Advances of Superlubricity

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1. Introduction

Superlubricity, as a new and an important area in tribology, has attracted more and more attentions from researchers over the world. In recent years, some new phenomena, new materials, and new mechanism both in liquid and solid superlubricity have been obtained. In the liquid area, a new system of superlubricity liquids has been found and the new mechanism has been proposed, which exhibits very good characteristics of superlubricity under the higher pressure. In solid area, more materials in superlubricity have been observed both by experiment and the molecular dynamics simulation (MDS), such as grapheme to grapheme surfaces, highly oriented pyrolytic graphite (HOPG) to grapheme etc. Mechanism for different tribo-systems has been discussed.

2. Liquid Superlubricity

2.1 Superlubricity of mixture of acid and polyhydroxy alcohol

The acid solution has been found having superlubricity properties between glass plate and Si_3N_4 ball in our group in 2010[1-3]. The superlubricity was achieved after a running-in process[4]. Li et al.[5] found superlubricity is related to hydrogen ions and proposed that the existence of hydrogen bond network among H_3PO_4, $H_2PO_4^-$ and H_2O is in favor of getting superlubricity. Based on such assumption, most acid solutions mixed with polyhydroxy alcohol have been found to realize the superlubricity, as shown in Fig. 1.

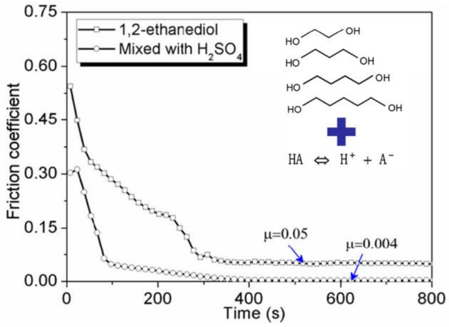

Fig. 1. The friction coefficient with time [5]

2.2 Superlubricity mechanism of the mixture of acid and polyhydroxy alcohol

In order to understand the superlubricity mechanism the mixture of acid and polyhydroxy alcohol, based on the film thickness measured, variation of the lubrication regime has been investigated in the running-in process. Experiments indicate that mixed lubrication is changed into thin film lubrication in the superlubricity state in the running-in period[6]. The acid solution in the running-in process plays the key role on achieving superlubricity. A superlubricity mechanism was proposed as shown in the inset of Fig. 2 [7]. The superlubricity is attributed to the ability of the acid to (i) provide favorable conditions for thin film lubrication, and (ii) generate a repulsive double-layer force through the adsorption of hydrogen ions on the friction surfaces.

2.3 Superlubricity of PAO oils with running-in by acid

There is a question of whether superlubricity can be achieved using oil-based lubricants. A novel approach was approached, that the superlubricity of silicone oil can be achieved between tribo-surfaces (Si_3N_4/glass) by running-in with an acid solution[8]. As shown in Fig. 3, the friction coefficient of silicone oil (100) after the running-in with acid can be reduced to about 0.004, which is only one-thirtieth of its original value (μ=0.13).

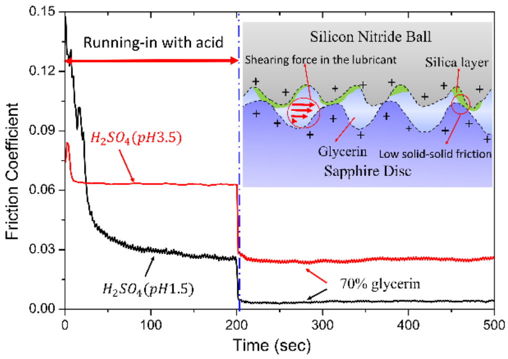

Fig. 2. Friction coefficient of the glycerin solution (70%) after the running-in process with sulfuric acid. The inset shows the schematic illustration of the superlubricity model [7].

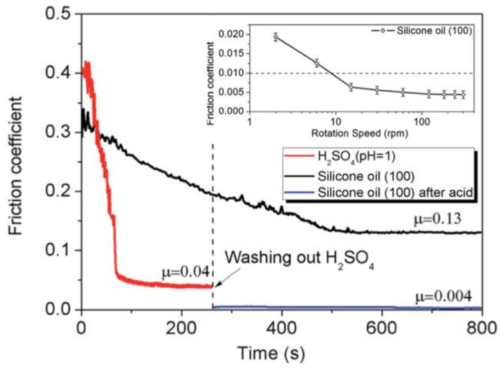

Fig. 3. Friction coefficient of silicone oil and that after running-in process with H_2SO_4 [8].

3. Solid Superlubricity

3.1 Superlubricity of graphene-coated microsphere

More solids have been found in superlubricity state in recent years [9-11]. In our group, a direct measurement of sliding friction between graphene and graphene, and between graphene and hexagonal boron nitride (h-BN) under high contact pressure has been achieved by employing a graphene-coated microsphere (GMS) probe prepared by a metal-catalyst-free chemical vapor deposition method, as shown in Fig. 4[11]. The exceptionally low and robust friction coefficient of 0.003 is accomplished. Moreover, the superlubricity has been achieved under the asperity contact pressure up to 1 GPa and is insensitive to relative humidity up to 51% RH. This ultralow friction is attributed to the sustainable overall incommensurability due to the multi-asperity contact covered with randomly oriented graphene nano-grains. This realization of microscale superlubricity can be extended to the sliding between varieties of two-dimensional (2D) layers.

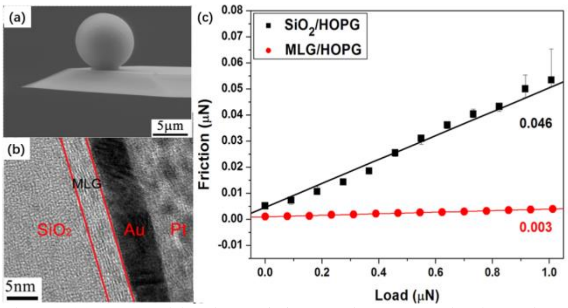

Fig. 7. (a) SEM side view of the graphene-coated microsphere probe. (b) Pt and Au films are deposited as the protective film during TEM sample preparation of focused ion beam process. (c) Friction force as a function of the applied normal load for SiO_2 microsphere sliding against HOPG and MLG-coated SiO_2 microsphere against HOPG respectively [11].

4. Conclusions

The recent researches on superlubricity in our lab have been reviewed. Several kinds of lubricants, including liquids and solids, have been found having superlubricity properties at macro- or micro-scale. These superlubricity phenomenon exhibited different dependences on sliding velocity, contact pressure and environment, due to diverse tribological mechanism. At present, there does not exist the uniformed mechanism for different kinds of superlubricity, nor a relationship between superlubricity at macro- or micro-scale. The application for superlubricity on the practical engineering is just the beginning. More efforts need to be carried out in the field of superlubricity.

Acknowledgment

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