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Short Communication

Ga-based liquid metal with good self-lubricity and high load-carrying capacity

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ABSTRACT

Extreme pressure lubrication is a great challenge for many mechanical systems like bearings and gears. Here, an novel functional material based on Ga-based liquid metal has been applied to successfully lubricate the steel-ceramic sliding pairs at extreme high load (1500 N), which significantly outperforms other liquid lubricants like oil and ionic liquid. Ga-based liquid metal provides a low friction coefficient (0.11–0.23) and wear rate (10^{-8}-10^{-7} mm^3/Nm) of AISI 52100 steel disc ($C_{0.98\text{-}1.10}Mn_{0.25\text{-}0.45}P_{\leq 0.025}S_{\leq 0.025}Si_{0.15\text{-}0.30}Cr_{1.30\text{-}1.60}Fe_{96.5\text{-}97.32}$, mass %; American Iron and Steel Institute standard) when it slides against Si_3N_4 balls over a load range 100–1500 N. To elucidating these interesting results, the lubrication mechanisms of Ga-based liquid metal are studied by tribo-surface analysis.

1. Introduction

Room temperature Ga-based liquid metals are a family of innovative and multifunctional materials that display many intriguing and unique physicochemical properties [1–3]. Zhang et al. [4] have successfully developed a self-powered motor based on Ga-based liquid metal by "eating"a small Al flake as "food". Zheng et al. [5] have utilized Ga-based liquid metal as an ink to directly write out electronics. Zavabeti et al. [6] used Ga-based liquid metal as a reaction solvent to synthesize the metal oxide nanosheet at room temperature. Now, the multi-functional characteristics of Ga-based room temperature liquid metal provide many inspirations for other research areas and attract tremendous attention. In nuclear energy, Ga-based liquid metal is a good medium to cool or lubricate the drivetrains due to its nontoxicity, high thermal conductivity and high viscosity, etc. Recently, Li et al. [7] found an interesting result that Ga-based liquid metal performs well as a lubricant to resist the wielding of steel-steel contacts in a four-ball test maintaining for 150 s at a rotation speed of 1800 rpm and an applied load of 10 KN. However, the tribology study on liquid metal is still in a very premature phase and considerable works need to be done.

Therefore, this communication is aimed to evaluate the lubricity and load-carrying capacity of Ga-based liquid metal (designated as LM) when it used as a medium to cool and lubricate the steel-ceramic sliding-pairs, which may be a potential mechanical moving systems in nuclear reactor.

2. Experimental procedures

In this study, room temperature Ga-based liquid metal (63% gallium, 22% indium, and 12% tin) is introduced to lubricate the steel-ceramic tribo-pairs. The preparation details refers to the literature [5] and is described briefly herein. The raw materials are gallium, indium and tin silks with purity of 99.99% and diameter of 1 mm. These materials with target mass ratio were added into a cone bottle and all melted at 200 °C. Subsequently the mixture was stirred uniformly by a magnetic stirrer and then cooled for the following tests.

The lubrication behavior of Ga-based liquid metals was evaluated on Optimol SRV oscillating tribometer, where 9.6 mm diameter ceramic balls (Si_3N_4) slide against AISI 52100 steel discs. Test parameters were selected at load from 100 N to 1500 N, frequency of 25 Hz, slip amplitude of 1 mm and duration of 20 min. Before tests, liquid metal droplets were injected into the contacting pairs' interfaces. During sliding, the instrument recorded the friction coefficient automatically. Following tests, AISI 52100 discs and ceramics balls were taken out from the specimen holder and cleaned by ethyl alcohol. The wear volume and 3D images of AISI 52100 discs were measured by a MicroXam-800 non-

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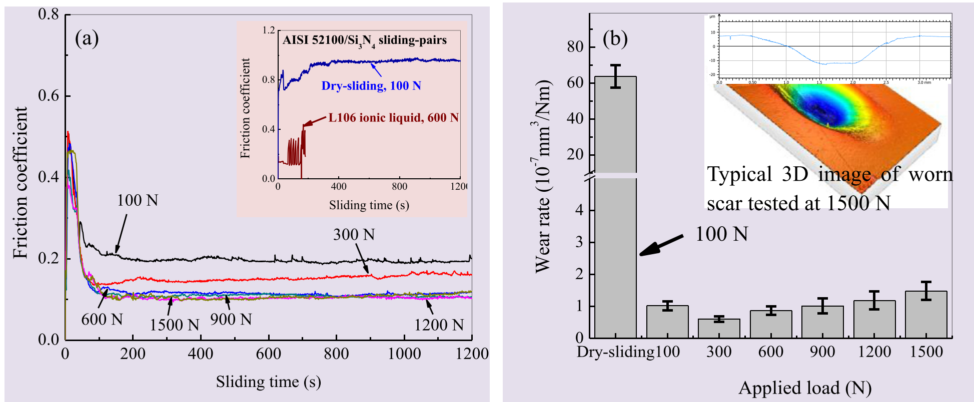

Fig. 1. Friction coefficient and wear rate for AISI 52100 steel in contact with Si_3N_4 ceramics measured at different conditions.

