Supplementary Material

Nano- and macroscale study of the lubrication of titania using pure and diluted ionic liquids

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Macrotribology

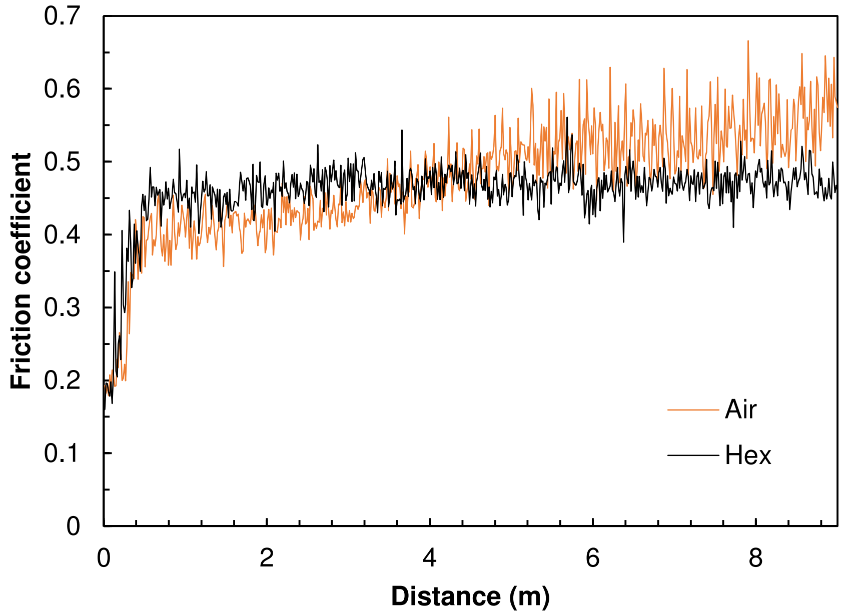

FIGURE S1 | Friction coefficient vs sliding distance measured in air and hexadecane under a load of 5 N and at 25 ℃.

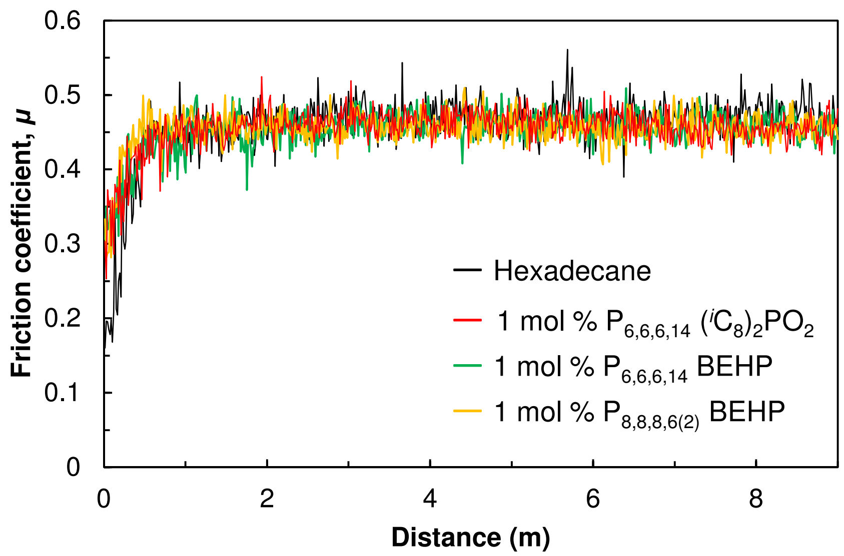

FIGURE S2 | Friction coefficient as a function of sliding distance for three stainless steel balls sliding on a titanium surface in 1 mol % mixtures of IL in hexadecane. Sliding was carried out under 5 N of normal load and a temperature of 25 ℃.

