ENGINE & DRIVETRAIN

Effect of Organic Friction Modifiers on Friction Properties and Surface Film Formation at Steel and Paper Clutch Materials

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The effect of organic friction modifiers (FMs) on friction properties at steel and paper clutch materials was investigated, and their working mechanism was estimated by the observation of reaction and adsorption films formed on the surface. The FMs are essential additives for drivetrain lubricants to manage friction properties, so that it is highly demanded to elucidate their detailed behaviour on the substrates. In this study, friction properties of organic friction modifiers, oleic acid, oleyl alcohol and glycerol mono-oleate, were measured by TE77 and MTM using steel and paper specimens. The surface films on the post-test materials were studied by EDX, XPS and ATR-FTIR to assess the influence of the FMs. The results indicated that the frictionproperties were highly affected by the substrate material and test temperature as well as the chemical structure of the FM. The relationship between the friction and the surface films was also considered.

Interactions of Ethanol with Friction Modifiers in Car Engine Lubricants

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When used as an engine fuel, ethanol can accumulate in the lubricant during use. Previous work has shown that this ethanol contamination affects friction and EHL film formation, and also the growth and stability of anti-wear tribofilms. The present work uses spacer-layer ultrathin interferometry and MTM tests to investigate how ethanol (both hydrated and anhydrous) interacts with friction modifiers in engine lubricants. Small amounts (5%wt.) of ethanol were added to solutions of friction modifier (one Mo-DTC and three organic friction modifiers) in a Group I base oil. For the three organic friction modifiers,
the presence of ethanol promoted the formation of thick viscous boundary films so that very low friction coefficients were measured at low entrainment speeds. For the Mo-DTC additive, the presence of
ethanol prevented the formation of a low friction film at low speeds at 70oC, but this effect disappeared at 100oC, probably due to ethanol evaporation.

Using the Ultra Shear Viscometer and Understanding the Effect of Measurement Method on the Results

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The PCS Instruments Ultra Shear Viscometer (USV) is used to measure viscometry of lubricants in the 106-107 reciprocal seconds. There is some concern that, particularly when measuring viscosity modifiers, that permanent shear may occur. The question arises as to how many measurements can be taken before this occurs and by how much this may affect the results. A number of lubricant containing different viscosity modifiers were run through the USV. Initially they were run through shear sweeps and temperature sweeps. These data points were then repeated with fresh lubricant for each measurement. The results will be presented and the difference in results discussed.

BIOTRIBOLOGY

Characterizing the Lubricating Properties of Model Synovial Fluids

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Hip joint arthroplasty is one of the most common orthopaedic procedures, however it remains one of the most challenging tribological problems. Artificial hips are lubricated by synovial fluid which contains proteins, lipids and hyaluronic acid. In this study we investigate the lubricating film properties of model synovial fluid, particularly proteins, under simulated physiological conditions. Novel in-contact visualization techniques were employed to characterize lubricant behavior using thin film interferometry and laser induced fluorescence. This allowed us to measure film thickness, possible protein/surface interactions and observe protein flow. Earlier work showed the existence of a new protein-rich inlet phase which determined film formation in the contact and this will be studied further in the current research. Results will be presented and discussed on lubricating film thickness under gait-like transient loads and motion as well as protein flow and behavior.

Understanding Lubrication During Shaving

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Traditional experimental techniques to measure in-contact lubrication properties involve hard contact interfaces. However, there are many applications where one or both of the contacts are soft. Shaving is one such example which is interesting to study as typical razor cartridge consists of both hard and soft components and is loaded against skin during use. Skin is a difficult material to model due to the variation in its mechanical properties, which depend on the individual person and environmental conditions. In-contact fluid flow imaging using laser induced fluorescence has been developed to better mimic skin contacts and show fluid distribution and film thickness in a hard–soft contact and a soft–soft contact.

