Tribology International 107 (2017) 233–239

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Two phosphonium cation-based ionic liquids used as lubricant additive Part I: Film thickness and friction characteristics

A. Hernández Battez[a,e,*], Carlos M.C.G. Fernandes[b], Ramiro C. Martins[b], M. Bartolomé[c], R. González[c,e], Jorge H.O. Seabra[d]

[a] Department of Construction and Manufacturing Engineering, University of Oviedo, Asturias, Spain
[b] INEGI, Universidade do Porto, Campus FEUP, Rua Dr. Roberto Frias 400, 4200-465 Porto, Portugal
[c] Department of Marine Science and Technology, University of Oviedo, Asturias, Spain
[d] FEUP, Universidade do Porto, Rua Dr. Roberto Frias s/n, 4200-465 Porto, Portugal
[e] Department of Design and Engineering, Bournemouth University, Poole BH12 5BB, UK

ARTICLE INFO

Keywords:
Ionic liquids
Additive
Film thickness
Coefficient of friction

ABSTRACT

The lubricant film thickness and friction properties of a mineral base oil and its mixtures with two phosphonium cation-based ionic liquids: $[P_{66614}][(iC8)_2PO_2]$ and $[P_{66614}][BEHP]$ at 0.5 and 1 wt% concentrations were studied under different slide-to-roll ratios (SRR) and temperatures in an EHD2 ball-on-disc test rig. All lubricant samples showed similar lubricant film thickness in full film lubrication and behaved similarly in friction tests with polished discs at SRR of 5%, but the mixtures outperformed the neat base oil at SRR of 50%. The mixtures were also better in tests with rough discs. Tribological improvements with mixtures were achieved under mixed and boundary lubrication regimes. Real application such as rolling bearings will be presented in the second part of this work.

1. Introduction

Ionic liquids (ILs) have become an increasing research topic in tribology since 2001 [1]. The interest of the lubrication field for the ionic liquids is due to their exceptional properties such as high thermo-oxidative stability, non-flammability, non-volatility, ashless character and controlled miscibility with organic compounds [2–7]. The good lubricating properties of the ionic liquids are linked to their high polarity [8] and the adsorbed tribofilms formed on the metal surfaces, which contribute to reducing friction and wear [9–13].

In general, the ionic liquids have a low solubility in non-polar hydrocarbon oils. Due to this fact, many research works have been developed in the last decade using the ionic liquids as a lubricant additive or as a component of emulsions [14–17]. Since 2009, the commercial availability of phosphonium cation-based ionic liquids has increased interest for their potential use in lubrication [18–20]. Some of these phosphonium based ILs have a good solubility in oils, so their application as a lubricant additive has become a current research topic [15–17,21–29]. Most of the above-mentioned works studied the tribological behaviour of these ILs using reciprocating sliding tests under a mixed or boundary lubrication regime. However, the study of the lubricant film thickness of IL-containing mixtures and their friction properties under different testing conditions should also be addressed.

About 33% of the fuel energy is wasted by cars due to friction losses and from that amount the engine and the transmission systems represent the 35% and 15%, respectively [30]. These systems work under the three general lubrication regimes: boundary, mixed and elastohydrodynamic/hydrodynamic [15]. Among the potential mechanisms to reduce friction in these systems are the use of low-viscosity and low-shear lubricants as well as the development and use of novel additives [30,15]. Recently, the improvement of mechanical efficiency during engine cold start by increasing the oil temperature more quickly has been proved by using different solutions under the New European Driving Cycle (NEDC) [31]. For all the studied solutions, the oil temperature reached values from 95 and 105 °C. Roberts [32] reported that 11 min was the average trip duration and two-thirds of the trips did not go over the line of 11 min, and for this duration, the oil temperature was between 70 and 95 °C under the NEDC.

This work studies the film forming and friction properties of a mineral oil used in the formulation of fuel economy motor oils and its mixtures with two phosphonium cation-based ionic liquids used as additive. These lubricant samples were tested at room temperature in [29]. However, the main goal of this study is to understand the influence of the type and concentration of the ionic liquid on the

* Corresponding author at: Department of Construction and Manufacturing Engineering, University of Oviedo, Asturias, Spain.
E-mail address: aehernandez@uniovi.es (A. Hernández Battez).

http://dx.doi.org/10.1016/j.triboint.2016.10.048
Received 27 July 2016; Received in revised form 4 October 2016; Accepted 28 October 2016
Available online 24 November 2016
0301-679X/

Table 1
Physical and chemical properties of the base oil and its mixtures with the ionic liquids.

Physical properties	Unit	Yubase4	05IL1	10IL1	05IL2	10IL2
Density at 21 °C	g/cm^3	0.829	0.829	0.829	0.830	0.830
Viscosity at 40 °C	mPas	12.79	12.81	13.03	12.95	12.99
Viscosity at 70 °C	mPas	4.87	4.78	4.92	4.89	4.92
Viscosity at 100 °C	mPas	2.48	2.43	2.49	2.54	2.55
Refractive index	–	1.4606	1.4606	1.4603	1.4603	1.4603

Table 2
Main characteristics of the ball and disc.

Parameters	Ball	Disc
Elastic modulus – E (GPa)	210	64
Poisson coefficient – ν (–)	0.29	0.2
Radius – R (mm)	19.05	50
Surface roughness – Ra (nm)	20	≈5
Spacer layer thickness – (nm)	–	≈500
Spacer layer refractive index – (–)	–	≈1.4785

lubricant film thickness and coefficient of friction under different temperature and sliding/rolling conditions. Stribeck curves will be used to characterise the tribological performance of the lubricant samples.

