Tribological Characteristics of MoS2 and DLC film in Sliding Contacts under Different Lubrication Conditions

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Keywords: Mixed film lubrication, MoS2, DLC, friction

Abstract. The objective of this study is to investigate the effect of solid and liquid lubrication on friction and wear performance of selected solid lubricating coatings, comparative experiments have been carried out on magnetron sputtered MoS2 coatings and chemical vapor deposited hydrogenated diamond-like carbon (DLC) films against Si3N4 ball using a ball-on-disk tribo-tester under the conditions of room temperature and different lubrication condition. The friction coefficient (COF) of solid films also was analyzed. It was shown that the friction be greatly reduced when the MoS2 and DLC solid film lubricated with oil and grease simultaneously compared to lubricated singly at the start-up or under boundary lubrication conditions.

Introduction

Most of the traditional solid lubricants have been used successfully in various engineering applications when liquid lubricants do not meet the advanced requirements of modern technology [1,2], and the present state of the art in solid lubricant coatings has reached a point where they can now be produced on all kinds of tribological surfaces at thickness ranging from a few nanometers to several micrometers [3].

As surface films, MoS2 has successfully and widely been applied for space applications than any other lubricating solid [4,5], diamond-like carbon (DLC) films are of great interest as a protective coating in industrial tools and medical implants for its' excellent chemical stability, high hardness and high elastic modulus, and considered to be a candidate of next generation solid lubricants for space applications due to its supreme tribological properties both in atmospheric and vacuum conditions [6-8].

Many factors or conditions also affect sold lubricant performance: type of substrate material, type of counter-face material, contact stress, sliding speed, and environment, etc [8,9]. When surfaces running under thin film conditions, enough oil is often present, so that part of the load is carried by fluid films and part is carried by contact between the surfaces, but the effect of oil to the performance of solid coatings is not clearly yet [3].

To achieve better lubricity in demanding tribological applications, more and more attention be paid on solid lubrication coatings using with liquid lubricants simultaneously in recent two decades [10-12], but knowledge of the tribological performance of the coatings in lubricated conditions is still quite limited.

Many authors have studied the properties of MoS2 and DLC films working with liquid lubricants, Luo [13] invested the friction and wear performance of sputtered MoS2 film sliding against steel ball under high—speed lithium grease lubrication with ball—disc tester as early as 1994, and shown that sputtered MoS2 films possesses excellent frictional characteristic under the testing conditions. Ihsan Efeoglu [14] got the lowest friction coefficient of the MoS2–Nb composite film when which work in oils, compared to air, nitrogen and water vapour. Ando J. et al [15] reported on the tribological properties of a Si-containing diamond-like carbon film under an automatic transmission fluid (ATF) lubricated condition, which dramatically improves the performance of an electromagnetic clutch used in electronically controlled All-wheel-drive (AWD) coupling. Ksenija [16] described that the graphitic-type DLC coating initially gave very low boundary friction with additive-free base oil, but after a few minutes of rubbing in thin film conditions friction rose to a higher value. Kalin and Vižintin[17] compared the wear and friction behaviours of two type of DLC coatings after experimented under severe boundary-lubrication conditions during reciprocating sliding, and obtained better wear and friction performance when oils were used that contain large amounts of polar and un-saturated molecules. As mentioned above, solid lubricating coatings-liquid lubricants composite lubrication theories cannot be applied because of the difference of the coatings and lubricants causing difference and certainties of the performance.

In this study, the authors present some results of tribological investigations of coated elements lubricated with different lubricants in view of compound mechanism of liquids and coatings. Comparative experiments have been carried out on magnetron sputtered MoS2 films and chemical vapor deposited DLC coatings against Si3N4 ball using a ball-on-disk tribo-tester under the conditions of room temperature and different lubrication condition. Surface morphology of coatings were investigated by atom force microscope (AFM), friction coefficient (COF) and wear rate of solid films be analyzed also.

Experiment set-up

Three Kinds of standard single thin coatings were prepared by state key laboratory of solid lubrication in Lanzhou institute of chemical physics, they are magnetron-sputtered MoS2 thin film, and chemical- vapor-deposited diamond-like carbon (DLC) coating, respectively.

The liquid lubricants used in the experiments on solid lubrication films-liquid lubricants composite lubrication were synthetic oil and grease, both were commercial supplied and possess excellent lubricity. The synthetic oil was aviation precise instrument oil (4122), produced in China. The kinematic viscosity of lubricating base oil at 40˚C and 100 ˚C are 42 mm2.s-1 and 14.48 mm2.s-1, respectively.The lubricant grease was rolling bearing grease L252 (KE2G-40), made in Germany. Base oil is synthetic ester and the complex thickener is lithium soap, the kinematic viscosity is 150 mm2.s-1 at 100 ˚C.

