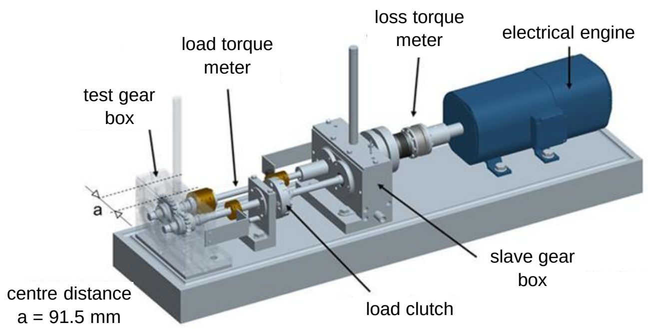

Fig.1 FZG efficiency test rig

The improved calculation of the mean coefficient of friction $\mu_{mz|opt}$ is based on a calculation approachaccording to Doleschel[2], which distinguishes between the solid coefficient of friction in asperitycontacts $\mu_{mz,s}$and the fluid coefficient of friction $\mu_{mz,f}$.Depending on the fluid load portion ξa regression analyses of allexperimental results was made.Thereby, the influence of the driving direction is considered by thelength of addendum path of contact of the driven and driving gear$g_{\alpha a1}/g_{\alpha a2}$, whichaffects only the boundary and mixed lubrication regime ($\xi < 1$).

$$\mu_{mz|opt} = \begin{cases} \left((1-\xi)\cdot\mu_{mz,s|opt} + \xi\cdot\mu_{mz,f|opt}\right) & \xi \geq 1 \\ \left((1-\xi)\cdot\mu_{mz,s|opt} + \xi\cdot\mu_{mz,f|opt}\right)\cdot\left({g_{\alpha a1}}/{g_{\alpha a2}}\right)^{0{,}04} & \xi < 1 \end{cases}$$

The local mesh and contact conditions along the plane of action are considered by the numerically calculated local gear loss factor. Thereby, the local gear loss factor $H_{VL|opt}$ is extended to include the influence of the change of contact ratio under load.

$$H_{VL|opt} = \frac{1}{p_{et}} \cdot \int_{y=0}^{b} \int_{x=A'}^{E'} \frac{f_N(x,y)}{F_{bt}} \cdot \frac{v_g(x,y)}{v_{tb}} \cdot dx \cdot dy$$

A comparison of the improvedcalculation procedure with the state of the art shows improved accuracy when determining the load-dependent gear loss of gear boxes.

ACKNOWLEDGMENTS

The presented work was sponsored by the "ArbeitsgemeinschaftindustriellerForschungsvereinigunge.V. (AiF)", by funds of the „Bundesministerium für Wirtschaft (BMWi, IGF no. 17151N/1)“ and with an equity ratio by the „Forschungsvereinigung Antriebstechnik e.V. (FVA)“. The results shown in this work were taken from results of the research project FVA 686/I. More detailed information is given in the final report. Special gratitude is owed to the active members of the attendant working team for the joint research work.

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

AN EXTENTED R_P-R_F FRICTION ENERGY APPROACH FORMALIZING THE NORMAL FORCE FLUCTUATION EFFECTS ON FRETTING WEAR RATE.

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KEYWORDS
Fretting-wear; friction energy approach; normal force fluctuation effects

ABSTRACT
In nuclear power plants, tubes of the rod cluster control assemblies undergo impacts at low contact pressure against guides, causing specific wear on the contact surfaces. The present study investigates fretting wear behavior under complex loading, using an original double-actuator fretting wear system which allows independent control of tangential sliding and normal force fluctuation. Using this experimental set-up, the fretting wear response of a nitrided 316L SS cylinder fretted against a 304L SS plate in air is investigated.

The effect of normal force fluctuations, quantified by the $R_P = P_{\min} / P_{\max}$ ratio ([1]-[2]), combined with the effect of frequency ratio defined by $R_f = f_{fretting} / f_{impact}$, was investigated keeping the tangential sliding amplitude constant. Surface damage evolution was followed by 3D profilometry and the specimen surface and cross-section were characterized using different analysis techniques (SEM, EDX, EBSD) (Fig.1).

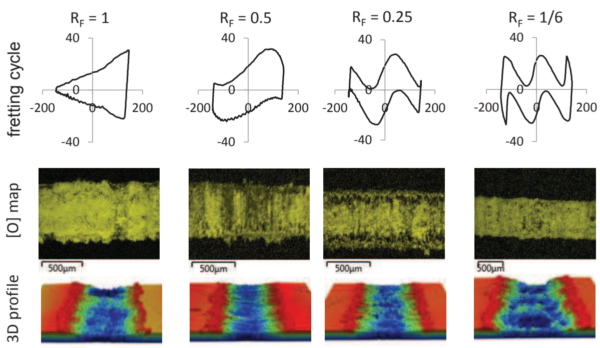

Fig.1 Evolution of fretting-cycle, oxygen map and 3D profile with R_f

Finally, to quantify the wear volume extension (V), a R_P - R_f -friction-energy-wear model is introduced with $V = \alpha^* \times \Sigma Ed$ where $\alpha^* = R_P{}^{\eta} \times R_f{}^{\omega} \times \alpha$ with α the energy wear coefficient when $R_P = R_f = 1$ and ΣEd the accumulated friction energy (Fig.2). This new description of the wear coefficient allows us to account for friction work, normal force fluctuation and frequency ratio all at once. For a dry interface, both η and ω are found to be very low and of the opposite sign ($\eta = -\omega = 0.15$), suggesting that the wear volume is controlled by the friction work and nearly not affect by normal force fluctuations in amplitude and frequency.

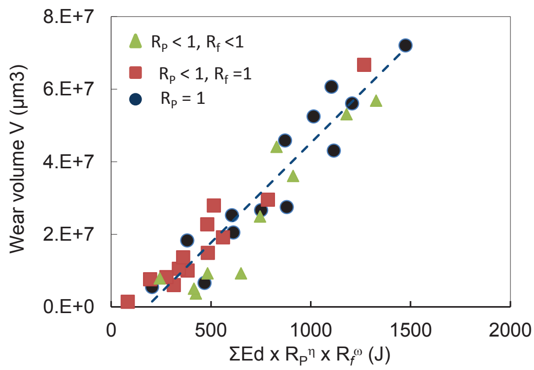

Fig.2 Fretting-wear volume versus accumulated effective R_P - R_f - weighted friction energy.

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

INFLUENCE OF TRIBOFILM FORMATION IN DLC–STEEL LINE CONTACTS ON FRICTION

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KEYWORDS

DLC; tribofilms; friction; lubrication; efficiency

ABSTRACT

Diamond like carbon (DLC) coatings have proven to be a valuable asset for the automotive industry in order to continuously improve the performance of machine elements throughout the last decade [1]. However, detailed understanding for interactions of conventional engine oils, which originally have been formulated for applications in steel-steel contacts, regarding the build-up of tribofilms with DLC is still lacking [2]. In the present study *Stribeck* experiments are conducted with a novel block on ring (BOR) configuration developed for a high speed rotational tribometer under different temperatures. Results reveal, that the amount of formed tribofilms can be linked directly to changes of the boundary friction coefficient (COF). Furthermore, tribofilms can trigger topological surface adaptations, leading to a different frictional behaviour in the fluid friction regime as well. Optical, energy dispersive X-ray (EDX) and thermoelastohydrodynamic (TEHD) numerical analysis are carried out in order to gain a holistic understanding of phenomena taking place in steel-DLC tribosystems operated with conventional engine oil. Findings indicate, that anticipated positive effects of DLC coatings are suppressed due to these films under certain conditions.

ACKNOWLEDGMENTS

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

WEAR ACCELERATION MECHANISM OF DLC FILMS UNDER BOUNDARY LUBRICANTIN IN THE PRECENCE OF MO-CONTAINING LUBRICANT ADDITIVES

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KEYWORDS
DLC; MoDTC; Wear mechanism;

ABSTRACT

Diamond-like carbon (DLC) films are most successful coatings in tribological fields in recent years because they can provide much lower friction and wear rate than other sliding materials under various sliding conditions. Especially, many recent works have shown that DLC films can exhibit the good tribological performance under boundary lubrication with the presences of friction modifiers and anti-wear additives. There are a large number of studies which have reported that the tribochemical reaction between DLC films and lubricant additives produces tribofilms on the sliding surface, which lead to the positive effects on the tribological performance such as low friction and high wear resistance. On the other hand, it is well known that the combination of DLC films and molybdenum dithiocarbamate (MoDTC) triggers the negative effects: “wear acceleration” [1-4].

In previous works, the wear acceleration mechanism has been suggested by several research groups [1-4]. Shinyoshi et al. suggested that the wear acceleration could be caused by the oxidation–reduction reaction between carbon atoms and molybdenum (Mo) oxide molecules [1]. Jia et al. also suggested that Mo-oxides derived from MoDTC caused the abrasive wear of DLC films because of its sharp edge crystalline solid structure [2]. Moreover, new insights of wear acceleration have been suggested recently [3,4]. De Feo et al. have suggested the new wear mechanism of DLC films lubricated with MoDTC solution by systematic analytical results [3]. From their results, the tribochemical reaction between the dangling bond of DLC films and Mo atoms formed the Mo-carbides and the reaction led to the wear acceleration [3]. Moreover, we have suggested that the specific structural transformation of DLC films was observed by in-situ Raman analytical method, and the specific structural transformation could be explained by the formation of Mo-carbides, which could lead to the abrasive and chemical wear of DLC films [4]. From these new insights [3,4], the formation of Mo-carbides strongly relates the wear acceleration of DLC films under lubrication with MoDTC solution. However, the details have not been clarified yet.

In this study, the following points were discussed to reveal the wear acceleration mechanism completely:

I. Effects of the types of DLC films [hydrogenated amorphous carbon (a-C:H) and tetrahedral amorphous carbon (ta-C)] on the wear acceleration under lubrication with MoDTC solution.

II. Effects of the chemical structure of Mo-containing lubricant additives on the wear acceleration.

III. Effects of the presence of zinc dialkyldithiophosphate (ZDDP) on the wear acceleration

All friction tests were conducted on the in-situ Ramn tribometer as reported in [4] to monitor the structural transformation of DLC films and tribological properties. Wear tracks were evaluated by leaser scanning microscopy(LSM), Raman spectroscopy and X-ray photoelectron spectroscopy (XPS).

ACKNOWLEDGMENTS
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FRICTION MODIFIERS FOR MOTORCYCLE WET CLUTCH APPLICATIONS: IS COMPROMISE NECESSARY?

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ABSTRACT

Most high performance motorcycles use a multiplate lubricated ("wet") clutch. The main reasons for the lubrication are cooling and to protect the steel and friction plates from excessive wear. Selecting a friction modifier for use in a standard transmission fluid is not difficult, generally compounds that; raise the friction, ensure friction increases with sliding speed, and increase the lifetime of the fluid are chosen [1]. However, for a motorcycle the choice becomes more complex [2]. This is due to the fact that the same reservoir supplies lubricant to the engine, transmission and gears. Therefore it must perform well in several, seemingly contradictory, environments.

1. Engine: should reduce frictional losses to improve fuel efficiency and reduce power loss.
2. Transmission: friction should be high at both low and high speed to ensure efficient torque transfer and quick clutch engagement respectively
3. Gears: effective wear protection is important here to increase component lifetime

As is currently the case in many walks of life one of the major drivers for the development of new motorcycle engine oils is that of lowering emissions and improving fuel economy. To achieve this there is a general trend towards lower viscosity engine oils with reduced levels of sulfur and phosphorous. This has the effect of reducing the coefficient of friction in the clutch and the antiwear properties of the lubricant. For these reasons the Japanese Automobile Standards Association (JASO) introduced a standard which grades engine oils based on their performance in the SAE no.2 test for clutch friction. Attaining the correct clutch friction is therefore extremely important when developing a new engine oil.

To streamline this process we have developed a benchtop screening method (see Figure 1). Here we show results obtained from tests of different friction modifiers (FMs) when used to toptreat a commercial motorcycle engine oil.

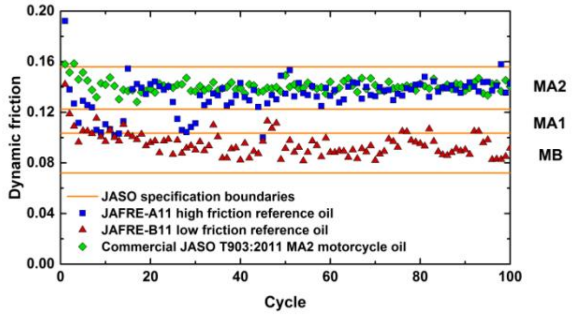

Figure 1: "Dynamic friction" coefficient (measured at 3.5 ms^{-1}) for the two JASO T903:2011 reference fluid, and an MA2 rated commercial motorcycle engine oil.

It is often the case that if a FM reduces friction in a steel/steel contact it will also reduce friction in a steel/friction material contact to at least some extent. Therefore it is usually viewed that there will be a necessary compromise between maximizing engine efficiency and maintaining efficient clutch performance. In this work we investigate whether we must always accept this compromise or whether, by careful selection of FM, it is possible to achieve both aims.

Secondly we propose a benchtop screening method for investigating gear pitting. This is recognized as a potential problem area for motorcycle oils as the trend towards lower viscosity continues. There have been discussions around including a gear pitting test in JASO specification for several years; however nothing had been decided as of the last revision in October 2016. The FMs that were screened for clutch performance are also then tested using an SRV method which investigates the performance of a lubricant in preventing gear pitting and wear.

These results highlight the importance of the surface chemistry and also roughness in determining the performance of a friction modifier.

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

THE ELECTROSTATIC ORIGIN OF POLAR HYDROPHOBICITY: WETTING AND FRICTION OF FLUORINE-TERMINATED CARBON SURFACES

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KEYWORDS
Fluorinated carbon; wetting; friction; atomic-scale simulations

ABSTRACT

The carbon-fluorine (C-F) bond is a polar, covalent chemical bond that is responsible for the chemical stability, hydrophobicity and low friction of many fluorinated carbon compounds [1,2]. However, the inconsistency between the polarity of F-terminated carbon surfaces and their hydrophobicity is still a controversial phenomenon that goes under the name of “polar hydrophobicity” [3]. Here, we first present the results of quantum-mechanical (QM) simulations that explain the microscopic origin of polar hydrophobicity of F-terminated carbon surfaces. We then show how the QM results can be extended to larger time- and length-scales by means of classical molecular dynamics (MD) simulations that are used to investigate wetting and friction of F-terminated diamond surfaces.

Density functional theory (DFT) simulations of fluorinated and hydrogenated diamond (111) surfaces interacting with single water molecules reveal that, despite the polarity of C-F bonds, “polar hydrophobicity” of the fully F-terminated surfaces is caused by a negligible electrostatic interaction between surface and water [4]. The densely packed C-F surface dipoles generate a short-range electric field that decays within the core repulsion zone of the surface, thus vanishing in regions accessible by adsorbates. As a result, water physisorption on fully F-terminated surfaces is weak and dominated by van der Waals interactions. Conversely, the near-surface electric field generated by loosely packed dipoles on mixed F/H-terminated surfaces has a considerably longer range, resulting in a stronger water physisorption that is dominated by electrostatic interactions. The suppression of electrostatic interactions also holds for perfluorinated molecular carbon compounds, thus explaining the hydrophobicity of many fluorocarbons.

This electrostatic phenomenon is only possible because of the limited electronic spill-out of C-F and C-H bonds. Our QM simulations can indeed be reproduced and rationalized by a simple point-charge model, and a classical force field can be developed to simulate length- and time-scales that are far beyond those accessible by means of DFT simulations [4]. Examples of classical MD simulations will be presented for friction and wetting of F/H-terminated diamond surfaces (Fig. 1).

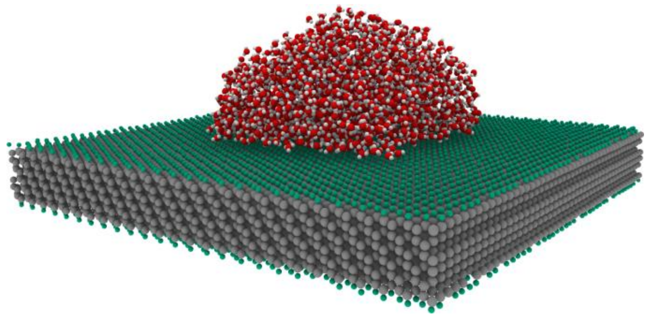

Fig. 1: Classical MD simulation of a 2000-water-molecule droplet on a F-terminated diamond surface

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We are grateful to ExxonMobil Research and Engineering for funding and to the John von Neumann Institute for Computing for the computer time provided on the supercomputer JURECA at the Jülich Supercomputing Centre.

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EFFECT OF HIGH PERFORMANCE POLYMER COMPOSITES ON CONTACT TEMPERATURE DURING RUBBING

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KEYWORDS

Polybenzimidazole, Transfer film, In-situ thermography, Polymer tribology

ABSTRACT

High performance polymers such as Polybenzimidazole (PBI) and Polyetheretherketone (PEEK) are increasingly used in tribological applications under high temperature and corrosive environments due to their self-lubricating properties. However the main limiting factor for demanding applications is the excessive heat generated from friction. The increase in contact temperature during rubbing will affect the material properties as well as the transfer film formation. In this work, an infrared thermography technique [1] was applied to map the contact temperature *in-situ*. The technique uses a camera with IR detector to collect thermal radiation from the sample with known emissivity, which is related to temperature. In this study, the contact temperature was measured between a polymer ball and sapphire counterface at different speeds. The frictional behaviour of the different polymers and blends was then correlated to the rate of heat generated inside the contact. It was observed that an increase in speed increases the temperature rise within the contact area. The properties of the polymer and blends greatly influenced the heat accumulation inside the contact. Finally the interfacial temperature due to frictional heating was estimated with a temperature prediction model [3] and compared to the experimental data.

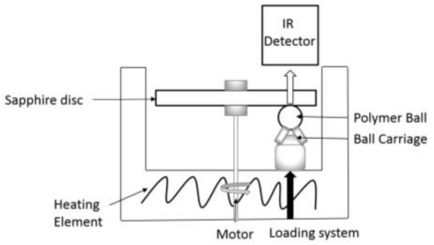

Figure 1: EHL -IR camera set-up

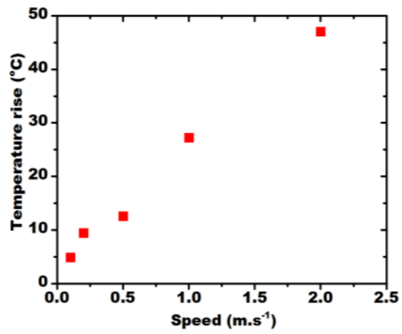

Figure 2: Contact temperature rise of PBI under different speeds

ACKNOWLEDGMENTS

The authors would like to acknowledge Tom Reddyhoff for developing the technique as well as the supports of EPSRC and Hoerbiger

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THE INFLUENCE OF MICROPITTING ON THE FRICTION COEFFICIENT OF TWO LUBRICATED SURFACES - AN EXPERIMENTAL INVESTIGATION

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KEYWORDS
Micropitting; Friction; Twin-Disk Machine.

ABSTRACT

Micropitting is a common failure for gear made of hardened steel. Literature considers that micropitting modifies surface aspect and thus roughness [1]. In gear mesh the link between friction and roughness is also highlighted [2]. Yet, the direct correlation between the friction coefficient and micropitting still needs to be quantified. Twin-disk apparatus allows simulating gear lubricated contacts for specific positions of the line of action by adjusting load and slide-to-roll ratio.

The proposed approach is based on a two phase cycle: (i), a twin-disk fatigue test rig is used to generate micropitting on a specimen; (ii), another twin-disk machine is then used to measure the coefficient of friction generated by this specimen. Traction curves are derived from those measurements.

This cycle is repeated in order to increase micropitting magnitudes on a single specimen. After each cycle the mean roughness amplitude (Rq) and slope (Rdq) are estimated from the surface measurements. These parameters are used to numerically estimate the friction coefficient [2].

These repeated cycles should allow to experimentally quantifying the link between micropitting magnitude and friction coefficient of hardened steel in lubricated contact. This study aims also to investigate the capability of surface ratio to take into account micropitting magnitude in theoretical models which estimate the coefficient of friction.

ACKNOWLEDGMENTS

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EFFECT OF CHEMICAL COMPOSITION OF TRIBOFILM FOR TRIBOLOGICAL PROPERTIES OF SOFT-METAL/DLC NANOCOMPOSITE COATINGS

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KEYWORDS
Me-DLC; Tribofilm; Composition; Friction coefficient

ABSTRACT
Diamond-like carbon (DLC) coatings have been widely studied by many researchers as excellent tribo-materials, and the tribological properties such as friction coefficient (FC) and wear resistivity are largely depending on the additives or dopant as well as the nano-structure of the coatings [1]. Adding metals to DLC coatings (Me-DLC) is thus considered as one of the solution to modify the tribological properties under the various loading conditions. We has reported the tribological properties of the Copper/DLC nanocomposite coating (Cu-DLC) and Silver/DLC nanocomposite coating (Ag-DLC) which were prepared using hybrid deposition process composed of plasma enhanced chemical vapor deposition (PECVD) and DC magnetron sputtering of metal target [2, 3].

The tribological properties of both Ag-DLC and Cu-DLC deposited by RF magnetron sputter using composite targets have been presented in this study, as a function of metal concentration in the coatings. Ag-DLC and Cu-DLC were deposited on an Si (100) wafer by commercial RF magnetron sputtering apparatus. Metal/carbon composite target was employed for RF magnetron sputtering process. A Ag or Cu tablet having diameters ranging from 5 to 20 mm was located concentrically on C base target with a diameter of 50 mm. Hereafter, the composite target having this arrangement is termed as "Concentric Composite Target (CCT)". Since metal tablet with high sputter yield is located on the center of C base target where the etching rate is quite low, metal concentration in the Me-DLC becomes low relatively. By changing the diameter of metal tablet, Ag-DLC of Ag concentration from 6 to 50 at.%, and Cu-DLC of Cu concentration from 7 to 75 at.% were prepared. The metal concentration in the coatings was estimated by energy dispersive X-ray spectroscopy (EDS). The thickness of Ag-DLC and Cu-DLC, which were measured by surface-profile measurement between coating surface and substrate, were 0.5 μm and 1.0 μm, respectively. Transmission electron microscopy (TEM) observation showed that the cross-sectional nano-structures of both Ag-DLC and Cu-DLC were granular structure where the nano-crystals of metals were dispersed homogeneously in the coatings, and that the grain size decreased as decrease of the metal content.

The tribological experiments of Ag-/Cu-DLC were performed using linear reciprocating tribometer. A mirror-polished JIS SUJ2 bearing steel ball with a diameter of 6 mm was used as counter materials. The friction coefficient of Ag-DLC with Ag content of 46 at.% showed relatively stable value less than 0.2, but the friction coefficient increased to more than 0.5 as decrease of Ag content to 12 at.%. Furthermore, when Ag content in Ag-DLC decreased to 6 at.%, the FC of Ag-DLC decreased again lower than 0.3. The transition of FC depending on the Ag content in Ag-DLC indicates the correlation to the transition of chemical composition of tribofilm formed on the counterface. The similar result was obtained from the tribo-test of Cu-DLC. These results indicate that the chemical composition of tribofilm plays an important role to control the FC of both Ag-DLC and Cu-DLC. The correlation between FC of Ag-/Cu-DLC and chemical composition of tribofilm on the counterface is discussed.

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MICROSTRUCTURE SENSITIVITY OF FRETTING CRACK NUCLEATION FOR FERRITIC-PEARLITIC STEEL

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KEYWORDS

Fretting Fatigue; Crystal Plasticity; Microstructure Variability; Dual-phase Steel

ABSTRACT

Ferritic-pearlitic steels are widely used in structural applications involving highly-loaded contacts, including railway tracks and flexible marine risers. Fretting wear and fatigue are specific failure modes relevant to such nominally-static contacts, where micro-scale relative slip and contact width are typically at the same length-scale as key microstructural features in these materials. Previous work has shown the statistical significance of average grain size in fretting crack initiation for a CoCr alloy [1]. The material investigated here contains two distinct phases. The distribution of these phases and other microstructural attributes (e.g. crystallographic texture) in the contact zone is likely to play an important role in crack nucleation. A crystal plasticity (CP) computational framework is developed to assess the microstructure sensitivity of a ferrite-pearlite steel in fretting.

The microstructure of the material is characterized using optical microscope and SEM techniques to facilitate the generation of realistic micromechanical finite element geometries with respect to grain size, grain shape, and phase volume fractions via a weighted Voronoi tessellation approach. A physically-based material model [2], with length-scale effects, based on strain gradient theory, is implemented to simulate the micromechanical behavior of the material. Mechanical cyclic test data is employed to calibrate a representative volume element model to identify CP parameters for the material. The calibrated model successfully predicts the experimentally measured cyclic stress-strain behavior across a number of strain ranges.

A 3D fretting contact model, which incorporates the calibrated CP material model and microstructure geometry in the contact zone, is developed to investigate microstructure sensitivity in fretting fatigue. The evolution of friction and wear is characterized via a recently-developed piezoelectric fretting wear test rig. A study is performed to assess the significance of phase distribution and texture in crack initiation. A scale-consistent fatigue indicator parameter strain energy dissipation W is implemented to predict number of cycles to crack initiation. Specific recommendations are made in relation to the optimization of the microstructure of ferritic-pearlitic steels for fretting crack initiation.

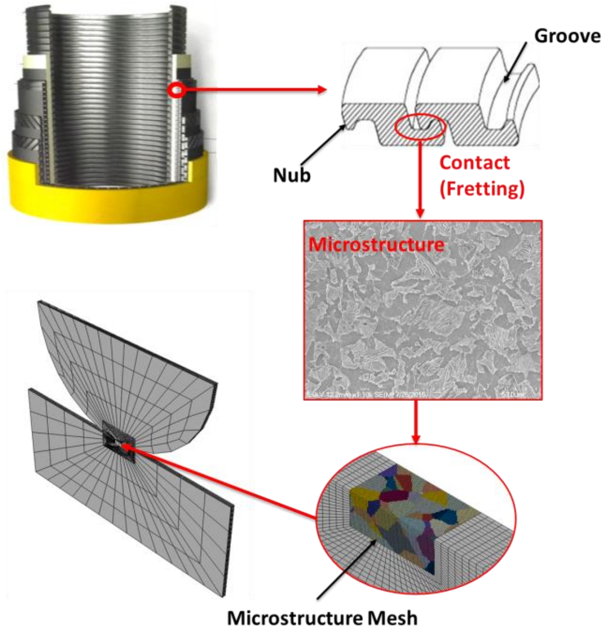

Fig.1 Schematic of micromechanical fretting modelling of marine risers.

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STUDY OF RUBBER/ROAD DRY FRICTION IN ROLLING SLIDING AND LINEAR SLIDING CONDITIONS

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KEYWORDS

Dry Friction; Rubber Friction; Tire friction

ABSTRACT

For safety and energy consumption reasons, friction in tyre/road contact is an important property when designing tyres. But the origin of friction in tyre/road contact and its relationship with the kinematic conditions are still not well understood. In this study, we carried out experiments to characterise rubber/road friction in two different kinematic conditions. With a first experimental device, a flat rubber sample is put into contact with a circular road sample. After a certain time spent in such a static contact, the road is put in rotation at a constant speed. Both the normal and friction forces are monitored as a function of time. We vary the shear speed and the age of contact before sliding. Indeed as it has been shown in Baumberger and Caroli [1], shear speed and age of contact have a strong influence on the friction behaviour of the system. In the second type of kinematic conditions, a cylinder of rubber is put into contact with the same road sample than previously. Both solids are now put in rotation. The slip ratio i.e. the ratio between the relative speed between the two solids and the road speed, is controlled and varied. We use an analytical model develop by Carter [2] to calculate the effort in the rolling friction contact. We will present the evolution of the friction coefficient as a function of the sliding velocity and contact age. We will also present the friction coefficient as a function of the slip ratio for several normal loads and average speeds. Both types of results will be compared and discussed.

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ELASTOHYDRODYNAMIC LUBRICATON OF ISOTHERMAL POINT CONTACTS AT ZERO ENTRAINMENT VELOCITY

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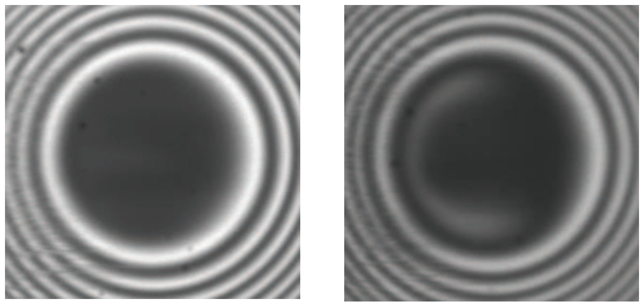
KEYWORDS
Boundary slippage; EHL; Zero-entrainment-velocity.

ABSTRACT
The paper presents a new lubrication mechanism based on boundary slippage to facilitate hydrodynamic lubrication for surface contacts running at zero entrainment velocity (ZEV) conditions. ZEV experiments were devised and it was observed that effective elastohydrodynamic lubrication (EHL) films were generated with low speeds at ZEV conditions.

INTRODUCTION
Theoretically, no hydrodynamic lubricating effect can be generated without any entrainment of lubricant into the bearing contact. The contacts between the adjacent rolling elements in a retainerless bearing (or termed as full complement bearing) run under ZEV conditions. The contact surfaces slid against the other with the same speed but in opposite directions. The resultant entrainment is null, which leads to serious friction and wear problems. To solve the lubrication problemof ZEV contacts, Cameron [1] proposed a lubrication mechanism termed as "thermal viscosity wedge" which is based on temperature differences between the two moving surfaces. The effect of "thermal viscosity wedge"was verified by Yang et al. [2]. However, the necessary thermal criterion may not be fulfilled, especially when the running speed is not high enough. Thus, another lubrication mechanism is needed for isothermal conditions. Inspired by Cameron's thermal viscosity wedge, the two bounding surfaces are made different in oil affinity. While the oleophilic surface drags oil into the contact, the opposite running surface cannot dragit out due to its oleophobicity. Thus, net entrainment of oil to the ZEV contact can be realized.

Boundary slippage [3] has been applied to reduce friction of hydrodynamiclubricated contacts.However, its application to the lubrication ofZEV EHL contact has never been mentioned.

RESULTS
Effective hydrodynamic lubrication for ZEV point contacts was successfully realized using the boundary slippage concept.The experiments were carried out on an optical EHL test rig. Theball and disk were run under ZEV conditions. The glass disk was initially treated using a commercialoleophobic coating.The surface of steel ball is oleophilic. Thus, the tests were conducted with anoleophobic/oleophilic surface contact. PAO40 was adopted as the lubricant. The affinity of different surfaces with PAO40 was represented by the contact angle and the contact angle hysteresis. The interference images of the lubricated contact werecaptured. Figure 1(a) shows that no hydrodynamic lubricating film is formed at ZEV using no oleophobic treated contact, but a classical horseshoe-shapedEHL film was obtained witholeophobic-coated glass disk and steel ball contact, as in Fig. 1(b).The typical EHL film signifies that effective hydrodynamic lubricationisrealized even the entrainment velocity is apparently "zero".



(a) Untreated glass disk/steel ball   (b) Oleophobic-coated glass disk/steel ball

Fig. 1 EHL contacts of steel ball/glass disk at ZEV conditions (speed: 100 mm/s, p_o: 0.46 GPa, PAO40)

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SYNERGISTIC EFFECTS OF IONIC LIQUIDS AND ZINC DIALKYLDITHIOPHOSPHATE (ZDDP) ON TRIBOLOGICAL PROPERTIES UNDER BOUNDARY LUBRICATION

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KEYWORDS
ZDDP; ionic liquid; AFM; Tribofilm

ABSTRACT

Recently, there has been an increasing demand for lower-viscosity formulated oils to improve fuel efficiency of auto moutive engines because they can reduce friction and drag under fluid lubrication. However, lower-viscosity formulated oils have severl issues: sevier friction and wear under boundry lubrication. Therefore, lubricant additves such as friction modifiers and extreame pressure (EP) additives are important for achiving low fricton and wear under boudnary lubrication.

In such a background, zinc dialkyldithiophosphates (ZDDPs) are one of the most important additives for reducing wear under boundary lubrication. It is well known that ZDDPs form rough and pad-like tribofilms which can control wear by reducing direct contact of the two rubbing substrates [1]. However, in recent years, reducing ZDDP in formulated oils has been needed as it causes catalyst poisoning, generates sludge, and creates corrosion on copper-based alloy component [2]. Therefore, it is important issue to develop novel anti-wear additives for low- or zero-ZDDP formulations.

On the other hand, ionic liquids (ILs) have been explored as a new category of lubricants over the past dozen years. There are currently two approaches, using ILs as neat lubricants or base stocks and using ILs as lubricant additives. The latter approach has been reported by several research groups [2-3]. Qu reported that IL added lubricants exhibited much lower wear compared to pure base oils [3].

In this research, the effectiveness of ZDDP and IL mixed solutions were studied to achieve good tribological properties and low- or zero-ZDDP formulations.

Base oil used in this research was dioctyl sebacate (DOS). Lubricant additives were C3 & C6 secondary alkyl ZDDPs and 1-Butyl-3-methylimidazolium trispentafluoroethyl trifluoro-phosphate ([BMIM][FAP]).Lubricant solutions used in this research were pure DOS, DOS + ZDDP, DOS + [BMIM][FAP] and DOS + ZDDP + [BMIM][FAP]. Tribological properties were evaluated by using a cylinder-on-disk type tribotester. Worn surfaces were evaluated by using atomic force microscopy (AFM).

Fig. 1 shows the wear volume of steel disks after the friction test. In Fig.1, DOS + ZDDP + [BMIM][FAP] exhibited lower wear volume than the other solutions. Fig.2 shows the AFM topography images of steel disks lubricated with DOS + ZDDP and DOS + ZDDP + [BMIM][FAP] after the friction test. In Fig.2, for DOS + ZDDP + [BMIM][FAP], the tribofilm which is similar to ZDDP-derived tribofilms [as shown in Fig.2 (a)] was observed

All our results suggest that the synergistic effects of ZDDP and IL lead to low wear due to the formation of tribofilms on the worn surfaces.

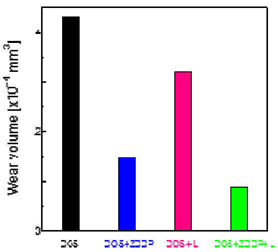
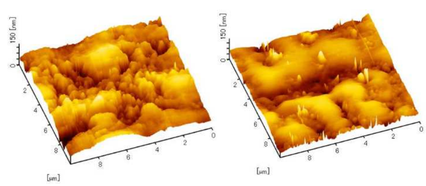


Fig. 1. Wear volume of each lubricant



(a) ZDDP (b) ZDDP+IL

Fig. 2. AFM topography images of sliding surfaces

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AN INVESTIGATION INTO THE EFFECT OF LAMBDA RATIO ON ZDDP TOPOGRAPHY AS ANALYSED IN AN ATOMIC FORCE MICROSCOPE

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KEYWORDS
topography; atomic force microscopy; ZDDP

INTRODUCTION

The use of Atomic Force Microscopy (AFM) for nanomechanical mapping has been increasingly popular in tribology over the last two decades [1][2]. It is well established as a method of qualitatively measuring the topography of a surface and is increasingly used to semi-quantitatively determine the thickness of tribofilms[3][4].

This research will determine the full extent to which atomic force microscopy can be used to characterize tribofilms formed, from oil containing primary ZDDP, under differing operating conditions. . This research will focus on the topography and thickness of tribofilms produced using an MTM and a TE77.

METHODOLOGY

A Dimension Icon Scan Asyst AFM was utilized to analyse tribofilms formed with an MTM and a TE77. The conditions used were speeds within the range of 200mm/s to 500mm/s, contact pressures of 1.105GPa to 1.216GPa and temperatures within the range of 80°C to 120°C.

The topography of each sample was measured using a scan size of 30µm x 30µm and a scan rate of 0.528Hz. The thickness was determined by partially cleaning the samples with discrete droplets of 0.5M EDTA and then taking an 89µm x 89µm scan. The friction coefficient was determined and the wear was measured using the talysurf, once all tribofilm analyses had been completed.

RESULTS

Figure 1 shows some of the current results.

DISCUSSION

This work shows the significance of initial lambda ratio on tribofilm topography. This enables a better understanding into the decomposition of ZDDP, such as the effect of sliding direction on phosphate pad elongation. Having investigated the different topographies ZDDP can form under given conditions it is now possible to better compare ZDDP tribofilms that have been formed using traditional tribometers, with those formed within an AFM.

FUTURE WORK

In the next stage of this research ZDDP tribofilms will be generated in the AFM, such that the topographies can be compared between the different generation methods. If the topographies are comparable, although on a considerably different scale, future work will consider the efficacy of analyzing tribofilm topography in-situ. This will be investigated by conducting a topical investigation utilizing both techniques, such as the effect of water contamination.

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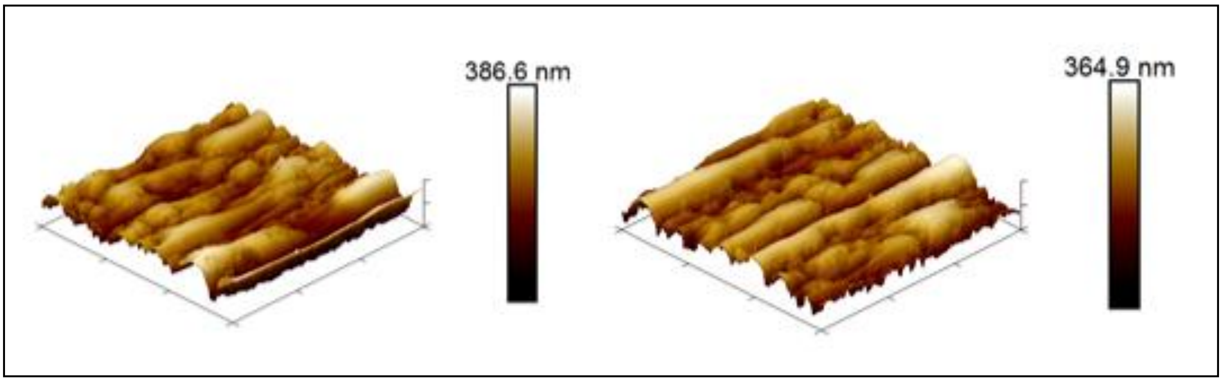

Figure 1. 30µm x 30µm AFM topography images of a ZDDP Tribofilm

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A NEW METHOD TO EVALUATE THE ENERGY DISSIPATION RESPONSE OF SURFACES UNDER FRETTING CONDITION

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KEYWORDS
Fretting; energy based parameter; experimental characterization

ABSTRACT
Non-permanent mechanical assemblies subjected to vibrations provide complex study cases for tribology, especially when submitted to a wide spectrum of vibrations, and multi-directional loads. The interfaces are mostly surface contacts, with local normal load widely influenced by shape and waviness surfaces defects.

The assessment of the durability of such structures is linked to the fretting phenomenon which can induce a mix of cracking and wear damage. The characterization of such a behavior requires an overwhelming number of tests. That's why studies essentially focus on the identification of the main damage mechanisms and critical load cases in those structures in order to perform a reduced number of significant tests, and implement a comparative evaluation of the performances of various materials pairs, coatings of lubricants.

The damping ability of mechanical assemblies turns out to be a dimensioning issue in a context of more and more compliant structures, since energy dissipation in contacts often leads to surface degradation, then loss of functionality. Energy based parameters have been related to wear rate for decades, and refined to work even under complex loading conditions [1], but typical damage-oriented experimental methods provide insufficient tools to evaluate the damping properties of the surfaces and their evolution caused by cumulative damage.

In this study we propose to use a parameter introduced in recent PhD work [2] in which the behavior of the contact surface is related to that of the test bench. This parameter, A_{el}, is calculated from force-displacement fretting cycles, and is defined as the ratio of the dissipated energy E_d by the maximum elastic potential energy of the mobile assembly of the tribometer $E_{el\text{-}max}$. It was first shown that this parameter could be used as a sliding regime transition criterion.

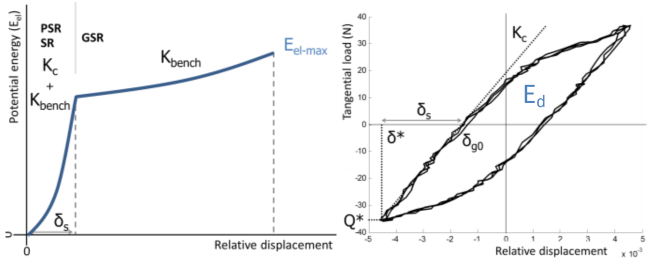

Fig.1 Definition of $A_{el} = E_d / E_{el\text{-}max}$ [2]

Experimental tests based on imposed tangential force piloting (for damage cycling) and tangential force sweeps at various moments of the cycling (for characterization purpose) have been analyzed. These sweeps have similar goals as shock hammer tests in vibration testing. The evolution of this parameter with the tangential applied force can quantify the dissipation behavior of the surface for a wide range of loads, not only the one applied during the actual damage test. An analytical modelling of this parameter for a ball on plane contact configuration [3] has also been studied, and qualitatively compared to experimental results to highlight the influence parameters.

This study globally aims to investigate the potential uses of this parameter as a tool to assess the damping potential of different tribological design choices.

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EXPERIMENTAL OBSERVATION ON THE DEFORMATION OF DIMPLED SURFACE IN SOFT-EHL CONFORMAL CONTACTS

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KEYWORDS
Surface texture; Deformation; Dimple; Soft-EHL conformal contace; Optical interferometry

ABSTRACT
Surface texture has proven to be an effective method to improve tribological properties of lubricated sliding surfaces. The contacting situation becomes much more complicate when it comes to soft tribo-contacts, such as joint prosthesis and elastic sealing ring. Under these circumstances, the elastic deformation of textured surface has been found to influence the tribological properties significantly [1-3].

In order to study the effect of deformation of textured soft surface on the lubrication performance, a simple and low-cost chemical deposit approach was applied to form a thin reflective layer of silver on the surface of polydimethylsiloxane (PDMS) substrate to satisfy the experimental requirements of optical interferometry. A BK7 glass disk was driven to rotate against the substrate of PDMS. The observation on the deformed surface around the dimple in soft-EHL conformal contacts was realized and conducted systematically under a simple sliding condition with constant loads by using optical interferometry (Fig. 1).

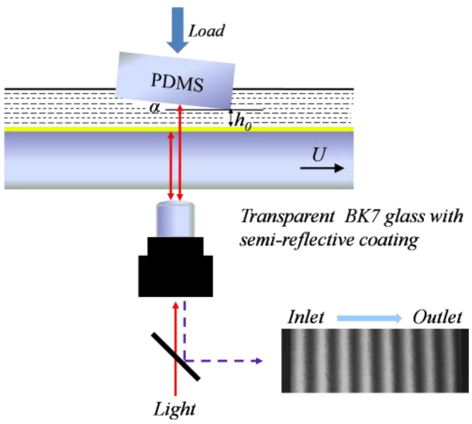

Fig.1 Schematic diagram of the slider-on-disc setup using optical interferometry

The results show that uneven deformation emerges around the dimple in soft-EHL conformal contact. Both the applied load and sliding velocity have significant influence on the deformation of the soft surface, even the deformation pattern. The representative interferograms around dimples in soft-EHL conformal contacts under different loads are shown in Fig. 2. It is generally recognized that the soft surface will be depressed due to the effect of hydrodynamic pressure, but observational results show that maximum deformation of the soft surface not occurred at the position where maximum hydrodynamic pressure generated. Some region in convergent wedge even raises in some cases, just as shown in the dotted box in Fig. 2 when load=6.86. This may be attributed to the shear strains of the soft surface, which make the leading edge of the dimple much easier to collapse, it is of course required further numerical simulation to verify.

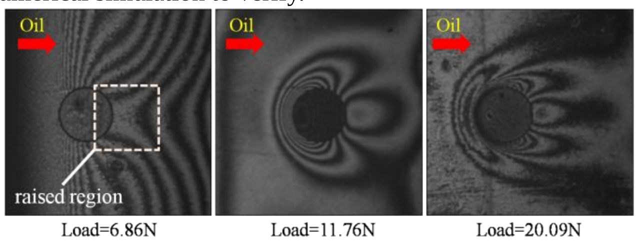

Fig.2 Representative interferograms around dimple in soft-EHL conformal contacts under different loads

ACKNOWLEDGMENTS
The research work is supported by the National Nature Science Foundation of China (NSFC) (No. 51675268).

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Effects of Normal Load and Temperature on the Frictional Characteristics of Hydrogenated Nitrile Butadiene Rubber Composites with Varied Filler Concentration

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KEYWORDS
Viscoelasticity; Rubber friction; Persson's contact mechanics; Low temperature

ABSTRACT

We present experimental results for rubber friction of carbon black filled Hydrogenated Nitrile Butadiene Rubber (HNBR) composites on a rough surface having isotropic surface roughness. The experiments are carried out in a custom built linear reciprocating rig capable of measuring friction force over decades of velocity in the temperature range from -40 to +20°C (see Figure 1). Viscoelastic properties of the rubber compound are characterized by dynamic mechanical analyzer (DMA) and then used for tackling the load, velocity and temperature dependences of rubber friction with the help of Persson's contact mechanics and models of rubber friction.

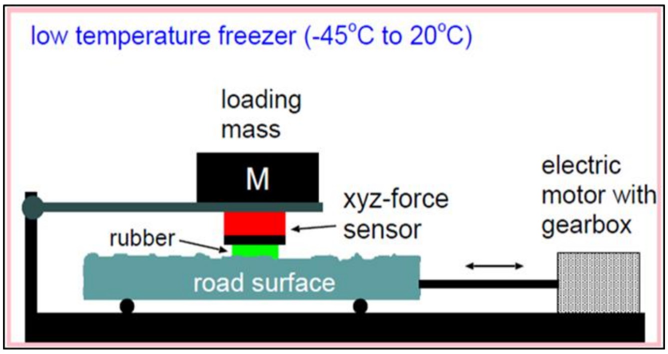

Figure 1. Linear reciprocal friction tester capable of measuring friction from -45 to +20°C.

ACKNOWLEDGMENTS

The research work was supported by the Research Council of Norway (Project 234115 in the Petromaks2 programme). This work is supported in part by COST Action MP1303. We would also like to thank Deutsche Forschungsgemeinschaft (DFG) for the project support under the reference German Research Foundation DFG-Grant: MU 1225/36-1.

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EFFECTS OF VISCOELASTICITY AND SURFACE ROUGHNESS ON RUBBER ADHESION

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KEYWORDS
adhesion; viscoelasticity; roughness; rubber

ABSTRACT

Adhesion between glass and various types of rubber is investigated experimentally and analyzed theoretically. The work of adhesion during pull-off appears to vary strongly depending on the system, where the two effects, namely viscoelastic energy dissipation close to the opening crack tip, and surface roughness play the main role. Adhesion during multiple repeated contacts can be affected by molecular transfer from the rubber to the glass.

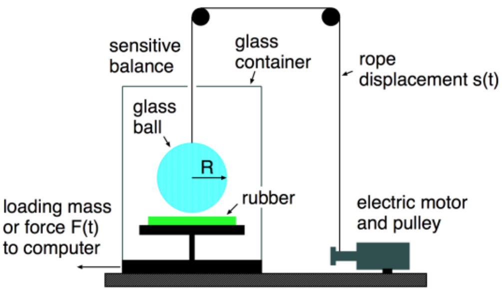

Fig. 1. Schematics of the experimental set-up for measurements of adhesion.

In general, we have distinguished the three major contributions to rubber adhesion acting at different length scales: bulk viscoelasticity, roughness and molecular mobility. The time-dependent viscoelastic contribution leads to higher adhesion for the softer compounds at the same velocities. The roughness contribution can have different sign depending on the stiffness of the rubber compound. This different behavior can be explained by the additional elastic energy stored while contact formation of the stiffer rubber with the rough surface and the additional contact area in the case of the compliant softer rubber. Mobile molecules in the weakly cross-linked structures can get attached to the countersurface and are pulled out from the substrate accompanied with energy dissipation and the increased work of adhesion.