LUBRICATION FUNDAMENTALS

Influence of Polymer Shear Thinning on Friction and Film Thickness in Hydrodynamic Lubricated Contacts

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Viscosity modifier (VM) polymers are added to engine lubricants primarily to reduce the viscosity-temperature dependence of their blends. It is now widely recognised that temporary shear thinning can make a valuable contribution to fuel economy by reducing hydrodynamic friction. This presentation describes an experimental study of the impact of polymer solution shear thinning on hydrodynamic film thickness and friction. The shear thinning behaviour of polymer solutions is measured over a wide shear rate range. Film thickness and friction measurements are then made in low pressure, sliding lubricated contacts using a compliant ball on flat contact. Flow curves are then compared via hydrodynamic theory with friction and film thickness measurements in order to quantify the impact of shear thinning on hydrodynamic friction.

Elastohydrodynamic Friction Properties of Well-Defined Base Fluids

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There is currently great interest in reducing friction in lubricated mechanical components. In components based on concentrated contacts, such as gears and rolling bearings, friction originates in part from the EHD friction of the lubricant. In such contacts all lubricants, including even simple molecular fluids, show extensive shear thinning and this controls the EHD friction. In order to build useful predictive solutions of EHD friction we need valid descriptions of this shear thinning behaviour. Unfortunately there is still considerable uncertainty concerning appropriate models to describe stress-strain rate behaviour in EHD conditions [1]. This paper describes experimental friction measurements on a range of simple, pure base fluids have well-defined molecular structures. The results are analysed in terms of the main,

Comparison of Different Types of Friction Modifier Additive

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Progressive reduction in the viscosity of liquid lubricants means that lubricated contacts are operating with thinner and thinner lubricant films and thus increasingly in the mixed and boundary lubrication regimes. This places growing importance on the use of friction modifier additives that reduce friction in these regimes. There are several classes of friction modifier additive and these are believed to work in quite different ways to reduce friction [1]. This presentation describes a comparison of the effectiveness of the various types of friction modifier additive in both base oil and formulated engine oil under a range of test condition. The differences in behaviour seen are related to the different types of film that the additives form on rubbing surfaces. The effectiveness of combinations of the various classes of friction modifier additive is also explored.

ZDDP Tribofilm Formation under Pure Sliding Conditions

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Zinc dialkyl dithiophosphate (ZDDP) is used as an anti-wear additive in engine oils and is required to show good performance under pure sliding condition in order to protect piston rings and cylinder liner assemblies. Many researchers have studied its efficiency and reaction mechanisms combining wear tests and surface analysis. However the growth process of ZDDP tribofilms in pure sliding conditions is not fully understood.The authors have investigated the growth process using a MTM-SLIM (Mini Traction Machine and Spacer Layer Imaging tester). Results show that ZDDP film forming behaviour in pure sliding differs significantly from that in rolling-sliding. The nature of pure sliding also matters since in unidirectional sliding severe damage was observed while no such damage was observed on the surface under reciprocating motion.

Understanding Friction Reduction Mechanism of Polyalkylene Glycol Engine Oils

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Engine oil formulations using polyalkylene glycol (PAG) base stock have shown substantial friction reduction in motored and dyno engine tests over GF-5 SAE 5W-20 mineral oil formulation. Laboratory bench tests using MiniTraction machine (MTM), and High Frequency Reciprocating Rig (HFRR) were used for friction assessment. PAG oils with and without an additive package were evaluated at 100C. The wear surfaces were analyzed using a variety of surface sensitive techniques including SEM, Auger, XPS, ToF-SIMS, and Raman spectroscopies. MTM tests showed substantial friction reduction while HFRR tests did not. Tests with PAG base stock in HFRR showed only iron oxide formation while MTM tests showed presence of PAG molecules on the surface in addition to iron oxide. Formulated PAG oils in MTM tests showed presence of PAG molecules and additive-derived tribo-films. The presence of PAG molecules on surface is believed to be mechanism for friction reduction.

Study of Gear Oil Additive Tribofilms Using XANES

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Gear oils contain a variety of phosphorous and sulfur based chemistries that provide EP/AW protection for the bearings, friction surfaces, and gear teeth. Depending on the type of phosphorous or sulfur species used this can create a variety of of either sulfur rich or phosphorous rich tribofilms on the gear teeth. In this study we used a High Frequency Reciprocating Rig (HFRR) to model the tribofilms formed on the surface of gear teeth during extreme loading conditions and examined their chemical composition using X-Ray Absorption Near Edge Spectroscopy (XANES). The resulting XANES analysis revealed a variety of surprising syngergies and antagonisms of the EP/AW additives on the metal surfaces.