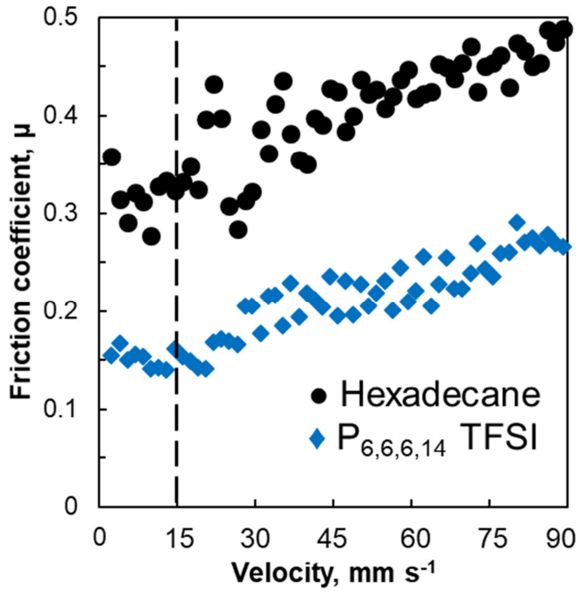

FIGURE S3 | Friction coefficient as a function of velocity for three stainless steel balls sliding on a titanium surface in hexadecane (black circles) and $P_{6,6,6,14}$ TFSI (blue diamonds). The dashed line shows the velocity at which the other experiments were carried out. Sliding was carried out under 5 N of normal load and a temperature of 60 ℃.

Calculation of Hertzian Contact Stress

The effective Young's modulus E_w can be calculated by:

$$\frac{1}{E_w} = \frac{1}{2}\left(\frac{1 - v_1^2}{E_1} + \frac{1 - v_2^2}{E_2}\right)$$

Where E_1, E_2 are the elastic moduli and v_1, v_2 are the Poisson's ratios associated with each body.

Contact area radius is given by:

$$a \cong \left(\frac{3RF}{2E_w}\right)^{1/3}$$

Where R is the radius of the sphere. F is the applied load.

Contact stress:

$$p_{max} = \frac{3F}{2\pi a^2}$$

The parameters used:

Titania: E = 230 GPa, v = 0.28

Stainless Steel: E = 200 GPa, v = 0.3

Macrotribology test:

F = 5 N, $p_{max} = 0.5\ GPa$

F = 10 nN, p_{max} = 0.6 GPa

In the nanotribology tests the exact dimensions and geometry of the tip are uncertain and subject to change. The contact pressures are significantly higher:

F = 50 nN, p_{max} = 11.8 GPa

F = 200 nN, p_{max} = 18.7 GPa

Hamrock and Dowson model

Using the Hamrock and Dowson model the central film thickness, h_c, can be calculated by the following equation (Stachowiak and Batchelor, 2005):

$$\frac{h_c}{R'} = 2.69\left(\frac{U\eta_0}{E'R'}\right)^{0.67} (\alpha E')^{0.53} \left(\frac{W}{E'R'^2}\right)^{-0.067} (1 - 0.61e^{-0.73k})$$

where a is the contact area radius from eq(2), U is the sliding velocity, η_0 is the viscosity of the lubricant at ambient pressure, E_w is the effect Young's modulus from eq(1), α is the pressure-viscosity coefficient, F is the applied load, and k is the ellipticity parameter. k = 1 for point contact. The pressure – viscosity coefficient of hexadecane varies from 11.6 to 13.2, and average of 12.5 is used here (Pensado et al., 2008; Paredes et al., 2012). For the pure ILs used in this study, the pressure-viscosity coefficient was not found in the literature. According to previous studies, the pressure-viscosity coefficient of ILs are generally between 12~21 GPa^{-1} (Pensado et al., 2008; Paredes et al., 2012; Mordukhovich et al., 2013; Gaciño et al., 2015), thus here the film thicknesses of the systems are calculated by assuming the limit values of 12 GPa^{-1} and 21 GPa^{-1} for the pure ILs.

Table S1 shows the calculated film thicknesses do not vary significantly for different chosen values of the pressure-viscosity coefficient.

TABLE S1 | The pressure-viscosity coefficients and calculated film thicknesses h_c for the lubricants used in this study.

Lubricant	h_c (nm) (α = 12 GPa^{-1})		h_c (nm) (α = 21 GPa^{-1})	
	5 N	10 N	5 N	10 N
$P_{6,6,6,14}$ TFSI	18	18	25	24
$P_{8,8,8,6(2)}$ BEHP	55	52	74	70
$P_{6,6,6,14}$ BEHP	40	39	54	52
$P_{6,6,6,14}$ $(^iC_8)_2PO_2$	42	40	56	54
Hexadecane	1	1	1	1

References

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