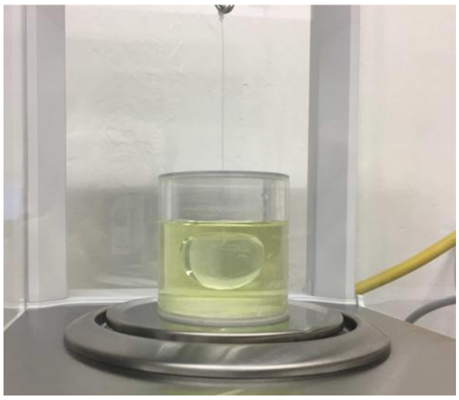

Fig. 2. Experimental set-up for adhesion studies in fluids (in this case water+soap; the light yellow fluid).

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MOLECULAR DYNAMICS OF HYDROCARBON LUBRICANTS UNDER EXTREME PRESSURES: ATOMISTIC INSIGHTS INTO THE FREE VOLUME ANSATZ

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KEYWORDS

Lubrication; extreme pressure viscosity; structure-property relations; molecular dynamics simulations

ABSTRACT

Fluid lubrication is one of the oldest technological measures to reduce friction and wear of materials in moving contacts. Nevertheless, the properties of liquids under tribological load are still not well understood. Lubricants in tribological contacts experience extreme conditions such as high temperature and pressure, high shear rates, as well as high confinement, especially in the boundary lubrication regime. Thus the tribologically relevant lubricant properties -- in particular the viscosity -- can differ considerably from expectations based on empirical extrapolations from normal conditions. The resulting lack of predictability presents a serious obstacle for the optimization of lubricated mechanical systems with respect to lifetime and energy consumption.

In this work, we show that the pressure induced viscosity variations of oil based lubricants can be quantitatively understood by identifying the underlying molecular transport phenomena by means of molecular simulations and theoretical modelling using tools of statistical mechanics. We present a molecular dynamics simulations study of the viscosities and self-diffusion coefficients of different hydrocarbon fluids (molecular weights from 170 to 565 g/mol, Fig.1(a-e)) under extreme pressures and elevated temperatures (~1GPa and 500K). This results in a physically motivated expression for the viscosity at low shear rates as a function of density and three characteristic fluid structure parameters. The key ingredients of this model are, on the one hand, an analytical extension of the free volume approach for molecular self-diffusion [1] to complex unisotropic molecules, and on the other hand, a quantitatively predictive definition of the molecules' Stokes radius [2].

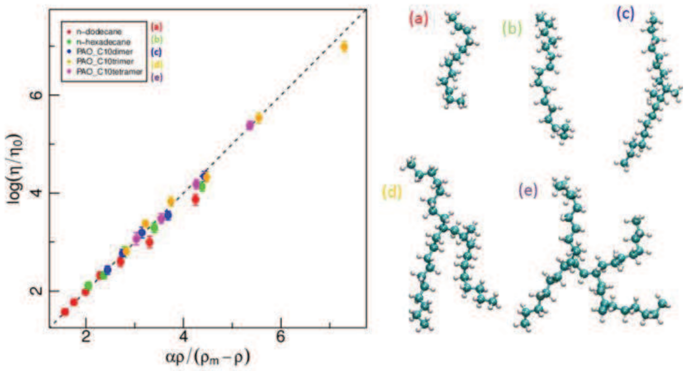

Fig.1 Scaling law for high pressure viscosities of complex hydrocarbons from molecular dynamics simulations

Based on the identified microscopic picture of the self-diffusion process, we further discuss the conditions which we expect to lead to a breakdown of either the free-volume ansatz or the Einstein-Stokes relation, and thus the limits of applicability of free-volume based viscosity models.

ACKNOWLEDGMENTS

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FRICTIONAL COEFFICIENTS OF LIVING VASCULAR CELL MONOLAYERS

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KEYWORDS
biotribology; stents; cells

ABSTRACT

Advancements in the field of biotribology have generated considerable interest in the frictional properties of cells. The nature of the interface between biomaterial and living tissue is especially pertinent from a medical device perspective.

Annually, there are 800,000 vascular stents implanted into coronary arteries alone, with rising numbers due to the global burden of cardiovascular disease and Type 2 diabetes (1). The most prevalent cause of death in diabetic patients is a cardiovascular event, accounting for half of total diabetic deaths (2).

Currently, further work is needed to understand the effect of tribological interactions during stent deployment on cell response. Excessive forces enacting upon mechanically reactive cells may eventually result in failure of the stent via cell-mediated in-stent restenosis (ISR) (3-5).

Human primary smooth muscle cell (SMC) monolayers from non-diabetic (ND) and Type 2 diabetic (T2D) patients were isolated and cultured. Triplicate friction measurements of 0.5mN and 100μm sliding distance at 50 Hz were recorded for 20 cycles using a 2mm ruby pin.

A load of 1mN, the wear track and a denuded area of cells was visible. At a load of 0.5mN the SMCs remained adhered to the tissue culture plate. There was a significantly higher coefficient of friction in SMCs from diabetic patients compared to non-diabetic patients (0.45±0.009 vs. 0.37±0.018, ND vs. T2D, mean ± 95% confidence intervals, p<0.001) (*Figure 1*).

Further work will include equating tribological parameters, such as friction and load, with biological effects including cell viability, gene and protein expression and adverse vascular cell function in the context of ISR.

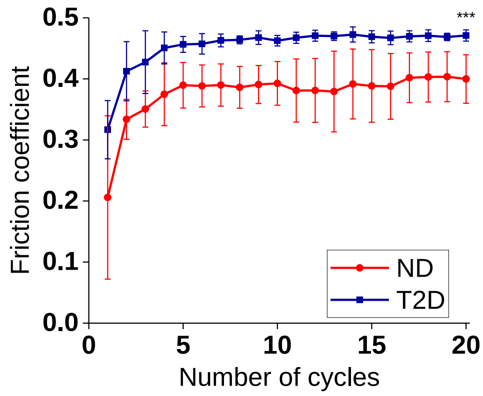

Figure 1Significantlyincreasedfrictional coefficient of T2D-SMCs vs. ND-SMCs, ***p<0.001

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NUMERICAL IMPLEMENTATION OF ROUGHNESS EFFECTS ON FRICTION-INDUCED VIBRATIONS

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KEYWORDS
Friction-induced vibrations; surface roughness; contact law.

ABSTRACT

Friction-induced vibrations have been deeply addressed in literature both numerically and experimentally [1]. The interest in this issue arises from the complex nature of friction dynamics, which is the cause of multiple mechanical phenomenon, such as brake squeal [2], stick-slip [3] and wear [4]. The reproduction of the dynamic response to the contact excitation has been always a challenge, because of the several parameters that interact in the contact dynamic. In this framework, the object of this study is to analyze and reproduce the contact dynamic response of a system composed by two beams in overall frictional sliding.

The approach to simulate the effects of roughness on friction-induced vibrations is based on the implementation of a friction coefficient composed by two terms: a constant one, as for the Coulomb law, and a perturbative term, to introduce an equivalent broad band excitation by the contact:

$$\mu = \mu_{const} + \mu_{perturbative} = \mu_{const} + A|v(t)|^{b} R(x)$$

In order to validate the contact law, the perturbative term *R(x)* has been retrieved experimentally by inverse methods.

The proposed method has the dual purpose to correctly reproduce the friction-induced vibrations and to save computing time, which undergoes an unacceptable increase when introducing the surface roughness within a finite element model.

A parametrical analysis has been carried with respect to the normal load, the sliding velocity and the surface roughness.

The numerical results from the proposed method have been validated by comparison with the experimental measurements, showing a good correspondence between the experimental and the numerical results.

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INFLUENCE OF ANODIZING CONDITIONS ON THE TRIBOLOGICAL MECHANISMS OF STICK-SLIP

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KEYWORDS
Stick-Slip; hard anodizing; Surface roughness

INTRODUCTION

A sliding contact between different anodized rods and a polymeric seal is analysed. Some rods displays a stick-slip phenomenon and others present a continuous sliding contact. The aim of this study is to investigate the topographical difference between these two configurations. This will lead to find the machining signature of the machining process used on rods tested and to analyse the radial and axial topographical homogeneity. The main purpose of this study remains to retrieve the most relevant roughness parameter able to characterize the stick-slip phenomenon and the most appropriate spatial scale threshold.

MATERIALS AND METHODOLOGY

Hard anodized and clogged rods are made in different aluminium alloys (AlSi7Mg0.6 and AlCu4MgSi). They are tested in sliding contact with a seal in polyethylene.

A white light interferometer (NewView 7300, Zygo™), with Mirau objectives x5, x20 and x100 is used to characterize and to quantify surface roughness. The software Mesrug™, developed in the authors' laboratory, is used in order to get a multi-scale decomposition of the surfaces and finally select the relevant parameters able to characterize the stick-slip phenomenon. Therefore, cylinders topography is analysed at different scales all along their axis.

RESULTS AND INTERPRETATION

According to the multiscale analysis, the stick-slip phenomenon is not discriminated at spatial scales over 100µm. At this scale, a factor two on the S_{dq} (Root mean square surface slope) highlights a difference between the stick-slip surfaces and the others. A possible explanation of this result can be that the stick-slip phenomenon appears when the roughness is increasing on the calculated slope (more obtuse angle). Consequently, a segmentation analysis of the surface topography based on the 3D motif analysis approach is investigated (figure 1).

The surface without stick-slip shows that large motif oppose the stick-slip phenomenon. Surfaces without stick-slip have a motif area 6 times larger than stick-slip surfaces.

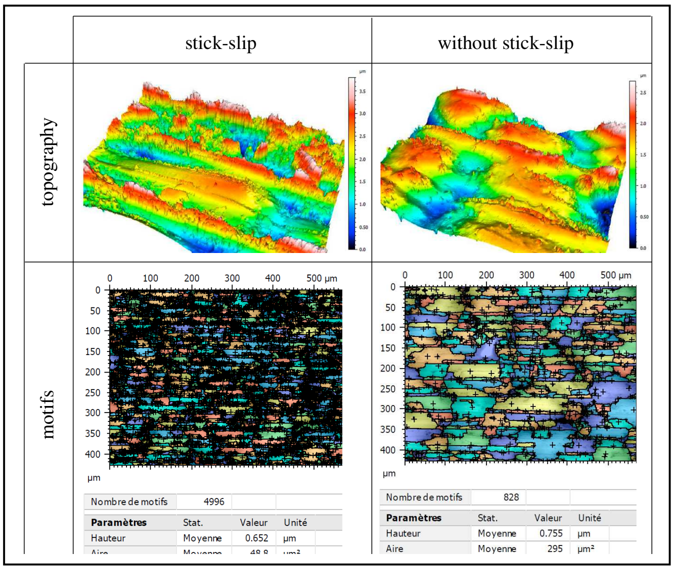

Fig.1 Stick-slip and without stick-slip surface topography 3D Motifs analysis

This will increase the contact area of each asperity. On measured surface topography at nanometre scale, it is also observed that a more important number of peaks and fractal dimension lead to a stick-slip structure. The clogging treatment has an important impact on the surface morphology. A crazing phenomenon due to the this process is most of the time due to the difference of mechanical and physical properties between the substrate and the oxide layer, mainly because of the difference between the expansion coefficient and the elastic modulus.

These results suggest that stick-slip mechanism is due to a low clogging of pores that increase the surface roughness and making the surface roughness less smooth. The bibliography confirms the 10 µm on porous aluminium structure by multiscale analysis [1].

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ON THE GLAZE LAYER FORMATION IN ZINC AND MANGANESE PHOSPHATE COATINGS

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KEYWORDS
Phosphate conversion coating; glaze layer; wear protection

ABSTRACT

Casing connections in the oil and gas industry are typically coated with zinc and/or manganese phosphate for corrosion protection during storage. The presence of phosphate coatings is also known to give beneficial tribological performance during the assembly by preventing galling.

It was shown in previous work that zinc and manganese phosphate coatings form a hard and smooth glaze layer in dry sliding [1]. This was explained by the generation and compaction of the generated phosphate debris particles. Owing to this property, phosphate coatings provide excellent surface protection [2].

The research presented here is aimed at exploiting these properties for the design of environmentally friendly lubricants. Therefore, the mechanism behind its formation needs to be understood to fully benefit from the generation of this glaze layer and the surface protection.

Glaze layers were generated in a pin-on-disc and ring-on-ring set-up under dry and lubricated conditions. Six base oils with different polarity and viscosity were used. The generated glaze layers were investigated with atomic force microscopy to measure the particle size and their packing. The crystal structures of the initial and glaze layer were determined with X-ray diffraction. A cross section of the glaze layer was made using focused ion beam and inspected using a scanning electron microscope. Hardness was measured using nano-indentation.

The results show that glaze layer hardness is driven by Van der Waals interaction and governed by particle size and their packing. The highest hardness is achieved in dry sliding conditions because this generates the smallest particles and closest packing.

The interaction is modified by the presence of a lubricant in two ways. The particle size generated is larger because of the lower interfacial shear stress and the Van der Waals interaction is weaker because of encapsulation by the lubricant. Therefore, the glaze layer generated has a lower hardness in lubricated conditions.

Based on the experimental work a model is developed for the resulting hardness based on Van der Waals interactions as a function of the Hamaker constant, particle size and packing.

The model can be used to select a base oil that maximizes the synergy with the phosphate coatings based on its physical properties.

ACKNOWLEDGMENTS

Shell Global Solutions International BV is acknowledged for permission to publish this work.

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

VIRTUAL TEXTURED HYBRID BEARINGS

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Magnetorheology; Electrorheology; Hydrostatic bearing; Virtual texturing; Tribotronics

INTRODUCTION

In order to achieve low wear and friction, full film lubrication is desirable since this guarantees no contact between the bearing surfaces and so no wear. Full film lubricated bearings can be divided into hydrodynamic (HD) bearings and hydrostatic (HS) bearings. HD bearings are a low cost and low friction solution, however they require a sufficiently high speed to ensure zero mechanical contact between the moving surfaces. HS bearings exhibit zero contact at all operating speeds but have the drawback that they rely on a failure sensitive supply pump (Fig.1). Hybrid bearings combine the advantages of both bearing types, but their design is regularly a trade-off between both operating regimes [1], as the surface texturing needed for an optimal HS working regime decreases the efficiency of the HD working regime and vice versa.

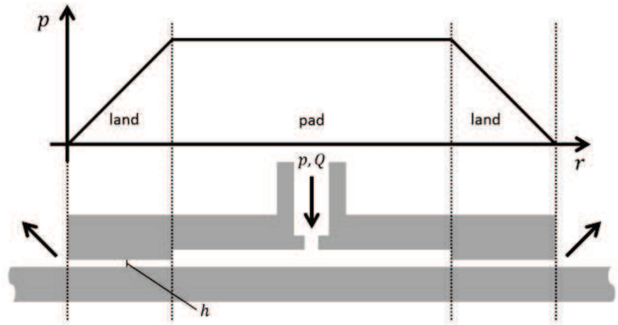

Fig. 1. Conventional HS bearing: resistance is increased locally by decreasing the bearing gap h.

VIRTUAL TEXTURED JOURNAL BEARING

This work presents a new type of hybrid bearing that does not compromise between the HD and HS working regimes. This so called “Virtual Textured Bearing” uses a local variation of the viscosity of the lubricant to modify the local resistance (Fig 2.). This can be realized with for example a magnetorheological fluid (MRF) or an electrorheological fluid (ERF). This furthermore facilitates active control of the bearing as is done in [2].

The absence of physical texturing results in a conventional converging wedge that better facilitates HD lubrication (Fig. 3). Supply inlets in the journal together with virtual texturing adds HS lubrication to the bearing operation. This yields a bearing system that predominantly uses HS lubrication at low speeds and naturally switches to efficient HD lubrication at high speeds.

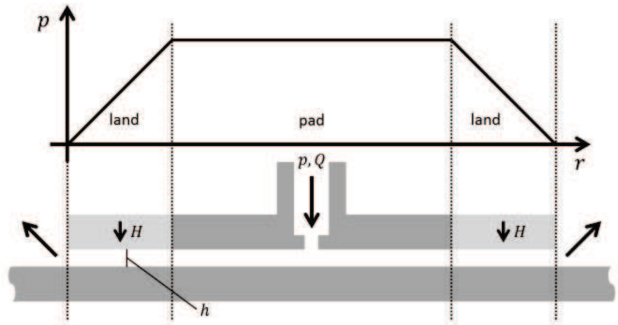

Fig. 2. Virtual textured HS bearing: resistance is increased locally by using an MRF and a local magnetic field.

Fig. 3. Virtual textured journal bearing: A smooth bore journal bearing is supplied through the holes with a MR-lubricant. Virtual recesses are created by the magnetic field created in the dark zones. In operation both hydrostatic and hydrodynamic load carrying capacity is generated.

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ZDDP DEGRADATION AND TRIBOCHEMISTRY REVEALED BY MASS SPECTROMETRY

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KEYWORDS
Boundary lubrication;zinc dialkyldithiophosphate (ZDDP);oxidation;mass spectrometry (MS);X-ray photoelectron spectroscopy (XPS)

ABSTRACT

Tribochemistry of ZDDP antiwear additives is reported by numerous publications, e.g., comprehensively summarised in a review by Spikes [1]. For tribofilmcharacterisation, secondary ion mass spectrometry (SIMS) is known forharsh ionization, hence connected with significant loss of molecular info. For the identification of ZDDP degradation products in lubricants, chromatography and nuclear magnetic resonance (NMR) spectroscopy, particularly ^{1}P-NMR, are known [2].

To overcome the limitations to satisfactorily describemech-anisms of ZDDP degradation and tribochemistry on the molecular level, an analytical approach based on MS is proposedjoining findings from oil degradation and ZDDP tribochemistry [3-4].

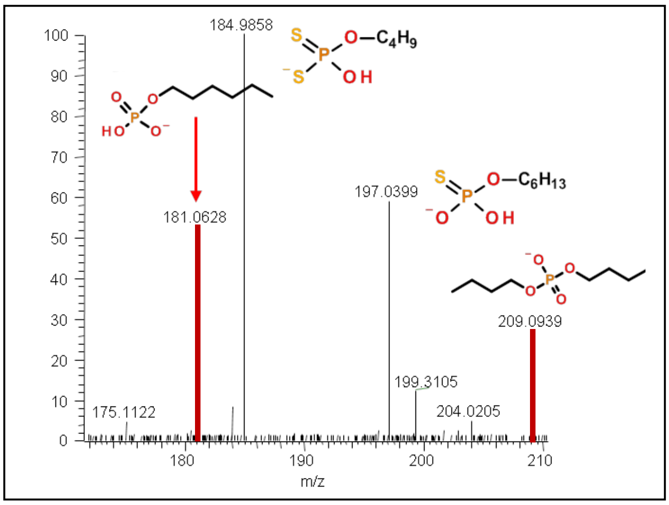

Fig. 1 Exemplary MS findings on ZDDP degradation – comparison of fresh and used oil – red bars indicate ZDDP degradation products only found in the used oil [5]

Used oils generated by oxidative and/or tribologicalstress were characterised fordegradation products using highly accurate MS and compared with fresh oil for a proper description of the used oil condition. Mass spectra disclosed the formation of alkyl phosphates in used oils originating from ZDDP (Fig. 1). It could be also shown that the fresh oil can contain ZDDP derivatives, being either by-products or oxidation products.

The findings from oil chemistry were connected with tribological performance assessed in an oscillating steel-steel contact. Mapping of the wear scars with MS and XPS revealedspecific distribution patterns of organic and inorganic moieties on the surface that account for the local tribological conditions along the disc wear scar.

ACKNOWLEDGMENTS

This work was funded by the Austrian COMET-Program (Project XTribology, no. 849109) and the work was carried out at the “Excellence Centre of Tribology” (AC2T research GmbH).

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ULTRASONIC RHEOLOGY USED AS AN ASSESSMENT OF OIL DEGRADATION

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KEYWORDS
Oil Degradation; Ultrasound; Measurement, Viscosity.

ABSTRACT
The viscosity of lubricating oil is a major indication of quality and efficiency of oil, principally of the oils capacity to provide a sufficient oil thickness between two articulating surfaces to reduce friction. Correct lubrication systems prevent wear and disruption to produce reliable and efficient tribosystems.

Fully formulated oils can degrade by a number of mechanisms which may all affect the viscosity of the lubricant. Viscosity changes are often the first indication of a problem in a tribosystem, this could be as a result of oxidation, thermal destruction, fuel contamination or additive decomposition [1].

Conventional viscometers are incapable of measuring the viscosity of lubricating oils within operating mechanical systems. For example the viscosity of oil inside a pipe could not be measured in situ using conventional techniques. Ultrasonic techniques can act as a non-invasive sensor system to improve control and analysis of lubricants.

METHODOLOGY
Ultrasonic viscometers have traditionally used direct coupling between the transducer and oil to measure viscosity [2]. This reduces the number of applications of the technique and may disturb functionality of the system. A new approach uses a polyimide matching-layer to couple sound from the sensor, through a metal bearing shell and into oil [3].

This methodology has been combined with a multiple reflection method to increase the sensitivity of dynamic viscosity measurements.

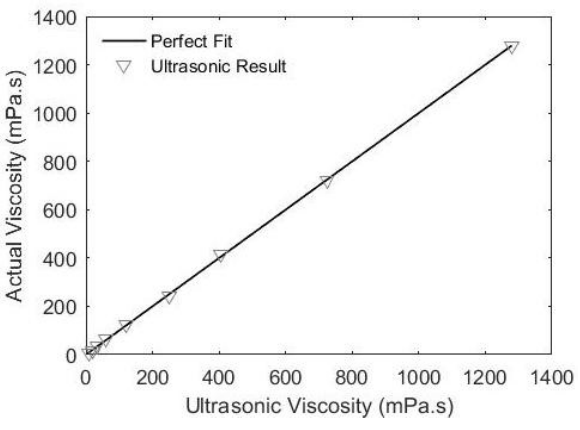

Fig.1 A comparison of ultrasonic and actual viscosity

An excellent agreement is seen between ultrasonic viscosity values and actual viscosity, seen in Fig. 1, using the engine lubricant viscometer, shown in Fig. 2, for Newtonian viscosity ranging from 3 and 1279mPa.s.

Oil degradation has been measured in-line in a purpose built oil degradation rig by connecting the chamber, shown in Fig. 2, to the lines that contain the circulating oil.

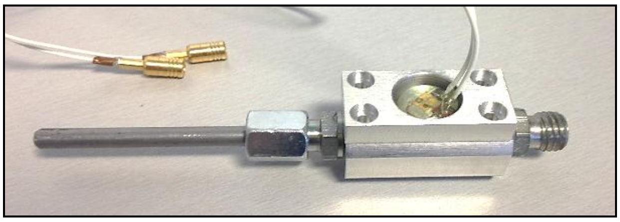

Fig.1 An engine lubricant viscometer connected to a lubrication pipe.

The rig degrades the oil using a constant temperature of 190ºC and oxidation through an air flow rate of 5L/minute. The oil was degraded over 2 months and ultrasonic measurements were periodically taken to track the level of degradation during this time.

The engine lubricant viscometer consists of a chamber which houses an aluminium plug that is instrumented with two transversely polarized 5MHz transducers. Oil is measured from the counter face of this plug. The instrumentation can be seen below the connecting wires in Fig. 2 above.

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COMBINED EXPERIMENTAL AND NUMERICAL SIMULATION OF ABRASIVE WEAR AND ITS APPLICATION TO A TILLAGE MACHINE COMPONENT

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KEYWORDS
Abrasive wear simulation; finite element method; boundary element method; wear prediction; tillage machines

ABSTRACT
Abrasive wear of key components is a critical process limiting the lifetime of machinery for mining or farming. Technologies such as laser surface cladding have been developed to increase service life. However, materials and process parameters are mostly based on empirical data since the underlying wear mechanisms in the field are not well known.

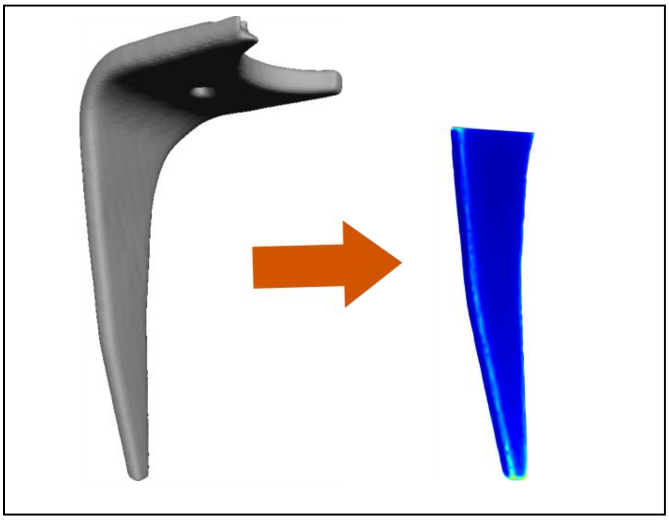

Fig. 1 Initial component geometry and simulated friction power density

In order to assess and predict the effects of abrasive wear on typical tillage machine components, the authors developed a combined experimental and numerical simulation procedure based on a time- and space-resolved version of the Archard wear equation [1, 2]. In our approach, a 3D laser scan of the real machine component is incorporated into a finite element model (FEM), and the abrasive flow – in this case, the soil moving around the component – is modelled as a Bingham fluid [3], resulting in a locally resolved friction power density (see Fig. 1). In an iterative computation, the component geometry is gradually altered based on the local wear rate as obtained from the flow simulation. Thus, the wear on the machine component can be predicted as a function of the soil parameters and the driving distance.

The experimental part consists of a laboratory-scale abrasion test (ASTM G65) and a subsequent 3D profilometric scan of the worn surface. In addition, the test is simulated numerically using the boundary element (BEM) code developed at AC²T, thus providing a validation and calibration of the employed wear model.

The applicability of the aforementioned procedure is demonstrated on a tooth of a circular harrow. The simulated worn geometry shows good agreement to the real geometry of a tooth used in a tillage field test.

ACKNOWLEDGMENTS
This work was funded by the Austrian COMET-Program (Project XTribology, no. 849109) and the work was carried out at the “Excellence Centre of Tribology” (AC2T research GmbH).

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NUMERICAL AND EXPERIMENTAL STUDY OF WATER LUBRICATED SPIRAL GROOVE FACE SEALS

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KEYWORDS
Spiral groove, face seal, hydrodynamic lubrication, two-phase flow, non-laminar flow

ABSTRACT
The sealing of rotating machines such as pumps is usually ensured by mechanical face seals. They are basically composed of two flat annular rings in relative motion and their contacting interface is the sealing dam. To avoid friction and wear spiral grooves can be machined on one face to enhance hydrodynamic lubrication. Figure 1 presents an example of spiral groove face seal with a cross-sectional view of the seal rings. Spiral groove seals were initially proposed to seal gas in turbomachinery but they can also be used with liquid when face contact is an issue [1]. However, there is a lack of experimental data as well as simulation results for this type of component in the literature. The objective of this work is to present experimental results and comparison to numerical results for a wide range of operating conditions.

The numerical model solves the Reynolds equation and the energy equation in the fluid film. It allows calculating the fluid pressure and enthalpy in liquid or two-phase flow configurations. The thermal and mechanical coupling between the fluid film and the seal rings is moreover considered. An example of simulation result is given in Fig. 1. The hydrodynamic pressure generation can be clearly seen at the inner edge of the grooves. Because of the viscous friction, temperature rise is observed in the seal rings.

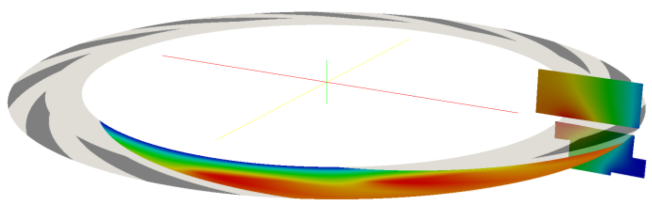

Fig.1 Pressure in the fluid film and temperature in the seal rings (Operating conditions: 40°C, 50 bars, 4000 rpm)

Some experiments have been performed on a test rig working with water. Several spiral groove seals have been tested on wide range of operating conditions which are given in table 1 while measuring the friction torque, leakage and temperature in the seal rings.

Table 1 Operating conditions

Parameter	Value
Water temperature	40 – 95°C
Water pressure	10 – 50 bars
Rotating speed	2000 – 6000 rpm

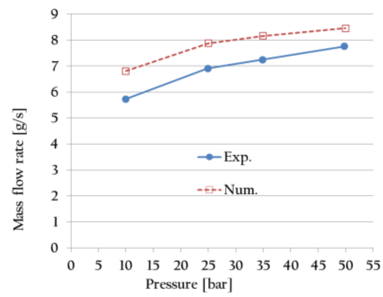

Fig.2 Comparison of the measured and calculated mass flow rate (Operating conditions: water at 40°C, 4000 rpm)

The variation of the mass flow rate with pressure is given in Fig. 2. As expected, the flow rate increases with the pressure but not in a linear way. The evolution is well captured by the model. The experimental results highlight some particular operating regimes: non-laminar flow, two-phase flow. The model is used to analyze the conditions of occurrence of these regimes.

ACKNOWLEDGMENTS
The CNES and ASL are due particular thanks for supporting this PhD part work

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ELASTOHYDRODYNAMIC LUBRICATION AND SURFACE FATIGUE MODELLING OF SPUR GEARS OVER THE MESHING CYCLE

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KEYWORDS
Gears, Surface Roughness, Fatigue, Elastohydrodynamic

ABSTRACT
This paper presents the results of a method for evaluating spur gears based on the transient elastohydrodynamic lubrication (EHL) simulation of the full meshing cycle, taking into account the transient variation of contact kinematics and loading during the meshing cycle. The simulation incorporates measured surface roughness, and evaluates elastic stresses in the gear flanks, calculating the transient variation of stress (the stress history) for the tooth material as it passes through the contact, and applying a range of stress and strain-life methods to calculate fatigue parameters and cumulative fatigue damage, using similar fatigue model evaluation techniques to Qiao *et al.*[1]. This allows a prediction of gear surface fatigue life for gears operating under mixed lubrication conditions, whilst taking into account the real, measured surface roughness.
The EHL model is formulated as the coupled system of the hydrodynamic Reynolds equation and the elastic deflection equation, which are solved simultaneously. The EHL model was developed based on the previous work of Davis [2]. The elastic stresses due to the superimposed discrete values of the EHL pressure and shear stress at the EHL mesh nodes are evaluated by carrying out the necessary convolution of the stresses by a Fast Fourier Transform method. The stresses are obtained on the EHL solution mesh and are interpolated to meshes fixed in the pinion and the gear flanks. They are then sorted and stored efficiently to enable fatigue life prediction algorithms to be applied in a straightforward manner.
Results of the fatigue calculations are shown for an analysis which considered test gears used in micro-pitting investigations. Contours of various fatigue parameters are shown in Figure 1, for a layer of gear tooth material extending to 300μm below the tooth surface. These analyses were carried out for the real extreme conditions used in gear testing, with surface roughness profiles measured from the test gears after initial running-in. The simulations therefore are representative of the true mixed lubrication conditions occurring in heavily loaded gears.

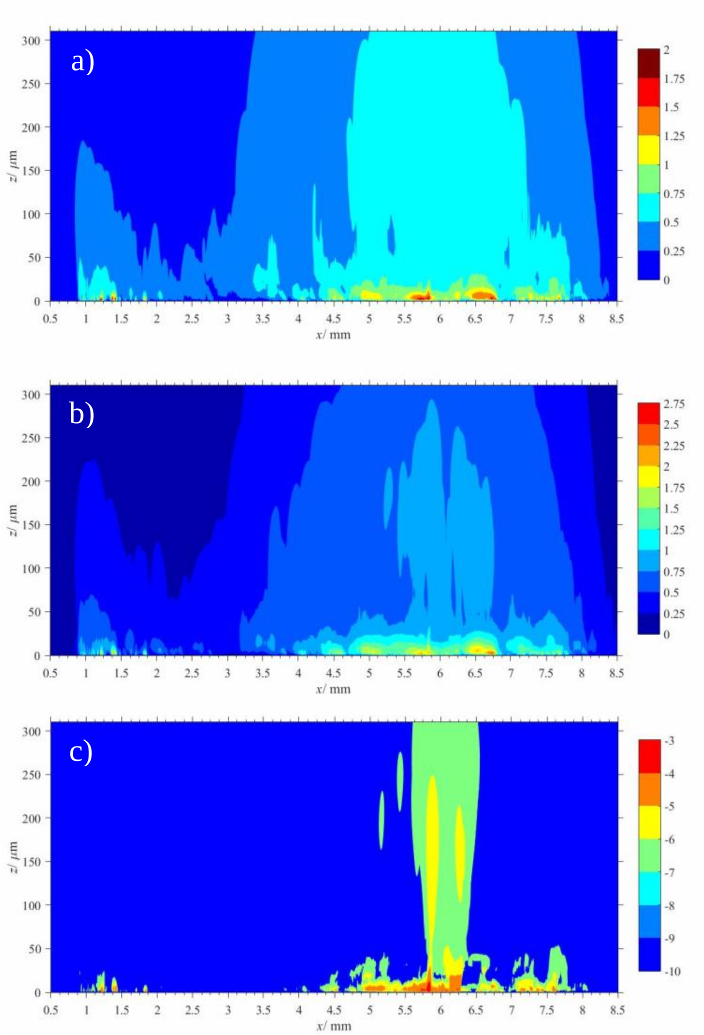

Figure 1. Gear: (a) Dang Van and (b) Findley fatigue parameters for 10^7 loading cycles and (c) Fatemi and Socie accumulated damage, 10^{-n}, indicating fatigue in 10^n cycles

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EFFECTS OF THRUST WASHER BEARING SURFACE CHARACTERISTICS ON PLANETARY GEAR TRAIN WEAR

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KEYWORDS
Thrust Washers; Planetary Gears; Wear

ABSTRACT

There is an ever ongoing effort to increase operating life, reduce power losses, and to ensure the overall functional performance of trucks. The main focus of the presented research is to enable development and production of extremely reliable and robust thrust washer bearings in heavy-duty truck drivetrains.

Washer wear gives frictional power losses that cause high local temperatures due to highly nonlinear thermo-mechanical effects that also possibly trigger thermo-elastic instabilities. These interaction phenomena may cause fatigue and local excessive wear with very hard particles that further damage adjacent high-performance components. A planetary gear train with spur gears was selected as a case study (Fig. 1), with washers in between the planet wheel and planet carrier. Inevitably, thrust forces occur in spur planetary gear trains, e.g. due to the design of the planet carrier which has an unsymmetrical stiffness – it is stiffer on the rear compared to the front side. This may cause a twisting torque on the carrier. This twisting torque is transferred by the planets to the needle bearings and further on to the washers. Thus, the system performance would benefit from a low-friction interface between the washer bearing surface and the planet wheel. See Jackson and Green [1] for more reasons of thrust washer failures.

Four differently surface treated washer materials were tested using a pin-on-disc tribometer. The tests were performed at 0.5 m/s and lasted for 5000 cycles at maximum Hertzian contact pressure 870 MPa, repeated three times. Three disc material tested was nitro-carburized and one was electroless nickel plated with teflon (or Nedox®), all with SS 2541 steel grade. The nitro-carburized test disc with teflon coating resulted in the lowest friction. Although the coating wears off at an early stage, it resulted in the lowest wear of the pin specimens which here represent the planet gear. The electroless nickel plated with teflon resulted in the most stable frictional behaviour and low wear of pin and disc specimens. High wear of pin specimens were the result when using the nitro-carburized disc with ANS Tribonite™. The nitro-carburized disc with no coating resulted in very high friction. The tests were compared with long-time running gear rig tests which resulted in favour for the electroless nickel plated with teflon, here on steel grade SS 1265-11. The electroless nickel plated with teflon did not give the lowest friction in the lab scale tests, the difference in steel grade might have affected the electroless process. The overall results indicate that lab scale tests can be made to try out new washer materials.

The results from the presented research will be applicable to a range of subsystems along the powertrain, including both motor and the drivetrain.

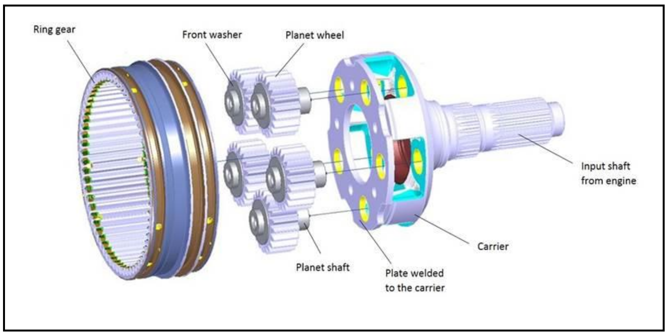

Fig.1 Exploded view of the planetary gear train.

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A FINITE ELEMENT TRANSPOSITION OF THE THIRD BODY CONCEPT TO PREDICT THE MAXIMUM WEAR DEPTH IN FRETTING WEAR

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KEYWORDS
Fretting wear; FEM simulation; third body;

ABSTRACT

Fretting is a surface load which is defined by two bodies in contact which experience small amplitude oscillatory movements. Fretting generates invariable damage process being wear and crack mechanisms. Depending on the loading conditions, normal pressure, displacement amplitude … different damage can be found. Wear is one important limitation to the lifetime of engines, gears or simply coatings.

To predict this lifetime, FEM simulations are generally used [1] but the third body or debris are rarely taken into account [2]. In this research work, we proposed an experimental campaign of test to characterize the occurrence and the evolution of the third body in the contact. We investigated a cylinder/plane contact, respectively made of 100C6 and 35NCD16. Numerous parameters were studied like cylinder radius, normal load sliding displacement and cycle number. Wear volume and maximum wear depth of the counterparts were systematically compiled. A simple method based on adequate superimposition of worn surface profiles allowed the estimation of individual cylinder and plane friction energy wear rates and quantification of third body thickness embedded in the interface. A local approach of third body law introduced by Fillot et al. [3], expressing the local height of wear and the local proportion of worn height transferred to the third body in function of local solicitation is proposed. From this model and in range of test, constants were found for the material couple. The Fillot's model describes debris like a fluid driven by source flow and wear flow which characterize respectively the detachment of particle from the bodies in contact and ejection of particles from the contact. This various quantitative variables were introduced in a coupled Matlab-Python-Abaqus algorithm where the local approach of Fillot's third body model was considered.

Quantitative comparison with experimental and numerical results confirmed the interest of this local approach of this new strategy (Fig. 1). The prediction of wear volume, wear shape and third body quantity were well estimated and allowed a better prediction of maximum wear depths compared to usual surface wear simulation without third body consideration.

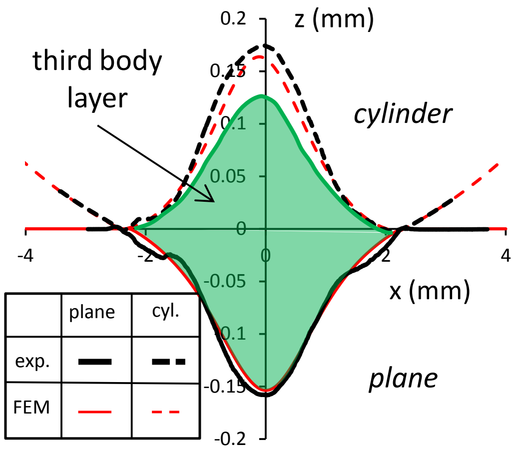

Fig.1 Comparison between experimental and FEM simulated worn fretting profiles for 40,000 cycles, 600 N load and 50 µm sliding displacement.

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EFFECT OF ABRASIVE PARTICLE SIZE ON FRICTION AND WEAR BEHAVIOUR OF VARIOUS MICROSTRUCTURES WITH THE SAME CHEMICAL COMPOSITION AND SIMILAR HARDNESS LEVELS

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KEYWORDS

Microstructure; hardness; abrasive wear; friction; abrasive particle size.

ABSTRACT

In the literature, the tribological behaviors in term of wear rate of various microstructures are investigated but only focused on wear and without fixing the hardness and/ or the chemical composition. Additionally, the investigation of the coupled contributions of microstructure and abrasive particle size are still lacking

A contribution is proposed by using of 25CD4 steel pins with various microstructures with the same chemical composition and similar hardness levels (310, 410 and 500Hv). In this study, pins are heat-treated to generate a brittle quenched martensitic microstructure, a tempered martensitic microstructure and three dual-phase microstructures, with different martensite colony morphologies, (Fig.1) for each hardness level. The friction tests are performed between these heat-treated pins against an abrasive paper with different sizes (15µm–200µm) and under different normal loads (50N-110N).

Whatever the hardness, it is shown that dual-phase microstructures, with a soft ductile ferrite phase and a hard martensite phase, present lower friction coefficient and wear rate than single-phase microstructures such as a tempered martensitic microstructure and a brittle quenched martensitic microstructure. For a hardness level of 410Hv, Figure 2 shows this effect of microstructure on friction coefficient and wear rate. Among dual-phase microstructures, granular and coarse martensite colonies present lower friction coefficient than fine and fibrous martensite colonies. This effect of microstructure on friction coefficient and wear rate are similar for the two other hardness levels (310 and 500Hv). In addition, whatever the abrasive particle size, as the normal load increases, these effects of microstructure on friction coefficient are reduced.

Whatever the microstructures and the hardness levels, the friction coefficient is minimized by an intermediate abrasive particle size of 35µm (Fig.2a) because of a transition between adhesive and abrasive wear mechanisms. Nonetheless, as abrasive particle size increases, wear rate and wear debris size increase (Fig.2b).

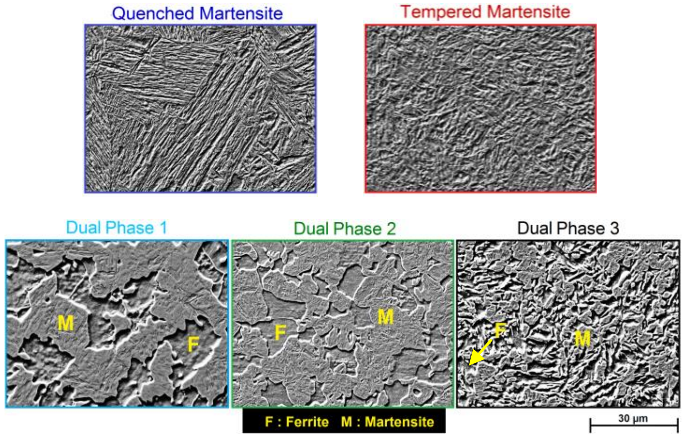

Fig. 1: Scanning electronic micrographs (SEM) of the studied microstructures of 25CD4 steel in the case of the hardness level of 410Hv.

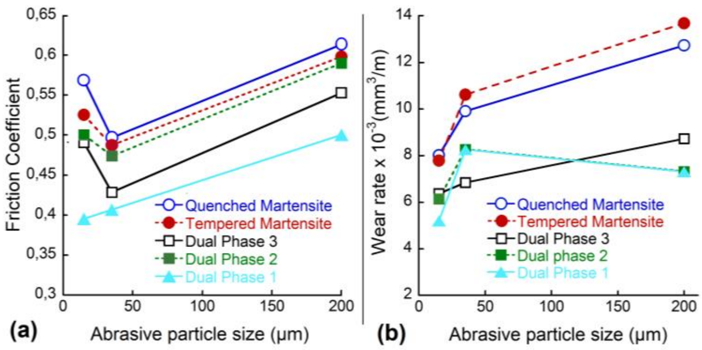

Fig. 2: Evolution of (a) the friction coefficient and (b) the wear rate as function of the abrasive particle size in the case of the hardness level of 410Hv under a normal load of 50N.

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HYDROGEL CONTACT MECHANICS

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KEYWORDS
Hydrogels; viscoelasticity; soft matter

ABSTRACT
Polymeric hydrogels are one of the most widely used soft materials in biomedical devices, sensing platforms, and cartilage tribology, among other applications. The optimum functionality of a hydrogel in a specific application strongly depends on appropriate mechanical and rheological properties. We present a magnetic force-based direct drive modulation method to measure local nano-rheological properties of polyacrylamide hydrogels across a broad frequency range (10 Hz - 2 kHz) using colloid-attached atomic force microscope (AFM) probes in liquid. The direct drive method enables artefact-free measurements over several decades of excitation frequency, and avoids the need to evaluate medium-induced hydrodynamic drag effects. The frequency bandwidth was further expanded to lower effective frequencies (0.1 Hz – 10 Hz) by acquiring force-displacement (FD) curves. Slow FD measurements showed a recoverable but highly hysteretic response, with the contact mechanical behavior dependent on the loading direction: approach curves showed Hertzian behavior while retraction curves fit the JKR contact mechanics model well into the adhesive regime, after which multiple detachment instabilities occurred. Using small amplitude dynamic modulation to explore higher strain rates, the load dependence of the storage stiffness transitioned from Hertzian to a dynamic punch-type (constant contact area) model, indicating significant influence of material dissipation coupled with adhesion. The study highlights possible transitions in the probe-material contact mechanical behavior for soft matter especially when the applied strain rates and the material relaxation rates become comparable [1].

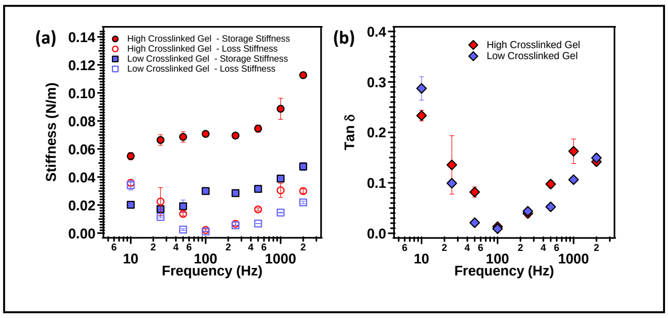

Fig.1 (a) The storage modulus (closed symbols), loss modulus (open symbols) and (b) tan δ as function of modulation frequency of the AFM cantilever for polyacrylamide gels with two different crosslinking densities.

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STUDY OF THE EFFECTS OF GASOLINE CONTAMINATION IN ENGINE OIL ON FRICTION AND WEAR

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1. Introduction

The effects of oxidation and contaminants such as soot, water, fuel and dust particles on engine lubrication have attracted significant interest and research within the area is growing as engine lubrication is critical factor of automotive performance and longevity [1-2]. Another reason industries and research are focusing on engine lubrications is due to their environmental impacts as the performance of engine lubrication effects such environmental factors such as exhaust emissions and engine efficiency [3].

Around 25% of automotive engine friction occurs in the valve train, with an estimated 80-85% of the friction losses taking place at the cam follower and the rest due to stem and valve guide, bearings, tappet and tappet bore [3-4].

This paper assesses how gasoline as an engine lubrication contaminant affects the tribology of the lubricant within valve train system. The study will focus mostly on the interface between the cam and follower to explore how gasoline affects the characteristics of the lubrication in these interfaces.

2. Methodology

The tribological experiments in this investigation were conducted using a high frequency reciprocating rig Cameron-Plint TE77. Fully formulated oil with various concentrations of gasoline from 0% to 12% were used at 25°C, 40°C and 80°C.

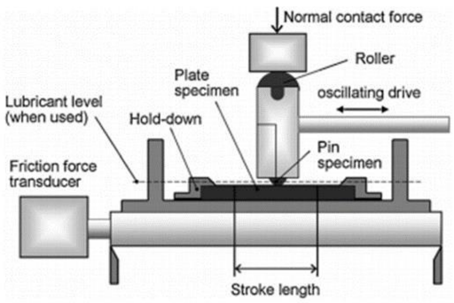

Figure 1: Schematic diagram of HFRR Cameron-Plint TE77 tribometer [1]

3. Results

The trends seen in friction at all three temperatures showed that there was an increase in friction coefficient mainly around 4% to 8% compared to the other concentrations.

For wear of the pins an inverse trend is seen to that for friction.

The viscosity of the solution also decreases as the gasoline concentration level in the fully formulated oil increases; this trend does not correspond with the friction and wear trends.

Investigations have also shown that due to the operating temperatures, lighter compounds of the gasoline evaporate at a higher rate than the heavier components, causing a build-up of heavier components of the gasoline which can be affecting the performance of the lubricant despite the decrease in viscosity.

