Supplementary Material

The film thickness ratio (λ) is used to estimate the lubrication regime under a specific lubrication system. In general, when λ > 3, the system is supposed to work in the hydrodynamic or elastohydrodynamic lubrication regime; when 3 ≥ λ ≥ 1, the system works in the mixed lubrication regime; and when λ < 1, it is the boundary lubrication regime. The study is to investigate the tribological properties of PILs under a boundary lubrication regime, so the operating parameters in this research are well designed accordingly.

$$\lambda = \frac{h_{min}}{\sqrt{(R_1^2 + R_2^2)}}$$

In the formula up there, h_{min} is the minimum film thickness, and R_1 and R_2 are roughness of surfaces in contact. Regarding the elliptical contact, the following formulas that developed by Hamrock and Dowson have been used to calculate the minimum film thickness [1].

$$\frac{h_{min}}{R'} = 3.63U^{0.68}G^{0.49}W^{-0.073}(1 - e^{-0.68k})$$

$$U = \frac{\eta_0 u_0}{E'R'}$$

$$G = \alpha E'$$

$$\mathrm{W} = \frac{F}{E'R'^2}$$

Among the parameters, R' is the effective radius, k is the ellipticity parameter, η_0 is the lubricant dynamic viscosity at atmospheric pressure and certain temperature, u_0 is the mean speed of the two contact surfaces, α is the pressure-viscosity coefficient at a certain temperature, and F is the normal load.

Table S1. Lubrication regime estimation for each lubricant at aluminum-steel contacts.

Lubricant	**U× 10^{-11}**	**G**	**W**	***k***	**h_{min}× 10^{-9}**	**λ× 10^{-3}**	**Lubrication Regime**
BO	1.47	1096.5	7.30×10^{-5}	1	4.63	8.6	Boundary
BOA	1.49	1096.5	7.30×10^{-5}	1	4.68	8.7	Boundary
1%Ets+BO	1.56	1096.5	7.30×10^{-5}	1	4.83	9.0	Boundary
1%Mts+BO	1.55	1096.5	7.30×10^{-5}	1	4.80	9.0	Boundary
1%Dts+BO	1.54	1096.5	7.30×10^{-5}	1	4.78	8.9	Boundary
1%Eds+BO	1.70	1096.5	7.30×10^{-5}	1	5.13	9.6	Boundary
1%Mds+BO	1.69	1096.5	7.30×10^{-5}	1	5.09	9.5	Boundary
1%Dds+BO	1.92	1096.5	7.30×10^{-5}	1	5.56	10.4	Boundary

1 Hamrock, B.J.; Dowson, D. Isothermal Elastohydrodynamic Lubrication of Point Contacts: Part III—Fully Flooded Results. *J. Lubr. Technol.* **1977**, *99*, 264–275. https://doi.org/10.1115/1.3453074.