Materials Letters 215 (2018) 140–143

Contents lists available at ScienceDirect

Materials Letters

journal homepage: www.elsevier.com/locate/mlblue

Liquid metal as novel lubricant in a wide temperature range from −10 to 800 °C

Yi Li [a,b], Songwei Zhang [a,c,*], Qi Ding [a,c], Dapeng Feng [a], Baofeng Qin [a], Litian Hu [a,*]

[a] State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, PR China
[b] University of Chinese Academy of Sciences, Beijing 100049, PR China
[c] Qingdao Center of Resource Chemistry & New Material, Qingdao 266071, PR China

A R T I C L E   I N F O

Article history:
Received 23 November 2017
Accepted 19 December 2017
Available online 20 December 2017

Keywords:
Metals and alloys
Liquid metal
Wear and tribology
Wide temperature range

A B S T R A C T

Microscopic contacts commonly exist on the surfaces when applying loads between the frictional pairs. Under harsh environments, such as extremely high temperature and load, sliding devices will encounter devastating wear loss, eventually leading to the materials failure. Traditional liquid lubricants could only work in a narrow temperature range due to their poor thermal stabilities. A kind of room temperature liquid metal (LM), $Ga_{68.5}In_{21.5}Sn_{10}$, could be used in an ultra-wide range of temperatures. In this work, the tribological properties of LM has been investigated for Si_3N_4/steel contact at three temperatures (−10, 20 and 800 °C), which was the first research in such wide range of temperature for liquid lubricants. Results indicate that LM exhibited excellent tribological performances. Surface analyses suggest that the predominant properties at −10 and 20 °C were ascribed to the tribofilms composed of metal oxides, such as Fe_2O_3, Ga_2O_3, In_2O_3, and SnO_2. The main product intermetallic compound $FeGa_3$ contributed to forming the boundary lubrication film at 800 °C.

1. Introduction

Many mechanical moving components are operating in extremely harsh environments such as, nuclear energy and aerospace industries. Due to the surface friction and wear at high temperature, the service life and reliability of these components are still suffering serious technical challenges [1]. Applying solid or liquid lubricants on the contact surfaces is an effective strategy to achieve lubrication. Solid lubricants, such as molybdenum disulfide, graphite and so on, are always employed and can effectively provide lubricating role under the elevated temperature conditions. Comparatively speaking, liquid lubrication possesses numerous advantages, such as low friction and wear, long term endurance and low noise emission [2]. However, liquid lubricants always have poor thermal stability while being used under these harsh environments. Liquid lubricants with narrow serving temperature range, such as mineral oils (−20∼100 °C), synthetic oils (−70∼300 °C) and ionic liquids (−40∼350 °C), will suffer total failure owing to coking at elevated temperatures (>500 °C) [2–4]. Room temperature liquid metals (Gallium based liquid metals, LM) as multifunctional materials, have drawn extensive attentions in many fields due to their remarkable properties such as broad liquid range, high temperature stability, low melting point, negligible vapour pressure and biocompatibility [5–10]. Besides of the excellent extreme pressure lubrication capability [11], LM will most likely to be used as novel liquid lubricants in a wide temperature range.

In present work, $Ga_{68.5}In_{21.5}Sn_{10}$, a kind of liquid metal with low melting point (−19 °C) [6,12], was investigated as novel lubricant for Si_3N_4/steel contact in a wide range of temperatures (−10 °C, 20 °C, 800 °C). The worn surfaces after the tribological tests were analyzed systematically. So far as we know in the previous studies, no liquid lubricants could provide good lubrication in this wide temperature range, especially up to the high temperature of 800 °C. Thus this work may make an obvious progress towards the novel LM lubricants in the application of lubrication engineering at harsh environment.

2. Experimental section

The liquid metal used in this research, $Ga_{68.5}In_{21.5}Sn_{10}$, was prepared as the followed process. The raw materials (gallium, indium and tin with purity of 99.99%) with mass ratios of 68.5:21.5:10 were added into a flask and were heated to 150 °C. Magnetic stirring was utilized to blend the mixture uniformly after the metals

* Corresponding authors at: State Key Laboratory of Solid Lubrication, Lanzhou Institute of Chemical Physics, Chinese Academy of Sciences, Lanzhou 730000, PR China.
E-mail addresses: zhangsw@licp.cas.cn (S. Zhang), lthu@licp.cas.cn (L. Hu).

https://doi.org/10.1016/j.matlet.2017.12.091
0167-577X/

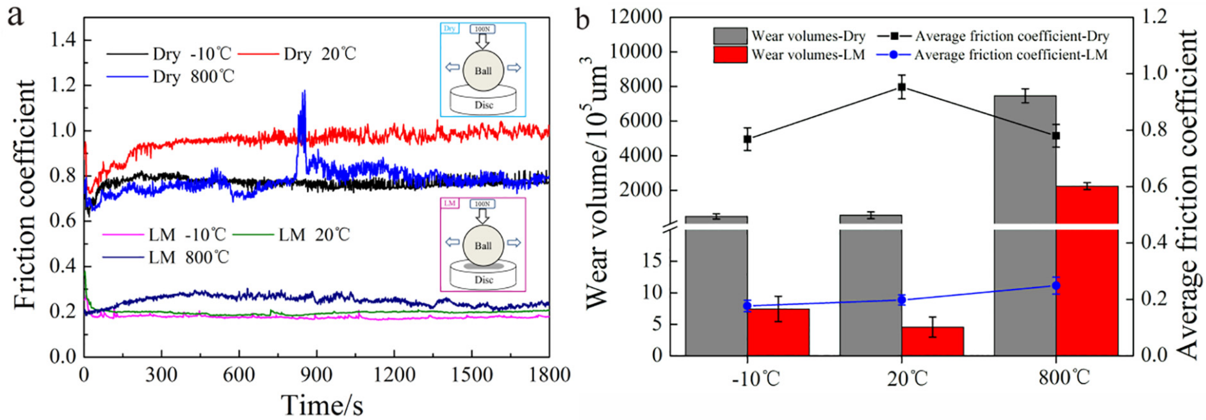

Fig. 1. (a) Evolution of friction coefficient with time for LM and dry sliding at different temperatures; (b) Average friction coefficients and wear volumes of steel discs lubricated by LM and dry sliding at different temperatures.