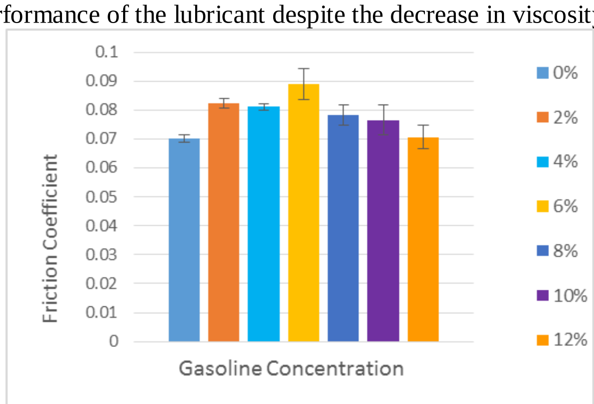

Figure 2: Friction coefficient results at 25°C tests

4. Conclusion

Results from this study have shown that the friction and wear experience in the presence of gasoline are not solely influenced by the viscosity change caused by the gasoline, and this paper assesses how gasoline affects the tribochemistry of the interface.

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INFLUENCING FACTORS ON THE DECOUPLING OF INDUCED ROTATIONAL OSCILLATION BY WET-RUNNING MULTI-PLATE PACKAGES IN CONTROLLED SLIP MODE

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KEYWORDS

Wet-running multi-plate package of clutch systems in slip mode, transfer and system behavior, decoupling of induced rotational oscillation

ABSTRACT

As a result of progressive mechatronization, modern clutch systems - for example, dual clutches or torque converter lock-up clutches - are increasingly controlled according to the situation and requirements. In order to improve controllability, they are operated in micro-slip. Additionally, it is possible, with appropriate adaptation and design, to implement a decoupling function of induced rotational oscillation at least partially aided by a specific slip operation [e.g. 1-3]. Slip operation has the decisive advantage that it can be regulated accurately according to the instantaneous requirements - until the clutch system is completely closed. This regulated slipping state has the consequence that the drive train is decoupled differently by the clutch system. These novel operating strategies lead to unknown phenomena which influence the dynamic behavior of the clutch system and the superordinate drive train. Wet-running multi-plate packages, as realized in dual clutches or torque converter lock-up clutches, are highly complex friction systems whose behavior is determined by the interactions of numerous influencing variables. Neglecting the masses or moments of inertia, stiffnesses and damping of the clutch system, the transfer behavior is determined solely by the multi-plate package and its tribosystems, wherein the greatest uncertainties lie. This is due to the lack of modelling and simulation approaches for tribological processes in such tribosystems at the current time as a result of a lacking holistic understanding of these systems.

The transfer behavior of the tribosystem depends on the structure of the tribosystem – e.g. friction pairing and lubricant as well as the input variables – e.g. kinematics, load and temperature in the tribological contact.

In addition to the validation, a targeted investigation of the complex tribological functional behavior is, therefore, necessary. This includes the interactions of the friction mechanisms in the tribosystem and the closed-loop interactions of the tribosystem with other components of the drive train. An innovative validation environment has been developed at IPEK - Institute of Product Engineering for a targeted investigation of these complex contexts. By the validation environment, all necessary input and output variables - torque and angular speed at the input and output of the multi-plate package - as well as state variables - clamping force applied to the multi-plate package and reaction force at the end of the multi-plate package, temperature of the steel plates, temperature of the cooling oil at the inlet and outlet of the multi-plate package - for determining the dynamic transfer behavior and the system behavior can be determined with high resolution. At the same time, all relevant interactions at the input and output of the multi-plate package are simulated over a wide frequency range up to approximately 150 Hz. This makes it possible to investigate the dynamic transfer behavior of multi-plate packages in a targeted and regulated slip mode for vehicle application [4-7]. In addition, a further purposeful investigation of the complex processes in the multi-plate package as well as the interactions of the tribosystems in the multi-plate package with the superordinate supersystem can be carried out.

This paper presents results from experimental investigations. The goal was the identification of relevant influencing factors on the decoupling of induced rotational oscillation by multi-plate packages in the slip mode as well as the objectification of their influence on the decoupling. It was also developed how the decoupling behavior can be described quantitatively – e.g. analogue hysteresis of DMF. By varying the input variables and the tribosystem an empirical model was developed in order to describe the transfer behavior of the tribosystem. For this purpose, both the tribosystem - by friction materials and lubrication oil variant and the input variables, e.g. kinematics and load, were varied.

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ANALYSIS OF THE RUNNING-IN BEHAVIOR OF A THERMALLY SPRAYED COATING

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KEYWORDS
Lubricated sliding wear, thermally sprayed coatings, running-in behavior, Stribeck Map

ABSTRACT

As thermal spray coated cylinder surfaces eliminate the need for cast iron sleeves or hypereutectic AlSi alloys, these coatings are becoming the main cylinder liner technology. Moreover, it has been found that these coatings also lead to low friction and wear. The reason for improved tribological performance is believed to result from a nanocrystalline layer that forms in the sliding contact. In this paper, we use on-line wear measurement to study the dynamics of the running-in process. A pin-on-disk tribometer coupled to a radionuclide wear measurement (RNT) system was used to investigate the friction and wear behavior of wire arc spray (LDS) coatings sliding against chromium coatings under lubricated conditions. After the friction experiments, X-ray photo electron spectroscopy (XPS) and Focused Ion Beam analysis (FIB) was used to characterize the worn surfaces.
By introducing a time-dependent Stribeck plot, we analyzed running-in under constant and transient sliding conditions and observed a strong reduction of friction in the boundary lubrication regime. Wear rates of the LDS disks as well as of the chromium plated pins are ultra-low. XPS revealed carbon diffusion at room temperature in wear tracks of disks that showed a very low coefficient of friction (CoF) of 0.01, whereas this carbon diffusion could not be detected in the wear track of a disk without running-in, i.e. a final CoF of 0.12. As this is the most significant difference found between differently run-in systems, the described carbon diffusion might be relevant for the observed friction behavior.
Running-in behavior can only be discussed in terms of friction, as, even with RNT, no significant wear could be measured. The comparison of running-in under transient and constant conditions showed only minor differences in the final friction behavior.

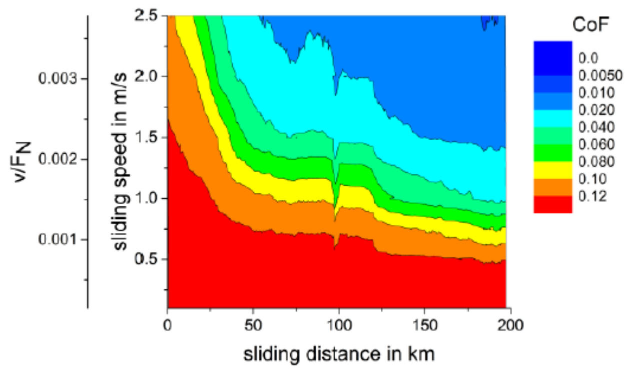

Fig.1 Stribeck map visualizing the running-in under constant load of 35 MPa and transient speeds.

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IMPACT OF SURFACE TEXTURE ON FRICTION PERFORMANCE OF CRANKSHAFT BEARINGS

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KEYWORDS

Belt texturing; Laser texturing; Crankshaft bearings; Surface texture.

ABSTRACT

Surface modifications and texturing in engine components is among valuables tribological solutions to the challenge of meeting more stringent energy efficiency requirements and environmental legislation [1]. This solution was interested Scientifics and industrials in last decade particularly for reducing friction losses at the piston ring and cylinder liner interface. It has led to the emergence of various honing finishing processes (plateau honing, helical slide honing…) and the proposition of alternative texturing process (laser texturing…). Nonetheless, for the journal bearing of the crank train in an automotive engine, second source of friction losses, there are not enough experimental results to confirm the improvement of texturing and its optimal features characteristics.

This paper is focused on the study of the impact of surface texture in the crankshaft bearings system for an automotive engine. Then, several surface textures and morphologies of a main crankshaft bearing are considered (Fig.1). They are generated respectively by conventional belt finishing [2], structured belt texturing [3] and hybrid laser texturing. Non textured "Mirror" smooth surface is also considered as reference.

Friction performance and durability of each crankshaft surface texture was evaluated by instrumented journal-bearing test-rigs under both static and dynamic loads experiments. Scuffing torque, scuffing temperature, minimal friction and Sriberg curve was then determined. The wear losses evolution of both crankshaft and pin was analyzed at different angular position after 15h, 30h and at seizure based on microscopic observations and topographic measurements.

Results highlight some potential geometrical specifications to consider to achieve reliable low friction bearings.

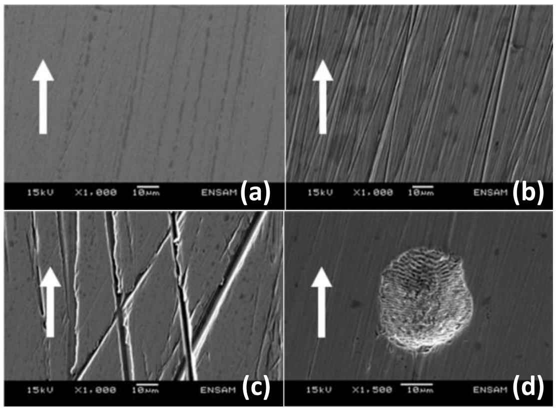

Fig.1 "Mirror" smooth surface (a) and crankshaft surface textures generated by conventional belt finishing (b), structured belt texturing (c) and laser texturing (d).

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THE IMPACT OF ANTIWEAR ADDITIVE ON SURFACE-FATIGUE PERFORMANCE OF DLC COATINGS IN ROLLING/SLIDING CONTACTS

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KEYWORDS
surface fatigue; hard thin-carbon coatings; ZDDP; tribochemistry; roller-element bearings

ABSTRACT
The surface fatigue performances of different types of DLC coatings including tetrahedral amorphous carbon (ta-C), tungsten-doped amorphous carbon (W-DLC) and (hydrogenated) amorphous carbon having a W-DLC bulk layer (W-DLC+a-C:H) lubricated with Base-Oil (BO) and BO+ZDDP are investigated using a modified-Micropitting Rig (MPR). The wear mechanisms in each coating have been studied using X-ray Photoelectron Spectroscopy (XPS), Scanning and Transmission Electron Microscopy (SEM and TEM).

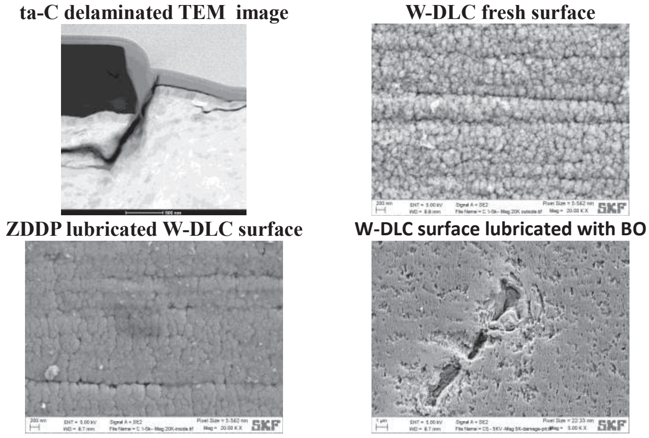
INTRODUCTION
Diamond Like Carbon (DLC) coatings due to their generally low wear and low friction properties are used in bearings, gearboxes and valve train components in automotive industry. Various parameters influence DLC coating properties and hence the tribological performance [1]. Moreover, lubricant formulation substantially influences the DLC coating performance [1] indicating the significant role of the tribochemistry.

In order to improve the lubricant performance anti-wear additives, such as Zinc Dialkyl DithioPhosphate (ZDDP), are used in bearings and gears lubricant formulations. Nevertheless, ZDDP under certain conditions enhances micropitting surface fatigue on steel surfaces [2]. The detrimental influence of ZDDP on micropitting and impact of tribochemistry on the performance of different DLC coatings necessitate mechanistic study of different DLC coatings with respect to different lubricant formulations under rolling/sliding surface-fatigue contacts.

METHODOLOGY
Experiments are carried out against rough steel counterbodies for durations of one and two-million contact cycles at 90°C under Slide-to-Roll Ratio (SRR) of 2%. W-DLC due to a superior performance was subjected to further experiments under SRR of 10%.

RESULTS AND DISCUSSION
While ta-C coating regardless of lubricant formulation undergone delamination originated from interlayer and substrate (Figure 1), a slight improvement in performance is observed for W-DLC+a-C:H where ZDDP was present in the lubricant showing a general local delamination and wear of the top a-C:H layer of the coating. In most of the regions the wear did not exceed the a-C:H exhibiting intact W-DLC bulk layer. Although ZDDP enhances micropitting on steel, it profoundly protects the W-DLC surface from wear and only slight polishing wear was observed on the surface as shown in Figure 1. Removing ZDDP from lubricant promotes micorpitting on the W-DLC. XPS confirmed that ZDDP-tribofilm formed on the surface protects the tungsten from oxidation and subsequent oxidative wear in agreement with TEM results.

Figure 1. TEM and SEM images of the castings



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EFFECT OF COMBINAION OF PROTEINS ON FRICTIONAL PROPERTY FOR JOINT PROSTHESIS MATERIALS

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KEYWORDS
protein adsorbed film; joint prosthesis; frictional property

ABSTRACT

The constituents included in natural synovial fluid affect on frictional properties of joint prosthesis materials. Authors has investigated the effect of proteins on frictional property[1]. As a results, BSA (bovine serum albumin) and HGG (human γ-globulin) formed lamellar structure when the adsorbed film had excellent tribological properties, but heterogeneous structure was formed when friction and wear increased. It was supposed that the lamellar structure slipped in BSA layer or between BSA and HGG layer. For understanding the mechanisms of excellent lamellar structure, it is necessary to clarify the frictional property of adsorbed protein film. In this study the frictional property of BSA and HGG was investigated and discussed the mechanisms of low frictional property of the lamellar structure.

UHMWPE (ultra-high molecular weight polyethylene, GUR 1050) pin and CoCrMo alloy (ASTMF 75) plate was employed for friction tests. Average contact pressure was varied from 0.047 to 14.6 MPa by changing load and pin end aspect. UHMWPE pin ends were 4mm diameter flat, 250mm radius sphere and 12mm diameter sphere. A reciprocating tribometer was employed to measure frictional properties of protein lubricant. Lubricants were PBS (pH 7.4) with BSA or/and HGG. Frictional test was carried out for 30 min under sliding velocity 10 mm/s (total sliding distance was 18 m).

Figure 1 shows relationship between contact pressure and coefficient of friction. BSA lubricant showed low coefficient of friction compared to HGG lubricant under 5 MPa. Coefficient of friction of BSA lubricant was decreased with increase of contact pressure. The transition indicates that adsorbed BSA was play a role of fluid film under 5 MPa. The experimental condition forms quite thin fluid film under 0.1 nm, so that the transition of BSA lubricant against contact pressure was due to adsorbed BSA molecules. On the other hand, HGG solution showed high coefficient of friction around 0.3 MPa. The different frictional properties of BSA and HGG indicate that shear resistance is different on contact pressure. The lamellar structure composed from BSA and HGG was observed around 0.3 MPa contact pressure, so that the difference induced low frictional property of lamellar structure due to low shear resistance of BSA molecules. Coefficient of friction over 5 MPa showed high compared to that under 5 MPa. In the range, BSA also showed similar property to HGG. Combination of BSA and HGG showed low coefficient of friction. In addition, combination of BSA and HGG did not showed increase of coefficient of friction with increase of contact pressure even over 5 MPa, and the property was similar to BSA lubricant under 5 MPa. Therefore, it is considered that frictional property of BSA was appeared by combination of BSA and HGG by forming lamellar structure.

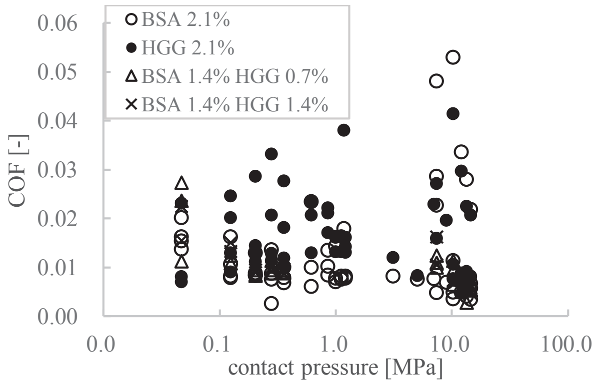

Fig. 1 Coefficient of friction with contant pressure

ACKNOWLEDGMENTS

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THE CONTACT BETWEEN ROUGH SURFACES IN PRESENCE OF A FLUID FLOW IN THE INTERFACE: A STRONG COUPLING SCHEME

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KEYWORDS
mechanical contact; surface roughness; trapped lubricant; fluid-structure interaction

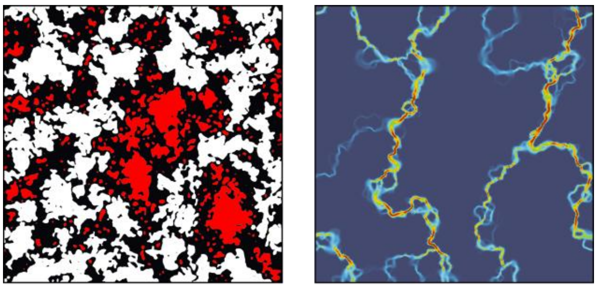
ABSTRACT
We study the problem of a thin-film viscous flow of compressible and incompressible fluids (governed by the Reynolds equation) across the contact interface between elastic solids with rough surfaces brought in contact by the external load. We derive a coupled weak formulation, perform finite-element simulations on a representative volume element (RVE) and consider a self-affine Gaussian roughness [1]. This problem has applications for static seals and lubrication in mixed regime, but also for poromechanics, slip in geological faults and basal sliding of glaciers.

The roughness of the surfaces determines the real contact area and the free volume distribution, and thus the transmissivity of the interface, while the fluid provides additional pressure on the contacting surfaces, see Fig. 1. Two approaches can be used for numerical treatment of the strongly coupled problem: (I) the partitioned approach, in which the solvers for mechanical contact and fluid flow are separated, and (II) the monolithic, meaning that the equations for contact and fluid are rendered into one system and solved simultaneously. We implement both of these approaches in the finite-element method (FEM) framework and compare their results.

It is important to note that under sufficiently high external loads or for sufficiently rich spectral content of the surface, non-simply connected contact patches can be present in the contact interface (see Fig. 1a, in red color), and the entrapment and pressurization of the fluid in the valleys between the contacting asperities must be taken into account.

In addition to the global coupling study, the particular problem of the trapped fluid is considered in detail using a simplified geometry: the frictional contact between an elastic body with a wavy surface and a rigid plane with incompressible or linear and nonlinear compressible fluid present in the valleys, see Fig. 2. This problem has an analytical solution under the assumption of small slope of the profile [2]. We derived a monolithic weak form for contact and fluid volume constraints and solved the problem in the FEM framework. We have shown that, unlike the analytical solution, if the slope of the profile is considered finite, then under the increasing external pressure the fluid will eventually open the contact interface, and the maximal static frictional force first increase and then decrease to zero under monotonically increasing external pressure [3].

We study also the generalization of the considered problem for the fluid flow across the wavy contact interface, using the aforementioned strong coupling framework and compare the numerical results with an approximate analytical solution.



(a) (b)

Fig.1 (a) Morphology of the contact interface: black is the contact area, white is out of contact, red is "trapped". (b) Incompressible fluid flow through the interface: the color represents the flow intensity.

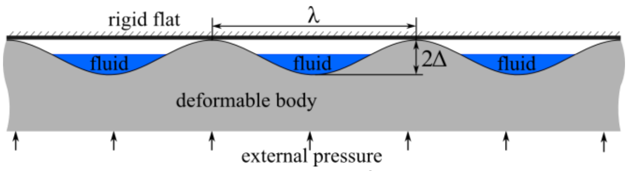


Fig.2 Fluid trapped in the contact interface between an elastic body with a periodic wavy surface and a rigid flat.

ACKNOWLEDGMENTS
The authors acknowledge the financial support from MINES ParisTech (Thèse-Open) and Safran Tech. Enriching discussions and help of JulienVignollet are greatly appreciated.

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44th Leeds-Lyon Symposium on Tribology-September 4-6, 2017, Lyon, France

Effect of tungsten carbide addition on the tribological behavior of Astaloy 85Mo powder consolidated via spark plasma sintering

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KEYWORDS

Astaloy85Mo; WC; spark plasma sintering, friction, wear

ABSTRACT

Hard particle additions in ferrous powders allow the production of sintered materials with higher toughness, hardness and wear resistance, with potential use in different applications [1-3]. This combination of properties is attained following correct mixture and sinterization procedures that result in the formation of composites with low porosity and adequate particle distribution (Fig. 1). In this work, Astaloy 85Mo ferrous powders were mixed with different WC additions (2, 5,7 and 10wt. %) by mechanical alloying (MA) and consolidated by spark plasma sintering (SPS), providing samples with higher real density, according to the rule of mixtures, and without increase in porosity (or apparent volume) [2,4]. SPS enhanced sinterability by using low sintering times that reduce carbon diffusion from WC to the ferrous matrix. Tribological evaluation was conducted by means of ball-on-disc tests with different loads (1, 5 and 10N). Specimens were in contact with a 100Cr6 ball with diameter equal to 6 mm diameter and the friction coefficient and wear volume were reported. Results indicated that an addition of 10 %wt of WC provided an increase (85%) in matrix hardness and that the higher amount of WC particles in the sliding contact contributed with higher load support and wear resistance (Fig. 2).

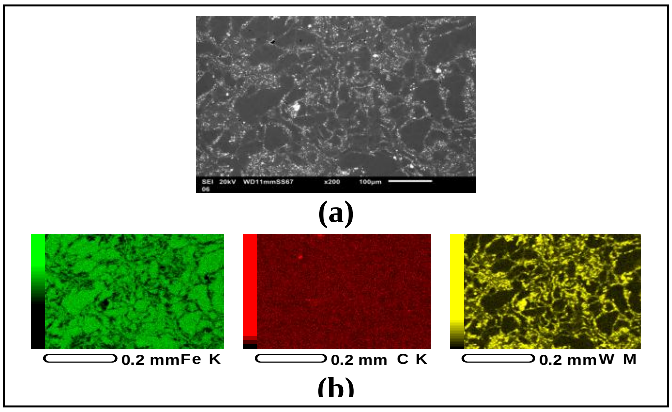

Fig. 1 Microstructure of Astaloy85Mo+10%wt WC powder mixture (a) MEV image and (b) EDS mapping.

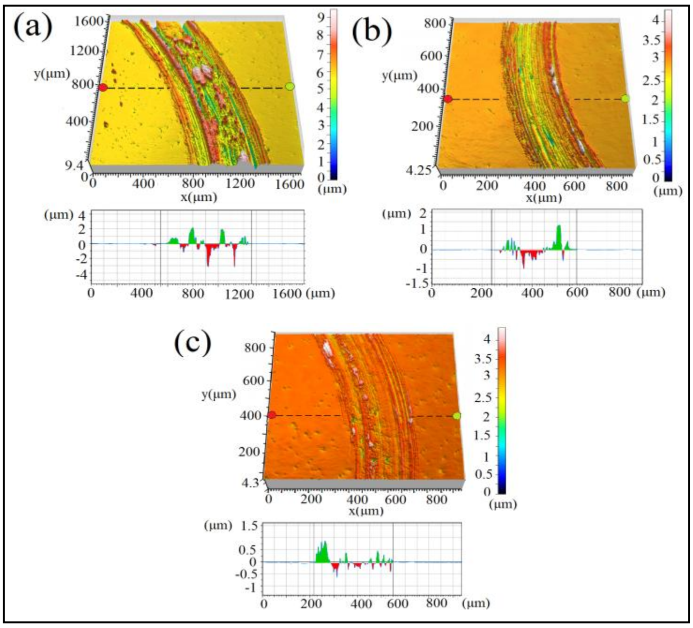

Fig. 2 Wear track profiles after ball-on-disc test using a load of 5N and sliding speed of 100cm/s for (a) Astaloy85Mo (b) Astaloy85Mo+5%wtWC and (c) Astaloy85Mo+10%wt WC

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ACHIEVING SUPERLUBRICITY WITH FULLY-FORMULATED ENGINE LUBRICANTS

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KEYWORDS
Friction; wear; trimer; DLC; CrN

ABSTRACT

Structural Superlubricity is the state in which two contacting surfaces slide with no resistance within measurement error (< 0.01 CoF). Real-world superlubricity aims to achieve significant friction reduction (≤ 0.04 CoF) of fully-formulated engine lubricants between real engine parts or in actual engines. Kano (1) reported a friction coefficient as low as 0.02 with actual engine parts (ta-C on steel). The lubricant he used was a binary blend of Glycerol Mono-oleate ester in PAO; this lubricant did not contain ZDDP, Anti-oxidants, or metal detergent, dispersant, or other components required for a fully-formulated oil.

This paper demonstrates the achievement of real-world superlubricity conditions between a coated piston ring and a cylinder liner in reciprocating motion. The noteworthy part of the attaining a 0.035 CoF was achieving it with a fully-formulated SAE 0W-20 engine oil. Furthermore, improvements in wear protection were found with this oil while using DLC-coated parts from the crankcase.

Surface coatings on the rings tested included CrN and Hydrogen-free DLC. Cylinder liner materials included both regular honed Gray Cast Iron and Coated bore with a Mirror-Like Finish. Elemental mapping, surface morphology, and chemical species on the surfaces were characterization by SEM-EDS, XPS, SIMS, and STEM. An example STEM image of a tribofilm cross section is shown in the Figure below.

Effects of Molybdenum chemistry and organic friction modifiers for friction reduction are discussed.

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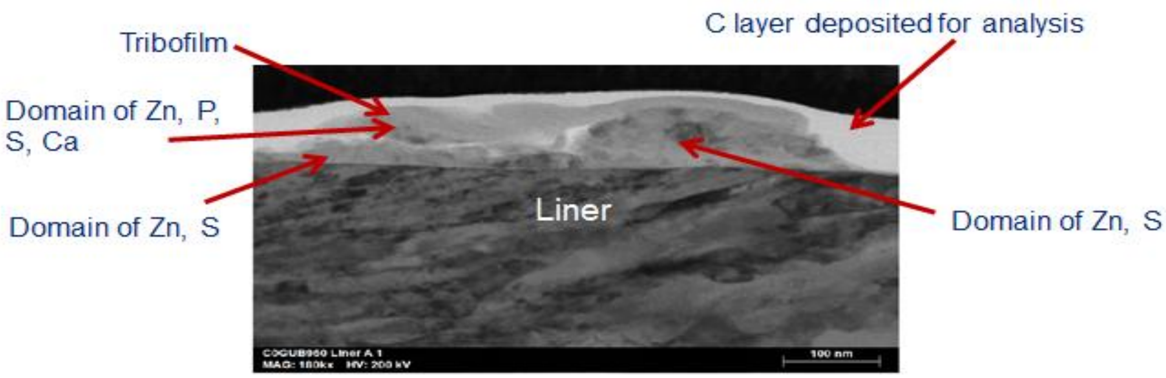
Figure 1. STEM Image of Tribofilm formed on an iron surface.



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FRICTION ON A BORDER OF MIXED EHL CONTACT

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KEYWORDS

Fluid film friction, mixed lubrication, rheology, lubricant flow

ABSTRACT

Numerous machine elements operate under conditions of mixed lubrication where load is carried by contact between asperities and elastohydrodynamic lubricating film. In this regime, generated mean film thickness is often lower than initial average surface roughness being deformed in the contact. Hence, there is an ongoing challenge in precise prediction of real transition to mixed lubrication. In classical theory, the initial point of transition is considered at increase of friction from EHL regime known from Stribeck curve. To further extend the knowledge it is necessary to simultaneously measure thin lubricating film and dynamic friction.

The aim of the study is to reveal relation between real surface separation and friction produced by thin-film lubricating film at the border between full film and mixed regime. Improved thin film interferometric technique and dynamic friction measurement are combined in ball-on-disc optical tribometer. Contacts between real rough surfaces were studied. Evolution of film thickness and friction during speed drop are presented for surfaces with various roughness. The results are discussed in relation with lubricant rheology and lubricant flow inside contact. This study presents new findings about origin of friction in thin-film lubrication.

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THE ROLE OF NAYAK'S PARAMETER IN ELASTIC CONTACT OF ROUGH SURFACES

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KEYWORDS

surface roughness, normal contact, Nayak's parameter, Hurst exponent, true contact area

ABSTRACT

Properties of contact between solids, whose surfaces are inevitably rough, to a great extend are related to characteristics of their roughnesses. In real life, surface topography can be very complex and, in general, it does not obey simple assumptions such as normality of high distribution, isotropy and self-affinity. However, some surfaces (for example, electroplated and, to a certain extend, sandblasted) respect them, and thus can be assumed to posses stationary roughness properties, i.e. the height distribution does not depend on the scale, at which the roughness is studied. For such isotropic self-affine surfaces with a Gaussian height distribution, Nayak's theory of roughness [1] can properly describe all geometrical characteristics needed to study the mechanical contact between rough surfaces, in particular, probabilities of summits and their curvature at different heights. Nayak's parameter is one of the key surface parameters in this theory and it is related to the breadth of the surface spectrum. Many multi-asperity models [2] are thus based on this theory, and all of them predict in the asymptotic limit of infinitesimal contact a linear growth of the true contact area with the increasing nominal pressure as it does Persson's model too [3]. But the constants of proportionality in these models differ significantly. For realistic values of the contact area, all multiasperity models predict a non-linear evolution of the contact area, which is strongly dependent on the Nayak's parameter: the greater it is, the smaller the contact area is for the same normalized pressure. On the other hand Persson's model predicts the contact area evolution, which does not depend on this parameter.

All aforementioned models are inevitably based on certain assumptions, because the contact problem is very complex as well as the roughness topography and cannot be fully treated analytically even in terms of the mean fields. To address the question “how the true contact area grows with the pressure?” and “what are the relevant roughness parameters?” we carry out a numerical study of normal non-adhesive and frictionless contact between linearly elastic half-spaces with the effective Gaussian self-affine roughness. A special contact-area correction technique is used to ensure that the results are independent of the surface discretization [4], which enables us to obtain the results with unprecedented accuracy even for surfaces with broad spectra including harmonics of several orders of magnitude.

Our numerical results confirm the dependence of the contact area on the Nayak's parameter, but contrary to multiasperity models, this dependence is significantly weaker: we found that for a fixed normalized nominal pressure, the contact area decreases logarithmically with the Nayak's parameter. Interestingly, surfaces with different Hurst exponents but the same Nayak's parameters show the same contact area for the same load. Moreover, our numerical results suggest that the contact area evolution up to approximately 20% obeys a second order polynomial dependence on the normalized pressure, with parameters changing logarithmically with the Nayak's parameter [5]. Finally, this parameter can be expressed through the Hurst exponent of the roughness or equivalently through its fractal dimension and the cut-off wavelengths. Thus we can estimate phenomenologically the effect of the Hurst exponent (which is sometimes easier to measure than the Nayak's parameter) on the true contact area growth.

In conclusion, this numerical study permits to deduce simple phenomenological equations for the contact area growth with the load, and to determine, based on roughness characteristics,physical meaning of coefficient in pressure-dependent friction laws.

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LOCAL OCCUPANCY OF VISCOELASTIC INTERFACES: A NEW RHEOLOGICAL PERSPECTIVE ON ANTIWEAR TRIBOFILMS

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KEYWORDS
Viscoelasticity; Rheology; Tribochemistry

ABSTRACT

The ultra-thin tribofilms generated from zinc dialkyldithiophosphate (ZDDP) and ashless dialkyldithiophosphate (DDP) have long been considered as rigid interfaces that act as a mechanical barrier [1], which helps protect the metal surface from severe wear. Although some studies suggested that these tribofilms can also behave as a viscous polymer [2] or a molten glass [3], no evidence was provided to confirm these proposed antiwear mechanisms. Using the Atomic Force Microscope (AFM), this study shows for the first time that ZDDP and DDP tribofilms work as viscoelastic interfaces, which under shear can flow and spread through the contact area. This can be easily observed in Fig. 1, which shows the structure evolution of a mature ZDDP tribofilm after sheared at different contact pressures. The results show that the tribofilm coverage changes as a function of time and contact pressure. The coverage evolves from an area of 5 um x 5 um under 2.1 GPa to an area about 7 um x 7 um under 4.5 GPa.

The remarkable rheological properties of the antiwear tribofilms of ZDDP and DDP have great implications in our understanding on how they provide their antiwear protection. Our initial results suggest that the rheological properties of these tribofilms enable them to maintain local order on the nanoscale through the motion, rearrangement and local reconfiguration of single and multiple patches at the interface. Eventually, these isolated patches coalesce to form elongated streaks in the direction of shear. The flowability of the tribofilm along with the local occupancy of its pads and their interaction with their nearest neighbors can affect the shape, growth and ultimately the tenacity and removal of the tribofilm.

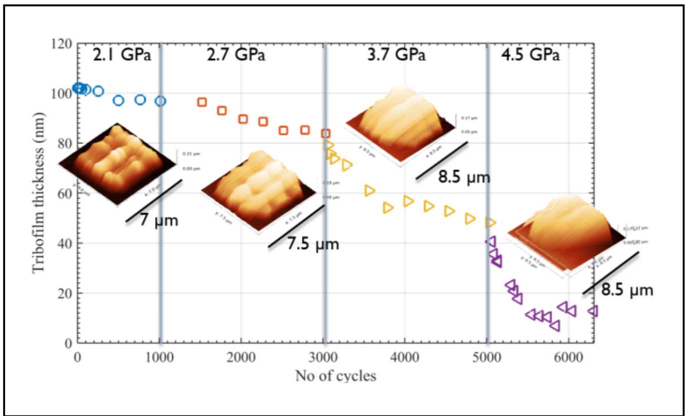

Fig.1 Evolution of the ZDDP tribofilm structure after sheared at different contact pressures

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TRIBOLOGICAL STUDY OF A MULTILAYER COATING OF Ta/ZrN PRODUCED BY DC MAGNETRON SPUTTERING ON AISI-361L STAINLESS STEEL

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KEYWORDS
Ta/ZrN multilayer coatings; wear; magnetron sputtering; 316L stainless steel

ABSTRACT
The implantation of artificial joints, in particular for replacing failed hard tissues such as artificial hip joints, dental implants, is used to help plenty of people to reestablish the function of damaged parts in their bodies. There is an increasing interest in the development of novel coatings or surface modification treatments to improve functional properties (mechanical, wear, corrosion, fretting, weight, cost, bioreaction, etc.) of metal biomaterials, such as stainless steel, titanium, and CoCrMo alloys are commonly used.

In this regard, Ta/ZrN multilayer coating with different modulation ratios was obtained by magnetron sputtering system and deposited. The DC power was fixed for Ta and Zr target at 200W and 45 W respectively. The working pressure was maintained at the range of 6×10^{-3} Torr. The N_2/Ar relation was 0.5. Pre-sputtering of 10 min was performed for cleaning the target surface prior to starting the deposition, with time deposition of 120 min for each layer. The multilayer was produces with and without nitrate injection time periods, obtaining coatings of 3 µm. The coating was characterized chemically and structurally with Scanning Electron Microscope-Energy Dispersive Spectroscopy (SEM-EDS) (Fig.1), X-Ray Diffraction (XRD) respectively.

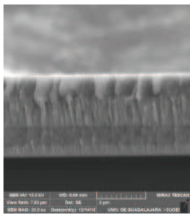

Fig.1 SEM image of TaZrN/TaZr multilayer coating.

The tribological tests were carry out by reciprocating sliding wear tests employing a 10 mm diameter Al_2O_3 ball as counter-body. The friction force was registered along the essays, the tests were carried out at applied loads of 0.5, 1, and 2 N, and a sliding time of 1800 sec at dry conditions. The wear tracks produced were characterized using optical microscopy (Fig-2), SEM, Raman spectroscopy and the wear lost was measured using stylus profilometer.

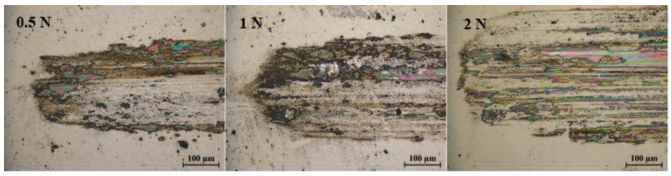

Fig.2 Optical micrographs of the wear tracks of the three layers TaZrN coating at different loads

ACKNOWLEDGMENTS
Authors want to thanks to REDISYT and CONACyT for the support, and to Eng. Sergio Oliva León for his help.

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"Study of adhesion and aging behavior of rubber blends analyzed under the Multiscale-Contact-Mechanics (MCM) and a theoretical kinetics framework of aging: Implications for their functionality"

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Abstract

Rubber blends have a complex behavior and it had been the subject of theoretical modeling from long time. Seminal works by Han, Cole-Parmer, Cole-Cole, and others have been directed to elucidate the behavior of a blend from their viscoelastic behavior. Their composition, structure and properties have also an impact on their functional behavior, for example friction and adhesion. Persson's contact mechanics theory is an excellent theoretical frame to study such complicated functional behavior.

Using DMA-stress relaxation, Differential Scanning Calorimetry:Oxygen Induction Time, and tensile pull off forcewe have studied the impact of aging on the functional performance of butyl, styrene-butadiene, and Isoprene rubber blends.
The adhesion of the rubber blends to glass and polymer substrates is presented. The additional characterization by DMA and preliminary friction results from a Leonardo da Vinci experimental set-up (constant driving force) allow to pin point the origin of the adhesion changes during aging.

The friction force depends non-linearly on the load, which we attribute to the influence of adhesion on the area of real contact. The calculated dependency of the area of real contact on the load is compared with the experimental results.

Comparisons between the functional changes due to aging and kinetic modeling of the aging phenomena is also presented.

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

NUMEICAL SIMULATION OF HYDRODYNAMIC LUBRICATION BY SMOOTHED PARTICLE HYDRODYANMICS METHOD

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ABSTRACT

Smoothed particle hydrodynamics method(SPH) method allows us to treat fluid flow with large deformation of liquid-air boundary, fragmentations and collision with solid wall.

Boundary conditions are required to solve Reynolds' equation for hydrodynamics lubrication. Especially, oil film rupture at the outlet of lubricated area has been an intense subject of interest [1]. It is difficult to know exactly the position at which oil film rupture will occur and the pressure in the area of oil film rupture [2].

To avoid the problems with boundary conditions, we applied SPH to the hydrodynamic lubrication. Time evolution of oil film profile can be obtained. Film rupture spontaneously develops at the outlet.

METHOD

The classical geometry of hydrodynamic lubrication shown in Fig. 1 is simulated. The motion of an incompressible fluid is governed by the Navier-Stokes equations,

$$\frac{D\boldsymbol{u}}{Dt} = -\frac{1}{\rho}\nabla p + \frac{\eta}{\rho}\nabla^2\boldsymbol{u} + \boldsymbol{F}_{ST}$$

Surface tension is incorporated as a body force $\boldsymbol{F}_{ST}$. According to the Akinci's model, $\boldsymbol{F}_{ST}$ is a combination of inter particle forces and forces based on surface curvature [3]. Calculating method for vector operaters in Navier-Stokes equation and solid wall boundary contion are same as Adami's way [4]. Numerical models is computed using the same operating conditions as described in the literature(Fig.3(a) in ref. [1]).

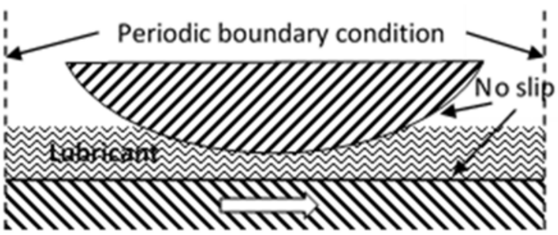

Fig.1 Model geometry

RESULTS

Figure 2 shows a snapshot and pressure profile. Positive pressure by SPH agrees with solution of Reynolds eq.. Fluctuation in outer region is attributed to surface tension model.

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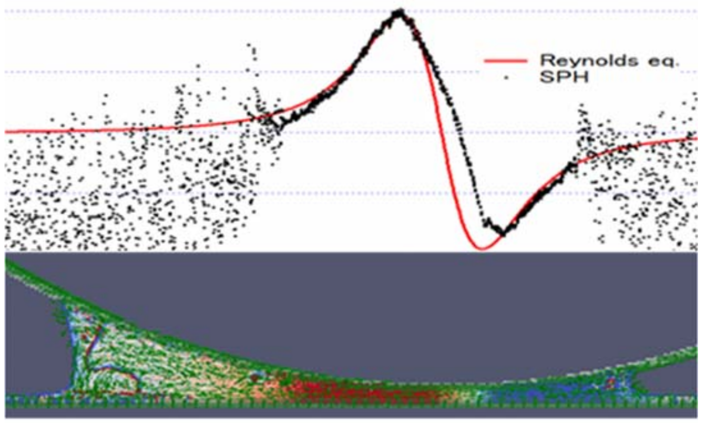

Fig. 2 Snapshot with arrows of velocity vector and pressure profile

A New Asperity-Scale Mechanistic Model of Tribocorrosive Wear: Synergistic Effects of Mechanical and Corrosive Wear

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Abstract

An electrochemical wear model is considered at the asperity-scale of a tribocorrosive wear system as well as the traditional Archard-type mechanical wear model. The geometry of the surface asperities are modified in a contact mechanics model with respect to both electrochemical and mechanical wear calculations. The model is then used to predict the chemical and mechanical components of the total wear of the system. Synergistic effect of corrosion on mechanical wear and mechanical wear on corrosion are modelled numerically in this work. The values are then used to explain different components of mechanistic tribocorrosive wear models present in the literature and wear maps are developed for different loads and sliding speeds. This deterministic model, for the first time, calculates the corrosion enhanced wear in a tribocorrosive wear environment and proposes that changes in the topography are responsible for this synergistic effect. The wear enhanced corrosion can be modelled using the electrochemical wear model due to the dynamic de-passivation and consequent re-passivation of the surface oxide layers.

Key words: *Tribocorrosion, Wear modelling, Electrochemistry, Wear map*

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EFFECT OF TEMPERATURE ON TRIBOLOGICAL PERFORMANCE OF MODTC

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KEYWORDS
MoDTC; friction modifier; temperature effect; tribofilm; MoS_2

ABSTRACT

Molybdenum dithiocarbamate(MoDTC) is well-known as a friction modifier to obtain low friction coefficient under boundary lubrication conditions[1]. It has been reported that the tribological performance of MoDTC is affected by many factors such as concentration of MoDTC, combination of co-additives such as an anti-wear additive, base oils, contact conditions and temperature[2]. In this report, we focused on the effect of temperature on lubrication property of MoDTC. Lubrication tests were carried out in 400 ml of lubricant oil containing ca.2000ppm of MoDTC and ca.2500ppm of calcium sulfonate(CaSU) at temperatures of 25, 40, 60 and 80℃.

Typical curves of friction coefficient obtained at different temperatures were shown in Figure 1. The friction coefficient decreased readily after an induction period and became to be constant at higher temperature than 40℃. It was found that a shorter induction period, a steeper slope and a lower friction coefficient at a steady state were observed at higher temperature. These results can be explained by the formation rate of MoS_2 from MoDTC becomes to be higher at higher temperature. It was observed that friction coefficient was sensitive to the temperature of lubricant oil. Friction coefficient was changed reversibly by oil temperature.

Tribo-films on ball surface were analyzed with HR-TEM and XPS after lubrication tests. XPS analyses revealed that the intensity ratio of Mo(IV)/Mo(VI) was increased at higher temperature. This result suggests that low friction coefficient can be obtained by high MoS_2 content in the tribo-film formed at higher temperature. Moreover, highly oriented structure of MoS_2 in the tribo-film formed at 80 ℃ was observed by TEM observation. It can be concluded that low friction coefficient at 80℃ is originated from the highly oriented MoS_2 structure in the tribo-film.

A steady state model of tribo-film formation will be discussed.

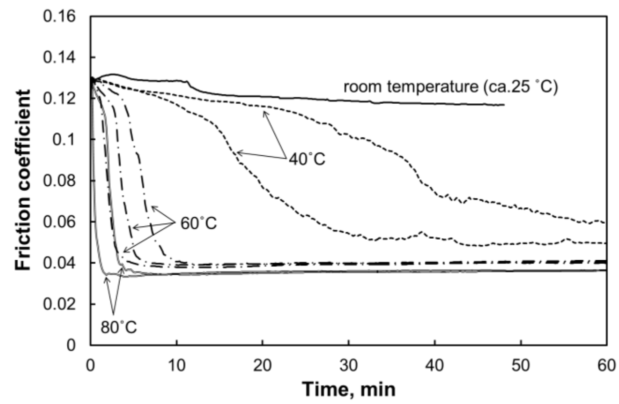

Fig. 1 Friction coefficient as a function of temperature for MoDTC-containing lubricant.

ACKNOWLEDGMENTS
This study was supported by "TIMT" funded by MEXT and Reconstruction Agency, Japan.

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STROKE-AVERAGED LOAD CARRYING CAPACITY AND FRICTION OF A ROTATED PARABOLIC-FLAT PISTON RING

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KEYWORDS
piston ring; starved lubrication; friction; isoviscous-rigid

ABSTRACT

Over the last two decades, the fuel consumption reduction of combustion engines has become an important environmental issue. Engine friction has to be reduced and the piston ring - cylinder liner contact is a major source of friction [1]. The current work analyses the friction and load carrying capacity of a rotated parabolic - flat piston ring. This friction and load carrying capacity are averaged over the operating conditions occurring over the entire stroke. The resulting friction and load carrying capacity are given as functions of twist angle, ratio of flat width and total width and the total width.

RESULTS

The current work is an extension of [2] introducing an exact rotation of the piston ring. The Couette friction W_C is given by the following expression:

$$W_C = \frac{SRR}{12}\left(\left(\alpha \ln\left(\frac{\left(M^2+1\right)J^2}{2Q\alpha^2}\right) + \frac{2\alpha Q^2}{J}\left(\arctan(\frac{\alpha^2}{J}) - \arctan(M)\right)\frac{\ln(R)}{\alpha}\right)$$

where α is the angle; SRR is the side-roll ratio and M, Q, J and R are expressions defined in [2] that allow a concise description

Similar expressions are obtained for the Poiseuille friction and the load carrying capacity. All these expressions are analytical and can be calculated very rapidly. As such, one can calculate the values for each crank angle and obtain a stroke-averaged result.

The figure below shows how the stroke-averaged coefficient of friction depends on the three parameters.

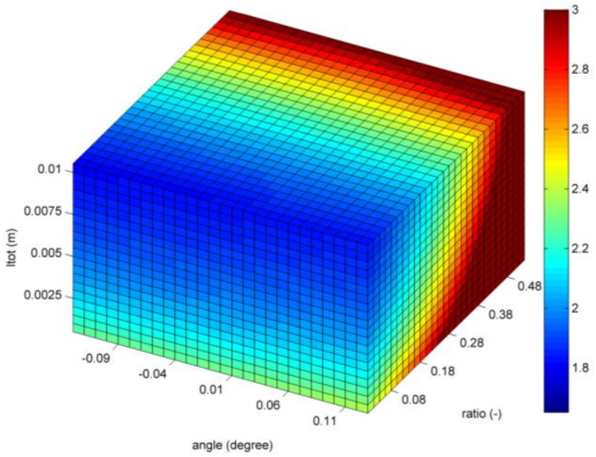

Fig.1 Stroke-averaged coefficient of friction

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SLIDING WEAR BEHAVIOR OF DLC UNDER LUBRICATED CONDITIONS AT ELEVATED TEMPERATURES

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KEYWORDS
Wear Volume; Aluminum oxide; Silicon Nitride; Lubricant; Tribo Oxidation.