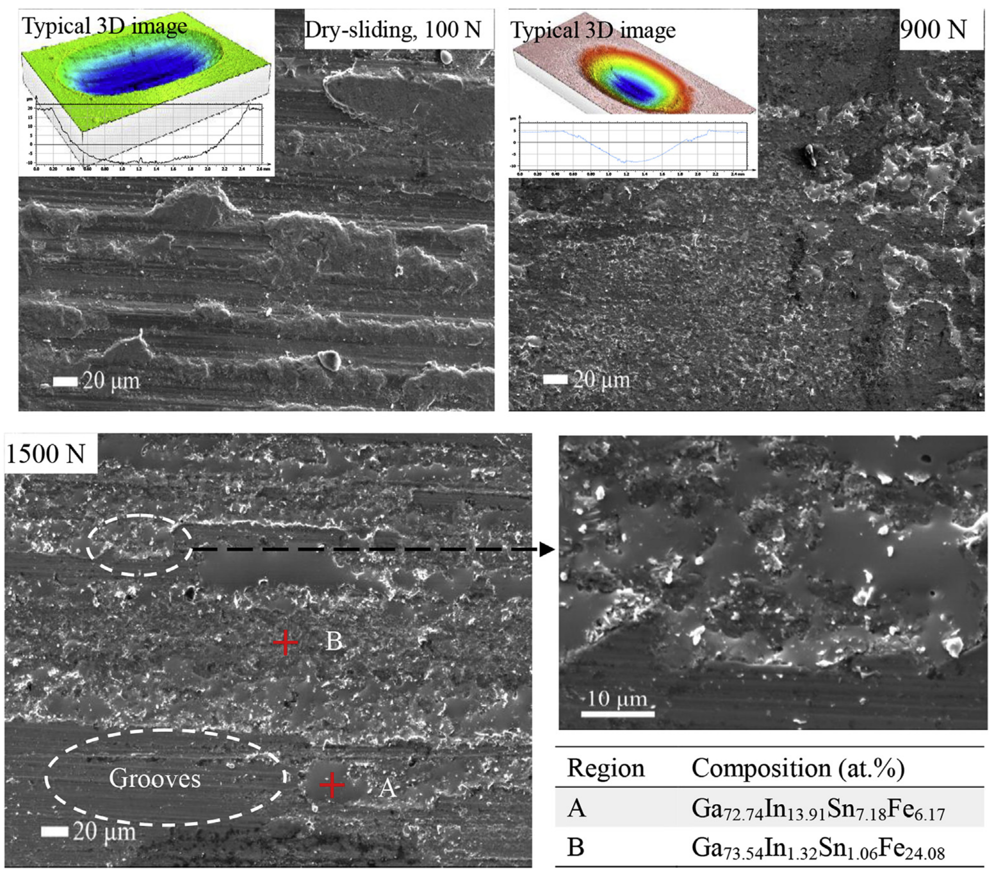

Fig. 2. SEM images showing the worn morphologies of AISI 52100 steel in contact with Si_3N_4 ceramic measured at different applied loads and Ga-In-Sn liquid metal lubrication.

contact surface profiler. Then the wear rate is the result of wear volume divided by sliding distance and applied load. Repeat number for wear test at each load is three times and the wear rate is average value.

Worn morphologies and composition of contacting surfaces were analyzed utilizing a scanning electron microscope (JSM-6700 F) equipped with energy dispersive spectrometer (EDS). Inspection of the element state on the worn surfaces of AISI 52100 steel was conducted on a PHI-5702 multifunctional X-ray photoelectron spectroscopy (XPS) that operated at 400 W and pass energy of 29.4 eV. The size of the X-ray spot in XPS is in the diameter of 800 μm and the detection depth is 3 nm. The structure characterization of the tribo-layer was carried out using a JEM-2010 TEM operated at 200 Kv.

3. Results and discussion

The results indicate that Ga-based liquid metal is a candidate for extreme pressure lubrication in steel-ceramic contact. Fig. 1 shows the curves of friction coefficient and wear rate for AISI 52100 steel in contact with Si_3N_4 ceramics measured at different conditions. The un-lubrication test at 100 N exhibits a remarkably high friction coefficient of approximately 0.9 and wear rate of 6.36×10^{-6} mm^3/Nm for AISI 52100 disc. Compared to this, it is impressive that Ga-based liquid metal displays good lubricity and load-carrying ability for steel-ceramic contact. Friction coefficient ranges from 0.11 to 0.23 at load from 100 N to 1500 N. In terms of limit load capacity, liquid metal that bears applied load of 1500 N remarkably outperforms ionic liquid that performs at several hundred newtons [8,9]. Due to the excellent lubrication of