The tribological experiments were carried out using a ball-on-disk tribometer (Fig. 1) in air and at room temperature. A Si3N4 ball having 6 mm in diameter loaded 6 N slide with a steel disk coated with single solid lubrication film under difference lubrication, and the mean surface roughness (Ra) of the ball having 75～80 HRC in rigidity value was baout 0.014 μm. The opposite of contacts is a steel disk, made from 9Cr18, with 60～65 HRC degree of hardness.

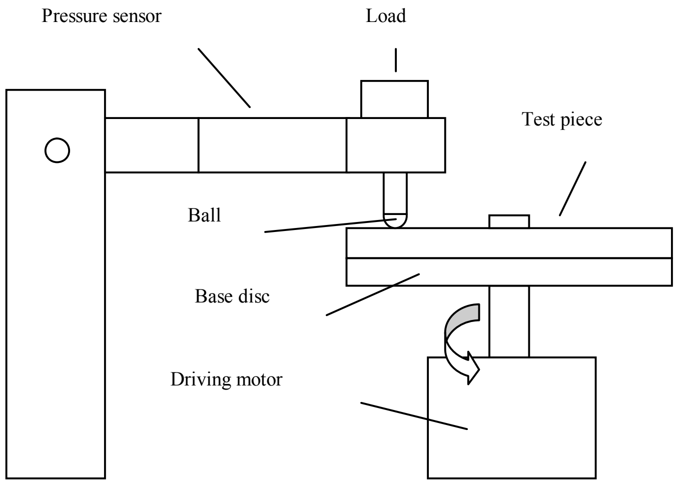

Fig.1 Test system of tribological experiment

The friction between the contact surfaces detected by a pressure transducer, and the coefficient varying with the change of the speed of disk from 0 to 2000 rpm described the effect of mixed-films lubrication.

Results and discussion

The coefficient of friction of MoS2 film and DLC coating sliding against a Si3N4 ball under a load of 4 N in different environments are pressed in Fig. 2.

The effects of lubricants to the friction of both thin films at start-up (see Fig. 2a and 2b) showed that the friction between the ball and the disk were both reduced much with liquid lubricants. The value of friction coefficient of MoS2 film lubricated with oil was 0.123, similar to lubricated with grease ((μ=0.123) and both lower than the film sliding directly against the ball (μ=0.133) in air. While the film was clear, the friction of both films reduced greatly when the mutual surfaces come into boundary lubrication. Figure 2.a shows that the friction coefficients of Si3N4 ball against steel coated with MoS2 film at speeds of 100 and 500 rpm were 0.096 and 0.098 respectively, and the change of the values was not obvious when lubricated with oil or grease in this experiment. When the experimental speed increase to 2 000 rpm, the friction heat caused abrupt rise of the coefficient of the MoS2 film lubricated with oils, on the contrary, the friction decreased much lower using with grease. The friction coefficient of DLC film when the oil or grease used as lubricant both reduced much than solid film singly at every test speed, and the difference between that lubricated with oils and grease is relatively small at low speeds, when the speed arrived at 2000 rpm, the effects of that used oils was better than grease.

Additionally, the friction coefficient of the DLC film descended gradually with the rising of sliding speed when lubricants were used or not. For the case of lamellar MoS2 film, the change of the friction was uncertain, except oils was used.

Solid lubricant film could increase the lubricity for the coating and transfer film separated the friction substituted by DLC, the value of friction between the film and the contacting surface reduced from 0.199 to 0.187 when lubricated with oil, and the coefficient of friction decreased further more to 0.17 when grease was used. The lubricity of MoS2 and DLC films under boundary lubrication were shown in Fig. 2 too. As is clear, the friction of both films reduced greatly when the mutual surfaces come into boundary lubrication. Figure 2.a shows that the friction coefficients of Si3N4 ball against steel coated with MoS2 film at speeds of 100 and 500 rpm were 0.096 and 0.098 respectively, and the change of the values was not obvious when lubricated with oil or grease in this experiment. When the experimental speed increase to 2 000 rpm, the friction heat caused abrupt rise of the coefficient of the MoS2 film lubricated with oils, on the contrary, the friction decreased much lower using with grease. The friction coefficient of DLC film when the oil or grease used as lubricant both reduced much than solid film singly at every test speed, and the difference between that lubricated with oils and grease is relatively small at low speeds, when the speed arrived at 2000 rpm, the effects of that used oils was better than grease.