ABSTRACT

The influence of temperature and counter body material on the tribological properties of a-C:H coatings deposited on Cronidur 30 steel has been investigated in a lubricated ball on disk contact situation with an oil temperature up to 250°C. The results show, that the wear volumes of the system increase exponentially with increasing temperature. Two different wear mechanisms seem to have a major influence: First, the abrasive action due to materials hardness and second, the tribo-oxidation when silicon nitride is counter material. The counter bodies were made of aluminum oxide and silicon nitride with a diameter of 10 mm. The DLC layer is an a-C:H layer (KYB Type A from KYB, Sagamihara, Japan) with a chromium intermediate bond layer of about 50 nm deposited on steel Cronidur 30-(X 30 CrMoN 151, annealing temperature of about 480°C). The tribological tests were carried out with SRV 3 tribometer (Optimol Instr., Munich, Germany) in a ball on disk configuration and a normal load of 10 N.

At room temperature the wear resistance of the a-C:H coating against α-alumina counter body is about 2.5 times higher than against silicon nitride. With increasing temperatures, the ongoing softening of the DLC layer leads to a stronger increasing wear volume with α-alumina counter body since its hardness remains high and tribo-oxidation is not existent. In the case of silicon nitride as counter material, the wear volume is initially higher due to the underlying tribo-oxidation on silicon nitride counter body. One possible oxidation reaction is the following:

$$\mathbf{Si_3N_4 + 5O_2 \longrightarrow 3SiO_2 + 4NO}$$

With increasing temperature, however, the wear volume increases, too, but not as sharply with temperature as in the case of α-alumina. This may be explained by, first, the lower hardness of silicon nitride (less abrasive) and second, by the increasing content of silica as a product of the tribo-oxidation process and its influence on wear as a wear modifying constituent of the lubricant [1]. This may also explain the observed difference in the coefficient of friction. At all temperatures the friction coefficient is significantly lower with α-alumina as counter material. Generally, these findings correlate well with the results of an earlier investigation on ta-C coatings under dry sliding conditions [2].

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EFFICACY OF COATINGS AND THERMOCHEMICAL TREATMENTS TO IMPROVE WEAR RESISTANCE OF AXIAL PISTON PUMPS

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KEYWORDS
Tribological performance evaluation and rating
Stainless steel; coating; nitriding; wear; axial piston pump;

ABSTRACT

A former study focused on wear mechanisms in helicopter axial piston pumps. It showed that the origin of wear in this system is the contact between piston shoes and swashplate, where the main wear mechanism is three-body abrasive wear due to coarse carbides removal. The resulting debris and particles are conveyed by the lubricating fluid and cause abrasive wear in the other contacts. In the literature, few studies report cases of wear due to carbides removal and hydraulic fluid pollution by hard debris. Moreover, these studies often characterize the origin of wear without suggesting solution to diminish it. This study consists in an experimental analysis of solutions to reduce wear between shoes and swashplate. Based on the former results, coatings, thermochemical treatment on stainless steel of swashplate (3S) have been proposed. The friction and wear tests have been performed on a rotative tribometer in order to simulate experimentally the shoes/swashplate motion. Wear mechanisms are analysed using Scanning Electron Microscopy (SEM) observations and Energy dispersive X-Ray (EDX) chemical analysis. The wear rates are quantified by using a 3D profilometry. Four different configurations are tested: ball-on-disk and pin-on-disk, both in dry and lubricated conditions. Ball-on-disk contact represents a first wear resistance test; it reproduces extreme conditions. Pin-on-disk contact reflects more accurately the friction between shoes and swashplate. The dry case is taken into account to model the most unfavourable case of limit lubrication regime. The observations and measurements reveal that the stainless steel of swashplate (3S) suffers carbides removal in the extreme cases, even with lubricant. Solid lubricant such as PTFE coating avoid carbide removal by diminishing the coefficient of friction but are less resistant in highly loaded contact. The nitriding treatment of 3S leads to further increasing of the wear resistance of the swashplate, but only under lubricated conditions. The DLC coating is the most efficient solution.
It minimizes the friction coefficient and wear rate under dry and lubrication conditions (figure 1 and 2). The latter configuration could be proposed as solution to increase the lifetime of axial piston pumps.

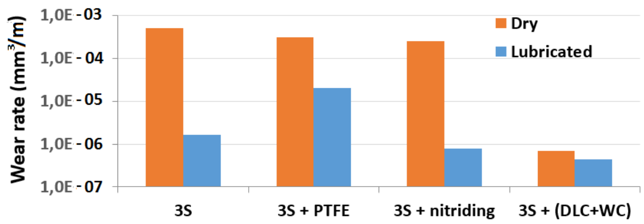

Figure 1: wear rate for each treatment on 3S: case of alumina ball on disks (40 N, 4000 seconds)

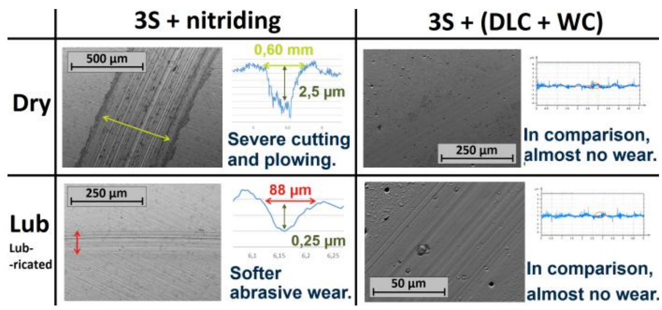

Figure 2: SEM observations and roughness profiles: Wear tracks in the case of alumina ball on disks (40 N, 4000 seconds)

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GLAZE LAYER FORMATION MODALITIES: FROM NANOSTRUCTURED WEAR DEBRIS TO GLOBAL ENERGY DISSIPATION

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KEYWORDS

glaze layer; wear; cobalt; ceramic; high temperature

ABSTRACT

A compact debris bed can be formed at high temperatures in a contact between two metals. This third body is usually called “glaze layer” and has also been created and described in a metal-ceramic contact in a previous study [1]. When formed, the glaze layer protects the interface from wear and provides low friction thanks to its nanocrystalline structure.

In the present work, the focus is on the formation process according to two approaches: the microstructural genesis and the influence of fretting parameters on the energy dissipated to create the glaze layer.

Firstly, the glaze layer formation mechanism has been studied through morphological observations with SEM and TEM-FIB (fig.1). It begins with nanograins whose size does not change from the early debris generation to the final sintering process, suggesting the leading role of dynamic recrystallization rather than grinding of already detached debris.

Secondly, the glaze layer formation has been quantified in defining N_{GL} as the number of cycles necessary to create the glaze layer (fig.2). N_{GL} is the basis of energy wear calculations to compare the effects of mean sliding speed varying with frequency and sliding amplitude. The influence of some fretting parameters [2] is extended here to high temperature lubricious phenomena.

The energy brought to third body creation is then interpreted in light of nanoscopic behavior of debris. Final aim is to anticipate the needed debris generation and time necessary to form the glaze layer, regarding a given fretting configuration.

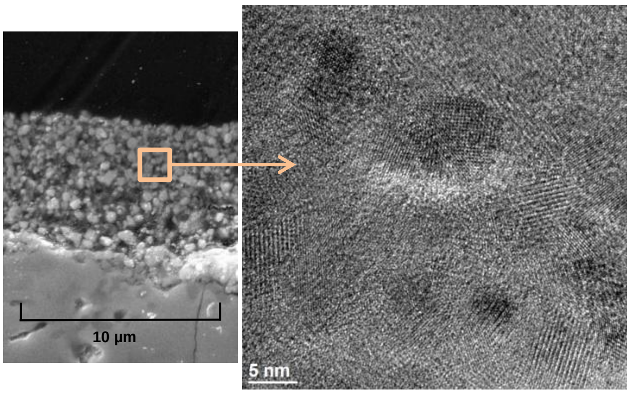

Fig. 1 – Glaze layer in formation at micro and nanoscale. The bulk tribofilm is already nanocrystalline

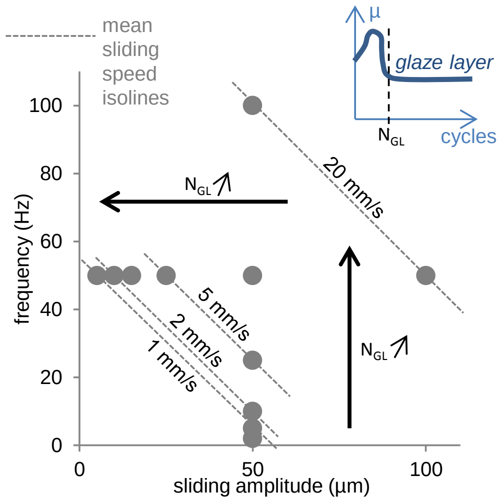

Fig. 2 – Experimental design to evaluate the influence of mean sliding speed on number of cycles necessary to create the glaze layer, N_{GL}

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VISCOELASTIC RECIPROCATING MOTION BETWEEN ROUGH INTERFACES

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KEYWORDS
Viscoelastic contact, reciprocating, friction.

ABSTRACT
The mechanics and physics of soft linearly viscoelastic materials is an intricate research field, where the strongly time-dependent constitutive stress-strain relations govern the response of this class of materials and often make classical methodology unfeasible for the solution of mechanical issues. Indeed, the determination of stresses, strains and dissipated energy result even more difficult when attention is focused on contact mechanics problems: in this case, the surface roughness on the contacting bodies often covers several orders of magnitude. Given the theoretical importance of these themes and, at the same time, the implications for many practical components, including a variety of scales and fields (earthquake dampers, mechanical seals, biological scaffolds are only possible examples), a large number of publications has been dedicated to shed light on the contact mechanics of rough viscoelastic solids [1–3]. These contributions include analytical [4, 5] numerical [6, 7] and experimental [8] studies.

The present work deals with an issue of fundamental importance: the reciprocating contact of viscoelastic materials, where the relative motion between the contacting bodies is periodically inverted. We develop a Boundary Element Methodology in order to determine the contact solution in terms of stresses, strains and hysteresis. Specifically, we provide the explicit solution, in terms of a Fourier series, of the Green's function of the reciprocating contact problem between a rigid punch and a linear viscoelastic solid. The periodic features, intrinsically marking the problem, enables us to carry out the parametric calculation of the contact solution for each time step without any necessity of employing the solution in the previous time interval. By implementing such a parametrically time-dependent approach, we obtain the full numerical convergence in each moment of the cycle and, interestingly at the dead points, i.e. when the punch inverts its motion.

Furthermore, we specifically study the influence of the surface roughness on the viscoelastic friction. This shows that, as in the steady-state case, viscoelastic friction strongly depends on the number of scales included in the simulation.

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MODELLING THE WEAR PROCESS IN COMPOSITE LINER BEARINGS

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KEYWORDS
Liner bearings, solid lubricant, wear modelling.

ABSTRACT

This paper presents a numerical method for modelling wear in spherical composite liner bearings. These are bearings that have two rings with spherical surfaces to form a ball joint. The concave spherical surface of the outer ring is lined with a thin composite liner material which is a made of a woven fabric impregnated with a thermoset resin. Two fibre types are used in the fabric, a structural fibre and a solid lubricant fibre. The liner is made up of two fabric layers impregnated with resin that are bonded together between heated pressure plates. The surface layer has a high proportion of the solid lubricant fibre in its weave whilst the backing layer has a predominance of structural fibres with fewer lubricant fibres. These bearings are used extensively in reciprocating motion applications in the aerospace industry.

The life of the composite liner bearing is determined by the wear occurring in the liner which leads to increasing backlash with use. The effective life limit is reached when the face layer is worn away and contact with the backing layer occurs with a significant resulting increase in friction and wear rate. The analysis method is based on a contact model where the liner is considered to develop a compressive stress in accordance with the normal strain caused by the eccentricity of the steel spherical rings. The eccentricity is calculated such that the liner pressure acting on the inner ring surface is in equilibrium with the load applied to the ring. An Archard wear model [1], $w' = kpu_s$ is used to calculate the liner wear, where w' is liner thickness loss rate, p is the liner pressure, u_s is the sliding velocity and k is the wear coefficient which is deduced from experimental tests. Figure 1 shows the development of the liner contact in a reciprocating test case where the load is fixed in magnitude and direction relative to the outer ring (and thus to the liner). The plots cover the load bearing area which extends over the full axial length, z_{max}, and different circumferential angle ranges as the wear develops. The initial contact has a diametric clearance of 50 μm which leads to a contact patch having a maximum pressure of 91 MPa. The evolution of wear in the liner is calculated in a sequence of wear steps where the pressure and wear rate is assumed to be unchanged so that the equation gives the change of liner thickness for the wear step. Wear steps with 1 μm maximum material removal were used for the analysis. Over 20 such steps the wear pattern redistributes the load to cover a larger contact area with a reduced maximum pressure of 40 MPa. This continues to the final calculated stage with maximum wear and pressure of 150 μm and 34.7 MPa, respectively.

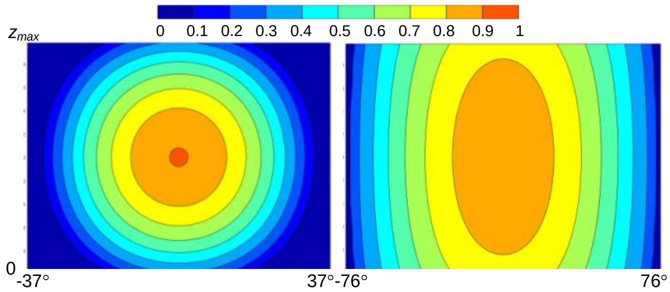

Figure 1. Contours of (a) p/100 MPa for first wear step and (b) p/40 MPa for last wear step.

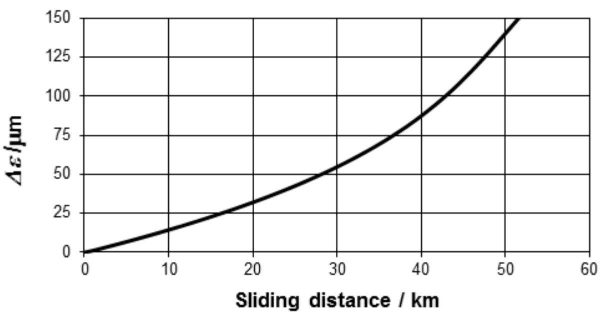

Figure 2. Best fit curve to the experimental test data.

The wear model was used to calculate the wear occurring in a bearing test where the change in dynamically measured eccentricity $\Delta\varepsilon$ with sliding distance takes the form shown in figure 2. It was found that the experimental results could be replicated in the model by adopting a wear factor that increases with wear depth in the form of a power law.

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EXTENDED LUBRICATION THEORY FOR COMPRESSIBLE FLOW

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KEYWORDS
lubrication; compressible; fluid mechanics

ABSTRACT

The present study extends the scope of compressible lubrication theory by considering a more complete formulation of compressible flow in a thin film. The classical compressible Reynolds equation is derived by first assuming incompressible conditions in the momentum equation. As a final step, density is substituted from the ideal gas equation to account for the compressibility. The present analysis starts with compressible conditions from the beginning. By averaging across the film, we obtain an approximation in terms of average flow velocity, which is common in basic studies of compressible flow. We examine a dimensionless formulation of the thin film compressible flow equations (continuity, *x*- and *y*-momentum, energy, and perfect gas). There are three dimensionless governing parameters: the Mach number the compressibility or bearing number, and a heat transfer number (a sort of inverse Peclet number). The classical theory assumes isothermal conditions (a consequence a large heat transfer number) and implicitly assumes low Mach number conditions. It turns out that neither of these conditions is met in many high speed applications such as foil bearings. We examine the influence of Mach number and heat transfer. The improved theory predicts much greater load than the traditional. This means that high speed air bearing design based on compressible lubrication theory would function satisfactorily, as borne out by their successful application; however, such bearings would be significantly over-designed. The present paper is an extension of previous studies by considering 2D bearing analysis.

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CYLINDER BORE HONING PATTERN OPTIMIZATION FOR IMPROVED ENGINE FRICTION AND WEAR

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KEYWORDS

Internal Combustion Engines; Film Thickness; Honing; Friction; Flow Factors

ABSTRACT

Friction between power cylinder components such as piston rings and cylinder bores is responsible for a significant part of total power loss in internal combustion engines. Fuel economy and emissions can be improved by reducing frictional losses. Piston rings experience a wide range of lubrication regimes in operation. In the mid-stoke, hydrodynamic regime is observed due to high speed and relatively lower pressure, whereas mixed lubrication occurs near top dead center as a result of peak firing pressure and lower speed. Squeeze film lubrication reduces the probability of metal-to-metal contact and wear in this case. In a typical piston ring and cylinder bore contact, smooth surfaces enhance hydrodynamic lubrication and reduce friction, wear and oil consumption. However, smooth cylinder bore surfaces are prone to scuffing due to starvation. Oil retaining and heat dissipating plateau honing patterns are necessary to maintain proper lubrication. Optimization of cross-hatched or textured cylinder bore patterns for improved friction, wear and oil consumption constitute a trust area for engine developers.

Patir and Cheng's average flow model with surface flow factors [1] has been used by many researchers to model rough surfaces, including piston and cylinder bore contacts with roughness orientation [2]. Surface flow factors compare flow in a rough bearing to that of a smooth bearing and obtained for roughness with Gaussian distribution and do not represent plateau honed cylinder surfaces. Several attempts have been made to model lubrication characteristics of honed cylinder bores [3].

In this study, three-dimensional surface patterns representing cross-hatched plateau honed cylinders (Fig. 1) were developed and used to calculate surface flow and shear factors for pressure driven and shear driven flows. Flow factors obtained by numerical simulations were used to calculate piston ring lubricant film thickness and friction for a heavy duty diesel engine using the existing piston ring and cylinder bore friction model [2]. The effects of various cross-hatch honing angles and surface patterns on lubricant film thickness, load carrying capability and friction were investigated.

The results showed that low honing angles generate resistance to fluid flow and enhance hydrodynamic lubrication reducing asperity friction. However, oil film transported to combustion chamber also increases in low honing angles that will result in increased oil consumption due to evaporation.

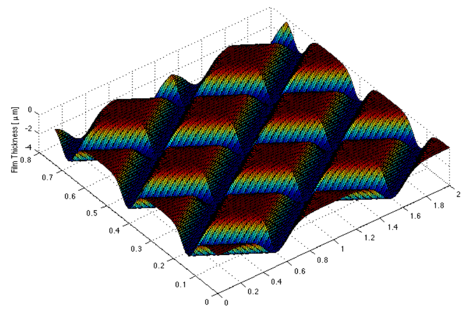

Fig.1 Generated plateau hones surface pattern.

ACKNOWLEDGMENTS

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THE EFFECT OF CORROSION INHIBITORS ON FRICTION

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KEYWORDS
Corrosion inhibitors, friction modifiers, surface adsorption, atomic force microscopy

ABSTRACT
Lubricants are multi-component fluids. They are designed simultaneously tofulfilmultiple roles by incorporation of various additives. Depending on their functions, some of these additives are surface active and thus can be used as friction modifiers and also corrosion inhibitors. It is commonly believed that their effectiveness might depend on their ability of forming homogeneous surface films.Since both corrosion inhibitor and friction modifier compete for surface sites, ideally it would be more efficient if we can have one additive that can function as both. Hence the objective of this work is to investigate if commonly used corrosion inhibitors can be used as effective friction modifiers.

This presentation is divided into two parts. The first part concerns surface film formation and hence to explore the packing mechanismof corrosion inhibitor. This is important for both corrosion resistance and friction reduction. Atomic force microscopy (AFM) with a liquid cell is used to visualise surface film formation in various additive concentrations and temperatures. The nature of surfaces is also investigated. The surface adsorption of additives are also examined with quartz crystal microbalance.

The second part of the presentation focuses on friction reduction effectiveness of the additive coated surface. This is obtained with the use of colloidal probe. Frictional properties of corrosion inhibitors are also examined with a conventional tribometer. These two tests give friction responses of corrosion inhibitorsat different length scales and their friction results are compared.These results are then correlated with the adsorbed film morphology. It is hoped that this work will shed light tothe potential of using corrosion inhibitors as friction modifiers, how surfaces and test conditions affect their effectiveness.

ACKNOWLEDGEMENTS
The authors would like to thank Oleon for the financial support.

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EFFECT OF WAVINESS AND ROUGHNESS ON CYLINDER LINER FRICTION

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KEYWORDS
Topography; Multiscale Filtering; Internal Combustion Engine; Piston Rings; Friction

ABSTRACT

The study of mixed-lubrication using 3D measured topographies and deterministic computer modeling is becoming widespread in both academia and industry. However, hydrodynamic and asperity pressures depend on all scale components of the surface topography and not only on the filtered roughness commonly provided by many measuring procedures. Characterization of areal surface topographies is still a challenge, since the use of 3D filtering techniques for separating the different surface components (i.e. form, waviness and roughness), as well as the definition of proper measurement parameters, have not been well-established in the literature. Besides, due to the small size of 3D measurement regions, standard procedures designated to 2D profiles are in general not applicable for 3D topographies.

In this work, the tribological performance of piston ring - cylinder bore contacts of internal combustion engines is investigated through deterministic mixed-lubrication modeling. A set of measured bore topographies are considered, from regular honed Grey Cast Iron (GCI) to “Mirror-Like” coated bores, the latter ones currently entering in production for passenger car engines. In contrast with honed GCI bores whose regular “average” topography is composed of relatively well-distributed peaks and valleys, the coated bores are composed of a much smoother plateau and localized deep pores.

The present investigation proposes that instead of using conventional standardized cut-off values to separate the waviness and roughness components of surface topographies, the consideration of the contact width of the counter-body (e.g. piston ring) should be taken into account in the analysis, since wavelengths components that seem “waviness” for a narrow counter-body may be behave as “roughness” for a wider one.

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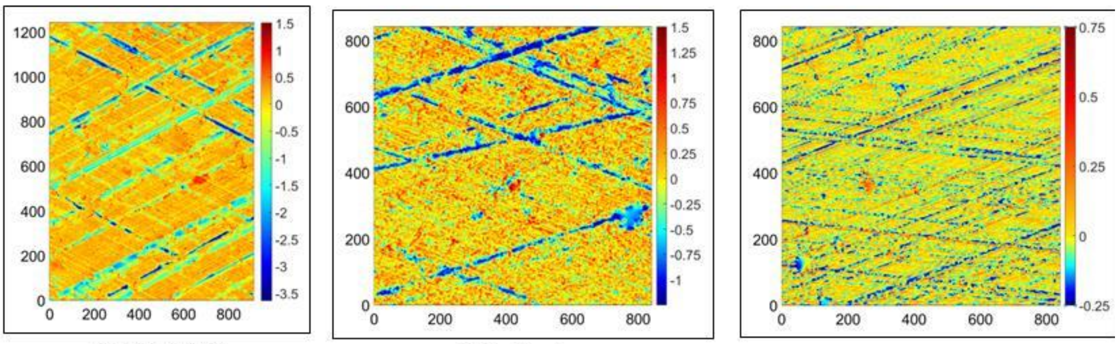

Slide Honing Grey Cast Iron — Slide Honing Coated Bore — Mirror Like Coated Bore

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INVESTIGATING APPLICATION OF HONEYCOMB ABRADABLE LINING IN AERO-ENGINE TURBINE STAGE

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KEYWORDS
Abradable materials; NiAl; Turbine Sealing

ABSTRACT

Modern aero-engines require increasing levels of performance and working efficiency. One of the ways this is achieved, is by increasing combustion temperatures in order to exploit leaner fuel combustion regimes. This in turn leads to hotter turbine temperatures, and an increased performance demand on turbine sealing systems. In the turbine, the sealing system comprises of a shroud containing a fin, which is mounted onto the end of the blades, along with an abradable material used to coat the turbine casing. The fins on the end of each blade in concomitance form a ring, which incurs into the abradable lining, producing a seal and thus minimizing axial gas flow [1]. A typical abradable system presently used in the hot section of the turbine, comprises of a nickel based superalloy honeycomb structure, combined with a nickel aluminide filler. However, this system has been found to harden as a consequence of thermal ageing leading to wear of the sealing fins, and gas flow leakage.

In this study, the performance of the aforementioned sealing system is investigated with a range of different fillers, each containing differing ratios of nickel and aluminium. Tests are conducted on a high speed abradable test rig, where the incursion conditions between a single sealing fin and the abradable are replicated. Tests are undertaken on both as manufactured and aged test samples, with thermal ageing performed at 1000°C for 100 hours. Sealing fins manufactured from Inconel 718 were used for all tests, with incursions performed at the same rate and to the same depth in each case. During the tests, stroboscopic imaging was used to monitor wear of the fin, along with a dynomometer and pyrometer to measure force and temperature respectively. Post-test, the worn grooves on the abradable samples and the fins are imaged, and the abradable sectioned and analysed using optical microscopy. Elemental analysis is also undertaken to determine material transfer between the abradable and fin, and vice versa.

The ratio of aluminium to nickel in the filler was found to have a significant impact on the wear behaviour of the sealing system. In the case of a stoichiometric mix of aluminium and nickel in the filler, the un-aged abradable was difficult to cut, resulting in high levels of fin wear. This led to cyclic peaks in force and temperature, culminating in the removal of compacted abradable material with accompanying sparking. A similar mechanism was observed in the case of the aluminium rich filler, whereas in the nickel rich case, good cutting with negligible fin wear was recorded. At the aged condition, this trend was reversed, with the aluminium rich filler minimising fin wear, due to its inherent brittleness leading to good fracture and dislocation on contact with the fin.

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MULTI-SCALE MORPHOLOGICAL CHARACTERIZATION OF AUTOMOBILE WORN BRAKE PADS

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KEYWORDS

Surface topography; roughness; Multi-scale analysis; brake

ABSTRACT

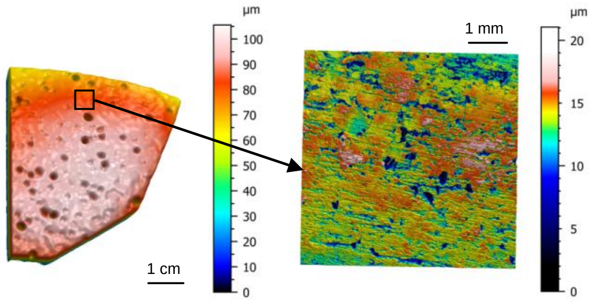
When dimensioning a braking system, the geometry of the brake pads is conventionally modelized with a flat contact surface. In reality, this surface presents a highly heterogeneous and stochastic morphology. This heterogeneity stems directly from the materials constitution and manufacturing process. The impact of the contact surface topography and its variability on thermal and braking noise had been discussed [1].

The aim of this work was to develop a method for characterizing the surface of the brake pads. The purpose was to be able to characterize the morphology, on the one hand on the scale of the pad (scale of the form and the waviness) and on the other hand on a smaller scale (the scale of the roughness).

For our study we had three sets of four pads used in the brake system of the front of a car. One consisting of new pads. The other are taken from tests conducted at Hyundai Motors. The procedure is inspered of the SAE J2521 standardized test (Disc and Drum Brake Dynamometer Squeal Noise Test Procedure). The number of brakes is 400 for the first set of pads and 2600 for the second.

For large-scale morphology, a focus variation system (InfiniteFocus, Alicona ™, Austria) had been used with low magnification. This device allowed us to measure the morphology on a large surface: typically, a half brake pad (29 cm²). This surface is reconstructed by stitching overlapping images.

For roughness at hight definition on localized area of 5x5 mm², measurements were made on a white light interferometer (NewView7300, Zygo ™, USA). A magnification 5 times greater than with focus variation was used. On a brake pad, we had measured nineteen areas of 5x5 mm² each constituted of 30x22 individual maps overlapping. (method of "stitching").



a b

Fig.1 Morphology of a worn brake pad (400 brakes)
(a) Large Scale (Alicona)
(b) High definition (Zygo)

Fig. 1 show typical results of surface topography measurement for a worn brake pad from the two experimental equipments

The evolution between new and worn brake pad had been discussed throw a multi-scale analysis performed with a laboratory developed software : MesRug Data System.

ACKNOWLEDGMENTS

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Thermal Effects in Rough EHL Contacts

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KEYWORDS

Friction and energy saving in machine elements

Rough EHL, Rolling-sliding, Thermal effects

ABSTRACT

Thermal effects dominate the behaviour of rolling-sliding EHL contacts with the heat generation and dissipation controlling the behaviour for all except the lowest amounts of sliding. The presentation will examined the behaviour of line contacts with low amplitude sinusoidal roughness and show how the fluid properties and the roughness interact to produce complex pressure, clearance and temperature variations that may change rapidly with time.

The theoretical treatment has been described elsewhere and the presentation will concentrate on the main physical effects present and will show, for example, how the pressure and temperature variations are closely linked and how this relationship is affected by the fluid viscosity at high pressures and temperatures. In addition, the role of the shear rate properties of the fluid will be outlined.

While the analysis deals only with line contacts, the roughness can lie at any angle to the contact and the effect of roughness wavelength and orientation will be discussed.

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Micromechanics of adhesive wear: Did Archard get it right?

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KEYWORDS
Archard's wear law, debris formation, Frictional energy

ABSTRACT

Despite the three-centuries-long history of inquiry into the understanding of wear and the existence of empirical laws (e.g. Archard's wear law [1]), wear remains one of the least understood areas of mechanics. The process emerges from a rich variety of complex mechanisms at disparate time and length scales (e.g. contact, friction, severe inelastic deformation, fracture, and fatigue) which has restricted wear prediction to empirical models.

A recently-developed novel numerical technique [2] presents a novel step towards understanding the physical origins of material detachment process. It reveals the existence of a critical length scale for junction size, above which surface asperities lead to "fracture" and thus produce wear debris particles, while smaller junctions exhibit "plastic" deformation (see figure 1).

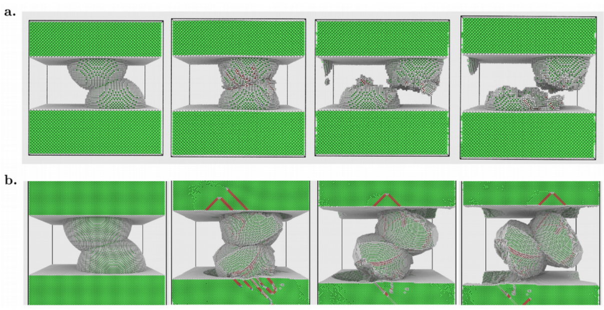

Fig.1 Numerical simulations of adhesive wear mechanisms: **a.** gradual plastic smoothing versus **b.** fracture-induced particle formation. See [2] for detailed information.

Inspired by this new finding, we analyze and quantify wear at the most fundamental level, i.e. wear debris particles. Our simulations [3] show that the asperity junction size dictates the debris volume, revealing the origins of the long-standing hypothesized correlation between the wear volume and the real contact area. No correlation, however, is found between the debris volume and the normal applied force at the debris level, contradicting the macroscopically-observed linear relation (Archard's law).

Alternatively, we show that the junction size controls the tangential force and sliding distance such that their product, i.e. the tangential work, is always proportional to the debris volume, with a proportionality constant of one over the junction shear strength. This provides an accurate prediction of the debris volume without any empirical factor, resulting for a wear coefficient of unity at the debris level. Discrepant microscopic and macroscopic wear observations and models are then contextualized on the basis of this new understanding.

ACKNOWLEDGMENTS

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PREDICTIVE MODEL OF WEAR INDUCED BY LOW-LOADED SLIDING IMPACTS

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KEYWORDS
Impact wear; Impact friction; Wear model

ABSTRACT

Repetitive impacts between steam generator tubes and anti-vibration bars in pressurized water reactors are studied with an analytical impact wear test machine. Repetitive impacts between an Inconel tube sample and a stainless steel flat bar target are performed in water environment at ambient temperature. Incident energy and angle of impacts are controlled, normal and tangential loads during impact are measured as well as rebound energy and angle of impacts.

Impact wear volume is observed to be directly related to energy loss during impacts. The proportionality coefficient between wear volume and energy loss is found to be dependent to the impacts incidence angle (Figure 1).

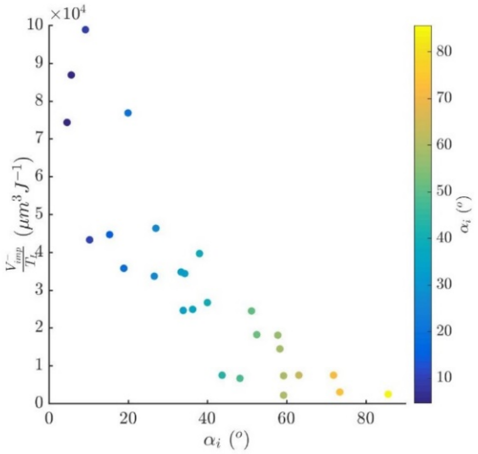

Fig.1 Wear volume per impact and per unit energy loss versus incidence angle.

Numerous abrasive scratches are observed on the worn surfaces. Their lengths correspond to the sliding distance measured during impacts (Figure 2).

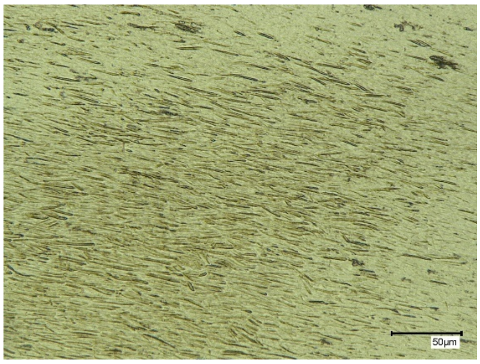

Fig.2 Tube wear scar microscope image.

A predictive model of impact wear is introduced based on these observations and previous studies [1–4]. Global wear volume is expressed as a function of the impacts number and the local wear volume of one single abrasive scratch. The volume of one abrasive scratch is determined from the incident characteristics of the impact and the materials properties. A good correlation is observed between the predicted volume and the experimental one.

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ELASTODYNAMIC SLIDING OF A LAYER ON A FLAT UNDER COULOMB'S FRICTION: VELOCITY DEPENDENCE, OPENING WAVES AND SUPERSONIC SLIP PULSES

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KEYWORDS
elastodynamic friction, frictional instability, opening waves, Coulomb's friction, velocity dependence, stick-slip fronts

ABSTRACT

Constitutive frictional laws, which are assumed to control interface behavior are deduced from macroscopic tests. At the same time, a numerical simulation of the same macroscopic test, with the deduced frictional law assumed to govern the interfacial behavior, may notproduce the macroscopic behaviorobserved in the experiment. This interesting effect is strongly related to the elastodynamic behavior of the macroscopic system [1]. For example, assuming in the interface the simplest Coulomb's friction law with a single coefficient of friction, may result in a velocity-dependent macroscopic friction law [2]. In this talk we will present recent theoretical results highlighting the difference between local and globalfrictional behavior.

We consider the following set-up: an infinite elastically isotropic layer is pressed against a rigid flat and is slid over it at a constant speed; the frictional behavior of the interface is governed by Coulomb law. This problem was addressed using the finite element method using periodic boundary conditions imposed on a finite-length elastic layer; the solution is integrated in time using HHT implicit integration. A parametric study was carried out, in which we controlled the Poisson's ratio, sliding speed and the coefficient of friction.

The particularity of this set-up is that the initial stress state of the interface is homogeneous along the sliding direction, which can be reproduced in circular contact systems, like ring-on-flat or cylinder-in-hole. Thus, in shear, all the points reach the frictional limit simultaneously and they all start to slide. However, this uniform sliding appears to be unstable independently of the friction coefficient [3], thus leading to localization of the sliding within slip pulses, propagating in the direction of motion at supersonic celerity, or within slip events resembling standing waves. This steady-state non-uniform sliding at local scale results in a velocity-dependent friction at global scale and thus naturally obey velocity-weakening friction law with a static and dynamic friction coefficients. In addition, the global friction was shown to dependent non-monotonically on Poisson's ratio.

This stationary regime persists if the coefficient of friction does not exceed the critical value of one [4], otherwise the sliding mechanism changes drastically. The frictional slip localizes within a single zone, which transforms into an opening wave. Since in opening no energy is dissipated, the global frictional force rapidly decreases and can even turn negative, i.e. can be inversed. This peculiar behavior is studied theoretically within a wave-guide theory and an intensive parametric finite element study is also carried out [4]. In Fig. 1 several snapshots of a finite element simulation demonstrating the formation of localized slip and an opening wave are depicted.

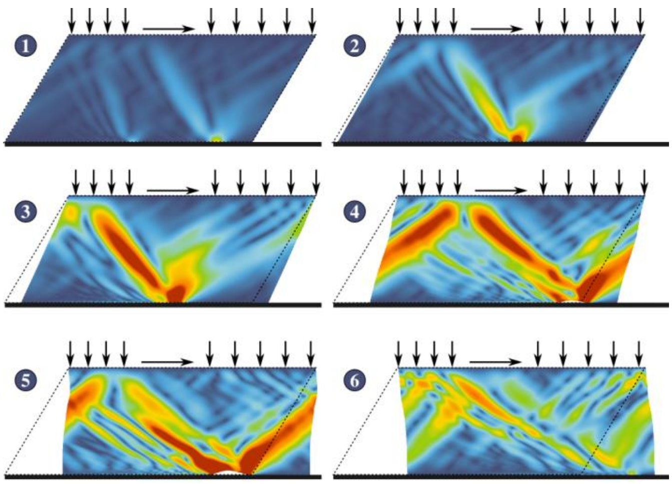

Fig. 1.Localization of slip and formation of opening waves in sliding of an elastic layer over a rigid flat under Coulomb's friction (the color represents material-point speed).

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ADHESION AND FRICTION OF A METAL-POLYMER MATRIX COMPOSITE PILLAR

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KEYWORDS
Damping; Composite pillar; Adhesion; Friction

INTRODUCTION

Tribological characteristic of elastomeric pillars such as adhesion strength has been shown to be altered via making a composite pillar by adding soft or hard material on the tip of the pillars [1,2] or a composite body with a stiff core and compliant shell [3].

This study investigates the change of mechanical properties of composite pillars by considering the contribution of homogenously distributed additive particles. Adding a homogenous metal particle inside a polymer matrix with different ratios results in a change in the stiffness and damping characteristics of the pillar which is likely to permit adhesion and friction properties to be tuned accordingly in the viscoelastic interface.

The previous works focuses on composite pillars made by adding another material on the tip surface or laminating different layers on the body of the pillar while this study deals with composite pillars made out of almost homogenously distributed additive materials in a composition of cured PDMS.

EXPERIMENTAL PROCEDURE

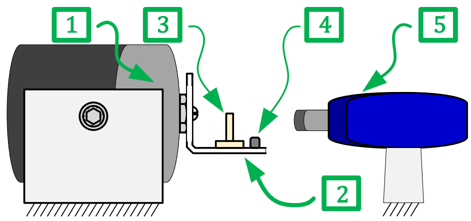
Internal damping mechanism of a composite pillar with fixed-free boundary conditions is identified via harmonic base excitation for different mass ratios of the materials. This procedure targets to reveal the contribution of additive particles to internal damping, which is obtained via frequency response function of composite pillars by using half bandwidth method.

Composite pillars are slidden on a smooth surface to observe the effect of mass ratio of additive particles to PDMS on the frictional damping. Contact between composite pillars and the surface is obtained under different sliding velocities and normal load which is chosen to be less then Euler critical buckling load of the corresponding composite pillars.

Two customized experimental set-up are built. In the first set-up as depicted in Fig.1, internal damping of a pillar is identified. The set-up consists of an electrodynamic shaker to provide excitation to observe structural response of a composite pillar, an accelerometer to measure the base excitation amplitude and a laser vibrometer to measure the displacement/velocity of a composite pillar to obtain the structural response of the pillar and the internal damping [4].

In the second set-up frictional damping of a composite pillar is obtained by laterally loading of the composite pillar in a frictional sliding contact under various normal load and sliding velocities.

a)



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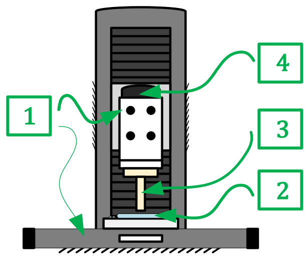

Fig.1 Drawing of the first experimental set-up (a) 1-Shaker, 2-Base, 3-Composite pillar, 4-Accelerometer, 5-Laser vibrometer, (b) 1- Motorized stage, 2- Smooth surface, 3-Composite pillar, 4- Force sensor.

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A SIMPLE EVALUATION OF STATIC SEALING PERFORMANCE OF ROUGH SURFACE USING WATERSHED CONCEPT

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KEYWORDS
Surface roughness; Contact mechanics; Real contact area; Seal

ABSTRACT
Static sealing, an important function of the real contact area, is obtained by collapsing the non-contacting channels. One of criterion of static sealing is percolation of contact area. To predict the percolation threshold of contacting area, multi-asperity contact models (ex. Greenwood-Williamson model [1]) are not suitable for existing interfered deformation. Conversely, full numerical analysis needs huge resources for calculation [2].

A new evaluation method about static sealing is proposed using watershed concept [3] (see Fig.1) for detection of clusterization of contact area. It is assumed that contact area expand along the watershed line as increasing contact pressure. According to this assumption, percolated contact area could be connected on watershed line. So percolated contact area could be predicted using truncation of original surface.

For verification of this hypothesis, predicted percolation threshold and truncated percolation depth are compared with percolation threshold and penetration depth of roughness (not including bulk deformation) that are calculated numerically (FEM calculation) for numerical generated rough surface by Hu-Tonder method[4], shown as Fig.2 and Fig. 3. Predicted values are almost agreement with the FEM results, whereas proposed method using watershed concept is a promising method for evaluation of sealing performance of static seal.

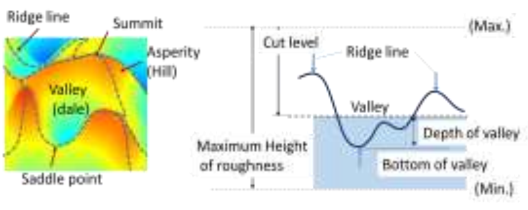

Fig.1 3D motif and watershed detection

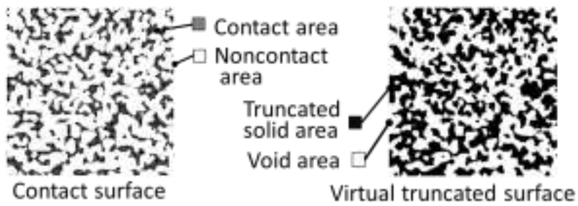

Fig.2 Comparison between numerical calculation of contact surface (left) and virtual truncated surface (right)

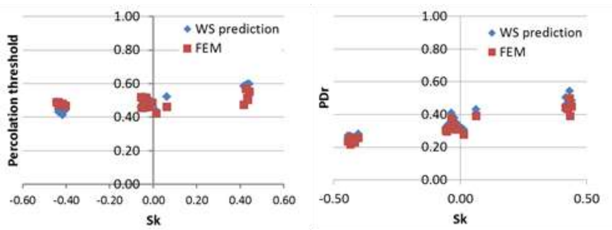

Fig.3 Comparison between percolation threshold of contact area and watershed percolation

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MECHANICAL RESPONSE INDUCED BY CHANGE IN SHEAR STRENGTH AT THE SLIDING CONTACT BETWEEN A FINGER AND A MOLECULAR LAYER-COATED SOLID SURFACE

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KEYWORDS

Finger friction; Molecular-film-coated solid surface; Tactile perception

ABSTRACT

The friction characteristics of a finger slid on a solid surface coated with an organic molecular film were investigated by changing in the interface between the finger and the solid surface. In addition, mechanical response induced by friction stimulationgiven to the finger was also evaluated by observing the change in shear strength of the interface when the finger was slid from the uncoated solid surface to the molecular layer-coated one.

Friction characteristics of an index finger pad slid on a surface of a test specimen was measured using a laboratory-made tribometer that can measure x and y component force and z component force perpendicular to plane surface simultaneously. Si wafer and a glass plate were used as a solid substrate and then coated with an organic molecular film composed ofoctadecyltrichrolosilane-based self assembled monolayer (OTS-SAM). In addition, contact area of the finger was measured with varying normal load by using a black stamp ink.Previous study by the authors has reported that the normal load dependency of friction coefficient was observed from the measurement of finger friction characteristics slid on a Si surface coated OTS-SAM having different film thicknesses [1]. It has been also found that there was the linear correlation between the contact area and the friction force, and then the linear slope was defined as a shear strength of the interface between the finger and the substrate. The shear strength decreased with increasing the thickness of OTS-SAM.

Pattern interval and width of the film was varied in order to investigate the effect of the change in the shear strength of the interface on the friction characteristics of the finger and on the response to the friction stimulation.The normal load changed as the friction force changed significantly when the finger crossed over the boundary between the areas with and without the OTS-SAM. The change in the normal load was probably due to the phenomena caused by the tactile perception. Based on the results,the relative normal load changewasplotted against the relative shear strength change, regarded as the response induced by the friction stimulation.Figure 1 shows that the negative correlation between the load change and the shear strength change was observed. This implies that the relation between the friction stimulation and the response could be estimated numerically.

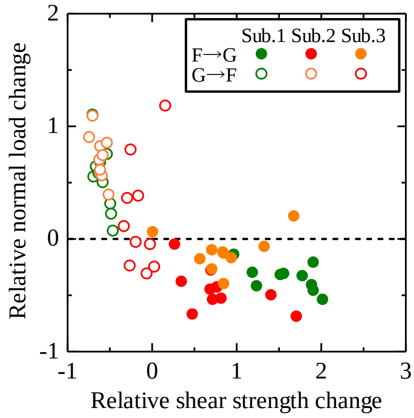

Fig.1 Correlation between the friction stimulation and the mechanical response

ACKNOWLEDGMENTS

This work was supported by JSPS KAKENHI Grant-in-Aid for Scientific Research (C) Number 16K06040.

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BIO-INSPIRED SURFACES FOR FUNCTIONAL AQUEOUS LUBRICATION.

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KEYWORDS
Polymer brushes, Zwitterionic, 2-Methacryloyloxethyl Phosphorylcholine Polymer

ABSTRACT
Polymer brushes have been studied through experimental and theoretical means over the past three decades because of the huge potential and possibilities to greatly improve surface properties [1]. Replication takes place by grafting polymers to substrates where one end is tethered to a surface while the other end is free to extend from the surface, constrained only by its elasticity [2]. The chains stretch perpendicular to the substrate due to the steric repulsion between the monomers and the substrate which is highly dependent on the concentration of solution.

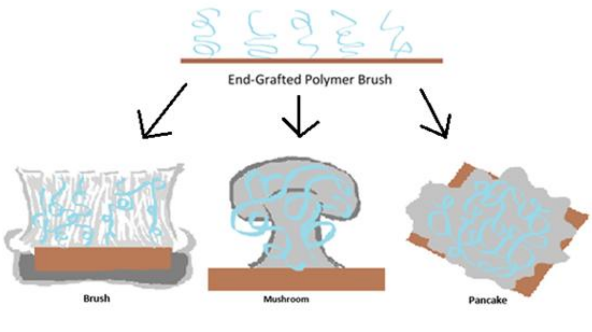

Fig.1 Figure caption

Charged and zwitterionic polymer [2-Methacryloyloxethyl Phosphorylcholine Polymer (MPC)] brushes surfaces can effectively achieve hydrated lubrication. The hydration layer can strongly hold and have the ability to support large pressures without squeezing out, but can also relax very quickly providing fluid response to shear. Such surfaces have been shown to be highly hydrophilic and as a result low friction coefficients (<0.001) have been achieved using nano-tribological methods [3].

The aim of this project was to investigate the feasibility of polymer brush technologies as a method of functionalizing a surface for use in water lubricated environments. This was be achieved through a systematic study in which the surfaces, polymer brush chemistry and tribological environment are varied. Whereby the focus will lie upon the effect of corrosion on zwitterionic polymer brushes under hydrated lubricated environments. Methods of optimizing and managing friction and wear response through functional grading and encapsulation within the films will be investigated. Surface characterisation will be conducted through AFM, ellipsometry and contact angle measurement as well as friction testing.

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EFFECT OF SURFACE TEXTURE ON THE PERFORMACE OF A FULLY-FORMULATED ENGINE OIL

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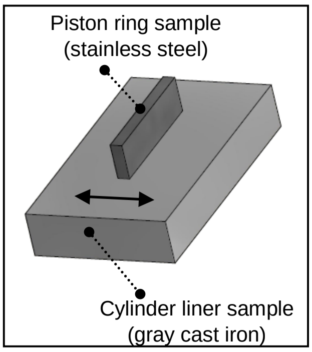
KEYWORDS

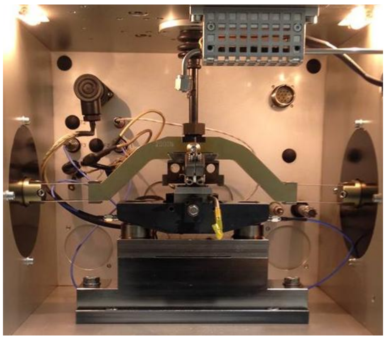
Surface Texture; Boundary Lubrication; Lubricant Additives.

