Electronic Supplementary Material (ESI) for Nanoscale.

Electronic Supplementary Information

Constructing a Novel and High-Performance Liquid Nanoparticles Additive from Ga-Based Liquid Metal

Jie Guo[a, b], Jun Cheng[a, b]*, Hui Tan[a, b], Qichun Sun[a, b], Jun Yang[a, b]*, Weimin Liu[a, b, c]

[a] State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, China

[b] Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 100049, China

[c] School of Materials Science and Engineering, Northwestern Polytechnical University, Xian 710072, China

*Corresponding author. Tel: +86-931-4968193; Fax: +86-931-4968019.

E-mail address: jyang@licp.cas.cn; chengjun@licp.cas.cn.

1. Calculation of the minimum oil film thickness (h_{min}) between the sliding-pairs

The h_{min} is calculated according to the Hou and Wen's formula:

$$\frac{h_{min}}{R} = 3.16U^{0.72}G^{0.50}W^{-0.10} \quad (1)$$

for estimating the film thickness under isothermal point contact and heavily loaded conditions based on the Elastohydrodynamic Lubrication theory. The expressions of the parameters used in the formula are listed in Table S1, and the parameters used in the papers are listed in Table S2. The results of h_{min} are 9 and 56 nm for this paper and the paper of Hu et al., respectively.

Table S1. Expressions of the parameters used in the formula.

Symbol	Expression	Description
U	$U = \frac{\eta u}{ER}$	Dimensionless speed parameter
G	$G = \alpha E$	Dimensionless material parameter (α is viscosity-pressure coefficient)
W	$W = \frac{F}{ER^2}$	Dimensionless load parameter (F is the normal applied load)
E	$E = \frac{2}{\left(\frac{1-\gamma_1^2}{E_1} + \frac{1-\gamma_2^2}{E_2}\right)}$	Effective elastic modulus (GPa) (γ_1 and γ_2 are the Poisson's ratios of the friction pairs; E_1 and E_2 are the Young's moduli of the friction pairs)
R	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$	Effective radius (mm) (R_1 and R_2 are the radii of the friction pairs)
u	$u = \frac{u_1 + u_2}{2}$	mean entraining velocity (m/s) (u_1 and u_2 are the velocities of the friction pairs)
η	$\eta = \nu\rho$	Dynamic viscosity of the lubricating oil (mPas) (ν is the kinematic viscosity of the lubricating oil; ρ is the density of the lubricating oil)

Table S2. Parameters used in the papers.

Symbol	Unit	Value	
		This paper	The paper of Hu et al.[1]
ν	mm^2/s	77.3	67.7
ρ	g/cm^3	0.8347	0.8583
R_1	mm	5	6.35
R_2	mm	+∞	6.35
γ_1	—	0.3	0.3
γ_2	—	0.3	0.3
E_1	GPa	219	219
E_2	GPa	219	219
u_1	m/s	0.05	0.5566
u_2	m/s	0	0
α	m^2/N	2.2×10^{-8}	2.2×10^{-8}
F	N	200	112.475

Note: For the four-ball contact, the sliding velocity is calculated as

$$v_1 = \frac{2\times\pi\times R_1\times n}{60\times1000} = 0.0003839\times n \text{ (m/s)} \quad (2)$$

where n is the rotating speed of 1450 rpm; the normal applied load is calculated as

$$F = P\times\frac{1}{3\cos\varphi} = \frac{\sqrt{6}}{3}P = 0.40825\times P \text{ (N)} \quad (3)$$

where P is the load applied by the tribometer (300 N).

2. Calculation of the adsorption amount of Sn element on the worn surface

It can be concluded from the paper of Hu et al. that there is a linear relationship between the adsorption amount of Sn element (A_{Sn}) on the worn surfaces and the additive concentrations (C). Therefore, the expression can be approximated as

$$A_{Sn} = 4.536C + 0.254 \tag{4}$$

When the additive concentration of Sn is the same as that of GLM-NP/C12 (0.17 wt.%), the adsorption amount of Sn element is calculated as 1.03 wt.%.

Table S3. Adsorption amount of Sn element on the worn surfaces varies with the additive concentrations.[1]

Additive concentration (wt.%)	Element	Weight (%)
0.1	Sn	0.87
0.5	Sn	2.23
1	Sn	4.92

Note: These values comes from the results shown in Figure 8 of the paper of Hu et al.[1]

REFERENCES

(1) S. Zhang, L. Hu, D. Feng and H. Wang, *Vacuum*, 2013, **87**, 75-80.