

Ionic Liquids as Performance Ingredients in Space Lubricants

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1. Material data

The data for the neat lubricants is listed in Table S1. Data for MAC and PFPE is taken from specifications, and P-SiSO and P-TFSA was measured using a Stabinger viscometer (SVM 3000, Anton Paar, Graz, Austria). This data is used to calculate the viscosity of the MAC & P-SiSO mixture.

Table S1. Properties of neat fluids.

Lubricant	v40 [mm ² /s]	v100 [mm ² /s]	VI	Pour point [°C]	Comment
P-SiSO	263	30	153	-30	IL
MAC	108	14.6	137	-55	Base Fluid
PFPE	157	49	358	-60	Reference

The ball and disc specimen used for the SRV-2 tribology experiments conform to the standard ASTM D6425-19. Their roughness were also measured with scanning white light profilometry (SWLI), and confirmed that the composite Sq was correct to within 10 nm. Sq values for the MVT-2 samples were measured using (SWLI) and are reported in Table S2.

Table S2. Root mean square surface roughness (Sq) of steel samples.

	Nominal Ball Sq [μm]	Nominal Disc Sq [μm]	Composite Sq [μm]
SRV-3	0.027	0.055	0.061
MVT-2	0.008	0.005	0.009

2. Normalized wear index

The normalized wear index, HzD, shown in Equation S1 is described in references [1], [2].

$$\mathbf{HzD} = \left(\frac{3\mathbf{PR}^*}{2\mathbf{E}^*} \right)^{\frac{1}{3}} \quad (\text{S1})$$

P refers to applied load, \mathbf{R}^* refers to the effective contact radius, and \mathbf{E}^* refers to the effective elastic modulus. Further details are found in [3].

3. Numeric data for Film Parameter

SRV-3 at 150 N:

$$R_x = 5e-3 \text{ m}$$

$$U = 1.0749e-11$$

$$G = 2.5251e+03$$

$$W = 2.7563e-05$$

SRV-3 at 300N:

$$W = 5.5126e-05$$

MVT-2:

$$R_x = 3.175e-3 \text{ m}$$

$$U = 3.2171e-12$$

$$G = 2.5251e+03$$

$$W = 1.8229e-05$$

k = 1.03 under all conditions.

4. SRV-3 friction Data for $\mu_{\text{avg}}-W_{\text{Hz}}$ charts

All SRV-3 friction-time plots corresponding to Figure 5 are shown in Figure S1.

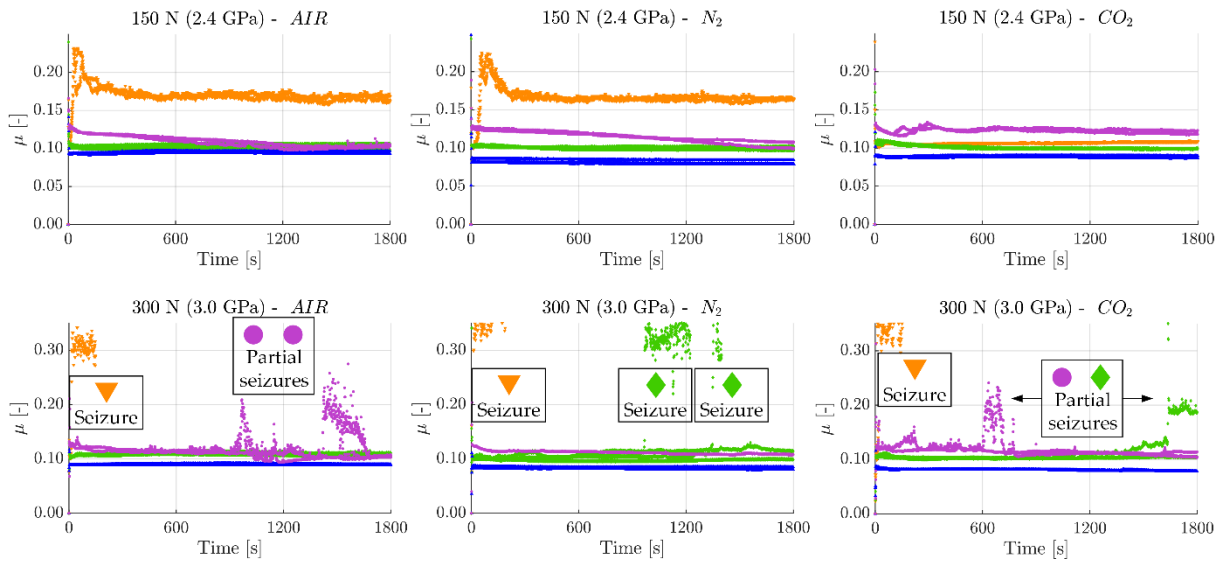


Figure S1. Friction traces recorded for neat MAC, neat PFPE, 'MAC & P-SiSO', and neat P-SiSO. Top row: 2.4 GPa contact pressure in Air, N₂, and CO₂ atmosphere. Bottom row: 3.0 GPa contact pressure in Air, N₂, and CO₂ atmosphere.