ABSTRACT

Reduction of parasitic losses of powertrain systems of automotive vehicles is an important component for energy conservation. For engine efficiency improvement, engine friction reduction is a key and relatively cost-effective approach, which has been receiving significant attention from tribologists and lubrication engineers alike [1]. This paper is aimed at evaluating through experimental reciprocating tests (see Fig. 1b) the effect of surface texture on the friction performance of fully-formulated engine oil. In the conducted experiments, the specimen were taken from actual piston ring and cylinder liner components (see Fig.1a). The cylinder liner samples were ground, sanded and laser textured. Spectroscopy RAMAN revealed the formation of MoS_2 and MoS_x ($x > 2$) layers over the anti-wear tribofilm on the untextured regions. The friction results showed a good correlation between the coefficient of friction and the shape and distribution of the surface asperities, hence indicating the influence of the surface topography on the additives activation (see Fig. 2). Furthermore, the portion of area covered by MoS_2 layers seems to be strongly associated with the higher asperity pressures verified for the rougher surfaces.



(a)



(b)

Figure 1 – (a) Strip-on-flat assembly with piston ring and cylinder materials. (b) Test chamber of SRV Optimol tribometer.

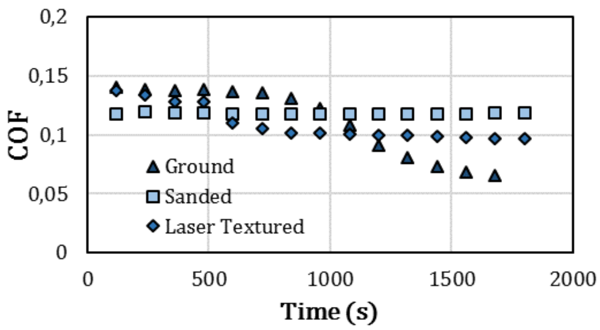


Figure 2 – Coefficient of Friction for topographies: ground, sanded and laser texturized. Reciprocating test with engine oil.

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EVOLUTION OF THE THIRD BODY LAYER: DYNAMIC CAUSES AND CONSEQUENCES ON SQUEAL OCCURRENCE

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KEYWORDS

Load-bearing area; Third body; Friction induced vibrations; Brake Squeal

ABSTRACT

For brake industry, friction is a major problem as environmental and economic issues. Friction induced vibrations and noises contribute to both the noise pollution and the related increased costs for sound insulation. Amongst these vibrations, squeal is the most problematic because of its frequency (more than 1000 Hz) and sound pressure (above 80 dB). Its unstable vibratory nature is well understood. It results from the coupling modes between the parts in contact. These couplings are due to changes in mode frequencies and by the changing circumstances of the contact. However, many factors come into play when there are friction induced vibrations.

Thus, the origin of squeal occurrence remains misunderstood as there are many micro as well as macro scale factors (wear, behavior of the tribological triplet and dynamics of the whole brake system) involved in its mechanism [1,2,3]. This interdisciplinary issue of brake squeal should be resolved by the integration of tribological and dynamic analyses.

The objective of this work is to study the link between the evolution of load-bearing area at the interface and the squeal occurrence. A simplified and original tribological assembly was established. Experiments were performed under low load and low speed with an elementary pad-disc tribosystem composed of a pad mounted on a flexible leaf and rubbing on a disc. Mode couplings that can led to squeal are well known and involve leaf bending, pad deformation and disc vibration modes.

The test configuration and the use of a glass disc allow observations of the evolution of the pad-disc interface during sliding. The introduction of an artificial third body and the adjustment of the pad-disc clearance generate the load-bearing areas.

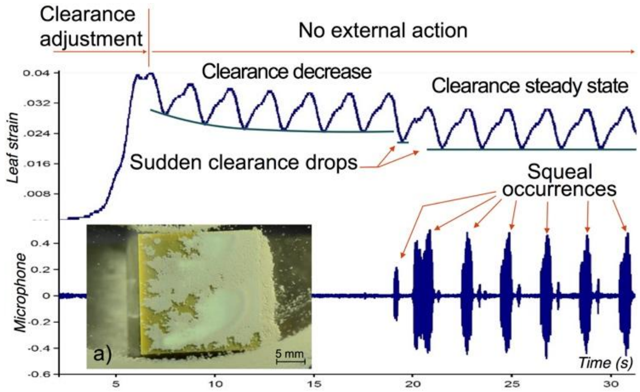

Fig.1 Noise occurrence vs. pad-disc clearance change during experiment. a) third-body layer and load-bearing area observed through the glass disc.

The study shows a wide influence of the third body on the occurrence of squeal, and experiments have good repeatability to obtain noise. The presence of a third body layer may be a condition to produce squeal. Disc runout along with third body also plays a role to obtain the periodic squeal occurrences. Experiments are analyzed in terms of contact location, extend and thickness of the third-body layer according to the opening and closure of the pad-disc clearance and time frequency spectrum of noise emission and related instable mode couplings.

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WEAR CHARACTERISTICS OF UHMW POLYETHYLENE BY TWIST METHOD

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KEYWORDS
UHMWPE; friction coefficient; twist movement

ABSTRACT

Ultra high molecular weight polyethylene (UHMWPE) has been used as the bearing surface of total joint replacements for several decades. Medical grade UHMWPE remains the material of choice for the bearing surface in total joint replacement components. This polymer offers unique mechanical properties as well as biocompatibility [1]. A wear test of the twist movement is studied as a new method to estimate the in vivo wear behavior of on joints replacements. Such properties play an important role in determining the long-term success of orthopedic devices [2]. This technique is relatively simple to perform. During which a ball is pressed with a constant force and then rotated. This allows to estimate the twist moment.

Two types of ultra high molecular weight polyethylene (UHMWPE), non-irradiated (conventional) and gamma irradiated (crosslinked) are tested under dry and lubricated conditions. The lubricant used is water. The wear tests of the twist movement are performed using an adapted tribometer.

This method is used also to determine the static and dynamic friction coefficient.

ACKNOWLEDGMENTS

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Tribological behaviour of steel against ceramic oxide Atmospheric Plasma Spray (APS) coating under boundary lubrication conditions

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KEYWORDS
Atmospheric Plasma spray; MoDTC; tribochemistry

ABSTRACT
Nowadays to reduce weight, gas emission and oil consumption of the passenger car engines, Atmospheric Plasma Spray (APS) coatings are used on cylinder liner [1-2]. MoDTC (Molybdenum Di-Thiocarbamate), a well-known organometallic friction modifier is commonly used to reduce friction by formation of layered molybdenum disulphide flakes. This study focuses mainly on tribochemical interaction of MoDTC with ceramic oxide APS coated cylinder-liner under boundary lubrication conditions.

Fused and crushed micron sized powders are used in the Atmospheric plasma spray process to obtain a 70 µm thick ceramic oxide coating with optimum surface roughness parameters. Linear tribometer with a ball-on-flat configuration is used to carry out tribotests at 100°C with a maximum Hertzian pressure of 0.7 GPa. Lubricants used for the tribotests are base oil alone and with the friction modifier (MoDTC). Optical microscopy is used to estimate the wear on both ball and flat. Raman spectroscopy is used to study the coating before the tribotests and also to investigate tribofilm composition on the disc and the ball. XPS (X-ray photoelectron Spectroscopy) is also performed to study composition of tribofilms on APS discs. FIB (Focused Ion Beam) sample preparation is carried out on the surface of the tribofilm for TEM (Transmission Electron microscopy) observations of the tribofilm.

Friction, wear and surface chemistry/tribochemical process will be reviewed.

ACKNOWLEDGMENTS
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Tribology of PTFE with Unusually Effective Nanofillers, including the Effect of Sliding Speed on Wear and Friction

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As opposed to microfillers, which have quite generally been shown to provide PTFE polymer with useful reductions of its high wear rate ~$0.4*10^{-3}$ mm^3/Nm typically by a couple orders-of-magnitude over a broad range of filler materials, when reduced to the nanoscale most such filler materials lose much of this wear reduction capability. One of the few notable exceptions to this trend is that of carbon, which has been shown in several forms to not only maintain useful levels of wear resistance but furthermore augment it to much higher levels of effectiveness. For example, at contents of 2%, mesoporous carbon and activated carbon nano-scale fillers have been shown to provide PTFE with rates of approximately 6.9 and 0.8 $*10^{-7}$ mm^3/Nm, while mixed micro/nano-scale multi-walled carbon nanotube filler at this content has been shown to comparably provide extreme wear rate reduction to PTFE down to $9.5*10^{-7}$ mm^3/Nm. Mixed micro/nano-scale graphene platelet filler has also been shown to provide PTFE with extreme wear resistance, especially at smaller platelet thicknesses which increase filler interfacial area for any given content, with a 1.25nm platelet thickness with $30*10^{-7}$ mm^3/Nm wear rate at 2% content reducing it much further to ~10^{-7} mm^3/Nm when increasing content to 10%. These several carbon nanofillers join the previously reported alpha-phase alumina among the very few exceptional filler materials whose ability to reduce PTFE wear rate increases markedly upon reducing particle dimensions from the micro- to the nano-scale. While from x-ray diffraction is appears that such nanofillers each stabilize a tougher Phase I of the PTFE matrix that is ordinarily only seen at higher temperatures, more importantly from FT-IR characterization it appears that these nanofillers also enable scission and chelation reactions that chemically bind thin PTFE transfer films to the metal of the mating countersurface. These studies have generally been done at a low sliding speed of 0.1m/s to prevent substantial frictional heating from confounding the effects of other variables (for example filler content, graphene platelet thickness) being investigated, and furthermore given the extremely long sliding durations required to achieve measurable mass losses from such wear-resistant materials at such modest sliding speeds, the wear tester with multi-station capability that has been employed to increase sample throughput has lacked the ability to measure friction at the individual stations. While some preliminary investigations on a single-station pin-on-disc tester have indicated that the friction coefficients of these nanocomposites do not differ greatly from the $\mu\approx0.2$ value typically measured for unfilled PTFE at 0.1m/s speed, this investigation further studies both the wear and the friction behavior of these unusually effective PTFE nanocomposites as a function of elevated sliding speeds.

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FRICTION IN HIGH PERFORMANCE ENGINE

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KEYWORDS
Friction; Crank-train; Internal Combustion Engine

ABSTRACT

Since many years there is a continuous trend in engine development for increasing the overall efficiency. This trend is not only limited to passengers cars: also for High Performance Racing Engines, the aim is transferring the biggest amount of energy from fuel to the tyres (and Energy Storage).

To reinforce this statement, it's sufficient to highlight that the regulation of some racing series have dramatically developed to provide a somehow "green" appearance. An example of that is Formula 1, where maximum instantaneous fuel flow rate and total amount of fuel during one race are both limited by regulation.

Power Unit architecture seems also being regulated in order to openly request to Constructors maximizing the amount of energy extracted from the limited available fuel quantity (energy recovery from braking, from exhausts gases,…). This turns again into the need for researching maximum mechanical efficiency.

Lubricant rheology, different friction mechanisms depending on the specific location where energy loss happens into the engine, … are all items which must be carefully considered together, since no single-part optimization is really possible but a more harmonious work is needed.

In this work, some considerations are done about possible ways of reducing friction losses. After a first review of existing literature, some additional thoughts will follow by considering the actual case of high performance engine.

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GREASE FORMULATION, FILM THICKNESS AND FRICTION - INFLUENCE ON ROLLING BEARING TORQUE LOSS

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KEYWORDS

grease lubrication; film thickness, friction; roller bearing; torque loss

ABSTRACT

Experimental batches of Polypropylene and Lithium greases, thickened with PAO and Mineral oils, as well as their base and bleed-oils were tribologically characterized through film thickness measurements over a wide range of entrainment speeds on a ball-on-disc test rig using optical interferometry.

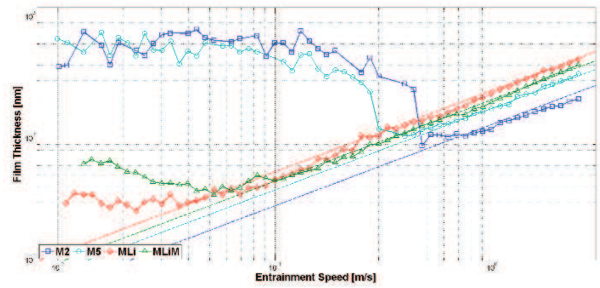
Under fully flooded conditions and low speed it was observed that thickener lumps enter the contact producing a high film thickness plateau. The transition speed or the "transition film thickness" at which the film thickness increases with decreasing speed is dependent on the thickener type, content and operating temperature. At moderate to high speeds, all the tested greases show a film thickness much higher than the base and bleed-oils, even though the bleed-oil's film thickness is closer to the grease's.

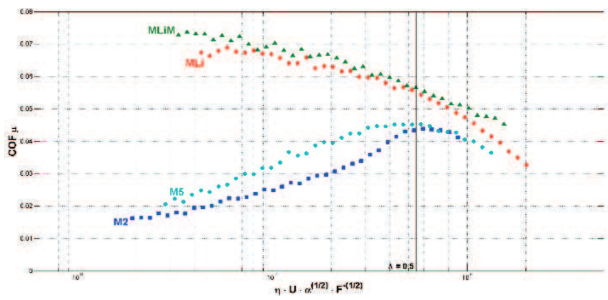
The same greases were tribologically characterized through traction coefficient and Stribeck curves at different operating conditions on a ball-on-disc test rig, ensuring that the contact was fully flooded. The tests were performed at constant load, but different operating temperatures while varying the slide-to-roll ratio (SRR) or the rolling entrainment speed.

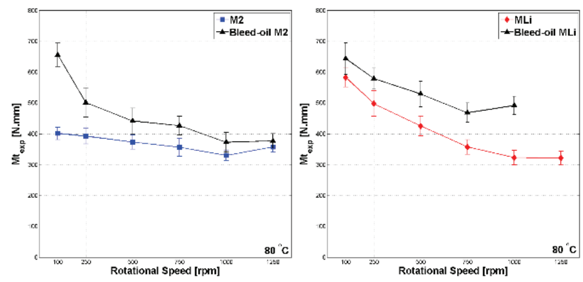
The results were correlated to the greases' formulation in terms of base oil viscosity, thickener and/or elastomer content. A relationship between the coefficient of friction (COF) of greases formulated with different thickener content was found and the thickener influence on the COF was addressed.

Experimental tests were performed in thrust roller bearings lubricated with the same greases. The friction torque was measured at constant temperature and load, while varying the rotational speed. The coefficients of friction under boundary and full film lubrication were numerically calculated through the optimization of a rolling bearing friction torque model to the experimental measurements.

The results show that the film thickness and friction behaviour of the greases at low and high speeds have a direct influence on the torque loss of thrust roller bearings.







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FRICTIONAL INTERACTIONS BETWEEN HANDS AND SPORTS EQUIPMENT

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ABSTRACT

The frictional interactions between hands and sports equipment play a key role in carrying out high performance tasks in a safe and controlled manner. These interactions are often highly complex due to the non-linear loading behaviour of human skin and materials involved and the presence of surface contaminants or products that are designed to modify friction.

This paper will describe the key experimental phases used in a number of case studies on the topic of hand-sports equipment interaction, namely: generating boundary test conditions; the replication of real-world loading scenarios in a repeatable test methodology; experimental design to include relevant input parameters; testing and analysis of data; modelling interactions using tribological mechanisms; and linking back to real-world context. The case studies cover interactions related to rugby ball handling, rock climbing, gymnastics and wheelchair racing. The effects of object surface material and texture; moisture and contaminants; friction modifiers such as chalk and the use of gloves will be discussed, based on the outputs from various studies.

Different tribological mechanisms and modelling will be used to explain the different trends observed. Finally the real-world effect of different parameters will be discussed in a context that has impact on sports equipment manufacturers and sports participants.

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MECHANISTIC INSIGHTS INTO THE FUNCTION AND PERFORMANCE OF POLYMERIC VISCOSITY MODIFIERS

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KEYWORDS

Viscosity Modifiers; Atomistic Simulation; Thickening Mechanisms

ABSTRACT

Viscosity modifiers (VM), or viscosity index improvers, are additives used in lubricants to mitigate the decrease of fluid viscosity with temperature [1]. Most VMs are long chain polymers that provide a thickening effect at elevated temperature. However, exactly how a given polymeric additive performs this function is not fully understood. For example, some viscosity modifiers are believed to expand with temperature, thereby providing additional thickening at high temperatures [1]. However, experiments and simulations have shown that not all VM polymers expand with temperature [2,3], so this is unlikely to be a universal mechanism. An alternative proposal is that polymers are more likely to associate or aggregate at higher temperatures, such that their effect on viscosity is correspondingly larger [5]. In this work, we use molecular dynamics simulations to model polymer-base fluid blends for several different additive molecules. The simulation-based approach enables us to isolate specific viscosity enhancing mechanisms and the findings show that indeed the mechanism by which a VM functions is related to the polymer itself. In general, this work suggests ways to tune polymer chemistry for a given VM application which in turn has the potential to improve the efficiency of lubricated interfaces, particularly in high temperature conditions.

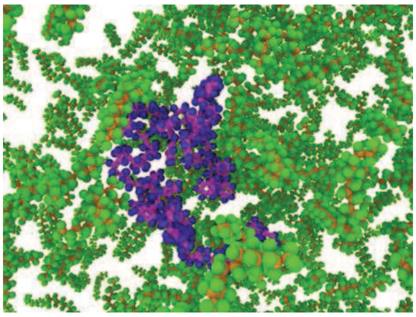

Fig.1 Snapshot of an atomistic simulation of a polymeric viscosity modifier (purple/blue) whose function is to increase the viscosity of the base fluid (green/orange) at elevated temperatures.

ACKNOWLEDGMENTS

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POSSIBILITY OF ELASTO-HYDROSTATIC EVOLVED-GAS BEARING AS ONE OF THE MECHANISMS OF SUPERLUBRICITY

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ABSTRACT

We have reported [1-3] that the friction coefficient reduced to the friction-tester noise-level of 0.0001 when ZrO_2 pin was slid against diamond-like carbon (DLC) plate under H_2 gas or H_2 and N_2 gas mixture environment, and we termed this behavior as friction fade-out (FFO). It was also reported that the tribofilm formation on ZrO_2 surface during run-in process played a very important role for the onset of FFO, and that the onset of FFO depended on an existence of alcohol vapour, humidity conditions of supply gas and applied load conditions. For the mechanism of FFO, we investigated the tribofilms on ZrO_2 and the worn surfaces of DLC by several kinds of chemical analyses such as FTIR, TOF-SIMS, Raman Spectroscopy and XPS, and by surface analyses such as nano-profiler, nano-indentation tests and SEM observations. It was found that the tribofilm involved short-chain hydrocarbons and hydrogen atoms coming from dehydrated alcohol molecules, in addition to the aromatic series ($C_6H_5^+$ and $C_7H_7^+$), condensed-ring ($C_9H_7^+$) and benzoic acid ($C_7H_5O^-$) which were also detected from the wear tracks of DLC surface, and that soft and semi-insulating polymer-like materials were attached on the tribofilms and grew with sliding. Based on these measurements, the possibility of elasto-hydrostatic gas bearing as the mechanism of FFO is investigated, where gas is not supplied from outside of pocket but evolved at the contact surface. Assuming the generation of hydrocarbon gases by ZrO_2 catalytic action and dissociative H atoms, the pressure distribution at the contact area and the evolved gas amount required for supporting a heavy applied load of 60 N will be shown.

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FROM VEHICLES TO MOLECULES
TIRE TRIBOLOGICAL PERFORMANCE BALANCE

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KEYWORDS
Tires; Rolling resistance; Multiscale

ABSTRACT
The pneumatic tire has to offer the customer a delicate balance of performances, among which traction (and handling), wear and rolling resistance [1] have to be balanced because of their relevance for safety and economy. We will show the many different relevant scales implied [2]. In the future, new improvements in the rolling resistance of tires will be necessary to decarbonize transport, and this without any adverse effect on its safety or environmental footprint.

Through the description of road surfaces [4], and the knowledge of non linear viscoelastic properties of rubber [5] some prediction of the hysteretic contribution to wet friction may be attained [6]. At the smallest scales [7], the dewetting phenomenon enters into play [8] and offers an extra molecular contribution which also brings dry friction to higher levels [3].

Dewetting of an intercalated lubricant film behind nucleators

Experimental [9] as well as numerical [10] methods have been recently developed to further this understanding.

ACKNOWLEDGMENT
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FEATURES EXTRACTION FOR SURFACE TOPOGRAPHY BY MORPHOLOGICAL COMPONENTS ANALYSIS

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KEYWORDS
Surface topography; Features; Extraction

ABSTRACT
Surface topography is one of the important factors influencing the tribological performance such as friction, lubrication and wear. Tremendous development has been occurred in the characterization of surface topography for last 20 years in order to meet the requirement of industry and academia. The characterization of functional properties of surfaces attracted more and more attention. In the latest standard (ISO 25178-2), motif analysis is recommended to characterize the functional features of surface. Although the 3-D motif analysis is successful to identify the features of surface, such as peak and dale, it cannot extract the data of these features as input values of the numerical simulation to predict tribological performance.

In this paper an extraction method is introduced, by which the original surfaces can be decomposed into superposed surfaces, each surface mainly retains one type of the major features in original surfaces. Such decomposition was well studied and named as morphological components analysis (MCA) by Starck et al [1]. Transforms are adopted by MCA, which are sensitive to different features. These transforms are taken as dictionaries to be used to optimize representations of the original surface. The extraction method flow chart is shown in Fig.1

The honed surface and lapped surface are measured and used as input data of the extraction method. The features of these surfaces are mainly scratches and micro-holes. Therefore, the dictionaries utilized here are the curvelet transform and undecimated wavelet transform, which are sensitive to curve feature and Gaussian feature respectively. The results show that the scratches and micro-holes are successfully separated into two surfaces for both honed and lapped surface (Fig.2). The decomposed surfaces are easy to use in the study of the relationship between surface features and tribological performance.

The extraction method proposed here is a general method, which can be easily modified for different features of surface topography by using corresponding dictionaries.

ACKNOWLEDGMENTS
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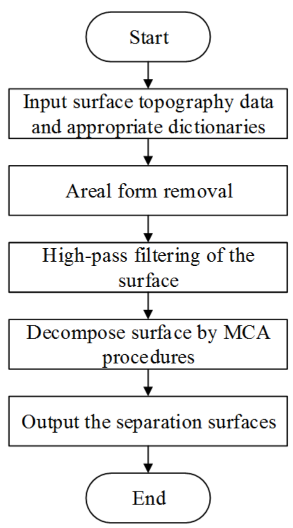

Fig.1 The flow chart of surface topography extraction

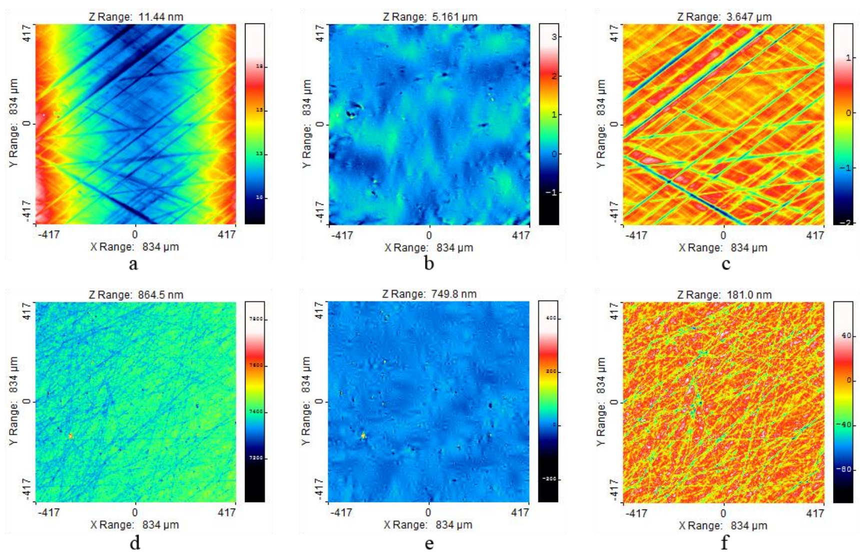

Fig.2 Original surfaces (a-honed and d-lapped) and their decomposed surfaces (b c and e f).

CERAMIC ON CERAMIC BEARINGS IN TOTAL HIP ARTHROPLASTY

PARADOXES: FRICTION, VIBRATIONS,SQUEAKING, FRACTURE.

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Keywords : ceramics bearings in total hip arthroplasty, squeaking , fracture , biotribology, energy diffusion.

Ceramic on ceramic bearing in Total Hip Arthroplasty (THA) is a favoured choice in youger and patients with high activity. Squeaking and fracture are speculated to be related to material properties. How to understand this phenomena? Firstly we analyse the chemical molecule then the biomechanical and thermo dynamical behaviour.

Alumina molecule is Al_2O_3 pure or Alumina toughened Zirconia. It explains the tribology: hardness and perfect polishing, no chemical and biological reaction, no ion emission, excellent thermal conductivity and lubrication. Adverse effect is: poor ductility and no deformation with friction-vibration, stick-slip phenomenon, squeaking fracture. Tribology qualities are in balance with fragility and instability: It is the first paradox.

THA is a global system with metal connexions between ceramic head and taper of the femoral stem and sometimes an intermediate neck. Ceramic insert is linked into a metal cup. Wear and vibrations are limited in standard conditions, meaning concentric sliding with lubrication. But THA is not a steady state mechanical system . Eccentric loading can occur randomly because microseparation between head and insert, impingement, edge loading and tensile stress. Consequences are 40 to 80 higher mechanical stress than in standard conditions with a mechanical unstable system then strip wear and vibrations into the new eccentric contact without lubrication and stick-slip phenomenon before a concentric loading again. From ceramic on ceramic loading friction, vibrations and waves spread as far as metal connexions and mix themselves with mechanical stress create by movement and realize a fretting-corrosion and crevice -corrosion with metal debris and biological reactions. Stem femoral vibration can create a squeaking when frequencies are similar to metal frequency vibrations. Thus ceramic on ceramic bearing and friction moment can be compromised by the metal links and their locking mechanisms : it is the second paradox.

A thermo dynamical analysis focuses on the fluctuation -diffusion phenomenon and the balance between kinetic energy and the opposite energy generated by friction. Here friction is entropy and is to diffuse into the system. When this system is unstable and in large disequilibrium (eccentric loading) , wear and vibrations are the larger ways to diffuse. Wear is a surface change then energy could be stock in the fissures as a stored energy as far as a crack propagation. But vibrations and lock- in frequencies fusion could be diffuse outside and sometimes as squeaking and exteriorised energy like a non linear system. This duality between wear as stored energy and vibrations as exteriorised energy is the third paradox.

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ON THE INDUCED-FRICTION BEHAVIOR BY CUTTING COATED TOOL KINEMATICS WHEN DRILLING NATURAL FIBER COMPOSITES

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KEYWORDS
Natural fiber composites; Friction; Tool kinematics; Tool coating; Machining.

ABSTRACT
Manufacturing of natural fiber composites is among the real current industry challenges. This type of material offers both economic and ecological advantages in order to promote sustainable development [1–3]. The good processing of natural fiber composites implies the mastering of the different tribological aspects during manufacturing processes, especially when machining because cutting processes generate strictest friction contacts that can cause material damage and tool wear [4–7]. Understanding the friction produced by the tool geometry, the tool kinematic as well as the surface properties of the cutting tool seem to be important to control the tribological phenomena during machining operations.

This work aims to investigate the tool coating impact on friction arisen between cutting tools and natural fiber composite materials during the drilling operation in function of the tool kinematic. Drilling experiments were carried out on bidirectional flax fibers reinforced polypropylene resin using the same drilling tool geometry and three different coating properties. Uncoated tungsten carbide, titanium diboride coated and diamond coated tools were used to conduct the drilling tests. The drilling friction is evaluated at each cutting configuration and the resulting machined surfaces are inspected using Scanning Electronic Microscope (SEM) and Orange Light Interferometry (OLI). The intrinsic friction response of each coating type is determined with Atomic Force Microscope (AFM).

Results demonstrate a difference between drilling friction behavior in function of the tool coating type and tool kinematic. The difference is also observed on the resulting machined surface states. This variation is inherently related to the intrinsic tribological properties of each coating nature that influence the tribo-contact between the cutting tool and natural fiber composites during the drilling operation.

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DEVELOPMENT OF A PIEZOELECTRICALLY-ACTUATED FRETTING WEAR TEST RIG FOR PRESSURE ARMOUR LAYER NUB-GROOVE CONTACT

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KEYWORDS
Fretting wear; experimental; partial-gross slip; test rig design

ABSTRACT
Fretting wear is a complex damage process: Dobromirski [1] proposed that there are up to 50 variables that affect fretting behaviour. Fretting is a surface damage mechanism that occurs in the contact region between two materials under combined normal load with non-uniform, typically small-amplitude, cyclic relative tangential motion. The present work is motivated by the potential for fretting damage in the pressure armour layers of flexible marine risers. Flexible risers are a key component in the delivery of offshore hydrocarbons from the seabed to sea level, typically to a floating structure, such as a platform or vessel and are comprised of a large number of layers with different functions. The primary function of the helically wound interlocked metallic pressure armour layer is to contain the internal pressure due to conducted hydrocarbons, primarily by hoop stress resistance. However, the riser itself will also be subjected to significant large bending and torsional deformations, as well as axial tensile forces, due to the combined effects of vessel motion, buoyancy and hydrodynamic loading, for example. These loading conditions result in high contact pressure and micro-scale relative displacement in the nub-groove contact of the pressure armour layer.

In this paper, the design, development, control and validation of a new fretting test rig to represent fretting in the pressure armour layer will be presented. A fretting rig must be able to: (i) apply a known (typically constant) normal load to achieve a clamping force between two or more test specimens; (ii) apply a small-amplitude (typically micro-scale) reciprocating tangential displacement between the test specimens; and (iii) test at high frequencies.

In addition to the mechanical requirements for the design of fretting test rigs, the test rig must be capable of measuring and recording the cyclical variation of displacement at the contact (or as close to the area of contact as possible) and the associated (induced) tangential force. The main components of the new fretting test rig include a linear drive line with a piezoelectric actuator to produce reciprocating micro-scale tangential displacement, a collet to fix test specimen in place and dead weight configuration for application of constant normal load, as shown in Fig. 1.

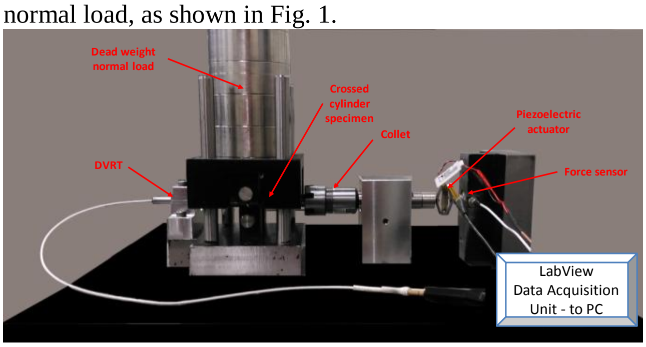

Fig.1 Fretting rig with dead weight normal load applied.

Test parameters (applied displacement, number of fretting cycles and test frequency) are controlled via a LabView GUI and data acquisition (DAQ) unit. Displacement and force sensors connecting to a PC via the DAQ unit allow for real-time visualization of fretting test conditions. The material tested is pre-service pressure armour wire.

Fretting loop and coefficient of friction evolutions with number of cycles for tests will be presented. These results show that both partial slip and gross slip regimes are achieved using this test rig. Wear scars have been measured using a profilometer; from this the wear rate is calculated. Frictional and wear results from this test rig have been compared to previous tests conducted on a similar material [2], to characterize the fretting performance of the flexible riser material, under peak contact pressure and contact width conditions representative of in-service operation. The results and trends are directly relevant to design of flexible marine risers against fretting fatigue and wear.

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WEAR CHARACTERISTICS OF PVD COATINGS DEPOSITED ON GENERAL PURPOSE STAINLESS STEEL AT HIGH TEMPERATURE

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KEYWORDS
keyword1; PVD coating, keyword2; high temperature, keyword3; Stainless steel

ABSTRACT

PVD coatings are widely used for cutting tools and forming tools due to their good properties of high hardness and oxidation resistance. In order to expand the application for other industrial machines, it is important to clear the wear properties of coatings deposited on soft materials such as stainless steel. In this study, focusing on the effects of substrate material and temperature on wear, the wear characteristics of several coatings were compared by reciprocating cylinder on plate sliding test in air.

The schematic image of specimens is shown in Figure 1. Coatings were deposited on plate specimens and cylinder specimens was made from cast steel (SCH21) as the counterpart. The plate specimen was fixed in a furnace and the cylinder specimen to which normal load was applied was reciprocated by a motor. Test temperature was changed at room temperature, 500ºC and 800ºC.

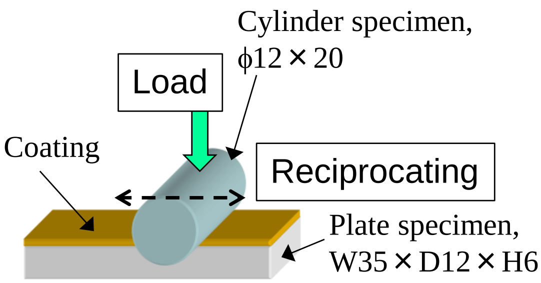

Fig.1 The schematic image of specimens

Figure 2 shows the effects of test temperature on coefficient of friction (COF) and maximum wear depth of AlCrN coatings deposited on stainless steel (AISI310S). COFs at 500ºC and 800ºC were lower than that at room temperature. It is considered that the decrease of COF occurred due to the oxidation of the specimens. In term of the maximum wear depth, plate specimens after the test at room temperature and 500ºC indicate lower values than the coating initial thickness (~4.5 μm). In the test at 800ºC, the delamination of the coating occurred and the maximum wear depth of both plate and cylinder specimens increased. Because the strength of AISI310S decreased at 800ºC, it was considered AlCrN coatings was not able to follow the plastic deformation of the substrate.

So as to apply PVD coatings to industrial machines, it is important to take account of the atmosphere and the strength differences between the coating and substrate.

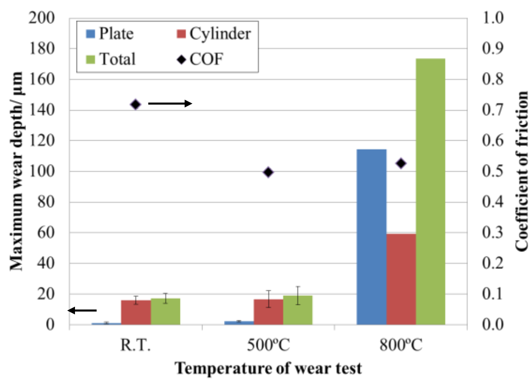

Fig.2 Coefficient of friction and maximum wear depth of AlCrN coatings deposited on stainless steel

ACKNOWLEDGMENTS

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SURFACE ENGINEERING OF ADDITIVE MANUFACTURED COMPONENTS (SEAM) – A FEASIBLITY STUDY

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KEYWORDS
Metal Additive Manufacturing; Plasma Assisted Smoothening; Polishing Machine

ABSTRACT

Surface finish strongly influences key tribological properties including wear, fatigue and corrosion.

A rough surface finish, characteristic of components produced through metal Additive Manufacturing (AM), is currently limiting the widespread adoption of this technology across a range of industries, particularly Aerospace, Automotive and Medical. The exciting potential of AM (complexity is free, no economies of scale, customisation, sustainability) remains unrealised due to the difficulty of appropriately finishing rough components of any geometry/complexity. The Surface Engineering of Additive Manufactured Components (SEAM) Feasibility Study will address the rough finish of parts manufactured through AM by undertaking a detailed investigation to assess the viability of an innovative, patent-pending, plasma-based finishing technology.

The in house prototype machine is designed and built up for the AM manufactured components aiming for the feasibility study. Surface characterisations of the treated components are carried out in terms of 3D interferometer, XRD, SEM/EDS, GDOES, Electrochemical corrosion and mechanical properties.

ACKNOWLEDGMENTS

The authors would like to thank Innovate UK for the funding opportunity of the SEAM project (Project No. 132375).

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44th Leeds-Lyon Symposium on Tribology - September 4-6, 2017, Lyon, France

FRETTING WEAR MECHANISMS OF SOLID LUBRICANT MOLYBDENUM DISULPHIDE COATED FAN COMPRESSOR BLADE ROOT AT LOW TEMPERATURE

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KEYWORDS
MoS_2; fretting; low temperature

ABSTRACT

There are a numbers of aircraft accidents due to engine fan blades failure. Blade dovetail joints of gas turbine engines are subject to centrifugal forces which produce cyclic stress and small-amplitude oscillations generated from engine vibrations. As a result, fretting occurs between contacts surfaces of dovetail joints. Solid lubricant coating Molybdenum disulphide (MoS_2) is applied on the joints to reduce fretting wear processes and improve the fretting fatigue life. However, the tribological properties of MoS2 are known to degrade in humid and high temperature environments. In vacuum applications at room temperature and above, MoS_2, particularly when combined with various metal fillers, is known to provide low coefficients of friction as well as low wear rates. Most of the fretting experimental studies are done at room temperature and high temperatures up to 650 °C and variation of gasses environment. Less research has been done looking into the tribological performance at low temperature environment. In this study, the effect of low temperature on the solid lubricant MoS_2 coating friction and wear performance is studied. The experimental test setup simulates the fan compressor blade root dovetail joint interface in which the Titanium alloy is coated with Copper-nickel-indium CuNiIn coating and on top with MoS2 coating while the counterface is Titanium alloy coated only with MoS2. The experiments were run down to low temperatures of -25°C, relevant to conditions experienced by an aircraft taxiing at low temperatures airports. The pin and disc fretting rig used measures tangential and normal displacements of the pin. Displacement amplitudes of 100μm were imposed to produce fretting and reciprocal sliding at contact at 1Hz frequency and normal load of 10 N. Steady-state value of the kinetic friction coefficient between coated pin and disc was found to be higher at lower temperature. The wear scar shows that the MoS_2 coating has been easily removed at lower cycles less than 5000 cycles and the sliding interfaces is actually between pin substrate Ti alloy and disc second layer of coating CuNiIn. The fretting regimes start to shows a gross slip titanium contact fretting regime at less than 2000 cycles.

Fig.1 Fretting apparatus and low temperature test chamber.

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EFFECTS OF REFRIGERANTS ON TRIBOLOGICAL PROPERTIES OF POLYOL ESTER REFREGIRATION OILS

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KEYWORDS
refrigeration oil; refrigerant; polyol ester; anti-wear additive

ABSTRACT
Unlike other types of lubricants, refrigeration oils are in contact with refrigerants during use. When developing refrigeration oils, it is thus critical to consider the effects of refrigerants on the tribological properties of the oils [1-3]. In this study, the authors investigated the effects of refrigerants on the tribological properties of polyol ester (POE) refrigeration oils.

Friction and wear tests were performed using a block on ring tribometer (Fig.1) under refrigerant atmospheres [4]. We evaluated VG68 POE oils formulated with tricresyl phosphate (TCP) under R410A (a mixture of difluoromethane and pentafluoroethane) and R32 (difluoromethane) (Table 1). The width of wear track on the block under R410A was smaller than that of R32. In addition, XPS analyses showed a lower P/Fe ratio and a higher F/Fe ratio on the sliding surface with R32 than with R410A. These results showed that R32 hindered the anti-wear effect of TCP, which could be due to the high polarity and reactivity of R32 as compared with R410A.

In the presentation, we will report other results obtained using different types of refrigerants and anti-wear additives, and discuss the relationships between their chemical structures and their effects on tribological properties.

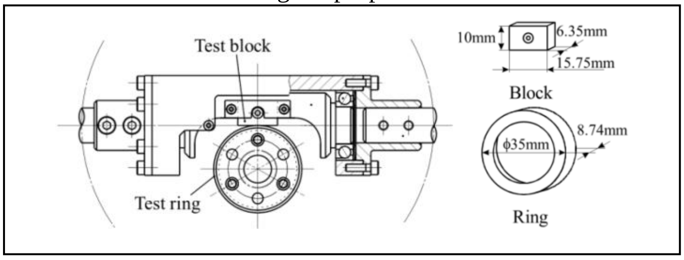

Fig.1 Sliding part of tribometer and shape of test pieces

Table 1 Results of friction and wear tests and XPS analyses of block surfaces

Base oil		VG 68 POE	
Additive		TCP 1.0 mass%	
Refrigerant		R410A	R32
Width of wear, µm		341	393
Atom ratio to Fe	F	0.13	0.20
	P	1.1	0.81

ACKNOWLEDGMENTS
We sincerely thank Prof. Emeritus Masabumi Masuko of Tokyo Institute of Technology for his helpful insights.

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HIGH-PERFORMANCE POLYMER COMPOSITES FOR EXTREME CONDITIONS

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KEYWORDS
polymer nanocomposites; extreme conditions; wear

ABSTRACT

The use of polymers is increasing throughout many different industries as their low weight and chemical resistance provide many advantages over metals. However polymers are limited by the temperature and load that they can withstand. By adding a reinforcement to a polymer, such as fibres or nanoparticles, the properties can be improved and the resulting composite material can be used over a much wider range of conditions. Composite material properties can be tailored to a particular application by appropriate selection of the materials and processing methods. This makes them attractive for applications involving extreme conditions (such as high or low temperatures, radiation or vacuum environment [1]). Extreme conditions are encountered in particular by aerospace components. The most commonly used polymer in aerospace is polyetheretherketone (PEEK), however interest is growing in other high-performance polymers such as polyphenylene sulphide (PPS).

A review of literature was carried out to ascertain the state of the art. There is growing interest in nanocomposites (where the reinforcement is in the nanoscale) and multi-scale composites, where nano-reinforcement is combined with micro-scale fibres or particles. These fillers affect the mechanical, thermal, chemical, electrical and tribological properties of the composites, therefore it is important to understand the mechanisms at work in the material when it is subjected to loads and a variety of environmental conditions. Composites with multiscale reinforcement demonstrate different wear behaviour than those with only one type of reinforcement [2].

As a preliminary study, the tribological behaviour of both pure PEEK and carbon fibre-reinforced PEEK (CF-PEEK) was investigated. These experiments formed the groundwork and established a suitable methodology for a larger investigation involving other high-performance composites.

Tests were carried out in dry sliding on a pin-on-reciprocating-plate rig. A spherical pin of aerospace grade steel (AISI 440) was used against a polymer plate, manufactured from either pure PEEK or PEEK with 30% carbon fibre content.

The sliding speed and test time were kept constant, while the load and temperature were varied. The coefficient of friction could be calculated for the duration of the test.

Analysis of the wear scar was carried out using microscopy, and the effect of the carbon fibres could be evaluated with regards to the mechanisms at work in the contact.

Building on the methodology developed with PEEK experiments, the next stage of the project will investigate the behaviour of PPS nanocomposites in a variety of environmental conditions. The project will include tests that simulate some of the conditions encountered by components used in space, with the aim of developing materials with the potential to be used in these environments. By improving the tribological properties of PPS with multiscale reinforcement, it is hoped that their performance will be more efficient and therefore designers will turn to these stable and lightweight materials more often in the future.

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Effect of contact area reduction under shear on static friction

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KEYWORDS
true contact area; contact imaging; optimization; mono-contact; shear rupture.

ABSTRACT

The frictional properties of rough contact interfaces are controlled by the area of real contact. Dynamical variations of this area are at the roots of our modern understanding of the ubiquitous state-and-rate friction law. In particular, the area of real contact is proportional to the normal load, slowly increases at rest through aging and abruptly drops at slip inception. Here, we use an opto-mechanical device similar to that used in [1] to perform direct measurements of the area of real contact on various elastomeric rough contact interfaces.

We show that, in addition to the above-mentioned dependencies, the area of real contact is also a decreasing function of the tangential load, with reductions as large as 30%, starting well before macroscopic sliding. All data are well captured by an empirical quadratic reduction law which enables excellent predictions of the observed static friction force.

To understand these results, we also performed experiments on model mono-contacts. The circular shape of the contact is found to be modified to a pseudo-elliptical shape as the area decreases. We compared our measurements with existing models from the literature [2, 3] and found that they cannot capture all of the observed behaviour.

There is currently no model relevant to the evolution of the area of real contact of rough contact interfaces under shear. But we observed that the overall reduction in rough contacts is the result of a shrinking of each micro-junction, with a similar behaviour as that of model mono-contacts. Our findings also apply to contacts involving human fingers.

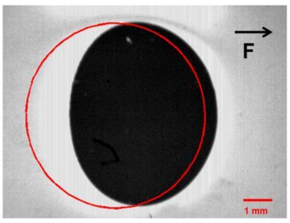

Fig. 1: Image of the interface between a smooth PDMS sphere and a smooth glass plate under shear force F. The red circle is the contour of the un-sheared contact.

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FRICTION AND WEAR EVALUATION OF SANDWICHED ENAMEL LAYER FOR CHITOSAN-HA COATING ON UHMWPE

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KEYWORDS
CS-HA; coating; UHMWPE; enamel layer; friction

ABSTRACT

There are many kinds of coatings composites which can vary from its preparation, nature of its components and type of deposition, to mention someones. Hybrid organic–inorganic materials offer high potential for elevated added-value applications in particular where they are proposed in biomedical applications.

In this work, an intermediate enamel layer (Pf) in the form of the solution was deposited on the substrate between the CS-HA coating to form a sandwich structure (Pf/CS-HA) to improve friction and wear resistance properties. The coating was prepared by immersion of UHMWPE substrate in ceramic solution. The PF solution was prepared with a 0.28% (w/w) acid acetic solution with of a commercial ceramic powder. The dipping was performed by a mechanical device, after that, the samples were left in the open air for 3 min, and then a thermal treatment at 120°C during 3 hours, subsequently the UHMWPE coated ceramic layer, a new coating was performed with the same parameters by the deposition of the CS-HA solution which was previously prepared as reported elsewhere [1].

Wear test were carried out on a CSM Instruments Tribometer with a pin-on-disk configuration in dry conditions using a WC ball with a diameter of 6 mm. The pin was loaded onto the test sample with precisely known weights of 2 N to 10 N. Kinetic friction coefficient (μk) value was determined during the test by direct measurement of the change in torque and obtained directly of the Tribox 4.1 software.

The rotation speed of the disc was 0.10 m/s with an acquisition rate of 2.0 Hz. The test was performed for 300m under room temperature conditions, 26±1°C and 30-40% relative humidity. After each test, the width of the wear scar on the coated substrate was measured with a digital optical microscope. The volume loss (V), due to wear, was then calculated by a standard test method as suggested by the ASTM G99-05 standard [2] assuming that there is no significant pin wear.

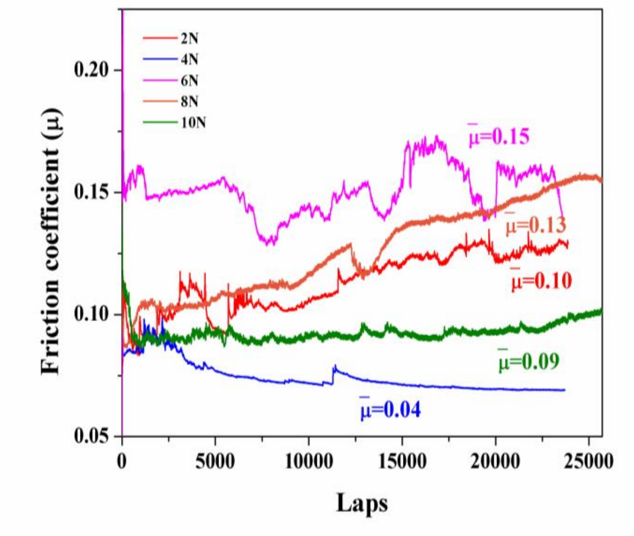

Fig. 1 Friction coefficients variation at different loads

Figure 1 exhibits kinetic friction coefficients variation with the laps at different loads. It can be observed that the test at 4N show the lower friction value, besides at this load there are lower fluctuations, similar behavior is observed for the load of 10N together with a low friction coefficient value.