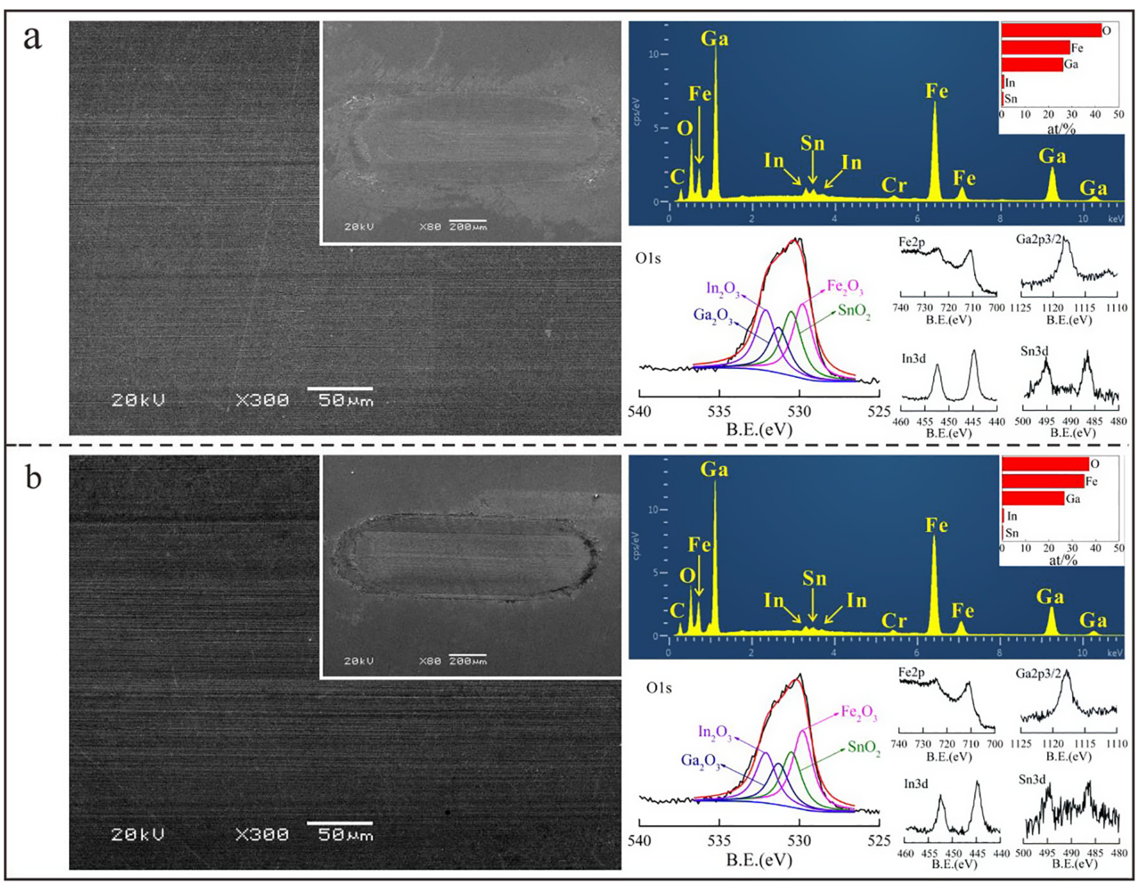

Fig. 2. SEM morphology, EDS and XPS analyses on the worn surface lubricated by LM at different temperature: (a) −10 °C; (b) 20 °C.

had all melted. After cooling the mixture, room temperature liquid metals were obtained.

The lubrication properties of LM were evaluated on the Optimal SRV-IV oscillating reciprocating friction and wear tester at three different temperatures (−10 °C, 20 °C, 800 °C). The lower stationary disc was AISI 52,100 steel (Φ24.0 × 7.9 mm). The upper ball was Si_3N_4 with 10 mm diameter. Tribological tests were performed under normal conditions (load: 100 N, frequency: 25 Hz, amplitude: 1 mm, relative humidity: 10–30%, test duration: 30 min). After the tribological tests, the worn surfaces on the steel discs were washed by 0.25 M NaOH solution to remove the residual adhering liquid metal [11]. Then, the samples were rinsed by distilled water and cleaned ultrasonically in ethanol to remove the NaOH. LM is unnecessary to be washed by NaOH before tests, as LM spontaneously forms an oxide skin in air, which could not be removed totally [11]. In addition, a noncontact surface mapping microscope profilometer MicroXAM-3D was utilized to calculate the wear volume of steel disc. An average of three replicates was presented in the results.

A scanning electron microscope (SEM, JSM-5600LV) equipped with an energy-dispersive X-ray Spectrometer (EDS, KEVEX) attachment was utilized to analyze the morphology and chemical