Simulating Realistic Organic Friction Modifier Films in Boundary Lubrication – The Importance of All-Atom Potentials

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Organic Friction Modifiers (OFMs) are becoming increasingly important automotive lubricant additives, not least because of progressively more stringent limits for elements found in traditional friction modifiers in specifications. Moreover, interest in lower viscosity base-oils means that more components may experience boundary conditions in the future. Molecular Dynamic simulations are a useful tool with which to give atomic-level insight into the behaviour of OFM additives. This current work compares the performance of different force-fields in terms of the reproduction of experimental OFM film structures and thier friction in the boundary regime. The OPLS all-atom force-field is compared to the computationally cheaper TraPPE united-atom potential. Whilst the united-atom potential can vastly decrease computation time by reducing the number of non-bonded interactions, it is shown that key aspects of the film behaviour are inadequately represented when the hydrogen atoms are removed.

ROLLING ELEMENT BEARINGS

Influence of Contact Conditions and Steel Properties on Propagation of Rolling Contact Fatigue Cracks

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Rolling contact fatigue (RCF) life data is normally obtained by testing large sets of samples until pitting failure. This approach allows for quantification of RCF lives but it does not offer much insight into the mechanisms driving the initiation and propagation of cracks. The study presented here attempts to better explain the behaviour of RCF cracks in terms of contact conditions and material properties. Pitting experiments were performed using a triple contact RCF rig on specimens made of a range of steels, including through-hardened 52100, M50 and case-carburised 16MnCr5. The experimental set-up includes a crack detection sensor, capable of detecting cracks at a very early stage, so that propagation rates can be monitored. Measured crack propagation rates are related to contact conditions and an attempt is made to explain the observed crack behaviour in terms of properties and microstructures of the steels studied as well as predicted stress intensity factors.

Influence of Rubbing Materials on the Effectiveness of Lubricating Boundary Films

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In lubricated sliding-rolling contacts operating under low specific film thicknesses, contacting components are generally protected by a thin boundary film formed on their rubbing surfaces. Such films are formed through the interaction of lubricant additives and the material of contacting surfaces. Despite the importance of this interaction, most studies of boundary lubrication only use 52100 bearing steel specimens, thus ignoring the potential effects of surface material composition. This paper presents results of an experimental study on formation and effectiveness of boundary films formed in rolling-sliding contacts of a range of steels and surface coatings. Steels studied are those typically used in bearings and gears, while the surface coatings were selected to assess the potential influence of individual steel alloying elements such as Ni, Cr, W and Mo. The study uses custom made fluids with a range of additive chemistries, including ZDDP and ashless anti-wear additives.

SYNTHETICS & HYDRAULICS

Oil Soluble Polyalkylene Glycols – A Versatile Component for Enabling the Formulation of Modern Gear Lubricants

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Oil-soluble polyalkylene glycols (OSP) are a versatile formulation component and find use as performance additives or as primary base oils in enabling the formulation of modern gear lubricants. These oxygen rich polymers can help boundary and mixed-EH&D friction control, improve the efficacy of surface active materials such as corrosion inhibitors and extreme pressure additives and also act as seal swell additives. As primary base oils their unique air release properties for use in compact gear systems will be discussed and compared with conventional products. Examples of their versatility for formulating products for the marine and food processing industries will be discussed.

WIND TURBINE TECHNOLOGY

Lubricant Effects on White Etching Cracking Failures in Thrust Bearing Rig Tests

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White Etching Cracking (WEC) is a contact fatigue failure mode in lubricated bearings, which is initiated in the subsurface of the metal matrix. WEC is particularly alarming as it cannot be detected in field applications. It can lead to fatigue failures more than an order of magnitude shorter than predicted lifetimes. The open literature suggests that the lubricant composition can influence the propensity for WEC failure. We have studied WEC failure in thrust bearing rig tests using lubricants known to promote WEC in this environment. We have determined that the lubricant additives have the greater effect on WEC propensity in these tests. Additionally, by selective additive removal, we found that the additive components zinc dialkyl dithiophosphate antiwear and various alkali-metal detergent components had the greatest influence on WEC failure propensity.