5. SRV-3 wear Data for μ_{avg} - W_{Hz} charts

SRV-3 wear scar images of balls and discs at 150N and balls 300 N are listed in Table S3, Table S4, and Table S5.

SRV-3 wear scars 150 N

Table S3. Ball wear scars at 150 N (2.4 GPa). One representative image per test (each test was repeated at least twice).

Lubricant	Air	N ₂	CO ₂
MAC			
MAC P-SiSO			

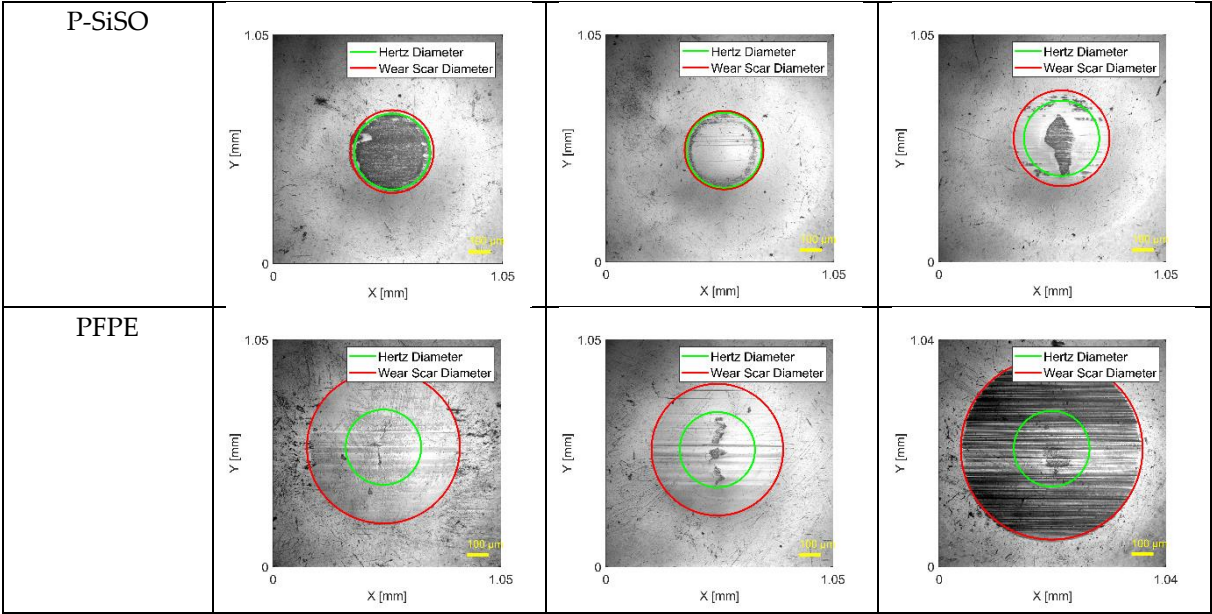