2. Experimental details

2.1. Base oil and ionic liquids

The base oil used in this work was a hydrocracked mineral oil (Yubase4/Group III) provided by Repsol S.A. and the two ionic liquids trihexyltetradecylphosphonium bis(2,4,4-trimethylpentyl) phosphinate or $[P_{66614}][(iC8)_2PO_2]$ (coded as IL1) and trihexyltetradecylphosphonium bis(2-ethylhexyl) phosphate or $[P_{66614}][BEHP]$ (coded as IL2) were provided by Ionic Liquid Technologies GmbH. The base oil was mixed with $[P_{66614}][(iC8)_2PO_2]$ at concentrations of 0.5 wt% (coded as 05IL1) and 1.0 wt% (coded as 10IL1). Also, mixtures of the base oil with $[P_{66614}][BEHP]$ at concentrations of 0.5 wt% (coded as 05IL2) and 1.0 wt % (coded as 10IL2) were prepared. The most relevant physical and chemical properties of the lubricant samples were measured before tribological testing and are shown in Table 1.

2.2. Film thickness measurements

A ball-on-disc test rig (PCS Instruments, model EHD2) equipped with optical interferometry, see Fig. 1, was used for measuring the lubricant film thickness in the contact formed between a 3/4 in (19.05 mm) diameter steel ball and a rotating glass disc. The glass disc is coated with a chromium (20 nm) and silica (500 nm) layer and the load-applying system is based on moving the ball against the disc. The disc and the steel ball are controlled by two electric motors for performing tests under rolling/sliding conditions. The system can accurately calculate the central film thickness from measuring the wavelength of the light returned from the central plateau of the contact.

The standard ball specimen with a high grade surface finish is made from carbon chrome steel and the glass disc can be tested up to approximately 0.7 GPa of maximum Hertz pressure. The ball and disc characteristics (provided by the manufacturer) are presented in Table 2.

The lubricant film thickness tests were made under fully flooded lubrication (120 ml of lubricant sample) for the base oil and all mixtures described in Table 1. A load of 50 N (corresponding with a maximum Hertz pressure of p_0=0.66 GPa) and three operating temperatures (40, 70 and 100 °C) were used. The tests were performed at 5% slide-to-roll ratio (SRR), defined by

$$SRR[\%] = 2 \times \frac{(U_{disc} - U_{ball})}{(U_{disc} + U_{ball})} \times 100 \qquad (1)$$

where U_{disc} and U_{ball} are the speed of the disc and ball on the contacting surfaces, respectively.

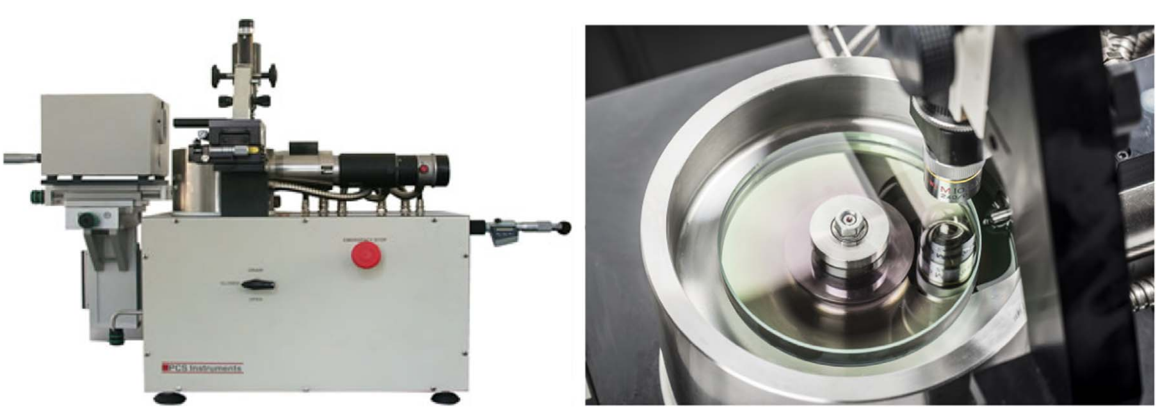
Different entrainment (or mean) speed values were used for each operating temperature. The lowest value was 0.1 m/s for 40 °C, 0.25 m/s for 70 °C and 0.5 m/s for 100 °C. These conditions avoid working with very thin lubricant film thickness protecting the glass disc. The highest entrainment speed used was always limited to 2 m/s because the optical device has a maximum film thickness measurement range of around 1000 nm. The entrainment (or mean) speed is defined as:

$$U_S = \frac{(U_{disc} + U_{ball})}{2} \qquad (2)$$

The lowest ball speeds were 0.097, 0.243 and 0.487 m/s for temperatures of 40, 70 and 100 °C, respectively, and the highest ball speed was consistently 1.950 m/s. On the other hand, the lowest disc speeds were 0.102, 0.256 and 0.512 m/s for 40, 70 and 100 °C, respectively, and the highest disc speed was consistently 2.049 m/s. The equipment automatically adjusts the disc and ball speeds, making the disc speed faster to obtain positive SRR and then making the ball faster to obtain negative SRR, while keeping the entrainment speed constant. The result is the average of both measurements. This procedure is performed for each entrainment speed.

2.3. Coefficient of friction measurements

The coefficient of friction measurements were also performed on



(a) General view (b) Ball-disc contact

Fig. 1. EHD2 ball-on-disc test rig (from PCS Instruments).