A Study of the Dominant Drivers of White-Etching Crack Formation in a Three-Ring on Roller Contact

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White-etching cracks (WECs) have been identified as the dominant mode of premature failure for bearings within wind turbine gearboxes. Though WECs have been observed in the field for over a decade, the exact mechanisms which lead to this failure are still debated. Some of the postulated drivers of WECs are sliding at the contact, load, and contact severity. In this paper, WECs have been replicated on a three rings on roller, benchtop test rig, which allowed for a direct investigation into the influence that sliding magnitude, sliding direction, lubricant film thickness, and normal load have on surface failures and WEC generation. It was determined that the formation of WECs within test samples can be turned on and off, and that the number of WECs within a sample is dependent on the aforementioned drivers.

Influence of Contact Conditions and Lubricant Properties on Pitting Failures in Rolling-sliding Contacts

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Surface initiated rolling contact fatigue, or pitting, is the main lifelimiting failure mode of modern rolling element bearings. Initiation and propagation of surface cracks, which eventually leads to formation of pits, is strongly influenced by asperity interactions, amount of sliding and lubricant properties, among other factors. Furthermore, bearing pitting failures in some applications, particularly in wind turbine installations, appear to be associated with the existence of extensive crack networks and presence of distinct microstructural changes in the immediate vicinity of the crack. This study uses a triple-contact fatigue rig to systematically study the influence of contact conditions including slide-roll ratios, specific film thickness and load, as well as lubricant composition, on the occurrence of pitting failures in 52100 bearing steel samples. An attempt is made to explain the observed phenomena by characterising crack behaviour and related microstructural changes.

Performance Characterisation of Wind Turbine Gear Oils

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Fatigue and wear performance of wind turbine gear oils play an important role in predicting not only durability but also efficiency of gearboxes. It is important to understand that wind turbine gears and bearings operate at fairly specific operating conditions, and herewith require that each application area is addressed individually. But how are these performances measured and assessed? This question is here addressed with a newly developed rolling contact fatigue screening platform, which is composed of well-defined test modules. Each of these test screening modules is designed to screen for specific operation condition of wind turbines. It can be shown, that with a systematic modular screening test platform, clear performance differentiation of wind turbine gear oils can be assed. Also, the new test methodology platform helps understanding how different components act together in a rubbing contact,

TRIBOTESTING IV

Friction Characterisation of Engine Oils for Predicting Fuel Economy

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There is a great need in the industry today for efficient, reliable new tribology screening tests that would enable to determine the potential of an engine oil to meet the requirements for ever more detailed and demanding specification tests for fuel economy and engine durability. A systematic approach using new tribology technologies and methodologies for friction study of engine oils will be presented. Key immerging tribology screening methodologies will be used in order to map friction performance of a series of current commercial engine oils.Their friction characteristics will be evaluated and presented. Further,also trends will be observed how key friction characteristics of engine oils developed through recent engine oil specifications.

Experimental Study of the Onset of Scuffing in Concentrated Rolling-Sliding Contacts Using a New Contra-Rotation Test Method

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Scuffing is a type of severe surface damage that arises due to excessive adhesion in loaded contacts that are subjected to a significant amount of sliding. Due to its rapid progress and the influence of both fluid and boundary films, scuffing is difficult to study experimentally in a systematic manner. This paper presents an experimental study of scuffing using a recently developed test method in which two metal surfaces are rubbed together in contra-rotation while the sliding speed is increased step-wise under constant load. This method enables the effects of fluid film and boundary film to be isolated while also minimising the changes in contact area, and hence pressure, as the test progresses. Results are presented to illustrate the reliability of the method and the influence of base oil type, oil additives and contact conditions on the onset of scuffing. An attempt is made to identify a reliable criterion for prediction of scuffing onset under all conditions tested in the study.