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EFFECT OF SURFACE INTEGRATED ROUGHNESS ON CONTACT TEMPERATURES IN TRANSIENT BOUNDARY LUBRICATION REGIME

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KEYWORDS
boundary lubrication; tribofilm; flash temperature; roughness; waviness;

ABSTRACT

Scuffing failure is no doubt one of the most common but the least understood failure mechanism in gear transmission and rolling element bearings. Friction-induced surface temperature rises greatly and influences the dynamic processes of lubricant boundary film formation and removal. Once this balance between tribofilm formation and removal is broken in the global scale, scuffing failure will occur. A deterministic boundary lubrication model in a transient thermal contact is proposed with consideration of plastic deformation, junction growth, running-effects and tribochemistry. Based on a numerical iteration procedure, the proposed model calculates simultaneously variables in the micro-scale, including local pressures, local gaps, local contact areas and local surface temperature rises. The new model particularly investigates the effects of surface integrated roughness on flash temperatures, based on the decomposition of surface topography on wavelet analysis. The scale-dependent material features are also considered in this paper, and flash temperature variations and distributions are investigated in the multi-scales. Due to the random features of surface roughness, the instantaneous contact and local surface temperature rises show significant stochastic features in the spatial distributions as well as transient natures varying with contact time. Firction measurements have been taken by in-situ tribotests and Raman spectroscopy is used to analyse the chemical composition of the wear scars. The numerical simulations are validated with experimental results. These results indicate the inhomogeneity of tribofilm due to the micro topography, and consequent onset and propagation of scuffing failure are desirable subjects for further investigation.

ACKNOWLEDGMENTS

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IMPROVEMENT OF FRICTION AND STRENGTH PROPERTIES ON SINTERED SULFIDE DISPERSED BRONZE

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KEYWORD
Sulphide; Friction; Seize resistance; Strength; Wear

INTRODUCTION

Sulphide could reduce friction coefficient by cleavage of microstructures, and also improve the seize resistance. However, strength of sulphide dispersed bronze tends to decrease. Because sulphide is not a solid solution for bronze and could become the origin of fracture. Therefore, friction and strength properties are evaluated in this study.

EXPERIMENTAL

A. Specimens

Four kinds of specimens were prepared. Bronze contained 10.4Sn (mass%). Sulphide bronze (SB) containted 10.4Sn-0.88S (mass%). SB+Sn contained 14Sn-0.84S (mass%) by mixing Sn powders with SB. SB+Cu-Sn contained 14Sn-0.55S (mass%)by mixing Cu-Sn powders with SB. Green bodies were loaded at 200 MPa, and they were sintered under vacuum conditions at 1053 K.

B. Experimental apparatus and conditions

Fig.1 shows the friction examination of 3 pin on disk type apparatus. The carbon steel disc was fixed to the disc holder on the shaft that has the friction torque measurement mechanism. The specimens were fixed as Fig.1. Speed of the drive shaft was 1 m/s and 0.92 MPa was loaded. No lubricant was used during the test. Radial crushing strength was evaluated based on ISO 2739[1].

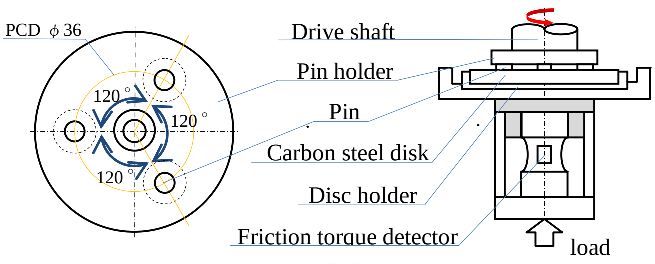

Fig.1 3 Pin on disk type apparatus

RESULTS

Fig. 2 shows the result of the friction examination and Fig. 3 shows the results of specific wear rate and radial crushing strength. The friction examination for bronze was stopped at sliding distance 168 m, because the friction coefficient was rapidly increased. It is thought that seizing phenomenon was occurred. At the beginning of the examination, the friction coefficient of SB was increased, but it became to be stable at sliding distance after 200 m. It seems that SB has the ability of the seizure resistance. The friction coefficient of SB+Sn showed the almost same behavior as the SB, but finally after 900 m of sliding distance, friction coefficient increased. It seems that this phenomenon occurred by lower sulphide contents of SB+Sn. The amplitude of the friction coefficient of SB+Cu-Sn is the largest. In addition, the friction coefficient is higher than SB. It was difficult for SB+Cu-Sn to show the enough anti-seizure properties, because it contained the lowest sulphide among the three specimens. The quantity of specific wear rate was decreased and radial crushing strength was increased when Sn content in the specimens was increased. It is thought that connection among the grains was strengthened. Because sintering properties were improved by the liquid phase of Sn.

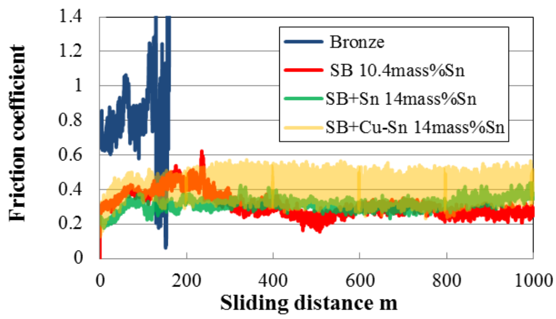

Fig.2 Friction coefficient as a function of sliding distance

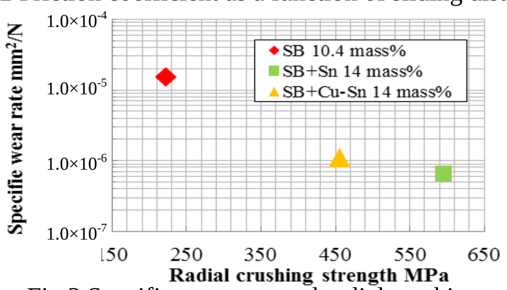

Fig.3 Specific wear rate and radial crushing strength

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Tribological properties of Ta and Ta-MoS_2composite coatings at elevated temperatures

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Keywords: Tantalum; Molybdenum disulfide Solid lubricant; Composite coating

Abstract: Thin film of Ta and Ta-MoS_2were deposited by magnetron sputtering in an argon atmosphere forthe purpose of analyzing their tribological properties, molybdenum disulfide is a good lubricant to combines with Tantalum in order to touch lubrication at elevated temperature. The crystallographic structure of the tantalum thin film dependent on the sputtering factors such as a power, high temperatures with maximum timeand gas impurities provide the best condition to produce smoother Ta films, the thickness of the tantalum layer was Ta = 6.2-8.5μm while composite coating was Ta-MoS_2 = 8.25-10μm.The morphology, phase structure of the films is investigated by scanning electron microscopy (SEM), X ray diffraction (XRD), energy dispersive spectroscopy (EDS) and Raman spectroscopy and atomic force microscopic (AFM).The tribological properties of the coating were tested by HT-1000 high temperature friction tester at room temperature, thefrictionpropertiesof the coatings wereContainingnickelbasealloysrubbingagainstN_3Si_4ceramicballfromroom temperature to200℃ and 600℃, for 20minutes weretestedbyaball-on-disktribometer. Wear test evaluated by 3d morphology of the wear traces measurement by no-contact 3d surfaceprofilometer.The morphologies and worn surfaces were observed by optical microscope and scanning electron microscope. The dispersion of tantalum and molybdenum affected by temperature are liable for the friction reduction at elevated temperatures.

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RELATING ROAD SURFACE TEXTURE TO TIRE FRICTION

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KEYWORDS

friction; road surface; texture; characterization; modeling

ABSTRACT

Tire traction is needed for driver safety. It depends on friction forces generated by the contact between the tire rubber and the road surface asperities.

This paper synthesizes works conducted at Ifsttar aiming at relating road surface texture to rubber friction. Mechanisms involved at the tire/road interface under wet conditions, in terms of friction generation and lubrication, are first described. They highlight the role of two road surface texture's scales defined as microtexture and macrotexture. Microtexture corresponds to fine asperities (size smaller than 0.5 mm) provided by the aggregates. Macrotexture corresponds to the space created by aggregates' arrangement.

The first work on microtexture dealt with its characterization. The concept of "indentors" was introduced [1] to consider only the asperities which are in contact with the rubber. Once indentors are identified from a surface profile, two parameters are calculated to characterize the indentors' sharpness and the relief created by their spatial distribution. High correlation was found between these parameters and friction coefficient. In subsequent works [2], tests have been done in laboratory to assess the dependency of friction coefficient on water depth. When the surface evolves from a dry to a fully wet state, the variation of friction coefficient is similar to a Stribeck curve (Fig. 1). A critical water depth was defined at the transition between boundary and mixed lubrication regimes.

In situ tests [3] performed with friction trailer and passenger car generalized observations made in [2] on a limited number of specimens to real road surfaces and added other important factors such as the vehicle speed and the road surface macrotexture. It was found that the tire/road friction can be written under the form:

$$\mu = \mu_{BL}.(1 - F_{HL}) \quad (1)$$

where μ is the friction coefficient; μ_{BL} is the friction coefficient in the boundary limit lubrication regime; and F_{HL} is a function expressing the hydrodynamic action induced by water in the tire/road contact area.

The μ_{BL} term depends on the road surface microtexture and rubber properties and can be calculated from a model considering rubber deformation by road indentors (hysteresis friction) [2]. The F_{HL} term is a product of four functions: two expressing the effect of water and speed on lubrication mechanisms; and two other the effect of tire tread depth and road surface macrotexture on delubrication mechanisms.

The described works, through experiments and modeling, help to understand the respective roles of road surface's microtexture and macrotexture.

Further developments to consider the action of traffic (polishing) and climate (ageing, presence of particulate contaminants) on friction are briefly presented and discussed.

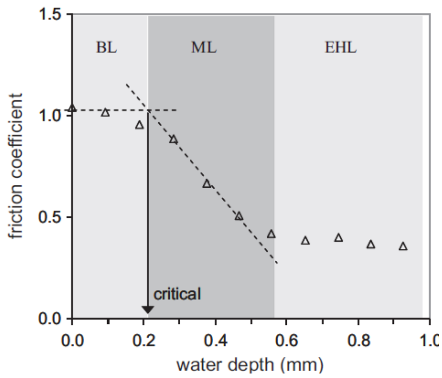

Fig.1 Variation of friction coefficient with water depth [2]

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TOPICAL TREATMENTS AND THEIR EFFECTS ON VOLAR FOREARM SKIN MOISTURE AND FRICTION

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KEYWORDS
Skin friction; UMT; skin hydration; forearm; stratum corneum

ABSTRACT
Skin friction was measured using a Bruker Universal Mechanical Tester (UMT) with a hemispherical probe exerting a normal load of 0.2 N, sliding unidirectionally, elbow to wrist, along volar forearm skin. Changes to the dynamic coefficient of friction (COF) were investigated in three conditions; no topical treatment, topical treatment applied and removed and topical treatment applied and not removed. The effects of three treatments (Cavilon, Vaseline and coconut oil) on three volunteers were investigated to determine effect on the dynamic COF.

Skin characteristic testing was carried out using a Corneometer, MoistSense, Sebumeter and Tewameter to test bare skin properties (moisture, sebum levels and trans-epidermal water loss) and how these varying properties change over time with application of topical treatments. These measurements and the relationships between them were used to assess tribological changes that occur between the skin and the environment.

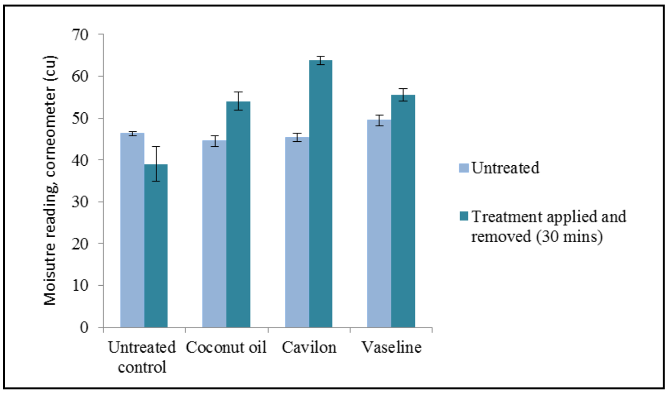

Fig.1 Moisture levels in the stratum corneum increased when treatment was applied and removed after 30 minutes. Results show mean of four corneometer readings per skin patch ± 1 SD.

All three of the investigated treatments caused moisture levels to increase in the top layer of the epidermis called the stratum corneum (SC), Fig.1. In turn the dynamic COF was found to increase, Fig.2, when treatment was applied and removed.

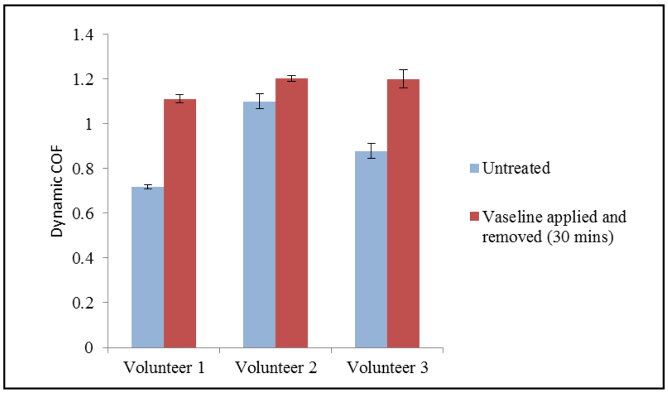

Fig.2 Dynamic COF increased with addition of Vaseline when applied and removed after 30 minutes. Results show mean dynamic COF ± 1 SD.

Applying treatments results in morphological changes occuring within in the SC [1], such as swelling and smoothing of the surface which increases the contact area between the probe and the skin, thereby increasing the friction force. When treatments (Cavilon and Vaseline) were applied and not removed the dynamic COF reduced, indicating a lubricating layer had formed between the skin and the probe. However, coconut oil applied and not removed behaved much like untreated skin, possibly due to the low viscosity of the oil.

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ENERGETIC COEFFICIENT OF FRICTION APPLIED TO CYLINDER LINERS LAB TESTS

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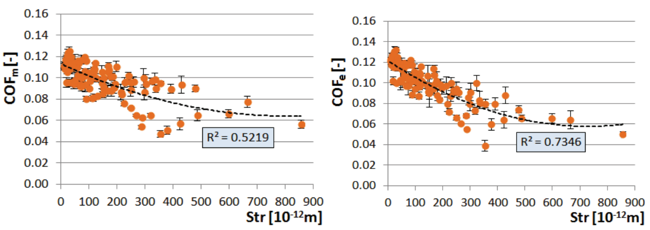
KEYWORDS
Coefficient of friction; Energy saving; Cylinder liners

ABSTRACT
This paper presents a proposal for evaluating the coefficient of friction (COF) under reciprocating test of cylinder liner and ring. This parameter called as 'energetic coefficient of friction' (COFe) is a weighted average by the in-track displacement.

To obtain the COFe two standardizations are imposed on energy of cycle. Firstly, the frictional force (Ff) is divided by the normal force (F_N); and secondly, the whole term by the sum of displacements. Then, the ratio of forces can be replaced by the instantaneous kinetic friction coefficient and the sum of the displacements corresponds to the track length, TL [mm]. In this way, the parameter is dimensionless, showed in Equation (1):

$$COFe = \frac{\sum \frac{F_f}{F_N} \Delta x}{\sum \Delta x} = \frac{\sum COF\ \Delta x}{TL} \qquad (1)$$

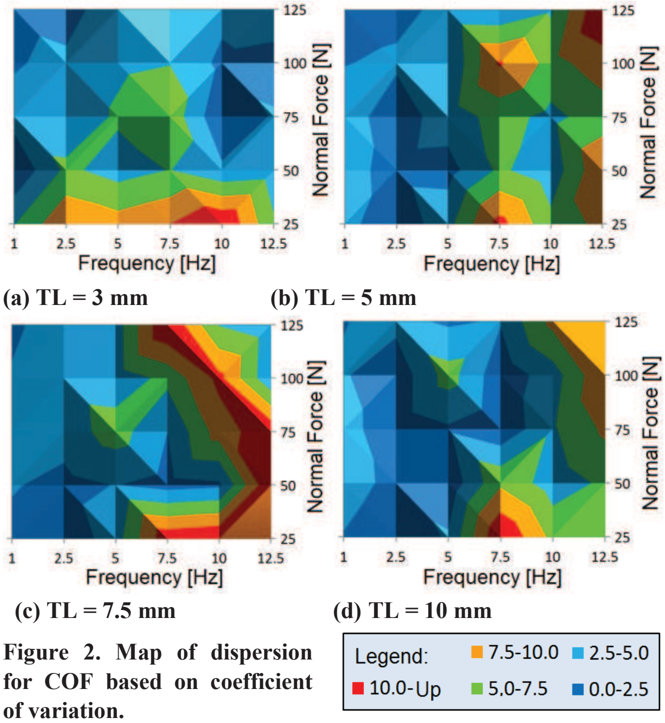
The useof Equation (1) allowed to minimize COF perturbations - mainly in the initial and final part of the track - associated with intrinsic accelerations of the movement. A direct consequence is that a better agreement with the Stribeck-like curve using COFe was verified (Fig.1), when compared to the average coefficient of friction (commonly used in this type of test)[1-2].



(a) COFm **(b) COFe**

Figure 1. Stribeck-like curves.

In addition, the concept of COFe was used during a building of a dispersion map, allowing a systematic approach to determine the optimum test conditions for the specific apparatus. The tribometer used was the CETR-UMT-Bruker, varying loads between 25-125 N, frequencies between 1-12.5 Hz, and displacements between 3-10 mm. For this evaluation, samples of compacted graphite iron were extracted directly from an internal combustion engine block. The piston ring used was a nitrided martensitic stainless steel with an asymmetrical profile and the lubricant oil was the SAE 30 CF, controlled to operate under 40 °C. The dispersion map(Fig. 2)is based on coefficient of variation of COFe and, indicates a less dispersion, for conditions with lower frequencies and higher normal forces.



(a) TL = 3 mm **(b) TL = 5 mm**

(c) TL = 7.5 mm **(d) TL = 10 mm**

Figure 2. Map of dispersion for COF based on coefficient of variation.

ACKNOWLEDGMENTS
Authors thank Tupy S.A. for providing the samplesand financial supportthrough Project ACT 10/2015 TUPY.

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TRIBOLOGICAL ANALYSIS OF PEARLITIC STEEL USING ATOMIC FORCE MICROSCOPY

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KEYWORDS
Nano-tribology; AFM; steel; wear; fundamental

ABSTRACT
In order to clarify the tribological properties of the surface of steel material, the friction characteristics of the pearlite structure were observed using Atomic Force Microscopy (AFM). It was found that different frictional characteristics precipitated iron carbide and ferrite. This shows that nano-sized friction properties depend on the friction mode and the interaction of the tip and the surface materials.

INTRODUCTION
It is important to understand the tribological properties of iron and steel products not only as products typified by bearings and crankshafts but also in manufacturing processes such as rolling and press mold forming. Therefore, although much research has been conducted [e.g. 1, 2], fundamental understanding is difficult due to the variety of elements and structures of steel. It is necessary to understand the influence of these elements and structures in order to elucidate the mechanism and further improve the tribological properties. In this work, we report on the friction characteristics of the nano-sized structure of pearlite steel using AFM.

EXPERIMENTAL
Nano-tribological experiments were conducted using Oxford Instruments ASYLUM RESEARCH Cypher ES in an Ar glove box, in order to decrease surface oxidation. AFM observations were performed in contact Lateral Force Microscopy mode with a Si-tip probe and a diamond-tip probe. The calibration factors were obtained using Sader-Thermal method [3, 4]. The pearlite steel (0.81C-0.48Si-1.5Mn-Fe in mass%) specimen was prepared by a thermal control process. In order to confirm the pearlite structure and remove the effects of polishing, the surface of the specimen was etched by Ar-ion sputtering.

RESULTS AND DISCUSSION
Figure 1 shows a friction force image of the pearlite structure of steel with an applied load of 61nN using a diamond-tip probe. From the topographic image, it is evident that iron carbide (cementite) has a higher friction force than ferrite. This result is believed to be due to the difference of mechanical properties in scratch mode. Conversely, using a Si-tip probe with a load of 19nN, iron carbide has a lower friction force than ferrite. This is believed to be due to the interaction of the Si-tip and the surface materials.

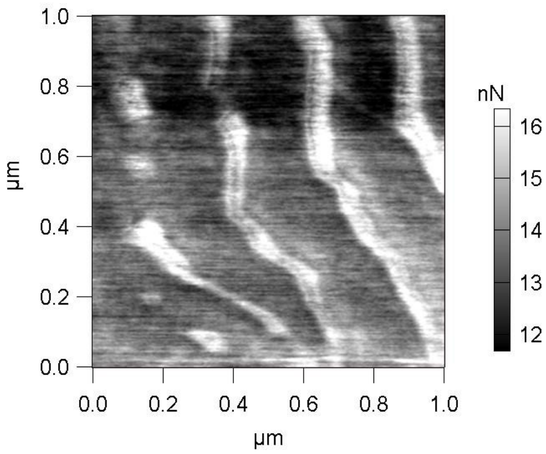

Fig.1 Friction force image of pearlite structure of steel using a diamond-tip probe

CONCLUSION
The results presented in this work, obtained from AFM on nano-sized pearlite steel structure, show that nano-sized friction properties of iron carbide and ferrite depend on the friction mode and the interaction of the tip and the surface materials.

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CHARACTIRISTICS OF AERODYNAMIC FOIL THRUST BEARINGS MANUFACTURED USING DIRECT METAL LASER SINTERING TECENOLOGY

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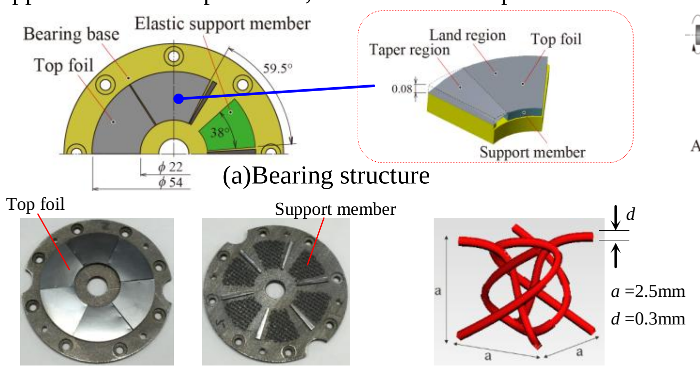
INTORODUCTION

In recent years, aerodynamic foil bearings have attracted considerable attention for the oil free bearings of the turbo machinery. This is because, aerodynamic foil bearings have advantages such as the superior stability at high-speeds in high temperature environment. However, as the performance of foil bearings improves, the shapes of the support member of the foil bearings become complicated and manufacturing problems are occurring. To overcome this problem, we have proposed aerodynamic foil thrust bearings manufactured using direct metal laser sintering (DMLS) technology. In this study, the test bearings were manufactured using DMLS 3D printer, and the characteristics of the bearings were investigated experimentally.

EXPERIMENTAL RESULTS

Figure 1 shows schematics and photos of the proposed aerodynamic foil thrust bearing. This bearing consists of three parts, top foil, elastic support member and bearing base. The support member is constituted by the unit cell shown in fig.1(c), and the stiffness of the support member changes depending on the arrangement density of the cells. In the production process of the test bearing, the support member and the bearing base were modeled with 3D-CAD software (Materialize, 3-matic STL) and manufactured using the metal 3D printer (3Dsystems, ProX DMP300). After that, the top foil was affixed on the base plate using spot welding. X5CrNi18-10 was used as the material of the top foil and 17-4PH powder was used as the material of the support member and the bearing base.

Figure 2 shows a schematic view of the experimental apparatus. In the experiments, the rotor axial displacement and the torque of the bearing gas film with respect to the changes in imposed load on the rotor were measured. Figure 3 shows the variation of the imposed load, w[N] *vs.* the rotor axial displacement, δ [μm] and the torque of the bearing gas film, T_b [Nm]. As shown in this figure, the proposed bearing has a maximum load capacity of 26 N at a rotor speed of 15,000rpm. Next, to compare the maximum load capacity of the proposed bearing with the conventional foil bearings, the load capacity coefficient [1] was calculated. Table 1 shows the comparison results. As seen in Table 1, the performance of the proposed bearing is comparable to the performance between the 1st generation and the 2nd generation aerodynamic foil bearings.



(a)Bearing structure

(b)Photos of proposed bearing (c)Unit cell of support member

Fig.1 Proposed aerostatic foil thrust bearing

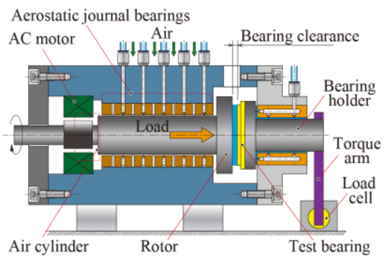


Fig.2 Experimental apparatus

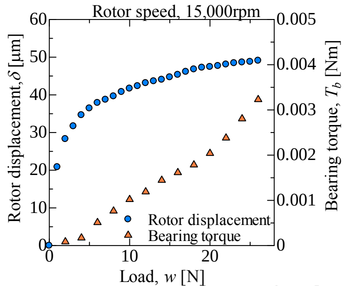


Fig.3 variation of w *vs.* δ and T_b

Table1 Comparison of load capacity coefficient, D_t

Generation	Reference	Load capacity coefficient, D_t [N/(mm^3)krpm] [1]
1st	Patent[2]	1.20×10^{-5}
2nd	Heshmat[3]	$3.86\sim6.74\times10^{-5}$
Proposed bearing		2.39×10^{-5}

ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Number 16H02310.

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MECHANICS OF METAL-POLYMER CONTACTS IN PARTIAL SLIP

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KEYWORDS

Viscoelasticity; metal-polymer; partial slip; dissipation; fretting;

ABSTRACT

Metal-polymer contacts have attracted increasing attention because of their importance in biomedical applications, such as the failure of total hip implants by fretting corrosion due to cyclic loading over routine use of the limbs. The contact pairs are typically a metal like 314 stainless steel / Ti6Al4V on a polymer like PMMA / UHMWPE. In metal-metal contacts, extensive analytical, experimental and computational work over decades has revealed the importance of accurate determination of edge-of-contact stresses under cyclic loading to predict the nucleation of fretting cracks. However, in contrast, the partial slip cyclically-loaded regime in metal-polymer contacts is a largely unexplored area.

The present work reports a comprehensive study of metal-polymer contacts with both coulomb (surface) and viscous (bulk) frictional effects operating. The contact configuration chosen is a pin-on-plate, which occurs widely in many applications. The approach is to use a validated semi-analytical method (singular integral equations, SIE) supported by finite element analyses (FEA). Our formulation is very general, allowing for the plate (polymer) to be a linear viscoelastic solid with an arbitrarily complex viscous Prony network, and the pin treated as rigid. Arbitrary pin load and remote plate stress histories are allowed with a view to better replicate realistic loading scenarios. In particular, we study the contact pressure and shear tractions, subsurface stresses, and other contact parameters under cyclic-bidirectional (fretting-type) loading for a wide range of load cycle times. We also make a study of the contact energy dissipation and investigate the existence of shakedown (alternating, cyclically steady states).

We find that cyclically loaded viscoelastic contacts for a polymer modeled as a three-element solid also shakedown under fretting loads (Fig. 1), but the number of cycles to shakedown is a function of the ratio of load-cycle time to the intrinsic time of the polymer. The viscous dissipation seems to dominate the coulomb dissipation even for moderately rapid load cycling. The viscoelastic fretting tractions and stresses differ appreciably from elastic tractions calculated using the long-term moduli over a wide parameter range. An interesting new challenge arises when materials with very long time-scales and a high ratio of instantaneous to long-term shear moduli (PMMA modeled as an 11 element solid) are considered. There is *effectively* no cyclically steady traction state, indicating the need to develop an alternative to the traditional edge-of-contact paradigm which has been a key precept of metal-metal fretting. More details of the present work may be found in Ref. [1].

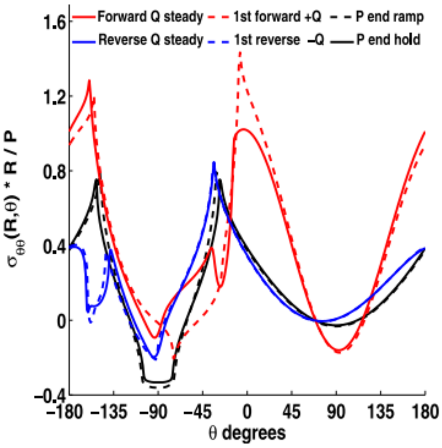

Fig.1 Surface hoop-stress $\sigma_{\theta\theta}$ in the polymer plate in a cyclically loaded metal pin-polymer plate contact showing transient stresses and shakedown states. The plate is subjected to a remote tension in phase with the horizontal pin load. The ratio of load-cycle time to the intrinsic time scale τ is 2.

ACKNOWLEDGMENTS

This work was supported in part by an Indian Space Research Organization (ISRO) / IISc Space Technology Cell research grant ISTC/CCE/NKS/335.

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FLUID-STRUCTURE INTERACTION ANALYSIS FOR INVESTIGATION OF INCRESE IN LOAD CAPACITY MECHANISM ON THE TEXTURED SURFACE

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KEYWORDS
Fluid-structure interaction; Hydrodynamic lubrication; Surface texturing

ABSTRACT
This study investigates a hydrodynamic lubrication mechanism of the textured surface. Under hydrodynamic lubrication, main effect of the surface texture is expansion of hydrodynamic lubrication regime caused by increase of dynamic pressure of lubricant. It has been considered that the cavitation, which cancels negative pressure inside the dimple, causes increase in load capacity [1]. Recently, a research confirmed that wedge film effect from the tilted surface increases pressure in oil film [2]. However, since this research assumes steady state flow, the effect of unsteady flow from the tilted sliding surface needs be considered.

In this paper, fluid-structure interaction analysis was used to express real sliding surface that was tilted by dynamic pressure. The tilted surface causes wedge film effect which increases or decreases pressure of oil film. By comparing one-way and two-way coupling analysis, it was revealed that the movement of sliding surface produces a squeeze effect and causes change of pressure distribution. Figure 2 shows time history of the tilted surface with texture and without texture. Dynamic pressure tilts the surface, which causes wedge film effect and increase load capacity. By utilizing fluid-structure interaction analysis, it was confirmed that dynamic pressure tilted the sliding surface and wedge film effect from the tilted surface increased load capacity.

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Table 1 Dimension properties of simulation

Dimple depth	d	[μm]	5.0
Dimple width	w	[μm]	50
Film thickness	h	[μm]	1.0
Computational area	L	[μm]	5.0×10^2
Structure thickness	H	[μm]	50

Table 2 Working condition

Fluid viscosity	ν	[cSt]	16
Fluid density	ρ_1	[g/cm^3]	0.82
Structure density	ρ_2	[g/cm^3]	7.9
Sliding speed	U	[m/s]	1.0

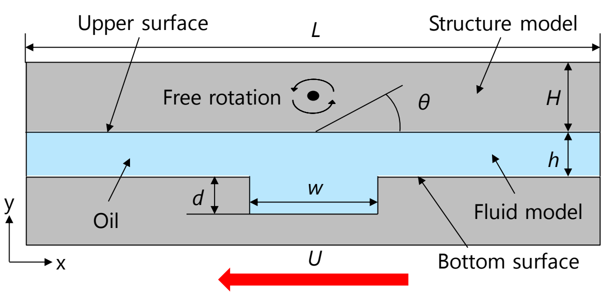

Fig. 1 Analysis model

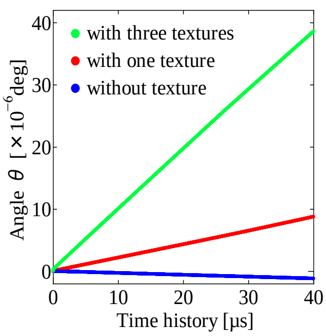

Fig. 2 Time history of incline

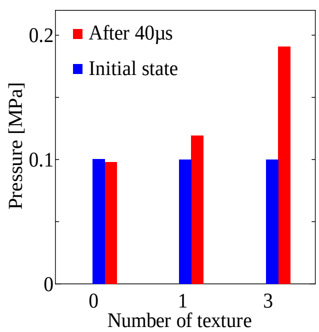

Fig. 3 Average pressure

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WATER-LUBRICATED RUBBER BEARING STICK-SLIP PHENOMENON BASED ON HIGH SPEED PHOTOGRAPHY

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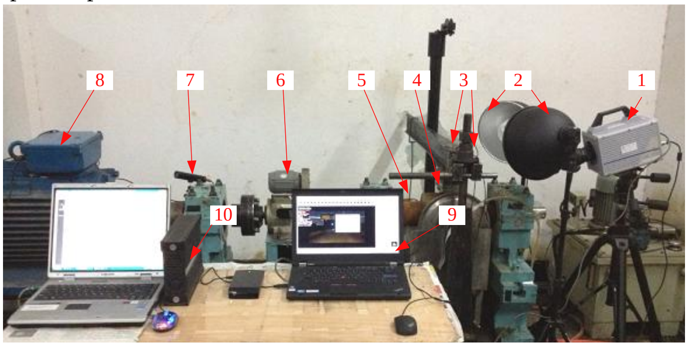
KEYWORDS
water lubricated; stick-slip; high speed photography

ABSTRACT
Audible vibration or bearing squeal generated in the water-lubricated rubber bearings are the results of stick-slip phenomenon. To investigate stick-slip phenomenon, a high speed photography system was used to image the elastic deformation and amplitude of rubber. The vibration frequency and amplitude varying in different lubrication condition, velocity and specific pressure were observed and recorded. The practical motion of the rubber sliding surface in the horizontal and vertical direction were investigated. Results showed that the impacts of the four factors ranked from the most important to the least as lubrication condition, specific pressure, hardness, thickness. It's desirable to alleviate stick-slip by supplying adequate lubrication condition, decreasing specific pressure.



1- High speed camera; 2- LED; 3- acceleration transducer; 4- sample; 5- weight; 6- Torque sensor; 7- Infrared velocimeter; 8- drive motor; 9- computer; 10- B&K

Fig.1 Apparatus of vibration characteristic testing system

Table 1 The variation of amplitude under different condition

pressure/MPa	Amplitude / mm		
	Water lubricated	Semi-dry friction	Dry friction
0.28	0.25～0.8	0.27～0.7	0.9～2.5
0.56	0.6～0.95	0.6～1.7	2.25～5

ACKNOWLEDGMENTS
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WEAR RESISTANT PARTS FOR FRICTION VS. ALUMINUM APPLICATIONS

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KEYWORDS
Wear-resistant, Aluminum, Polymer, Automotive, Lubricated

ABSTRACT
In its Center of Excellence for Lubricated Wear & Friction, a tribology laboratory, DuPont is developing application testing for the industry including automotive.

This study is about wear resistance of aluminum for transmission applications (..), especially when used for friction against polymeric solution such as for thrust washer in planetary gear system or seal ring for hydraulic clutch system.

The target of the study is to identify suitable material combination (polymer vs aluminum grade) and to understand wear mechanisms creating improvement opportunities in transmission environment for the automotive industry. Indeed, light-weighting of the passenger car is an important trend to reduce emission and the use of aluminum is often considered for that.

Data presented in this paper is a result of a 1-year study regrouping long term testing at different pressure and velocity conditions. One example is illustrated below on Fig1. Aluminum types with different Silicon content, have been evaluated to understand its effect on the wear resistance. Materials such as thermoplastic and sintered polymers, but also bronze, often use for friction application, have been compared using similar test procedures on application testing equipment.

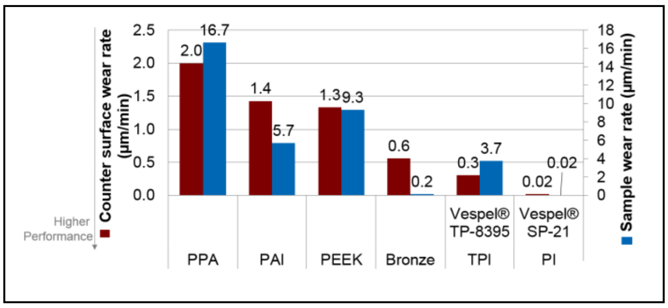

Fig1: Wear Performances – PV 7.5 MPa.m/s

Results have shown that by using the appropriate tribological system (aluminum and counter material) it is possible to extend the lifetime of transmission component significantly.

ACKNOWLEDGMENTS
Thanks to the Vespel® Application Engineering team, especially Thibaut Bernard, for the work achieved to gather data for this paper as well as the rest of the Global Vespel® Transportation team, led by Loic Chéreau, for advices and feedback regarding market needs.

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A CRITICAL REVIEW OF THE ASSESSMENT OF MEDICAL GLOVES

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KEYWORDS
Tribology, Medical Gloves, Friction

ABSTRACT

The first use of medical gloves surgeons wore as protective barriers, to protect from the risk of disease and cross-contamination, was used in 1889 [1]. Over time medical gloves have been developed to be manufactured with the most common materials we see and use today; natural latex and synthetic nitrile. These materials are used as they form easily to the shape of the hand and are elasticated for dexterity [2].

Placing a glove over the fingers forms a barrier, reducing the tactile feedback, which is essential for exploration of surfaces. Wearing gloves has also been shown to have an effect on dexterity when compared to carrying out tasks without wearing gloves [3]. This could lead to a surgeon missing out on salient information relating to patient care. The frictional properties of medical gloves have had limited testing with regards to the tactile and haptic feedback for surgeons carrying out real world surgical tasks [4]. The current literature assesses tribological effects of a rubber membrane barrier, as shown in Figure 1 [5]. Many of these test methods do not take into account the specific tasks that are carried out by surgeons (holding the same hand position, drilling, suturing etc.) and have little regard for the minuscule skin and organ surface anomalies that surgeons often have to detect.

The aim of this research is to critically review whether the current medical glove assessments are fit for purpose and assess the possibility of new methods being implemented.

Figure 1. Image of recessed grid used in Mylon et al. (2017) looking at the effects on sensation using gloves on a grid with 'bumps' on it.

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THE INFLUENCE OF LOW VELOCITIES IN THE RUNNING-IN PERIOD ON THE LONG-TERM PERFORMANCE OF A LUBRICATED STEEL CONTACT

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KEYWORDS
Third Body, Running-in, Boundary lubrication,

ABSTRACT

The initial contact period in a lubricated tribo system seems to be crucial for the development of low friction coefficient and wear rate. During this so called running-in period severe changes occur in the primary materials as changes in topography, subsurface microstructure and chemical composition, the so described third body evolves. This has been discussed and reported by several authors and is a well known, even though not well understood mechanism [1-3].
The initial contact parameters influence the evolving friction and wear of a lubricated contact which can be also correlated to the third body formation was shown among others by Scherge *et al.* correlating the performance of the system to the initial power density applied at the beginning of the running-in [4,5]**Erreur ! Source du renvoi introuvable.**.
The general influence of velocity on a tribo system has been mainly discussed on the base of shear gradient and flash temperature changes. Anincrease in wear for an increase in velocity was reported [6,7]. For lubricated contacts, the well known Stribeck curve indicates a decrease in friction for a velocity increase in the mixed lubrication regime.

However, this study aims at investigating the influence of velocity in the initial contact period on the long-term friction and wear behaviour of a lubricated steel-steel contact taking in account mechanisms of shear gradient and flash temperature changes.

The used material was a fine polished and lapped 56NiCrMoV7 and C45 steel sliding against C80 using a polyalphaolefine baseoil. For the experiments, different velocities were used, ranging from 0.05 to 1.5 m/s. The friction was compared after the initial period in a dynamical test and the surface was characterised with a 3D white light interferometer to detect roughness changes and to determine the total wear loss. The subsurface microstructure was analyzed after the tests by means of focused ion beam cross-sectioning and X-ray photoelectron spectroscopy.

In general, the results showed a decrease in friction and wear with a decrease in running-in velocity until a limit. This limit was specific for the different surface finishing and the material couple. The subsurface after the initial contact could be divided into a nanocrystalline layer on the top surface and a plastically deformed area underneath, revealing sheared grains in sliding direction.
The maximal displacement of the plastically deformed grains, the maximal depth of the deformation and the depth of the third body increase with the decrease of velocity to v =0,05 m/s. Chemical analysis reveals that changes in oxygen and adsorbate (C/CHX) concentration, which is correlated to intermixing of oil, did not correlate with the velocity and the depth of the third body but was apparently dominated by the earlier finishing process of the surface.
It can be summed up, that a reduction of velocity in a lubricated contact operating in the mild wear regime might have a positive influence on the long-term performance of a tribological system due to optimal microstructural changes in the subsurface layer.

ACKNOWLEDGMENTS
We acknowledge the Robert Bosch GmbH and Daimler AG for their financial support.

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TRIBOLOGICAL CAPACITY FOR SELF-LUBRICATING AND HIGH LOAD BEARING MATERIALS FOR LANDING GEAR PIN JOINT

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KEYWORDS

Landing gear pin joint, load bearing materials, tribological capacity, self-lubricating

ABSTRACT

In assessing material candidates for the application of landing gear pin joint, high pressure bearing capacity is one of the most demanded requirements as it is crucial in driving the size and therefore the component mass [1]. In addition, greasing of the pin joint is a significant recurring cost driver and therefore there has been and will continue to be pressure from aircraft operators to decrease the need for greasing [2]. Therefore, a self-lubricating material with high load bearing capacity will be a promising choice for the pin joint [3]. In this study, in order to evaluate potential material candidates for the landing gear pin joint, over twenty materials, covering metallic, polymer, composite, carbon based are surveyed including the specification of mechanical/physical properties. Representative materials are adopted for the ball-on-disc tests for the investigation of their tribological performance.

METHODOLOGY

The first set of experiment is conducted using a Bruker-UMT-3-Tribometer with a load range of 2- 200N through a ball on disc contact configuration. Forces in x and z direction, representing frictional force and normal applied force, as well as linear reciprocating or unidirectional rotating sliding speed were recorded for with a sampling rate of 0.01s. Normal load is increased in order to approach surface's bearing limit, e.g. severe wear, intensive friction and/or high heat generation.

The second set of experiments is to characterize worn surface profile using Stylus profilometer, Carl Zeiss Axiovision A1 optical microscope and Jeol 6500 Scanning Electron Microscope from the Leonardo Tribology Centre. Quantified parameters of friction and wear will be obtained and compared among materials for the analysis of their tribological capacity.

Due to manufacturing nature of different materials, i.e. fibers or resin in composites not being cut through by smaller sized ball, varying sizes of ball are adopted for the ball-on-disc tests. All tests are performed without adding any lubricants.

RESULTS

Table 1 shows part of experimental results for materials covering metallic, fiber reinforced polymer and carbon based material. Friction coefficient of the dry contact is determined from recorded frictional force. Worn surface profile is investigated for the analysis of wear mode/mechanism. Due to the current configuration, the maximum load applied to the contact is 500MPa which is greater than most materials' 'max static load' indicated in the manufacturer's brochure.

The material made by steel-backed sintered bronze is found to have the best tribological capacity due to the lowest friction coefficient and wear amount for both mating surfaces. It is therefore proven to be a potential self-lubricating material for application that requires good tribological performance, no lubrication but relatively high bearing pressure, i.e. the future landing gear pin joint. Further tests with even higher load will be performed to investigate the extreme cases that reach or approach surface failures.

Table 1 Part of testing materials and results

material	Max testing load, MPa	CoF	Max wear scar depth of specimen, µm	Ball wear volume, X10^{-3}mm^3
Aluminum Bronze	500	0.44-0.52	15.6	0.206
Spinodal bronze wrapped alloy	500	0.8-0.9	8.2	6.75
Steel-backed sintered bronze	500	0.13-0.22	0.1	0.351
ToughMet	500	0.8-0.9	9.8	5.49
Meldin® 5330 polymer	500	0.22-0.3	2.9	1.36
Orkot® C410	190	0.07-0.1	n/a	0.008
Carbon Graphite	500	0.12-0.14	2.3	0.655

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STUDY THE TRIBOLOGICAL EFFECTS OF CARBON NANO TUBE (CNT) IN CU/SIC/GRAPHITE HYBRID COMPOSITE BRAKE MATERIAL

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KEYWORDS
Brake; CNT; Friction; Graphite; Wear

ABSTRACT

The brake pad friction materials consist of binders, reinforcing fibres, fillers, solid lubricants and abrasives etc. Among various metallic binders and ceramic fibres, Copper (Cu) and Silicon Carbide (SiC) combination provide good wear resistance, high toughness, high thermal conductivity and low heat thermal expansion and also SiC is more compatible with Cu material [1]. In spite of having many components in brake pad materials, solid lubricants play an important role to enhance their tribological properties, particularly, frictional behaviour in automotive brake system [2]. And further some studies have shown that Multiwall Carbon Nano Tube (MWCNT) can also improve certain tribological properties like less wear rate and sustainable coefficient of friction etc. [3]. The aim of this work is to investigate the complementary role of MWCNT in a Cu/SiC/Graphite hybrid composite brake friction material.

For this study, an experimental investigation will be carried out to examine the tribological behaviour of NAO (non-asbestos organic) type brake friction materials containing the graphite as a solid lubricant with different volume ratios of 5%, 7.5%, 10% and 12.5%; keeping 50% Cu as metal matrix, 30% SiC as reinforcing fibre as constant and the remainder with barium sulphate ($BaSO_4$) as filler. From these experiments, the optimal volume percentage of graphite will be found. Further, keeping the test conditions are same, the experiments will be carried out for varying volume ratios of MWCNT (0.5%, 1.0%, 1.5% and 2.0%) combined with the optimized graphite content, 50% Cu, 30% SiC and adjusting $BaSO_4$ vol.%.

The test samples will be prepared by conventional powder metallurgy techniques and undergo microstructure analysis and material characterization. The experiments will be carried against grey cast iron as a disc material using a fully instrumented Pin-on-Disc (PoD) Tribometer with linear variable transducer (LVDT) for wear rate and strain gauge for friction measurement under dry condition for medium duty automotive applications. In post-test analysis, the morphology of worn out surfaces, wear mechanisms and compositions of brake friction materials will be examined by using scanning electron microscope (SEM) with energy dispersive x-ray spectroscopy (EDX).

The relative amounts and different types of brake friction materials are given in Table 1.

Table 1. Different types of brake friction materials [#]

Base compositions: Cu = 50%; SiC = 30 %					
Material	Function	Type A	Type B	Type C	Type D
Graphite	Solid lubricant	5	7.5	10	12.5
$BaSO_4$	Filler	15	12.5	10	7.5

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Poroelastic lubricity of micro-porous polydimethylsiloxane (PDMS)

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KEYWORDS
aqueous lubrication; biomimetic; cartilage

ABSTRACT

With an ever increasing need to reduce the friction and wear of machines, work has turned towards bio-inspiration in order to improve tribological systems. Natural synovial joints display particularly favourable tribological characteristics; extremely low friction and wear. It is postulated poroelasticity is one of the mechanisms responsible for these properties.[1]

Microporous PDMS was prepared using a templating technique with heat sintered poly(methyl methacrylate) (PMMA) beads. Compression tests were carried out using a Mecmesin compressor with a load cell of 10 N. Tribological tests were completed under a range of conditions using both a bespoke tribometer and an Anton Paar NTR^3 nano-tribometer with either water or glycerol as the lubricant.

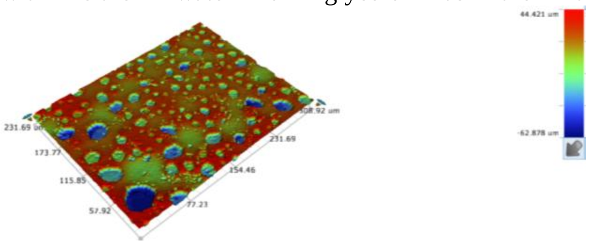

Figure 1. White light interferometry image of the surface of a porous sample

Although the porous samples did not exhibit significant poroelastic behaviour with aqueous lubrication, using glycerol as a lubricant did result in the porous samples demonstrating poroelastic properties, halving the frictional coefficient as compared with water, and under some sliding conditions reducing the frictional coefficient to as low as 0.15.

