Towards Superlubricity Under Boundary Lubrication

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Abstract

Fuel economy and reduction of harmless elements in lubricant are becoming crucial in the automotive industry. An approach to respond these requirements in engine components is the potential use of low friction coatings exposed to specific boundary lubrication conditions. Superlubricity is a new research field in tribology, dealing with very low friction values, typically below 0.01, and this even in dry or vacuum conditions. It is to be noticed that any friction coefficient below 0.001 is hardly measurable with the equipment at hand. Superlow friction was already experimentally observed only in ultrahigh vacuum and inert gas environment, with pure molybdenite (MoS2) coatings [1] and in presence of some hydrogenated DLC coatings [2]. Under boundary lubrication, we show here that the coupling of hydrogen-free carbon coatings and selected organic lubricant additives permits to reach friction values approaching superlubricity and also a wearless behavior.

Introduction

In this work we compare the friction reducing efficiency of different tribosystems: steel pairs lubricated with traditional additives and carbon-coated surfaces lubricated in presence of selected organic compounds. Two different tribometers were used in order to study the effect of different kinds of motion. First one is a unidirectional three-cylinder-on-disc friction machine. Contact pressure was about 700 MPa, maximum sliding speed was 1m.s⁻¹ and test temperature was 80°C. Second test is a reciprocating Cameron-Plint friction machine with cylinder-on-flat configuration (contact pressure 700 MPa, sliding speed 0.6 m.s⁻¹, temperature 80°C). Traditional additives (ZDDP, MoDTC) as well as esters (glycerol mono-oleate GMO) are used as additives added to synthetic base oil (PAO).

Steel-Steel Combination

The reduction of friction of steels pairs under boundary lubrication needs the use of special additives like molybdenum dithiocarbamate (MoDTC) often associated with zinc dithiophosphate ZDDP (see Fig. 1). The action mechanism of these additives has been extensively studied during the last five years and has been attributed to the triboformation of MoS₂ single sheets providing the ultralow friction regime [3]. However, it has not been possible so far to reach routinely friction values below 0.04.

Figure 1: Friction coefficients for different tribosystems and lubricants in the Cameron-Plint tribometer (contact pressure 0.7 GPa). The lowest friction is obtained with ta-C and GMO.

Hydrogenated DLC Coatings

Low friction properties of DLC coatings under boundary lubrication conditions have been investigated. Friction of hydrogenated carbon coatings (a-C:H) was evaluated in presence of traditional friction-reducing additives such as molybdenum dithiocarbamate (MoDTC) and zinc dithiophosphate (ZDDP). Our XPS and TEM data show that MoS₂ lamellar single sheets are also produced in the contact and are able to decrease the friction coefficient in the ultralow regime [4]. However, friction values below 0.04 were not attainable in our test conditions of boundary lubrication (Fig.1).

Hydrogen-Free DLC Coatings

Hydrogen-free sp³-rich DLC coatings (ta-C) were tested in presence of glycerol mono-oleate (GMO) blended to synthetic oil. For the first time, friction level below 0.04 was obtained in boundary lubrication (Figure 1). However, superlubricity was reached (µ=0.006) with this new tribological system in the pin-on-disc configuration (Fig. 2) [5]. The effect of the sliding speed is shown in Figure 2 for the two friction
machines. It is interesting to note that friction is lower in the unidirectional motion. Moreover, no visible wear was observed in this case. The mechanism of friction reduction with GMO/ta-C combination is found to be thoroughly different from that of the MoDTC/a-C:H combination.

Figure 2; Evolution of friction as a function of sliding speed in two different tests, using the ester-diamond combination. Top: 3-cylinder-on-disc (P=700 MPa); bottom: Cameron-Plint reciprocating in two different tests, using the ester-diamond combination. Top: 3-
unidirectional test. In the near future, the engine oil environment that provides different lubrication conditions could be actually very similar to that of H-terminated surfaces encountered in UHV friction of hydrogenated DLC in inert gases [2].

The role of tribochemical phenomena, like tribomicroplasma for example, may also be envisaged in the overall process because the coatings are basically electrical insulator materials. The idea behind this is that Ohmae [6] has recently shown that graphite is formed under irradiation of diamond by electrons (see Fig. 4). The second point is that triboplasma is able to produce such high energy electrons impinging the surface [7]. We suspect that the scenario is realistic in our lubrication experiment. Eventually, the alcohol reacts with the double bonds to produce the OH-terminated surface at the exit of the contact (Fig. 3). More analytical work is necessary to prove this mechanism.

Superlubricity under boundary lubrication has been reached for the first time, using a new tribological system in unidirectional sliding. In the near future, the engine oil environment that provides different lubrication conditions could provide such very low friction levels.

REFERENCES