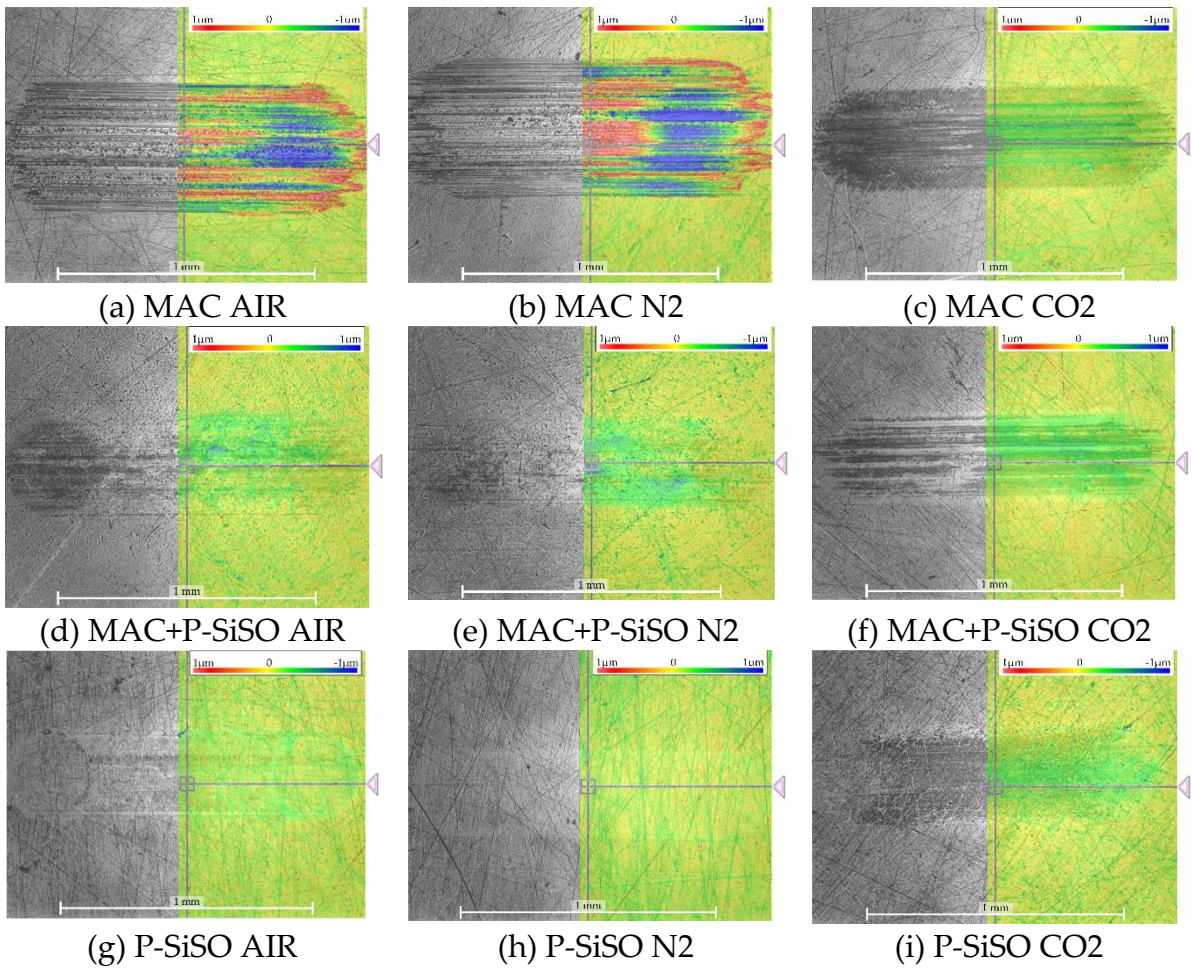
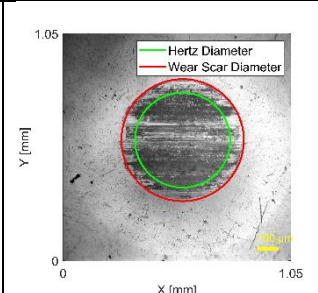
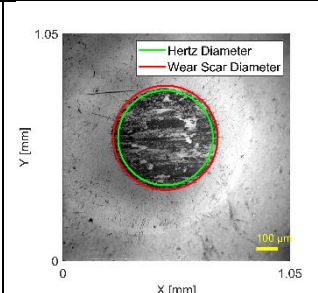
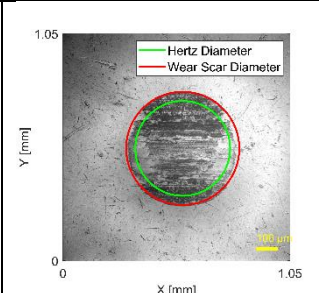
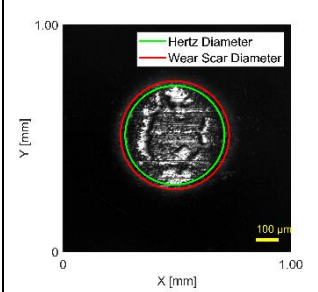
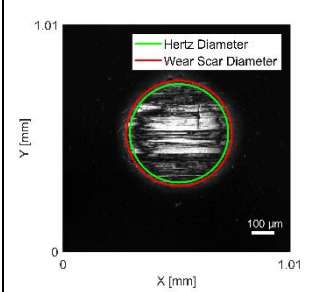
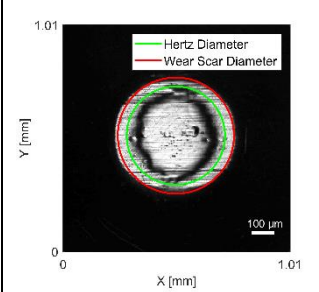
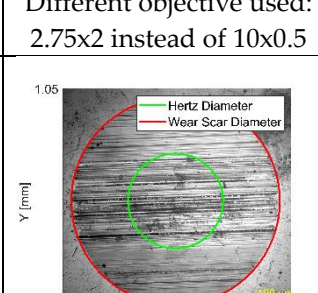
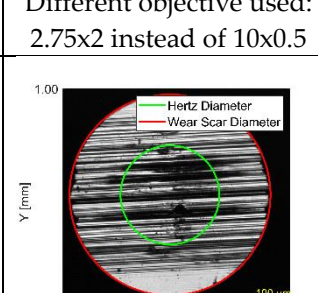
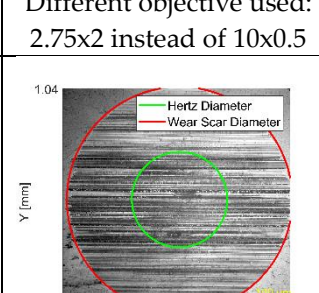