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BIO-TRIBOLOGICAL INVESTIGATION OF WEAR IN CERAMIC-ON-CERAMIC HIP REPLACEMENTS

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KEYWORDS
Ceramic; wear; total hip replacement; wear debris

ABSTRACT
The THA is becoming more common worldwide as the most performed solution for joint diseases. Nonetheless, a THR has a limited lifetime, i.e., an average of fifteen years. Moreover, hip replacement surgery is concerned younger and more active patients nowadays. Therefore, the reduction of wear in THR is a challenge for orthopedists, in order to improve its survivorship.

In this context, to provide better understanding of the wear phenomenon of CoC articulating surfaces, a tribological characterization was made for an in vitro tested THR with a hip joint simulator at the School of Mines of Saint-Etienne in calf serum. This prosthesis was subjected to very severe operating conditions (Shock tests + walking simulator following the ISO 14242 (6 million seconds)) in order to generate more wear debris. After the quantification and the filtration of the resulting particles, a primary cell culture of murine chondrocytes, which is a cell culture model used to simulate the mineralization process, was achieved followed by biological characterization tests as the viability and the cytotoxicity. The results of these tests were compared to those of a standard UHMWPE wear debris obtained from a hip simulator. The primary advantage of this study is the characterization of the morphology of rubbed zones on CoC articulating surfaces as well as proving the toxicity of ceramic wear debris comparing with those of standard UHMWPE and the effect of the size of particles on cells' cytotoxicity.

NOMENCLATURE
THA = Total Hip Arthroplasty
CoC = Ceramic-on-Ceramic
THR= Total Hip Replacement
UHMWPE = Ultra High Molecular Weight Polyethylene

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ROUGHNESS-GENERATED VERTICAL DYNAMIC EXCITATION OF SLIDING SURFACES: EXPERIMENTAL, NUMERICAL AND ANALYTICAL APPROACHES

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KEYWORDS
Roughness ; vertical vibration ; roughness noise ; extreme values statistics

ABSTRACT

Under weak normal load, when two surfaces are sliding one upon each other, the strain of the asperities is low, and a vertical vibration appears. More precisely, the physical origin of this vibrational state is directly induced by the surface topographies. This vibration, induced by the roughness of antagonist surfaces, leads to a so-called roughness noise [1]. It is also the excitation source of a vibro-impact regime [2-3] between micro-asperities of the two surfaces. By imposing the distance between the surfaces, it also drives variations in the dispersive force magnitude [4] (for example van der Waals, Casimir or Casimir-Lifshitz forces).

This excitation source may be modelized as a stochastic process of displacement kind, the spectral and statistical properties of which have to be described. These characteristics are intimately linked to the topographic properties of the surfaces, which are generally known. However, the properties of the topographies and of the induced excitation are not related in a simple way. Actually the excitation displacement is related to the statistics of the highest asperities of each surface. The aim of this study is to explore this relationship between surface topography and the induced vibrational excitation source. To achieve this goal, experimental, numerical and analytical methods have been implemented. We consider the fundamental case of a finite parallelepipedic rough pad sliding on a massive rough plate.

(i)Experimentally, the vertical motion of the rough slider is measured using a laser vibrometer, giving access to the spectral and statistical properties of this displacement.

(ii)Thanks to a (time consuming) numerical integration of a simplified model including simulated random surfaces, this motion has been investigated for a wide range of cases. Fractal surfaces with various low frequency cutoff and various Hurst exponents have in particular been studied. This method gives access to the spectral and statistical properties of the vibrational excitation displacement.

(iii) In order to interpret the above results, an analytical approach is developed in order to clearly link the properties of the topography to that of the vibrational excitation displacement. More precisely, the study of extreme value statistics allows us to find an analytical expression of the vertical motion statistics.

Those three methods give consistent results, leading to a quite good understanding of the main phenomena at stake. This work thus enables a complete description of the vibrational displacement excitation due to the roughness of the two antagonist sliding surfaces. Those results are useful as an excitation source for dynamical models such as the bouncing ball model [5], as well as various aspects of interacting surfaces in relative motion.

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NEW METHODS TO CHARACTERIZE TRIBOLOGICAL BEHAVIOUR OF COATINGS UNDER HIGH CONTACT PRESSURE

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KEYWORDS
Bridgman tribometer; RHEOS®tribometer; coating; galling resistance; high contact pressure

ABSTRACT

This work deals with the use of original methods to characterize tribologicalbehaviour of materials under high contact pressure. In metal working or threaded compound fields, a lubricant must ensure a low friction and galling resistance under high contact pressures. This implies a certain coefficient of friction and a good wear resistance. In the literature, there is many tests to characterize the tribologicalbehaviour under high contact pressure; cross-cylinder [1], galling tester [2], pin-on-disk [3], etc… For all these tests the surface contact is relatively small. In this study, two new methods to characterize coatings and a grease with a larger contact surface are presented; Bridgman and RHEOS®tribometers.

With Bridgman machine, samples are circular plates (contact surface: 7.1 mm^2) positioned between two WC anvils. Then, a normal load of 7000 N (contact pressure: 1 GPa)and one revolution at 1 rpm are applied. The coefficient of friction was recorded during the revolution. With RHEOS®tribometer, samples are also circular, but the higher load capacity (750000 N) allows to use larger samples (contact surface: 177 mm^2) for the same contact pressure of 1 GPa. Then, anvils were directly used as samples to increase contact surface. For all these tests, the flat contact is the same as metal working and threaded compound fields. These methods were used to characterize the tribologicalbehaviour of three lubricant coatings; Epoxy, Fluoropolymer and PolyUrethanecoatings, that we compared with a grease. Generally, circular plate samples give a good ranking in term of friction (Figure 1), but cannot be used to characterize galling resistance because of the samples size and the existence of an adherence area. The use of RHEOS® with anvils samples (contact surface: 374 mm^2) allows to characterize the galling resistance of coatings (Figure 2). Among tested coatings, fluoropolymer and polyurethane coatings showed a similar galling resistance to grease.

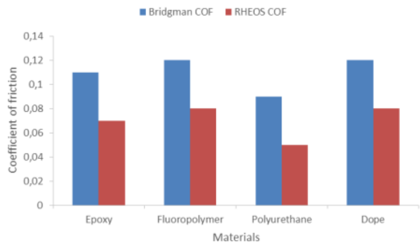

Fig.1 Bridgman and RHEOS coefficient of friction as a function of materials tested

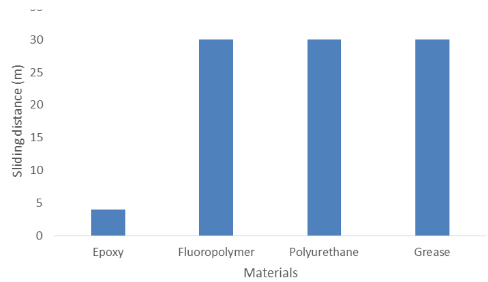

Fig.2 Galling resistance of materials tested

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CONTACT MECHANICS ON ROUGH INTERMEDIATE GAUSSIAN – EXPONENTIAL SURFACES

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KEYWORDS
contact mechanics; computer-generated rough surfaces; boundary element method

ABSTRACT
Once initiated by Hertz, [1] the contact mechanics achieved another of its highlights fifty years ago with the seminal work by Greenwood and Williamson. [2] Since that and in spite of some inconveniences, [3] the Greenwood-Williamson (GW) contact mechanics persists to be one of the most elegant analytical methods which correctly provides the linear dependence of the friction force on the applied load in dry and elastic contact situations. Some issues not considered originally within the GW-model, however, are still challenging. [4]

Among these, in this contribution, randomly rough surfaces showing an intermediate Gaussian – exponential distribution of heights are investigated. Originally, in Ref. 3 only the limiting cases of this height distribution, namely the Gaussian, as illustrated in Fig.1, and the exponential one were considered.

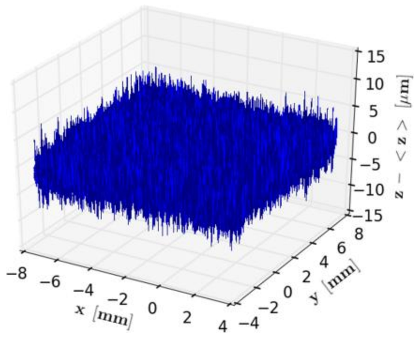

Fig.1 Computer-generated Gaussian surfaces.

An advantage of intermediate Gaussian – exponential height distributions is that its so-called roughness exponent α allows a continuous transition between the limiting cases of GW-model, and this also in all analytically derived GW-type formulas. Here, the randomly rough surfaces for a given α are numerically created by solving a Langevin-type stochastic differential equation by also setting the variance σ^2 and correlation length ξ, e.g., for the Gaussian ($\alpha = 1/2$) in Fig. 1, $\sigma = 8$ μm and $\xi = 0.75$ μm. The statistical moments of these computer-generated surfaces are then used to properly approximate and hence computationally verify the deduced analytical formulas.

Finally, the so generated randomly rough surfaces are also used as input for contact mechanics calculations performed within an in-house developed computational framework based on the boundary element method (BEM) and B-splines interpolation. Here these numerical results are then compared with GW ones.

Another goal of this contribution is to provide a model of machined surfaces showing a power-law dependence in the power spectral density without possessing a fractal topography.

ACKNOWLEDGMENTS
This work was funded by the Austrian COMET-Program (Project K2, XTribology, No. 824187/849109) and carried out at the 'Excellence Centre of Tribology' (AC2T research GmbH).

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ADDITIVE MANUFACTURING AND LASER-OPTICAL MEASUREMENTS IN THE INVESTIGATION OF DRAG LOSSES IN WET MULTI-PLATE CLUTCHES

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KEYWORDS
Drag torque; groove design; laser-optical measurement

ABSTRACT

Wet multi-plate clutches and brakes are widely used as starting and shifting elements in drive trains for industrial and vehicle applications. In open state and at speed difference, hydrodynamic friction generates drag losses. New requirements in electrified drive concepts and the need to increase energy efficiency require a reduction of these losses. Experimental studies are widely used to identify the influencing parameters on these drag losses. The physical formation mechanisms are largely unknown. Existing analytical models predict the drag losses under very simplified conditions. Especially important influencing parameters, e.g. the groove design of the friction plates, are often simplified or not taken into account. The quantification of drag losses is limited when using analytical models. By using numerical simulations it is possible to calculate the influence of any groove design to the drag losses. However, their use is currently limited by computational capacities [1]. The necessary experimental validation of variation of the groove design is time- and cost-intensive with conventional production processes.

In this paper, a research and validation environment for the identification of the influence of the groove design on the drag losses is presented. For the production of geometric and functional prototypes additive manufacturing methods are used [2]. This allows a systematic experimental investigation of the influence of the groove design on the drag torque. The experimental characterization of the relevant flow-mechanical processes in the lubrication gap is possible by a suitable combination of laser-optical measurement systems [3] and the groove design can be coupled with the drag losses by the corresponding velocity fields. A contribution is thereby provided for the physical modeling and the validation of numerical simulations. This further supports a targeted and functional groove design to reduce drag losses in wet multi-plate clutches.

When using additive manufacturing processes for the production of prototypes and variation of groove design is to ensure that these are valid as regards conventional friction plates and a correlation of the experimental results is permitted. Within the scope of this paper, an evaluation of different additive manufacturing processes, materials and their geometrical, physical and chemical properties is carried out and a suitable additive manufacturing process is selected. Topographical investigations are carried out to determine the manufacturing accuracies and surface properties of the individual processes, see **Fig. 1**. Furthermore, experimental investigations of the drag losses are carried out and the results of conventional friction plates are compared with prototypes under varying boundary conditions of oil flow rate, temperature, clearance and groove design. Based on a model test rig, the potential of the laser-optical measurement is shown.

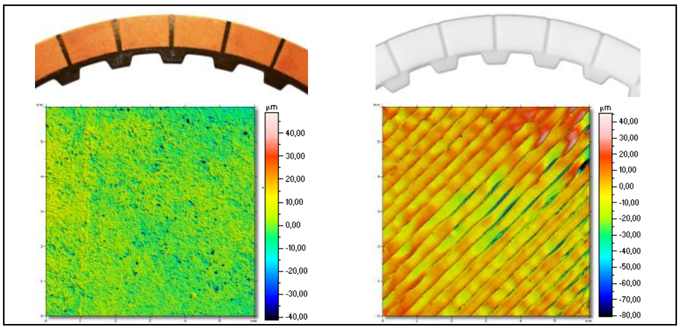

Fig.1 Conventional (left) and prototypical (right) friction plate and respective surface

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TRIBOLAYER FORMATION IN HEAVILY LOADED SLIDING CU-FE CONTACTS USING LARGE-SCALE MOLECULAR DYNAMICS SIMULATIONS

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KEYWORDS
Sliding contact, tribolayer, face-centred cubic, molecular dynamics simulation

ABSTRACT

Tribopairs of copper- *vs.* iron-based materials are frequently used in heavily loaded sliding contacts. Analytical research in the last 10-15 years was dedicated to TEM studies on tribologically induced changes of the microstructure near the surface [1]. Numerical methods focused on the description of deformation mechanisms and strain hardening effects of bulk materials. For tribological contacts, molecular dynamics (MD) simulations proved to be a powerful tool to simulate small-scale effects of crystal plasticity and wear volume generation. The surface topography and the microstructure of the sliding material have great influence on the wear volume, as shown by the authors in [2] for bcc.

Nanocrystalline tribolayers in copper alloys exhibit wear behaviour significantly different than larger polycrystals as shown in [3], but predictive models for tribolayer formation are not well established yet.

In our contribution, we used an MD set-up to model various Cu polycrystals with comparable grain structures, but different initial grain orientations in a heavily loaded tribocontact. Lubrication was implicitly taken into account by tuning the energy parameter of the Lennard-Jones potential determining the interaction strength between the rigid iron counterbody and the soft copper sample. The changes of the microstructure and the coefficient of friction were monitored as functions of sliding time as well as of the normal load.

Plastic deformation processes in nanocrystalline structures are likely to be dominated by grain boundary sliding. In an effort to enable numerous plasticity modes, the grain size in the MD model was maximised, approaching analytically measured scales. Without comprising the feasibility of the simulation due to artefacts introduced via periodic or fixed boundary conditions, a multi-stage method for the preparation of a numerical polycrystalline sample was devised including explicit sintering and heat treatment processes. This led to a copper sample with “large” grains (d ≅ 25 nm) close to the sliding interface and smaller grains further away, where the amount of plastic deformation can be assumed lower.

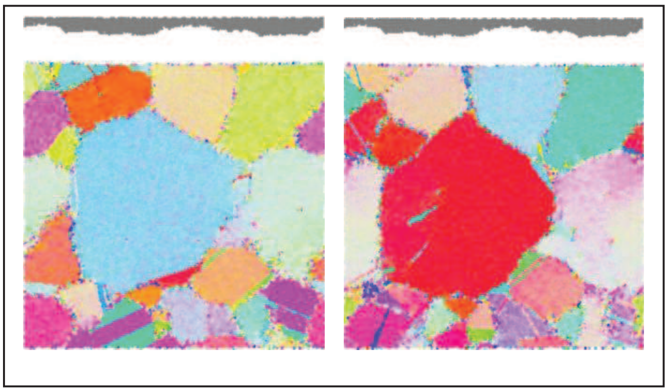

Fig.1 Polycrystalline MD models with similar grain structure, but different initial grain orientations

We will show Cu sample tomographs coloured according to electron backscatter diffraction (EBSD) standard to analyse the formation of a tribolayer during prolonged sliding under high pressure. Finally, we will discuss local stress states, and visualise as well as quantify lattice defects as a function of load.

ACKNOWLEDGMENTS

This work was funded by the Austrian COMET-Program (Project XTribology, no. 849109) and the work was carried out at the “Excellence Centre of Tribology” (AC2T research GmbH).

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A COMPARISON OF DIFFERENT MODELING APPROACHES FOR SIMULATING DRY FRICTION ENERGY DISSIPATION IN GAS FOIL BEARING ROTOR SYSTEMS

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KEYWORDS
Gas Foil Bearing (GFB); Fluid–Structure–Rotor Interaction; Dry Friction Energy Dissipation; Self-Excited Vibrations

ABSTRACT

During the last few decades, successful applications of refrigerant-lubricated gas foil bearings (GFBs) in air cycle machines of commercial aircraft have confirmed the remarkable potential of this technology in the light of an increasing demand for oil-free and energy-efficient turbomachinery [4]. Besides excessively low wear and power loss due to the absence of solid-to-solid contact between the airborne rotor journal and the bearing sleeve, the use of GFBs permits to overcome yet insurmountable speed, temperature, size, weight, and cleanliness limitations of conventional rolling-element bearings. However, most GFB rotor systems are prone to undesirable self-excited vibrations with comparatively large amplitudes which occur for higher rotational speeds and may ultimately lead to machine failure [2,3]. As a countermeasure, the compliant and slightly movable foil structure (bump foil and top foil) inside the lubrication gap of a GFB is supposed to dissipate a certain amount of energy via dry sliding friction mechanisms [1,5], thus reducing the amplitudes of detrimental vibrations [6,7].

In currently conducted research on GFB rotor systems, sophisticated models and runtime-efficient numerical tools are of major interest with regard to the complexity and costliness of experimental investigations. Considering a nonlinear and fully coupled fluid–structure–rotor interaction model, the gas pressure inside the lubrication gap can be described by a generalized form of the classical REYNOLDS equation which is applicable for compressible fluids and yields the bearing forces acting on the rotor journal [2,3,6,7]. Moreover, with a particular regard to refrigerant-lubricated GFBs under heavy dynamic loading, the REYNOLDS equation can be further generalized and may be completed by equations accounting for heat transfer, gas–liquid phase transition, and turbulence [4].

Concerning the foil structure, complex FE models as discussed by many recent publications prove to be inapplicable when it comes to a transient analysis of the overall system due to an excessive computational cost. However, with some similarity to [1,5,6], the presented minimal dynamic structure model is reduced to a reasonable complexity and considers energy dissipation assuming a COULOMB-type dry friction law applied to a spring–mass arrangement representing the bump foil. This model is compared to a homogeneous foundation model with equivalent viscous damping as discussed in [7]. In doing so, the main objective of this work consists in gaining an advanced understanding of why energy dissipation in GFBs by dry friction is unique and substantially different from viscous damping. Therefore, the stability of stationary operating points and the occurrence of self-excited vibrations are investigated. Summing up all results, dry friction energy dissipation reveals a remarkably beneficial effect upon the overall system's behavior and thus merits a thorough consideration in reliable simulations.

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METAL-TO-METAL CONTACT BETWEEN ROUGH ELASTO-PLASTIC SOLIDS IN LOADING AND UNLOADING WITH APPLICATION TO STATIC SEALS

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KEYWORDS

Leakage; Elasto-plastic contact; Persson's theory, Loading/unloading cycle, metal-to-metal seals

ABSTRACT

Studying leakage through contacting surfaces is important for many applications where the percolating fluid might be hazardous for the environment or vice versa where environmental fluids can be destructive for the interior of a system. If sealing materials behave non-linearly and their deformations involve energy dissipation, it becomes relevant not only to study the leakage at a given load but also to take into account the loading history. This becomes critical for visco-elastic (polymers and elastomers) and for metal-to-metal seals. The latter seals constitute the topic of this study.

Metallic surfaces, especially during first loading/unloading cycles, can accumulate significant amount of plastic deformations and thus the surface topography can change significantly. If used appropriately, this plasticity can be beneficial for the sealing performance, as a more intimate contact between the surfaces can be achieved. A preliminary study using a boundary element method (BEM) [1] showed an interesting hysteretic behavior, depicted in Fig. 1.

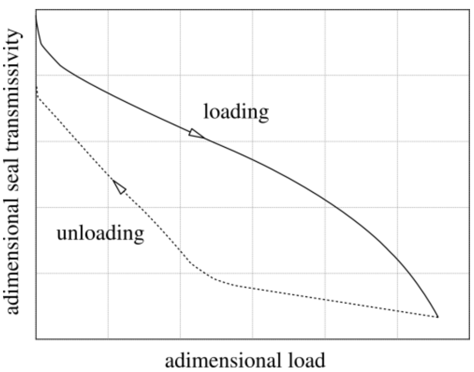

Fig. **1** Schematic representation of the transmissivity behavior obtained when studying loading (solid line) and subsequent unloading (dashed line) of an elasto-plastic seal with a self-affine rough surface.

It was found that, given the right conditions and surface parameters, the seal could be partially unloaded without increasing significantly the total flow.

In this study we first compare on simple geometries the full scale finite element (FE) model with the boundary element model, in which the plasticity is included in terms of saturation of the contact pressure at the hardness limit. This comparison reveals a good agreement between the BEM and FEM results, proving that the former can be safely used in the analysis of metal-to-metal seals. We then perform a parametric study of big rough surfaces, which can be hardly simulated using the full FE analysis [2], and gain a better understanding of how different conditions and surface parameters affect the unloading of metal-to-metal seals. In addition, we analyze how the roughness changes after every loading/unloading cycle. A deeper understanding of the loading/unloading cycle can be obtained employing an analytical (or semi-analytical) model of rough contact coupled to a viscous fluid transport model. In order to construct such a model, either multi-asperity approaches or Persson's theory coupled to the effective continuum model for the leakage can be utilized. In particular, the method that Persson suggested in [3] to study the effect of plastic deformation on the leakage of seals can potentially be adapted for this study. The validity of the approach for this particular case will be tested.

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DYNAMICS OF NORMAL VIBRATION OF A ROUGH BODY SLIDING ON A ROUGH TRACK UNDER ITS OWN WEIGHT

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KEYWORDS
Rough/rough sliding contact; normal vibration; jumping dynamics

ABSTRACT
When a rough slider is pressed onto a rough track, the highest antagonist asperities of the two bodies meet and deform to create a population of discrete micro-contacts [1]. At very low loads, only a few micro-contacts are created, with a normal indentation much smaller than the *rms* roughness of the solids. In this regime, when the slider is set into tangential motion, it also undergoes a vertical motion necessary to pass over the asperities of the track. When the sliding velocity is large enough, we expect this vertical motion to end up as actual jumps of the slider over the track [2]. Here, we will present an experimental test of such a scenario (see Fig. 1).

We consider a rough stainless steel slider on a rough stainless steel track, both with a *rms* roughness of 26µm. The slider is let under its own weight and driven horizontally at constant velocity in the range 1-200mm/s. Its vertical vibration dynamics are followed using either accelerometers or laser vibrometry. The average tangential force is monitored during the experiments. The existence of a contact between slider and track is also followed at high frequency through electrical measurements.

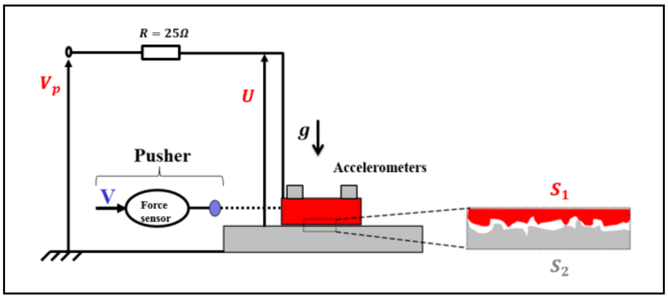

Fig.1 Sketch of the experimental device.

We found a transition between two regimes, separated by a critical velocity of about 10mm/s. In the low-velocity regime, the friction coefficient is constant, and the slider is in contact with the track at all times. In contrast, in the high-velocity regime, the slider moves with jumping dynamics, *i.e.* a succession of free flights and impacts, while the friction coefficient increases with velocity. At the highest velocities explored, the slider spends about 80% of its time out of contact with the track.

We explored the effect of various parameters, including the slider mass, the apparent contact area, the roughness and the driving mode of the slider. For each situation, we characterized the statistical properties of the vertical motion, including the jump duration and the jump frequency.

We will discuss these results and relate the changes in the frictional behavior to those in the vertical dynamics of the slider, in particular in the light of a recently revisited bouncing ball model [3].

ACKNOWLEDGMENTS

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CONSIDERING SURFACE ANISOTROPY IN TRIBOLOGICAL CHARACTERIZATION OF ARTICULAR CARTILAGE

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KEYWORDS
Articular cartilage; Biotribology; Synovial fluid; MCR Tribometer; Surface topography

ABSTRACT
Tribological measurements are used to generate valuable insights into the processes at lubricated articular cartilage interfaces. Tribological characterizations are relevant for the understanding of prevention and treatment of cartilage diseases as well as for the design of prostheses[1].

Cartilage surfaces from natural origin show uneven and varying surface topographies. Rotational tribological measurements are influenced by this factor meaning that the shape of the surfaces influences the measurement result excessively. One can approach this issue by averaging over complete rotations[2] and thereby averaging out the effects of surface inhomogeneities just by running several rotations and generating a mean value. Another approach is to focus on how the tribological properties change as a function of rotational deflection. An MCR Tribometer has been used in this study to characterize how small changes in the surface topography affect the tribological measurements. Porcine articular cartilage specimens were punched out from the knee joint of pigs, respectively being cut out with a sharp knife. For the tests, one punched specimen was rotated on a cut specimen. During one single rotation at low speed, the surface inhomogeneities were recorded qualitatively and were taken into consideration for the interpretation of the tribological measurements, e.g. torque measurements. Here, the authors intend to present a methodology to a more precise approach in the characterization of natural origin cartilage specimen. The effect of surface anisotropy of cartilage samples can be considered to draw more precise conclusions on other relevant factors like the synovial fluid characteristics or the surface properties on a colloidal length scale.

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WEAR OF CO-BASED COATINGS: A COMPOSITE WEAR LAW FOR THE DESCRIPTION OF THE TRANSIENT REGIME OF GLAZE LAYER FORMATION

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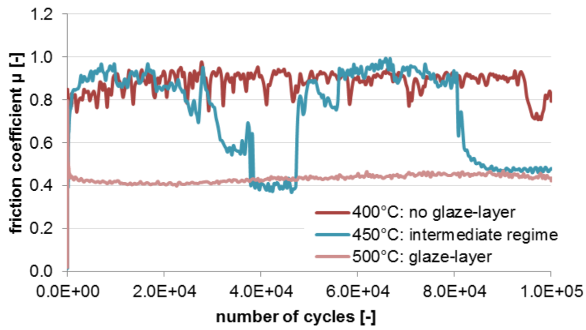
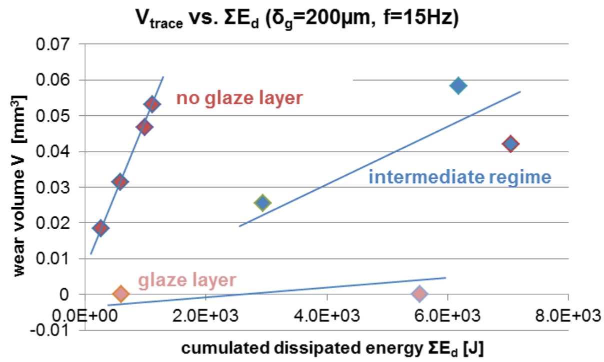
KEYWORDS
Cobalt-based plasma-sprayed coatings; glaze-layer; composite wear law

ABSTRACT

Cobalt-based plasma-sprayed coatings are widely used for thermal protection and wear stability of structural components. The Aerospace-grade coatings investigated in this study are Cobalt-based superalloys that form a protective glaze-layer at temperatures above 400°C when subjected to fretting loads.

In this study we investigate the stability and kinetics of formation of this glaze-layer in the temperature range between 350° and 500°C. Predominant factors influencing the formation and stability of the glaze-layer include the temperature, the imposed displacement amplitude as well as the frequency and number of cycles. Fretting tests in this study are carried out at temperatures of 350°C<T<500°C, displacement amplitudes of $50<\delta_g<200\mu m$ at a frequency of 15Hz for test durations of 25k<n<100k cycles. A dissipated energy approach was employed in order to quantify the wear rates. We propose a composite wear law for the unstable regime at intermediate temperatures which expresses the wear volume V as a function of the effective cumulated dissipated energy ΣE_d which itself is a function of the time spent in the glaze-layer and non-glaze-layer regime, corresponding to friction coefficients below and above μ=0.4, respectively.





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TRIBOLOGICAL BEHAVIOR OF DIFFERENT STEELS UNDER DRY SLIDING: EFFECT OF HARDNESS[1]

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ABSTRACT

The effects of hardness on wear (and friction) of dry steel-on-steels systems was investigated. Tribological tests were carried out in an SRV®4 tribometer in a ball-on-disc contact configuration (i.e. counter-formal). The disc materials were two commercial steels, AISI 310 and AISI H13, and one special valve steel: SAE XEV-F. The selected ball steel for the counter-body was the AISI 52100. Room temperature and fixed conditions of load, frequency and stroke, and sliding distance, were used. There were three characterization stages: *1)* characterization of materials and surfaces, *2)* wear examination, and *3)* process analysis. The characterization techniques were scanning electron microscopy (SEM), coherence correlation interferometry (CCI), and X-Ray diffraction (XRD). Friction coefficient signals were monitored to identify transitions in behavior (i.e. from running-in to steady-state). Hardness correlated inversely with wear, as indicated by the size of the wear scar and the mass loss. All materials showed presence of iron oxides in the worn surfaces, distributed somewhat uniformly and in amounts estimated to be from ~60% to ~100% of the nominal worn area. Marked differences in wear (and friction) were observed between the tested steels.

Keywords: Dry Sliding wear; Friction; Hardness; Ball-on-disc; Nominal contact area.

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PHOSPHOLIPID VESICLES IN MEDIA FOR TRIBOLOGICAL STUDIES AGAINST LIVE CARTILAGE

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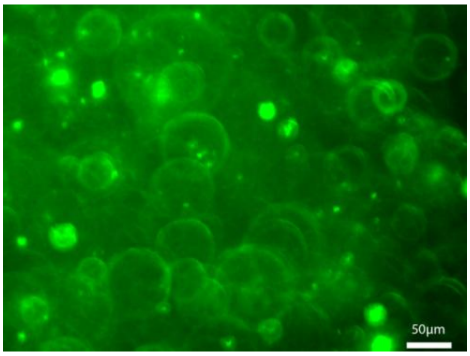
KEYWORDS
Biotribology; cartilage; friction; phospholipids; DPPC;

INTRODUCTION: Osteoarthritis (OA) is one of the most prevalent musculoskeletal disorders affecting 65% of the population over 65 years old and 80% over 80 years old. OA is characterized by cartilage deterioration, and in its advanced stages can require surgical interventions such as partial or full joint replacement. Artificial components which replicate the joint surface are typically studied extensively in-vitro before they go in-vivo. The lubricants used in in-vitro joint simulations vary greatly from the joint's natural synovial fluid. The predominant methods for tribological testing of these components involves the use of water, cell-culture media, or calf-serum; however it was our goal to develop and test a new serum which contains the properties of culture-media to nourish the cells, as well as contain the mechanical properties of synovial fluid to minimize friction.

METHODS: We synthesized a new serum for tribological testing of cartilage which contains lipid vesicles formed by the evaporation of chloroform from a DPPC phospholipid solution. After preforming the evaporation, hyaluronic acid and the standard tissue culture media used in the Tribology Laboratory at Rush University Medical Center were added to form a solution. Lipids were marked with a fluorescent dye and imaged using a fluorescent microscope to detect the structure of the lipid vesicles [Figure 1]. The vesicles are similar to those found in synovial fluid, and may act to reduce friction and subsequent wear during articulation[1]. For this pilot study, cartilage explants were harvested from the femoral trochlear groove of six to eight months old bovine stifle joints using a 4mm in diameter biopsy punch. Biopsies were cultured in the experimental serum or control media for 7 days. After the culture, live/dead images were taken of the biopsies using a fluorescent microscope. Viability tests were performed to ensure the constituents of the serum would not harm the cells.

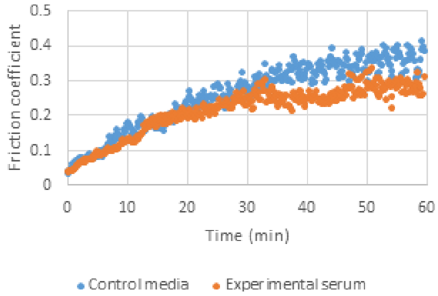
Figure 1: Flourescent image of lipid vesicles in experimental serum (20x)



After confirming cell viability, we performed a friction test using full thickness (~3mm) oval articular cartilage explants in a tribological articulating bioreactor[2]. Both cartilage groups (experimental serum vs. control media) were pre-cultured for 3 days in culture media. During the bioreactor test, cartilage explants were placed in a 3mL bath of either serum or control media, and articulated against a cobalt-chromium hip head which rotated 60°/s in one direction for 1 hour. A load cell was placed below the explants to measure the normal force and a second load cell was placed adjacent to the sample holder to measure the tangential force. On a separate set of explants, in order to assess wear, an additional 3-hour bioreactor test was conducted to detect the PG/GAG release of the tissues using DMMB assay

RESULTS: After the 7- day culture we found no significant difference in cell viability between the experimental serum (62% ± 8%, 95% CI) and the control media (49.5% ± 5%) ($p = 0.009$). The results of the friction test showed a significant difference ($p = 0.030$) between the serum and control groups after 1h [Figure 2]. The friction coefficient at the beginning of the test was similar for both groups. The PG/GAG release was 19% lower for the serum than for the control media, when normalized to free swelling tissue samples.

Figure 2: Evolution of the average friction coefficient for experimental serum and control media during 1 hour



DISCUSSION: We observed lipid vesicles in our fluorescent images of the experimental serum, and our hypothesis that these structures would decrease the friction that occurs during articulation was confirmed by the results shown in Figure 2. With a similar testing setup, Li, et al.[3] have demonstrated an 8% decrease in the friction coefficient between cartilage articulated in a bath of control Ringer's solution vs. an HA solution. Our test demonstrated a 16% difference in the coefficient of friction between the control media and the experimental serum, suggesting that the unique lipid structure within this serum does indeed reduce friction separate from the effects of HA. This serum has the potential to enhance in-vitro experiments with cartilage and implant materials, by acting as a lubricant which more closely models synovial fluid.

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REACTION KINETICS OF ZDDP USING A NEW IN-SITU SYNCHROTRON XAS METHODOLOGY

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KEYWORDS
In-situ; Tribochemistry; Reaction Kinetics

ABSTRACT

For decades, extensive works have been carried out in order to understand the tribochemistry of zinc dialkyldithiophosphate (ZDDP) antiwear additive at high temperature. However, most of these studies were carried out ex-situ using mainly X-ray photoelectron spectroscopy (XPS) after the tribological test is stopped and the contacting surfaces are separated and rinsed with a solvent to remove any entrapped oil in the contact. Rinsing the surface with a solvent can remove part of the tribofilm layers and hence part of the information can be lost after washing.

To overcome this issue, a new design of a pin-on-disc tribological apparatus was developed and combined with synchrotron X-ray absorption spectroscopy (XAS). Using the designed apparatus, which is shown in Fig 1, it is possible to study in situ the transient decomposition reactions of various oil additives on different surfaces under a wide range of realistic operating conditions of contact pressure (0.4–3.0 GPa), temperature (25–120 ∘C), and sliding speed (30–3000 rpm or 0.15–15 m/s).

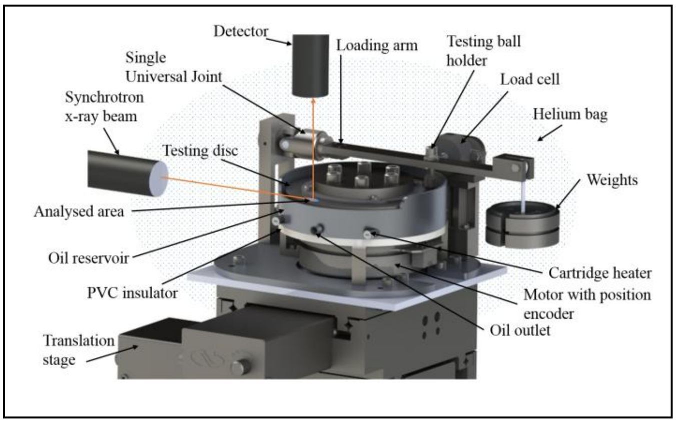

Fig. 1 Schematic of the in-situ rig

The XAS experiments indicate that the ZDDP antiwear additive decomposes in the oil to form a tribofilm on the iron surface at different reaction kinetics from the ones of the thermal film. The tribofilm composition evolves much faster than the one of the thermal film, which confirms that the formation of the tribofilm is a thermally activated process similar to the one of the thermal film but accelerated by shear. Furthermore, the results indicate that the sulfur of the formed film, whether a tribofilm or a thermal film, appears initially in the form of sulfate, with some sulfide, which under heat or shear is reduced into mainly sulfide.

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EFFECT OF GROOVE ON BEHAVIOR OF POINT CONTACT EHL FILM UNDER VERTICAL MOTION

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・KEYWORDS
EHL; Groove; High pressure viscosity; Outflow of oil

・ABSTRACT

The actual lubricated surface of machinery has surface roughness. It plays an important role for EHL film. In order to improve the working performance of machinery, it is necessary to elucidate the behavior of the EHL film. The purpose of this study is to make clear the influences of groove on the outflow of entrapped oil film.

The film thickness is measured by using the optical interferometry technique. The EHL contact is composed of a glass disc (E_D = 75 GPa) with Cr coating and a steel ball (E_B = 206 GPa) of 25.4 mm diameter. The steel ball has groove. Figure 1 shows a profile of groove. Groove depth d_G is 0.27 μm and groove width w_G which is width at half d_G is 34 μm. The experimental conditions are the load of w = 50 N and the temperature of 25.0 ± 0.5°C. A bright stock oil (BS, viscosity : 1.350 Pa•s) is used.

Figure 2 shows time variation of interferograms for l / d = 0.75. Here, l is the length of groove in the contact area and d is the contact area diameter. Due to low pressure inside the groove, oil near the groove flows out through the groove. The oil volume in contact area decrease with time.

Figure 3 shows the interferograms 100 seconds after the contact with various values of l / d. We can find that the oil outflow differs depending on the value of l / d.

Figure 4 shows time variations of the maximum film thickness h_{max} with different l / d. We make h_{max} just after contact 1.36 ± 0.1 μm. Figure 4 shows that the larger l / d causes the larger oil outflow. We think that it is possible to measure the high pressure viscosity by observing the oil outflow behavior.

・ACKNOWLEDGMENTS

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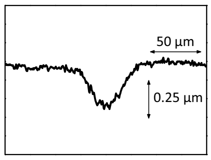
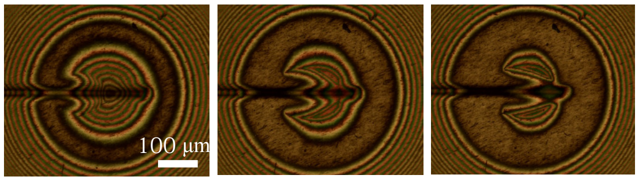
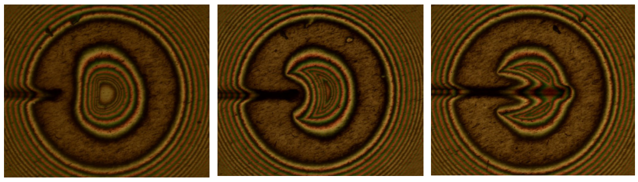


Fig. 1 Profile of groove



t = 0.1 s t = 77.2 s t = 300 s
Fig. 2 Time variation of oil film (l / d = 0.75)



l / d = 0.19 l / d = 0.37 l / d = 0.75
Fig. 3 Effect of l / d (t = 100 s)

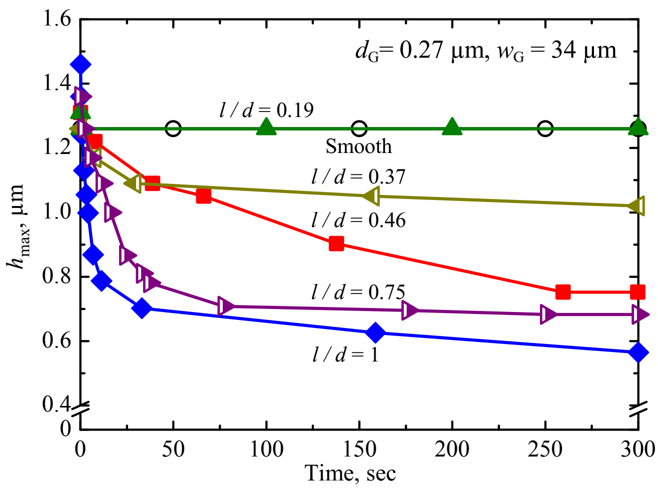


Fig. 4 Time variations of h_{max}

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TRIBOLOGICAL PROPERTIES OF POROUS STRUCTURED SURFACE MANUFACTURED BY SELECTIVE LASER MELTING

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KEYWORDS
Porous structures; Selective laser melting; Tribological properties

ABSTRACT

Selective laser melting (SLM) is a method in which metallic powder layer is selectively melted and fused to produce functional parts. Mechanical properties and density of parts manufactured by SLM are affected by process parameters [1]. It is known that some process parameters create porous structures [2]. Therefore, process parameters which shape nearly full density parts are demanded for structural materials. However, tribological properties can be improved by utilizing porous structures on a sliding surface. It is expected that porous structures can maintain and supply oil as a surface texturing pattern. In this study, effects of porosity on tribological properties of SLM parts were investigated.

To investigate the effects of porous structures on tribological properties, ball-on-disk type sliding test was conducted with poly-alfa-olefin (PAO) of four different viscosities as a lubricant. Specimens (φ 24 mm × t 7.9 mm), which were made from AISI S17400 powder by a SLM machine (ProX300, 3DSystems, US), have different porosity ratios. The specimens A ~ E have descending order of porosity ratio accordingly. The ball (φ 10 mm) was made of AISI 52100.

The experimental results revealed that different oil viscosities exhibit difference in friction behavior. When lubricated with low viscosity lubricant, lubricant was discharged from porous structures and not supplied to the sliding surface. On the other hand, porous structures maintained and supplied oil to sliding surface when lubricated with high viscosity lubricant.

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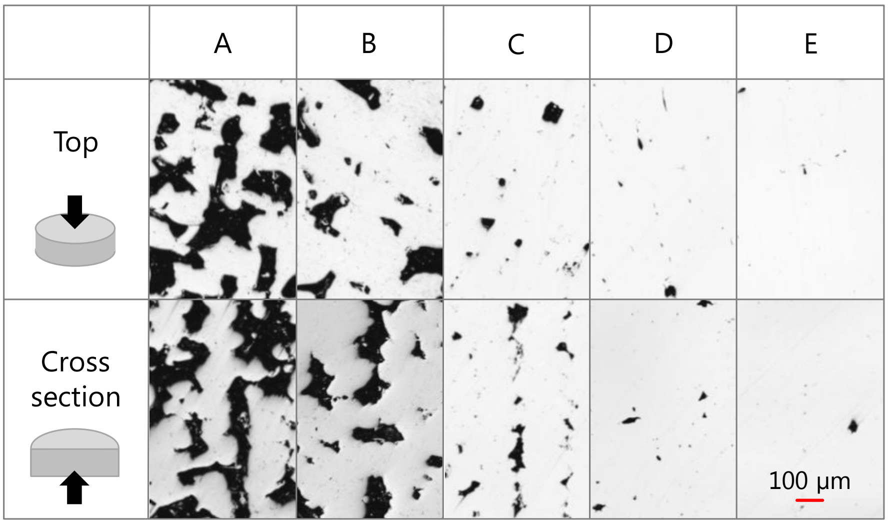

Fig. 1 Surface of specimens

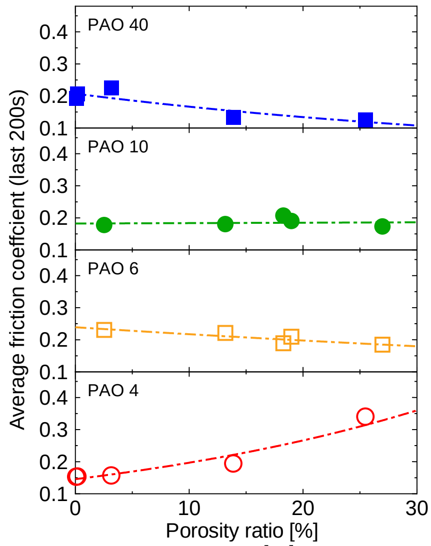

Fig. 2 Friction behavior

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FIB AND MICROSCOPIC OBSERVATIONS OF FAILURE MECHANISMS IN DLC COATINGS AND COUNTERFACE SURFACES

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KEYWORDS

DLC; FIB; formulated oil

ABSTRACT
Investigations were conducted in order to describe and confirm the failure modes of DLC coatings after rolling/sliding contact fatigue (R/S-CF) testing using precise focused ion beam (FIB). The FIB was performed using the FEI Nova 200 NonoLab high-resolution field emission gun scanning electron microscope (FEGSEM). This technique uses a focused beam of gallium ion sources to form a small non-destructive cross-section on the surface. FIB cross-sections were made at the failed portion of the coated substrates after millions of cycles and a pressure level of P_{max} = 1.5 GPa in formulated oil. Results as shown in Figure 1 confirm that the failure was probably of a fatigue character. If the failure were solely due to wear, then the coating would be worn down in a uniform manner until no coating remained on the substrate.
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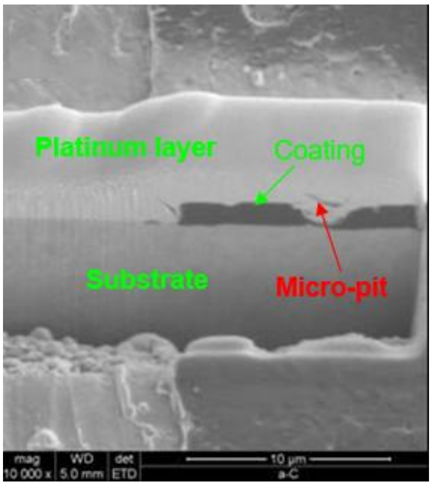

Fig.1 FIB cross-section showing the delamination is extended at the interface and showing the depth of a micro-pit.

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TRIBOLOGICAL BEHAVIOR OF BEHAVIOR TI-6AL-4V SLIDING AGAINST ALUMINA IN VACUUM

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KEYWORDS

Wear Volume; Aluminum oxide; Silicon Nitride; Lubricant; Tribo Oxidation.

ABSTRACT

Introduction and Methodology: Tribological experiments with Ti64 pins sliding against alumina disc under vacuum conditions have been studied; testing under vacuum conditions inhibiting the formation of protective oxide layer(s). As alumina is much harder than Ti64 it is expected that Mechanically Mixed Layers (MML) will be thin. The effect of sliding speed has been analyzed by varying the sliding speed (0.01, 0.1, 0.5, 1.0 and 1.5ms^{-1}) of the disc, while using a 6.6 mm diameter pin and the load and environmental conditions maintained the same for all experiments. Results indicate the wear under these conditions is dependent on the plastic deformation alone, which in turn are governed by the Adiabatic Shear Banding (ASB)/Strain Rate Response (SRR) (at low speeds) and the temperature induced effects thermal softening at high speeds.

Results and Discussion : Results from the tribological testing have been consolidated to depict the variation in Coefficient of Friction (COF) and wear rate of the pin & disc calculated using weight loss method, in Fig.1(a) and Fig.1(b) respectively, while using 6.6 mm pin, normal load of 137.3N, and at different speeds. The scatter in the test data was found to be within ±5%. The values of COF are relatively high (~ 0.7), characteristic of friction experiments involving metals in vacuum. The graph shows a marginal dip in COF at a sliding speed of 0.1 ms^{-1}, which increases when the sliding speed is increased further.

At sliding speed of 0.1 ms^{-1}, friction and wear rate are lower than 0.01 ms^{-1} due to low intensity of ASB [1]. The interface temperature for 0.1 ms^{-1} is higher than 0.01 ms^{-1} hence this reduces the intensity of ASB. At higher interface temperatures the microstructural response is more homogeneous [1-2]. The magnitudes of the wear rates obtained from the tests are characteristic of severe-wear, and the variation is as shown in Fig.1(b); the wear- rates for the disc being relatively low as compared to the pin. Similar to the trend in the variation in COF, the wear was also found to reduce at the sliding speed of 0.1 ms^{-1}.