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The lubricity of MoS2 and DLC films under boundary lubrication were shown in Fig. 2 too. As is surface peaks, known as asperities, when surfaces come into contact。 When the lubricants was used, a number of rubbing actions take place among the absorbed films under low speed, that generate from chemical additives in the lubricants, so the friction could be improved greatly for the synergistic effect of the double films at start-up or under boundary lubrication.

Base of the theory of graphitization and transform films of diamond-like carbon (DLC), the film will transform from metastable structural carbon to steady graphite when sliding under loading conditions. The lubricity of graphite layers depends on the atmosphere because of the surface energy of the edge plane (1010) are commonly 100 times high than that of basal plane (0001). When the graphite particles were surrounded by the oil molecular, the edge plane of microcrystal would be combined firmly with the oily agent of lubricant, so the lubrication performance of diamond-like carbon could be improved much if the lubricants were used.

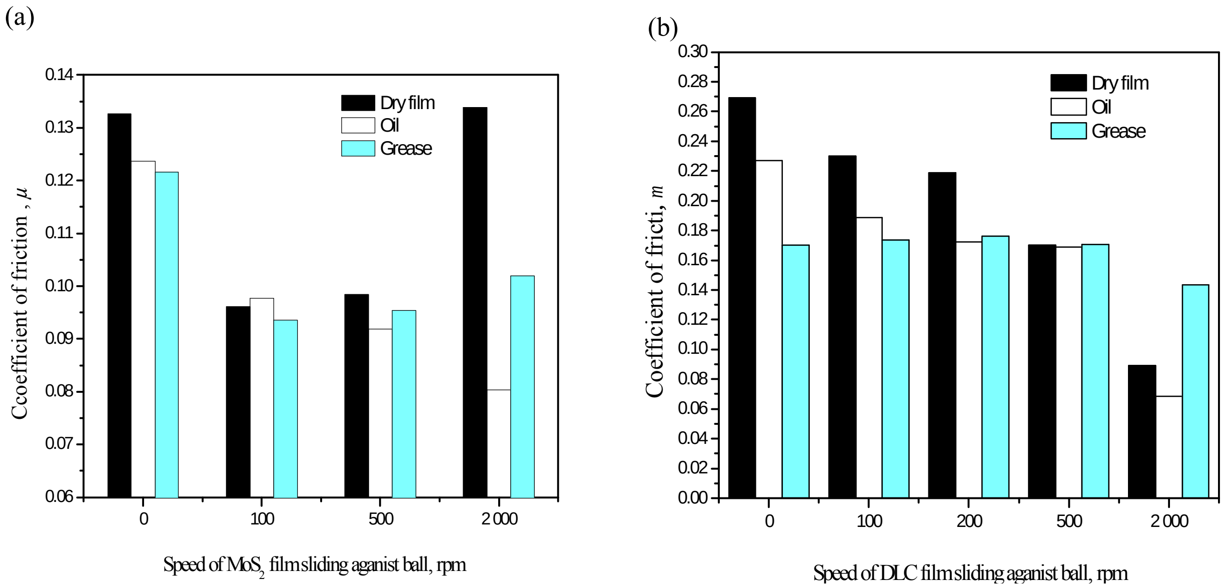

Fig.2 Coefficient of friction of MoS_2 and DLC films under different lubrications

Conclusions

In this study, Pin-on disc tests of MoS2 thin film and DLC solid coating sliding against in air under different tribo-test conditions were carried out, and the properties of combining a liquid lubricant(oil/grease) and solid thin film are summarized as follows:

The effect of liquid lubricant to the friction of MoS2 film and DLC coating films at start-up showed that the friction between the ball and the disk were both reduced when lubricated with oil, and that improved much more when lubricated grease. When the mutual surfaces come into boundary lubrication, the friction of the solid film lubricated with oil and grease simultaneously was greatly reduced than dry film.

Acknowledgements

This work is supported by National Natural Science Foundation of China under Grant No.50905174, No.11372309 and No. 61304017, the Natural Science Foundation of Ji Lin province under Grant No.20101530, No. 20150204074GX and No. 201101090, and the Industrialization project of Ji Lin province under Grant No.2014SYHZ0004, and STS project of Chinese Academy of Science under Grant No.KFJ-EW-STS-068.

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