Table S4. Disc wear scars from SRV-3 experiment at 150 N.



Wear scars 300 N

Table S5. Ball wear scars at 300 N (3.0 GPa). One representative image per test (each test was repeated at least twice, unless the result was immediate seizure).

Lubricant	Air	N2	CO2
MAC	Seizure – no data	Seizure – no data	Seizure – no data
MAC P-SiSO			
P-SiSO	 <p>Different objective used: 2.75x2 instead of 10x0.5</p>	 <p>Different objective used: 2.75x2 instead of 10x0.5</p>	 <p>Different objective used: 2.75x2 instead of 10x0.5</p>
PFPE		 <p>Different objective used: 2.75x2 instead of 10x0.5</p>	

6. EDS results at 300 N

EDS results from SRV-3 {300 N / 3.0 GPa / ATM} are displayed in Figure S2.

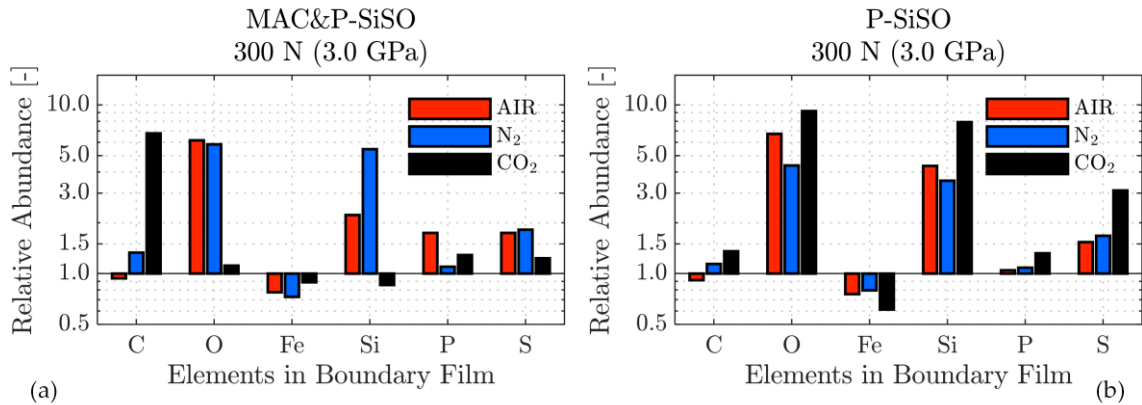


Figure S2. EDS results from SRV-3 {300 N / 3.0 GPa / ATM}.

References

- [1] M. Kalin and J. Vižintin, "Use of equations for wear volume determination in fretting experiments," *Wear*, vol. 237, no. 1, pp. 39–48, 2000.
- [2] E. Nyberg, J. Mouzon, M. Grahn, and I. Minami, "Formation of Boundary Film from Ionic Liquids Enhanced by Additives," *Appl. Sci.*, vol. 7, no. 5, p. 433, 2017.
- [3] K. L. Johnson, *Contact mechanics*. Cambridge: Cambridge Univ. Press, 1985.