There is a striking similarity in the pattern for the friction and the wear curves, the wear and friction curves seem to be correlated, characteristic of the adhesive wear mechanism active for these experiments [1]. As the sliding speed (0.5, 1.0 and 1.5ms^{-1}) is increased, surface damage was found to increase, this is due to the effect of heating/temperature becoming active as the sliding speed is increased [1]. This causes an increase in the intensity of adhesion, which results in high COF and wear rate. Plastic deformation due to thermal softening would be the dominant mechanism affecting wear at these speeds, while plastic deformation governed by ASB to be the governing mode at low speeds as explained previously [1, 2].

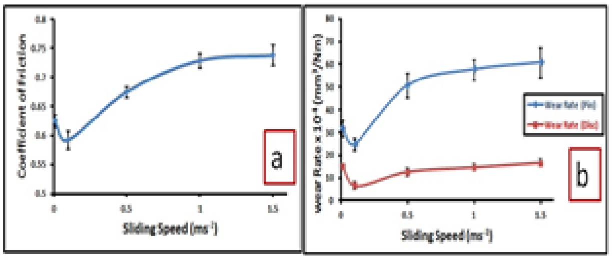

Figure 1: Coefficient of friction (a) and wear rate(b) as the function of varying sliding speeds (0.01, 0.1, 0.5, 1.0 and 1.5 ms^{-1}) at the constant pin diameter (6.6 mm) under vacuum conditions.

Conclusions: Coefficient of friction increases with increasing in sliding speeds. At low speed (0.01 ms^{-1}), COF increases due to high intensity of ASB and sudden drop in COF is observed for 0.1 ms^{-1} due to diffuse ASB. Further it increases with increasing sliding speeds (0.5, 1.0 and 1.5 ms^{-1}) because of high plastic deformation associate with phase transformation (HCP to BCC). The flash temperature evaluated for the experiments for the higher speeds are found to cross the phase transition temperature (~880˚C). Same trend observed for wear rate also.

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PARTICULAR BEHAVIOR OF THE DLC/DLC CONTATC IN MIXED LUBRICATION REGIME

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KEYWORDS

DLC/DLC contact; lubricated contact; additive interaction; viscosity effect

ABSTRACT

The use of DLC coating in automotive industry is now widely spread. For some application the coating used for friction reduction. In some particular case, like the cam lobe / tappet contact or cam lobe / finger follower, it is possible to coat the two parts with DLC.

Some tribology tests were done using a ring on flat test allowing to obtain the same friction conditions as in the real contact, i.e, contact pressure of around 500 MPa and sliding speed from 0.65 m/s to 2.66 m/s. DLC/DLC contacts were characterized in various fully formulated lubricants ranging from very basic lubricants like a classical SAE 5W30 up to a high performance lubricants with friction modifiers and low viscosities SAE 0W16. Varying temperature and viscosity grade, a range of 1 to 5 in terms of viscosity was covered. The Fig 1 show a typical result where the friction coefficient decreases when the speed increases, which is typical of mixed lubrication regime. Despite using extreme lubricants, the friction curves are superimposed. Considering the expected viscosity variation (1 to 5) the result is surprising (Fig.1).

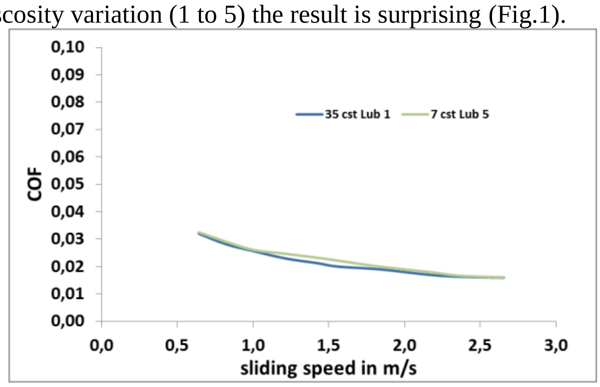

Fig 1 : COF as a function of sliding speed for a SAE 0W30 at 50°C and a SAE 0W16 at 100°C.

Using a pure fluid a very different result was obtained, the expected effect of viscosity is observed, i.e. friction curves obtained at 2 different temperatures are superimposed taking into account the expected viscosities as shown in Fig.2.

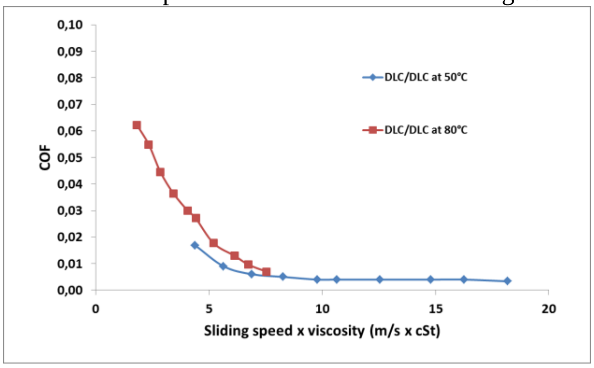

Fig 2 : COF as a function of sliding speed for a pure fluid at 50°C and at 80°C

Similar results were obtained in a cylinder on flat reciprocating test, the power dissipated by friction is around 100 mW. The same trend was observed, pure fluid exhibit an influence of the viscosity as expected, while the fully formulated fluids behaved as if their viscosity was 3 cSt whatever their grade.

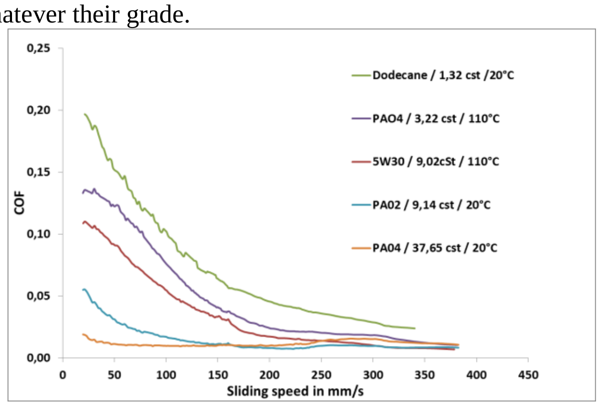

Fig. 3 Evolution of COF in the reciprocation cylinder on flat

These tests have allowed to exclude an overheating effect in the contact that could have modified the viscosity. Segregation of compound of the fully formulated oils could explain the particular behavior for the DLC/DLC contact.

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CHARACTERIZATION OF A HARD BI-LAYER COATING DEPOSITED ON TITANIUM

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KEYWORDS

Microabrasive, chrome, hard bi-layer, electrodeposition, wear coefficient, wear rate.

ABSTRACT

The aim of this work is to characterize a bi-layer coating deposited pure base titanium in a micro-abrasive tester, Plint TE 66. Firstly a zinc layer was deposited on the titanium to then later apply a chrome layer. Both layers were deposited using a novel electroplating technique. The micro-abrasive wear resistance was carried out using 4µm SiC in average diluted in distilled water. Tests were also performed on base titanium for a comparison. Lost volume (*V*) and wear coefficients (*k*) were obtained for the bi-layer coating and for the pure base titanium. The results showed that the pure titanium has a lower micro-abrasive wear resistance comparing to the bi-coating (chromium/zinc). Wear scars were fully characterized taking optical and SEM images identifying the wear mechanisms of three body rolling micro-abrasion.

Figures 1, shows the wear rates (Q) and the wear coefficients (*k*) of the specimens of titanium, which were uncotaed and coated with chrome.

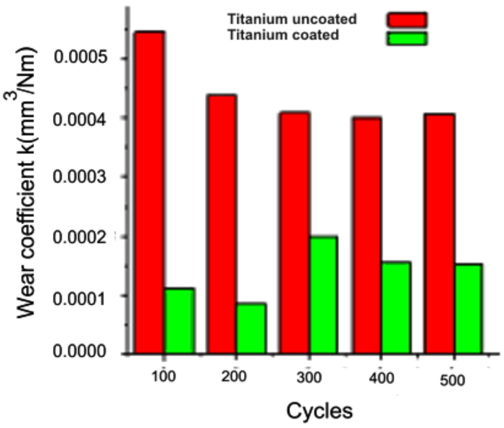

Fig.1. Wear coefficient of coated and uncoated titanium specimens.

The Figure 2, shows the present wear mechanisms.

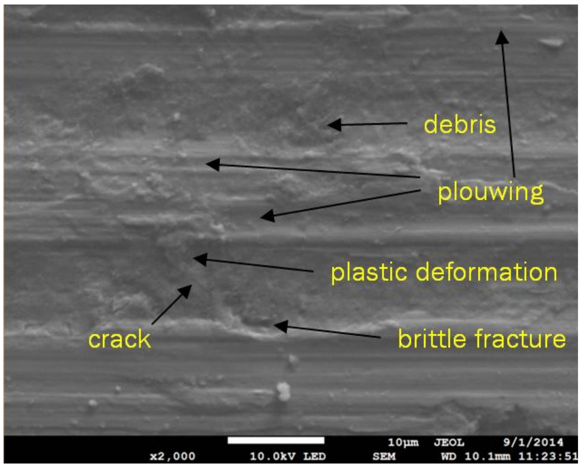

Fig. 2. Wear mechanisms on titanium coated (Cr/Ti)

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FRICTION REDUCTION IN TILTING-PAD THRUST BEARING BY BOUNDARY SLIP WITH TEXTURING

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KEYWORDS
Boundary slip; Texturing; Friction reduction

ABSTRACT
The load capacity enhancement and friction reduction for tilting-pad bearing can be achieved by slip/no-slip design, in which the boundary slip only occurs near the inlet edge. However, the hydrophobic compounds in slip region are likely to be exfoliated during start-up and shut-down due to wear. To protect the slip region from wear, a texturing combined with the slip condition was proposed by Fatu et al. [1] for journal bearings. Several studies [2, 3] concerning the texturing with the slip condition in journal bearings and parallel sliding contacts have since been carried out.

In this work, the depth of the recess with slip condition is optimized for the tilting-pad bearing in Table 1. The variation of texture depth of the recess bearings with and without the slip condition and reduction of friction is presented in Fig. 1.

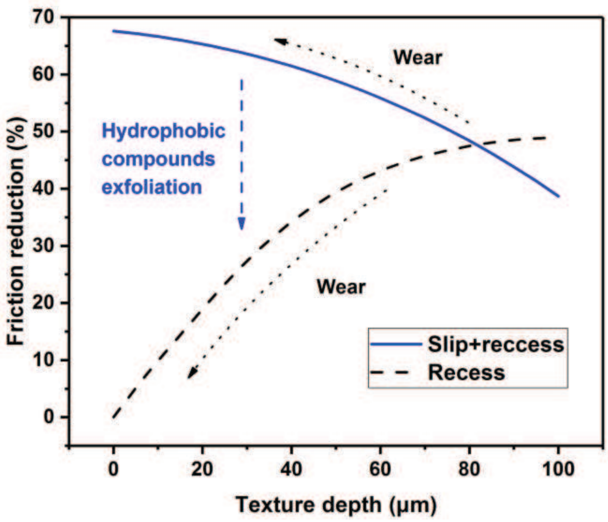

Figure 1 Optimization of the depth in the recess bearings with and without slip condition

The friction is found to increase with an increasing recess depth in the recess bearing with slip condition. For the recess bearing, the friction reaches the minimum value when the recess depth is 100 μm. When the depth is less than 80 μm, the slip condition enhances the performance of the recess bearing. Considering the protection of hydrophobic compounds and depth reduction as the pad wears, the recommended depth of the recess is 50μm. Even if the compounds are exfoliated during serious wear, the bearing may still function with a better performance than with conventional bearings.

Table 1 Parameters of tilting pad thrust bearing

Parameter	Value
Outer/inner diameter (mm)	800/400
Pad extend angle (°)	40
Eccentric position of pivot	Circumferential 0.609 Radial 0.524
Rotating speed (rpm)	1500
Mean pressure (MPa)	0.5443
Temperature (℃)	70
Slip length (μm)	100
Limiting shear stress (Pa)	0.4

ACKNOWLEDGMENTS
This study is financially supported by the National Basic Research Program of China (Grant no. 2015CB057303) and China Postdoctoral Science Foundation (Grant no. 2016T90087).

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Effects of using alternative extreme pressure (EP) and anti-wear (AW) additives with oxy-nitrided samples

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Keywords: tribology, heat treatment, additives, ZDDP, oxy-nitriding

1. Introduction

Friction and wear performance is influenced by a number of factors such as lubricant additives and surface modification, which can individually improve tribological properties or through a synergistic effect between the two factors. Nitriding is recognised as an effective surface treatment technique for improving tribological and anti-corrosion properties alongside increasing the hardness of the material [1].
The research from which this paper is derived focussed on investigating the optimisation of the friction and wear behaviour of oxy-nitrided samples with a range of extreme pressure (EP) and anti-wear (AW) additives, with the aim of improving the tribological properties and extending the life of components they are applied to.

2. Methodology

2.1. Characterisation and tribometer tests
Samples used during this work were salt bath oxy-nitrided working/nitriding steel (QPQ). The modified surfaces were characterized using Scanning Electron Microscopy (SEM), X-ray Diffraction Analysis (XRD), Energy Dispersion Spectroscopy (EDS) and microhardness tests, allowing the properties of the treated surfaces to be compared and differentiated. Using a large Cameron Plint TE77 reciprocating tribometer, wear and friction tests were carried out using the treated steel pins against graphite cast iron plates in the presence of a range of lubricants containing different EP and AW additives. The lubricants used were: fully formulated (ZDDP) lubricant, base oil + sulphurised olefin (SO), base oil + tricresyl phosphate (TCP) & base oil + SO + TCP. A contact pressure of 1.19 GPa was applied at a sliding frequency of 25Hz, with the lubricant being kept at a constant temperature of 80°C.

2.2. Post experiment wear and surface characterisation
Wear depth measurement was carried out using a Talysurf profilometer, which allows the imaging and calculation of the depth of the wear scars formed.

XPS analysis was carried out on the worn surfaces of the pin samples to identify the chemical species present in the tribofilms formed.

3. Results& discussion

It was observed that when using fully formulated (ZDDP) oil the friction response was higher than when using the other additives and similar to base oil. This was due to the formation of tribofilm composed of rough pad like structures. The wear response was also higher than the lubricants containing TCP, due to the competition between the detergent and ZDDP for surface sites reducing the lubricants AW properties.
SO & TCP additives made minimal impact on the friction response, mostly like due to their primary roles as EP &AW additives and the formation of low concentrations of key compounds such as FeS. The formation of $FePO_4$ when using TCP influenced its low wear properties, however the formation of FeS with SO had a detrimental effect of the additives AW properties.
A combination of SO+TCP lubricant produced the lowest friction results, literature [2] suggests lubricants composed of a combination of sulphur and phosphorous additives produced a more protective tribofilms than using the additives individually. The combination of FeS and $FePO_4$ within the tribofilm further helped with the additives friction and anti-wear behaviour.
The greater the exposure of the nitrided layer with larger wear depths, the more likely the formation of nitrides instead of organic species within the tribofilm, as seen when using the SO and fully formulated (ZDDP) lubricants.

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EFFECT OF FABRIC PATTERN ON FRICTION FORCE UNDER REGULATED PRELOAD

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KEYWORDS
Textile; Friction; Psychophysical Touch Test

INTRODUCTION

Human body have millions of mechanoreceptors under the skin that covers all the body that principally determines the qualitative perceptions such as the quality and comfort of the textile fabrics, skin care and medical products. The relative motion of the human body and clothes essentially results a friction on the interface where the degree of the normal and shear stresses on the skin depends mainly on the fabric characteristics, steady sliding conditions such as the preload and velocity and environmental circumstances. Yet, the most diverse mechanoreceptors are found in a human finger which makes it the most sensitive part of the skin. Hand discernment of the textile products is the first stage of the identifying the quality of the fabrics before trying on clothes and determines significantly the salability of the products.

MOTIVATION

The dynamic touch of the human finger on any surfaces comprises normal load and associated friction forces. Different type of mechanoreceptors on the dermis layer gives response to any local deformation on the skin and collaborative work of the unlike sensor receptors such as the nocioreceptors, thermoreceptors and mechanoreceptors results in a touch feeling. The mechanoreceptors also have diverse frequency response range which makes a human being to sense a frequency range of 0.4-1000 Hz [1]. The finger dynamic touch have similarly some special characteristics depends on the surface texturing of the finger such as the fingerprint ridges leads to oscillation amplitude setting in vibrotaction [2]. One other important feature of the human finger in contact with the substrate is the preload regulating behavior of the human being that is least investigated [3]. The human finger have an ability to trace different type of surface textures and regulate its normal force depending sliding comfort on the fly.

EXPERIMENTS

In this study, first, the regulating behavior of the human finger on different type of substrates is tested using touch psychophysical tests. The main output of this test is to evaluate the regulating behavior human beings when the finger is slide on different type of substrates such as the adhesive polymeric substrates and non-adhesive textile fabrics. The preload alteration during the adhesive sliding test is more obvious where the subject tried to change the motion type from stick-slip to steady sliding. Then, two different artificial experimental setups are designed in order to measure the friction forces on a repeated and non-repeatable patterned textiles under constant normal loads. The results show that if there is a control on the preload, the high frequency components of friction forces is eliminated and instructive frequency and magnitude of the friction force is revealed.

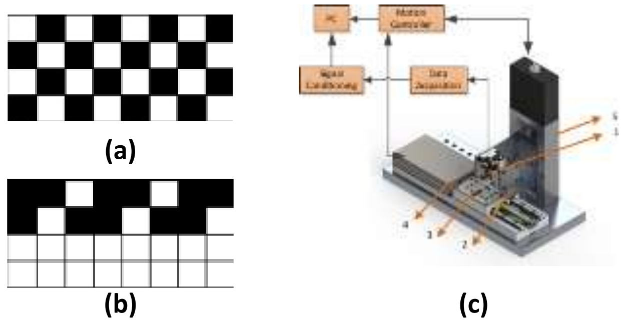

Fig.1 (a) Pattern of repetitive sample, (b) Pattern of non-repetitive sample (c) CAD drawing of kinematic friction experimental setup: 1) 3D Load cell, 2) end effector, 3) fabric sample, 4) horizontal motor, and 5) vertical motor.

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HYPERELASTIC MODEL OF A SPACER FABRIC

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KEYWORDS
Spacer Fabrics; Hyperelasticity; Contact Pressure

INTRODUCTION
Currently, there is a great courtesy to the 3D fabrics (spacer fabrics) due to its superior comfort properties compared to the conventional fabrics. Spacer fabric has two outer layer that is formed with multifilaments (knitted substrates), and spacer yarns (monofilaments) connect between the substrates. Spacer fabric is an example of a sandwich structure that provides high mechanical strength at a low specific weight. If it is designed properly, the spacer fabrics may reduce and distribute the contact pressure that leads a comfort feeling on the human skin. Moreover, while maintaining structural integrity, spacer fabric allows high breathability. Therefore, shoes, backpacks, car seat cushions, bras and mattresses are started to get benefits of spacer fabrics to manage heat and vapor better.

FINITE ELEMENT ANALYSIS
Finite element analysis (FEA) for compressive loading case helps to understand the behavior of the spacer fabric [1]. However, hyperelastic behavior should be considered to improve the modelling accuracy of the polymer monofilament materials. Hyperelastic model simulates more realistic deformation behavior by accounting highly non-linear stress vs. strain relationship. To implement the hyperelastic properties of the polymer filament into the model, monofilament material response is captured by uniaxial and compression loading test. Then, these tests are simulated to check the hyperelastic model accuracy in the FEA. Another goal of the modeling is to understand the pressure distribution of the contacting body to a spacer fabric. Experimental and theoretical study of a sphere contact were conducted earlier [2]. After the model accuracy is established, various patterns of the outer layers are tested under different loads. This analysis shows the ability of the spacer to decouple the applied pressure. Also, fabric pattern comparison shows the favorable designs for a comfortable interaction between the user and the spacer fabric.

EXPERIMENTS
In the experimental section, a spacer fabric sample is tested to its ability to resist the normal loading in the compression direction. The upper side of the spacer fabric is loaded with different end-effectors in terms of geometry which simulates concentrated and distributed linear contact. Moreover, two different type of end-effector made of elastomer and glass are utilized to simulate the contact behavior of the compliant and stiff bodies such as the human skin and rigid attachments, respectively. The load carrying and transmission ability of the spacer fabrics is also measured using a dedicated experimental setup that uses force sensors which gives the degree of the stability for structure under compression conditions.

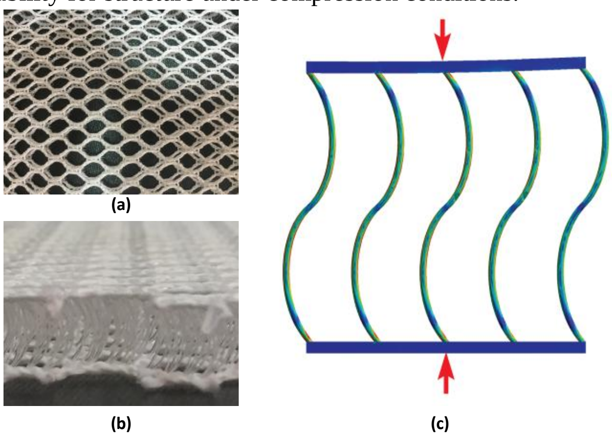

Fig. 1 (a) Top side picture of a spacer fabric, (b) Side view picture of the spacer fabric, c) a sample FEA result.

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THE USE OF MULTISCALE DECOMPOSITION OF ROUGHNESS FOR THE ANALYSIS OF THE MICROWEAR OF BONES

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KEYWORDS
surface, roughness, micro-wear, multiscale analysis, taphonomy

ABSTRACT

The assessment of wear features on bones and tools is important for archaelogists and anthropologists as this method is used to identify the activities undertaken by humans or their ancestors. Bones can show surface degradations at the micro- or macro-scales that can be caused by erosion, fragmentation, global or local deformations. More specifically, bone surfaces can be modified by several factors: climate (bad weather, exposure time, temperature …), nature of soil (pH, compaction), carnivore tooth marks or stone butchery marks…

Taphonomy is the study of the surface modifications of fossils. It aims at piecing together the story of fossils from their burial to their discovery by archaeologists. The study of taphonomic traces traditionally relies on qualitative assessment of wear features. This examination draws on the professional judgment of the observer or analyst. Recently, more modern methods and technologies have been introduced to examine wear on stone tools and bones [1]. However, the creation of more quantitative methodologies is required to enrich the analysis of micro-wear of bones and tools.

The proposed study is focused on the analysis of different fossils showing wear features caused by carnivores. Measurements were made using three-dimensional optical profilers based on focus variation (e.g. Fig. 1) and interferometry. First, the wear features were analyzed to determine the morphological parameters that best describe them. Then, a multiscale analysis was practiced on different fossils to determine the degree of similarity between the bone parts and the examined process. For the multiscale analysis, different filterings and a large set of roughness parameters (height parameters, functionality parameters, features parameters…) were used. Finally, maps of local properties of the surfaces were generated using different divisions of the surfaces in order to quantify surface texture inside and outside the identified wear features.

These first results enabled us to build the basis of a methodology for a better quantification of micro-wear analysis of fossils and thus improving the understanding of taphonomic traces.

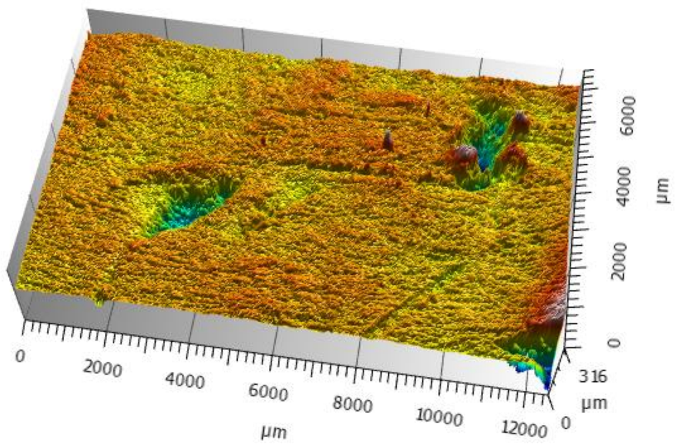

Fig.1 Example of measurements of micro-wear traces caused by carnivores using focus variation.

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EFFECT OF TEXTURE PARAMETERS ON THE ANTI-FINGERPRINT FUNCTION

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KEYWORDS
Numerical study, finger contact, wettability

ABSTRACT

The clean and aesthetic aspects of everyday life objects as the touch screens, packaging, automotive interiors, etc, become an important requirements. Actually, the attachment of fingerprints and skin oils on touch surfaces raise a challenging problem that threatens the surface aspects. To meet these requirements, surfaces that resist to fingerprinting and exhibit self-clean properties have been an interesting design target of several research works [1-2]. In our previous paper, we have rigorously reviewed the physics of fingerprints and we have highlighted the different issues related to the anti-fingerprint function [3]. It has been found that the surface texture is one of the key parameters governing the anti-fingerprint function.

This study is devoted to analyze the effect of some texture parameters on the surface functionality. To this aim, two complementary numerical approaches are proposed to address the mechanical and physical issues of fingerprinting. In the first approach, the mechanical response of the contact between the fingertip and differently textured surfaces is evaluated. In the second approach, the wetting behaviors of the textured surfaces are examined. This approach aims to test the surface affinity to fingerprint liquids by considering the physicochemical interactions between liquids and the surface texture. These two approaches are used to simulate the anti-fingerprint property of textured surfaces having different texture parameter values. Mechanics of finger contacts as well as the hydrophobic and the oleophobic properties are discussed and correlated with special focus on the texture effect.

The results show significant influences of the texture parameters on the anti-fingerprint function and suggest some design parameters that must be fine-tuned to achieve the function. Moreover, the design of a functional anti-fingerprint texture needs an optimal compromise between the finger contact response, wetting and properties of textured surfaces.

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PERFORMANCE EVALUATION OF GRASPING FORCE MEASUREMENT SYSTEM OF A LAPAROSCOPIC SURGICAL TOOL

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KEYWORDS
Laparoscopy; Tissue Viscoelasticity; Tactile Sensing

ABSTRACT
Measurement technologies are becoming more suitable for laparoscopic surgery according to research related to measurement of force, pressure, elasticity, viscoelasticity and hardness through laparoscopic surgery tools by using both novel and common sensors [1-2]. Blind operation in respect to surgeon's senses during surgery can be reduced by integrating these sensors such as resistive, piezoelectric or capacitive type of touch or tactile sensors to the surgical tools. Moreover, since it is possible to identify tissue properties by measuring contact variables such as force and indentation depth yielding elasticity, operator can identify condition of tissue by using recently advanced surgical instruments.

According to current literature, tip [3] and rod [4] of a laparoscopic surgery tool are the most favorable parts to integrate the sensing devices. In this study, a load cell is attached to rod of the laparoscopic grasper and additionally a tactile sensor is placed on the tip of the surgical tool. By using a previously developed analytical model of a laparoscopic grasper [5], in relation to force at the rod, grasping force at the tip will be measured and the clamping force gathered by tactile sensor is compared with the estimated force from the rod measurement. Afterwards, through measurements from tip and rod, mechanical properties of organic viscoelastic specimens are calculated and the properties will be compared with the ones obtained by conventional technique such as tensile or compression testing. As a result, both measurement techniques from the tip and the rod will be discussed thoroughly and viability of alternative measurement systems will be investigated.

METHODOLOGY
To be able to obtain the clamping force for ex-vivo experiments, two different possible locations will be tried by setting up two experimental test bench.

Firstly, in order to measure elasticity and damping coefficient of organic viscoelastic tissue, tensile testing method is used. Secondly, experiment whose apparatus is illustrated in Fig.1, is performed concerning the performance evaluation of grasper for measurement according to the most favorable location in the tool. The forces are synchronously measured from load cell and tactile sensor while the displacement is obtained from the linear stage. All experiments are implemented with various velocities and repetitions. Specimens (organic viscoelastic tissue) are cut into rectangular shape with a thickness of 5 to 10 mm. The results are discussed for force measurement and tissue identification.

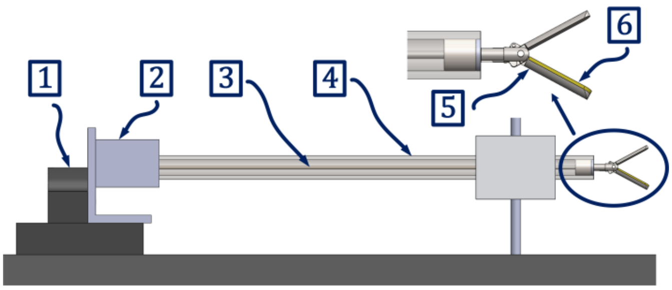

Fig.1 Drawing of the Experimental Apparatus: 1. Motorized Linear Stage, 2. Load Cell, 3. Grasper Rod, 4. Rod Cover, 5. Grasper Tip, 6. Tactile Sensor

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FRICTION AND WEAR PROPERTIES OF SOFT FIBER ARRAY IN A FRICTIONAL SLIDING CONTACT

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KEYWORDS
Friction; Wear; Soft fiber array

INTRODUCTION

Friction and wear are important conditions to be considered to obtain high performance of mechanical structures which are in contact with each other. One way to alter the friction and wear is to make a functional surface [1], which is managed by forming mechanical structures with varied configuration on the surface. In relation to this, soft fiber arrays have been used in coatings [2] and mobile robots [3-4].

This study focuses on friction and wear properties of soft fiber array made out of Polydimethlysiloxane (PDMS). The aim of this study is to investigate tribological properties of soft fiber array with respect to the different constructional and contact parameters. Different fiber array configuration such as changing the diameter and height of a single fiber is used to examine constructional effects on the tribological properties under different normal load and sliding velocities.

Wear of elastomeric materials are generally investigated by using a pin-on-disk test bench [2] or in flat [5]. This study focuses on the frictional and wear properties of fiber array in a sliding contact that is similar to nominal working conditions of fiber array while mobile robot is moving or climbing.

EXPERIMENTAL PROCEDURE

A customized experimental set-up as shown in Fig.1, is built to obtain the friction of the fiber array in a frictional sliding contact with a smooth surface under continuous motion with varied velocities. The wear of fiber array in terms of mass reduction, change of the tip geometry and volumetric losses is investigated for different time scales while change of friction force of fiber array is observed. Effect of single fiber dimension on the tribological properties is examined by changing fiber dimension.

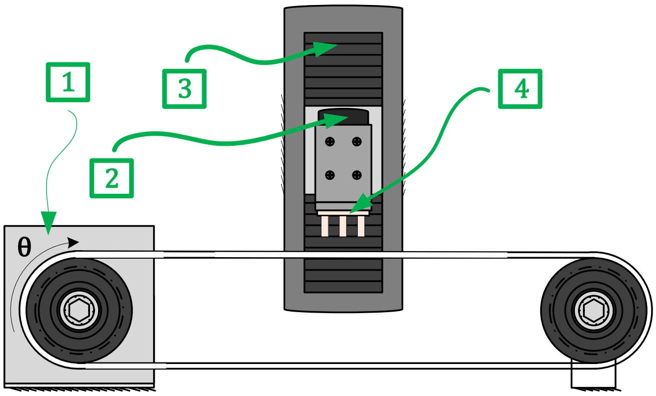

Fig. 1 Drawing of the experimental set-up: 1-DC motor, 2-3D force sensor, 3-Linear motorized stage, 4-Fiber array.

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EFFECTS OF CYLINDER LINER SURFACE TOPOGRAPHY ON FRICTION AND WEAR OF LINER-RING SYSTEM AT LOW TEMPERATURE

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KEYWORDS
cylinder liner, two-process surfaces, coefficient of friction, low temperature

ABSTRACT

The contact between a piston ring and a cylinder liner is a substantial source of friction, about 40% of the total losses [1]. The change of an initial surface topography of a cylinder liner is a way for reducing frictional losses. Researchers tried to find an optimum geometrical structure of a cylinder liner. A plateau-honed texture ensures good sliding properties of a smooth topography and the great ability to maintain oil of a porous surface. There are opinions that the cylinder surface after plateau honing ensured the running-in shortening and small wear in this period. The effect of honing angle on piston-ring pack friction is also substantial [2]. Experimental works in this field were conducted typically at high temperatures. However during winter, internal combustion engines initially operated at low temperatures.

This work aims to study experimentally effects of cylinder liner surface topography on friction and wear of piston ring-liner assembly at low temperatures (below 0^0C).

The experiments were conducted using an Optimol SRV5 oscillating wear tester under lubricated conditions. SAE 15W/40 mineral oil was a lubricant. Specimens were cut from cylinder liners made of gray cast iron. As the results of honing and/or plateau honing various surface textures of cylinder liners were obtained. Counter-specimens were cut from chromium-coated compression ring. Short time tests were carried out at temperature lower than 0^0C, a stroke was 3 mm. The other operating parameters, like a normal load and a frequency varied. Before and after tests surface topographies of liners and piston rings were measured by a white light interferometer Talysurf CCI Lite. For comparison, similer tests were conducted at temperature of 90^0C. It was found that coeffieient of friction and wear level at temperature of -20^0C were smaller than at temperature of 80^0C. At low temperature a decrease of cylinder liner height led to a reduction of the coefficient of friction .

Figure 1 presents an example of experimental results. Cylinder liners A and C were one-process textures after honing by diamond stones, cylinder liner heights determined by the Sq parameter were 2.77 and 1.4 µm, respectively. The sample B was two process texture after coarse and plateau honing by diamond stones, characterised by the following parameters: Sq = 0.57 µm, Spq = 0.25 µm. Tests were carried out for constant parameters: the normal force was 100 N, frequency was 10 Hz, the test duration was 15 min, temperature was -20^0C.

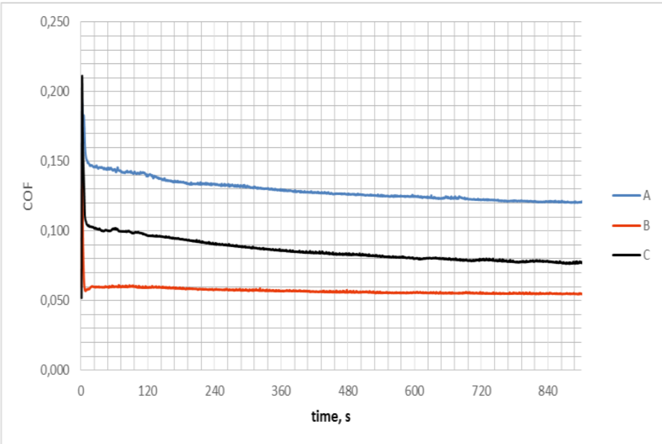

Figure 1. Coefficient of friction versus time

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Friction Properties of plasma spraying Nickel Based Self-Lubricating coatings at elevated temperatures

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KEYWORDS

Self-lubrication; High temperature; Coatings

ABSTRACT

The high power, high loads and energy saving of the development of engine requires the improvement of performance of key parts piston-ring. Silver has long been used as a solid lubricant and it shows a high coefficient of diffusion and forms lower shear stress junctions at sliding interface resulting in good lubrication at temperatures about less than 500 ℃ . This characteristic of silver either alone or in conjunction with other solid lubricants has been effectively utilized by several researchers, in composite coatings for high temperature tribological applications.

Solid lubricants of Ag, BN or CaF_2/BaF_2 were mixed with Ni-Mo-Al powders. The lubricious coatings of Ni-Mo-Al-Ag, Ni-Mo-Al-Ag-BN, Ni-Mo-Al-Ag-CaF_2/BaF_2 were prepared on the surface of plain steel by using atmospheric plasma spraying methods. The cross-section, surface of coating and wear scar were systematically analyzed by XRD, SEM, EDS. The friction and wear properties of coatings at room temperature, 200 ℃, 400℃, 600℃ were tested by HT-1000 high-temperature tribometer. The friction coefficient and wear rate at different temperatures were analyzed to assessing their friction and wear properties.

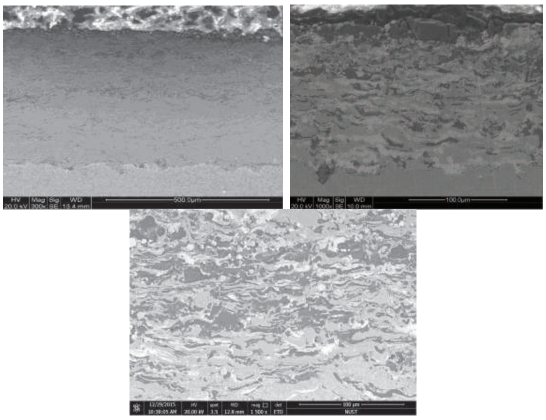

Fig.1 Cross section of coatings:(a)Ni-Mo-Al-Ag; (b)Ni-Mo-Al-Ag-BN; (c)Ni-Mo-Al-Ag-CaF_2/CaF_2

The coatings prepared by atmospheric plasma spraying show elongated lamellar morphology (Fig.1).

Fig.2 shows the friction coefficient of Ni-Mo-Al-Ag-BN and Ni-Mo-Al-BaF_2/CaF_2 coatings at elevated temperatures. The friction coefficient of Ni-Mo-Al-Ag-BN coating is about 0.2-0.5 from room temperature to 600℃ and the friction coefficient is higher (about 0.5) at higher temperature(Fig.2a). The friction coefficient of Ni-Mo-Al-Ag-BaF_2/CaF_2 coating is about 0.4-0.8 from room temperature to 600℃ and the friction coefficient at room temperature is higher (about 0.8) (Fig.2b).

With the temperature increases from room temperature to 400 ℃, the wear rate of Ni-Mo-Al-Ag coating increases from $3.9\times10^{-5}mm^3/Nm$ to $3.7\times10^{-4}mm^3/ Nm$. The wear rate is increased by an order of magnitude at 600℃ while it shows good lubricating properties under dry friction conditions. After the addition of BN lubricant, friction coefficient is reduced by 20%-30% at a wide temperature range. The wear rate is increased by six folds from room temperature to 400 ℃. The wear rate of Ni-Mo-Al-Ag-BaF_2/CaF_2 coating is comparable at 200 ℃ and 600 ℃. The best friction and wear properties were obtained at 400 ℃.

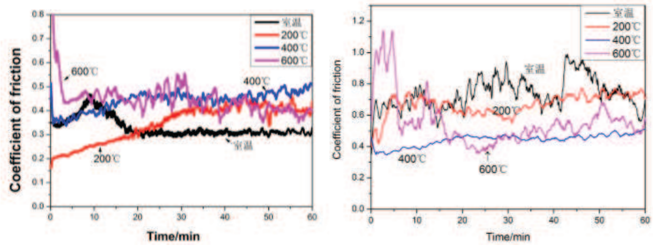

Fig.2 Friction coefficient curves of Ni-Mo-Al-Ag-BN(a) and Ni-Mo-Al-Ag-BaF_2/CaF_2 (b)

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FRICTION PROPERTIES OF PVA/PAAM DOUBLE NETWORK HYDROGELS FOR ARTICULAR CARTILAGE REPAIR

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KEYWORDS

Polyvinyl alcohol; acrylamide; hydrogel; friction coefficient

ABSTRACT

Polyvinyl alcohol/polyacrylamide (PVA/PAAm) double network hydrogels, which were prepared using a simple two-step polymerization method, exhibited the three-dimensional porous network structure with large amount of water, and the effects of different factors, including AAm content, friction contact modes, movement modes, and the friction pairs, on the friction coefficient of PVA/PAAm hydrogels were investigated in detail. And the surface wear morphologies of PVA/PAAm hydrogels were surveyed after the friction test. The results showed that the incorporation of PAAm into PVA hydrogels significantly improved the loading-carrying capacity and lubrication. The hydrogel-on-cartilage contact showed the loweat friction coefficient (~0.016), which could meet the demand of the natural cartilage.

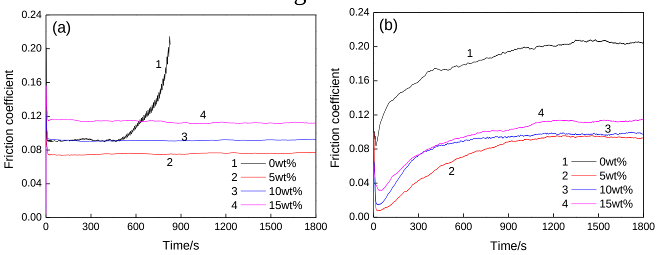

Fig.1 General trends in the rotary friction coefficient of PVA/PAAm IPN hydrogels over time under different contact conditions: (a) migrating contact; (b) stationary contact(5N, 0.08m/s, deionized water)

General trends in the rotary friction coefficient of PVA/PAAm IPN hydrogels over time under different contact conditions were shown in Fig. 1. Under migrating contact , the pure PVA hydrogel was worn out soon due to the poor mechanical strength. While the friction coefficient of PVA/PAAm hydrogels kept stable in the whole of test. In contrast, under stationary contact, the friction coefficient of hydrogels increased gradually. the friction coefficient of PVA/PAAm hydrogels increased with the increase of AAm content.

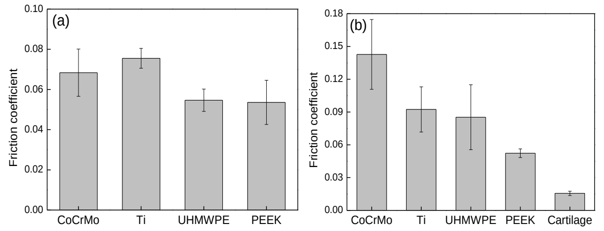

Fig. 2 Effect of friction pairs on the friction coefficient: (a) rotary motion; (b) reciprocating motion (5wt%AAm, 5N, 0.08m/s, bovine serum, stationary contact)

Fig. 2 gives the effect of friction pairs on the friction coefficient of PVA/PAAm hydrogels under both rotary and reciprocating motions. It was found that when the rigid material such as CoCrMo or Ti alloy served as the friction pairs with the hydrogel, the system showed the relative high friction coefficient, despite of the movement modes. When the PVA/PAAm hydrogels were sliding against with the natural cartilage, the lowest friction coefficient of ~0.016 was obtained, which was in the range of the natural cartilage.

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ANALYSIS OF ULTRAFINE-GRAINS LAYER FORMATION AFTER MULTI-PASS SCRATCH TESTS ON PEARLITIC STEEL

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KEYWORDS
Work-hardening, pearlitic steel, scratch test, ultrafine grains

ABSTRACT

The formation of sub-superficial deformed layer in pearlitic steels under dry sliding conditions has been widely researched, especially for the rail/wheel system [1–3]. The presence of interfacial particles (e.g. contaminants) in this system could act as abrasive particles having correlation with micro-stress and local heating that contributes with ultrafine-grains refinement and superficial hardening [4]. The understanding of abrasion process and the correlation of wear mechanisms with the formation of ultrafine-grains layer require special attention. A large number of papers reported in the literature simulate abrasive process using single-pass indenter tests [5,6]. In this work, the influence of multi-pass indenter using scratch test in the formation of ultrafine- grains was analyzed. Pearlitic steel without work hardening was studied. The characterization of grooves was performed using Coherence Correlation Interferometry (CCI) and Scanning Electron Microscopy (SEM). Focus Ion Beam (SEM/FIB) and X-Ray Diffraction (DRX) were used for the analysis of the sub-surface microstructure after scratch test. The results suggest an influence of number of indenter pass on the thickness and size of the ultrafine-grains layer. The orientation of cementita lamellae and the interlamellar spacing controlled the width of the grooves and the formation of chips (**Figure 1**).

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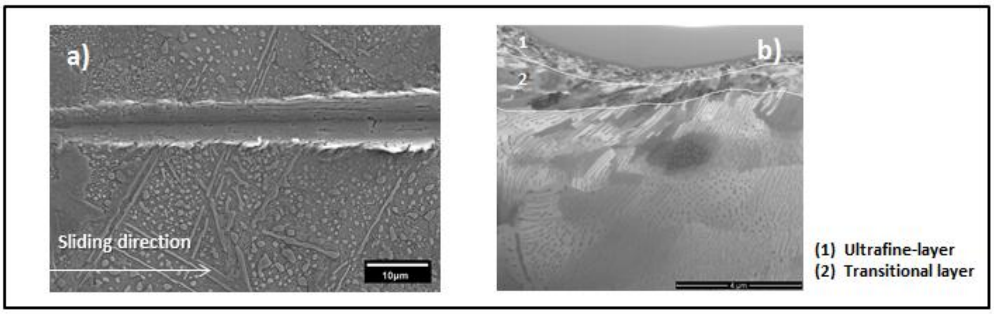

Figure 1. Analysis of the multi-pass indenter. a) Secondary electron SEM image of the groove in the microstructure etched with Nital 2%, b) A cross-sectional SEM/FIB image of the region deformed by the indenter pass

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ZWITTERIONIC SURFACES FOR CATHETER APPLICATIONS

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KEYWORDS: BIOTRIBOLOGY, HYDROGEL

ABSTRACT

Infection, erosion of mucosal and uro-epithelial layers, trauma and encrustation associated with urinary catheters is an issue faced by health-care professionals and patients – particularly prominent in elderly incontinent cohorts [1]. Without doubt, a functional catheter-biology interface is key if successful intermittent and indwelling catheterisation is to be achieved.

Over the past decade efforts have been made to optimise catheter surfaces in an attempt to reduce the occurrence of urinary tract infection and encrustation [1]. Organic and inorganic materials have been mooted as potential methods of reducing bio-film formation and increasing lubricity. Hydrogel coatings (i.e. networks of crosslinked polymer chains in an aqueous solvent) are available and effective in reducing bio-film formation and infection through addition of active pharmaceutical agents, trauma and encrustation due to their hydrophilic nature [2, 3]. However pain during insertion and infections with these technologies is still common.

Zwitterionic polymer brush technologies, consisting of a layer (~100 nm) of bio-inspired phospholipid polymers with one end chemically grafted to the surface, have received much research over the past decade [4]. Polymer brush modified surface have been shown to reduce bio-film formation and friction for vascular applications [5] with enhanced surface properties when compared to their hydrogel counterparts. However polymer brush technologies are yet to be considered for urinary catheters. This paper has investigated the feasibility of functionalising catheter surfaces with zwitterionic polymer technologies for the reduction of urethral trauma and infection for indwelling and self-catheterisation devices.

Lubricous coatings of poly[2-(methacryloyloxy)ethyl dimethyl-(3-sulfopropyl)ammonium hydroxide] with differnt monomer cross linker content have been created on silicone surfaces through free-radical polymerisation. The tribological properties of the surfaces were characterised using an NTR3 tribometer (Anton-Parr, Switzerland) against a Polydimethylsiloxane (PDMS – hydrophobic and hydrophilic) and urethral tissue probe in de-ionised water and phosphate buffered saline solution (PBS).

Fig 1 shows the average steady state coefficient of friction for the different zwitterionic surface in DI water and PBS against a hydrophobic PDMS probe. A decrease in CoF was seen with increasing monomer concentration. CoF was seen to further decrease (~ μ = 0.01) when pMEDSAH surfaces were slid against a hydrophilic probe. The evolution of friction with cycle time demonstrated a decrease in CoF with time, plateauing after 50 cycles. The primary mechanism for this reduction is thought to be hydration lubrication in which kinetics of friction are dependent on the distribution of charge at the surface.

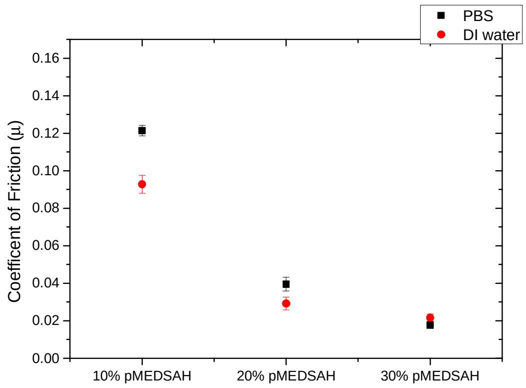

Fig 1. Average steady state coefficient of friction for the different zwitterionic surface at 10 mN against a hydrophobic PDMS probe.

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