Wear and Frictional Properties of Aluminum Bronze Alloy Lubricated with Molybdenum Trioxide at High Temperature

Yoshinori TAKEICHI
Toyohashi University of Technology, Toyohashi, Japan

Takashi CHUJYO
Toyohashi University of Technology, Toyohashi, Japan

Naoki OKAMOTO
Toyohashi University of Technology, Toyohashi, Japan

Ivan HAVETTA,
University of Žilina, Zilina, Slovak Republic

Marian DZIMKO
University of Žilina, Zilina, Slovak Republic

Masao UEMURA
Toyohashi University of Technology, Toyohashi, Japan

Summary

The wear and frictional properties of aluminum bronze lubricated with MoO_3 (molybdenum trioxide) powder were studied at the temperature ranging from room temperature to 700 °C. MoO_3 powder accumulated on the sliding surface of counterpart stainless steel reduced friction and wear of both materials at the temperature from 500 to 700 °C. The X-ray diffraction analysis of friction track revealed that the unknown material other than molybdenum oxide or copper oxide was genereted on the friction track of aluminum bronze slid against MoO_3 coated counterpart at high temperature. As the result of diffraction peak identification comparing with the database, the generated material was supposed to be $Cu_3Mo_2O_9$. It was suggested that the generated material acted as high temperature lubricant and reduced wear of materials and friction under high temperature conditions.

1. Introduction

Tribological properties of many kinds of materials under high temperature condition have been studied. Although ceramics is one of the capable materials which can be used at high temperature because of their thermal stability, their lubricity and wear resistance are required to be further improved. Some kinds of metal alloy are used as high temperature tribomaterials though their heat resistance are inferior than that of ceramics. Aluminum bronze is one of the conventional tribomaterials which can be used as bush bearing material at high temperature up to around 300 °C. However, at the temperature of over 400 °C, it shows high friction coefficient and poor wear resistance. In order to improve the wear resistance of the aluminum bronze bush bearing for the butterfly valve used in the exhaust brake system, the wear reduction effect by adding silicon and manganese particles to the aluminum bronze has been studied. As a result, the addition of silicon and manganese particles reduced friction and wear of aluminum bronze especially at high temperature [1].

On the other hand, the lubricity of many kinds of metal oxide at high temperature has been studied. It was reported that MoO_3 showed superior lubricity at high temperature of about 700 °C [2]. It was expected that MoO_3 enhances wear resistance of aluminum bronze at high temperature. In this paper, the effects of MoO_3 powder accumulated on the sliding surface on the friction and wear of aluminum bronze under high temperature conditions are reported.

2. Sample and experiment

2.1 Sample preparation

Aluminum bronze, C6191 (JIS H 3250, Japanese Industrial Standards), was chosen as a material under test. The compositions of C6191 are shown in Table 1. It is copper based alloy which includes about 10 % aluminum and a few % iron. Stainless steel, SUS304 (JIS G 4303) was used as a counterpart material for the friction test.

Generally speaking, oxide powders are difficult to adhere to metal surface. Therefore, in this sample preparation, MoO_3 powder was accumulated on the surface of stainless steel specimen as powder coating by the following method. The sliding surface of specimen was polished and then slightly sandblasted. Its surface roughness was around 1.0 μm (*Ra*). It was put in the acetone in which a certain amount of MoO_3 powder was mixed well. After dispersing MoO_3 powder in acetone by ultrasonic vibration, it was warmed up to 45 °C to evaporate acetone. Finally, the MoO_3 powder was uniformly accumulated on the sliding surface of the stainless steel specimen and this specimen was used as a MoO_3 coated specimen. The quantity of accumulated MoO_3 powder on the specimen was estimated by measuring the weight of specimen before and after coating treatment, and was controlled to be between 5 and 6 mg.

Table 1 Compositions of aluminum bronze C6191

Content	Cu	Al	Fe	Mn	Ni
Dens., %	81-88	8.5-11	3-5	0.5-2	0.5-2

2.2 Friction test

The friction test was conducted with the ring-on-disk tribometer with a furnace in which the ring and disk specimens were mounted. The picture of tribometer is shown in Fig.1. Stainless steel was used as a ring specimen and some of them were coated with the MoO_3 powder. The outer and inner diameter of the ring specimen was 20 and 15 mm, respectively. Aluminum bronze was used as a disk specimen and its thickness was about 5 mm. The applied load was 61.8 N which corresponds to the contact pressure of 0.46 MPa. The rotating speed of the ring specimen was 60 rpm which corresponds to the sliding speed of 55 mm/s. The sliding distance was about 200 m. The temperature in the furnace was controlled to be from the room temperature (R.T.) to 700 °C. The wear amount of the specimen was obtained as a weight loss by measuring the weight of the specimen before and after friction test. Preliminary to the friction test, it was confirmed that the weight increase of heated specimen by oxidation was negligibly small comparing with the value of wear amount.

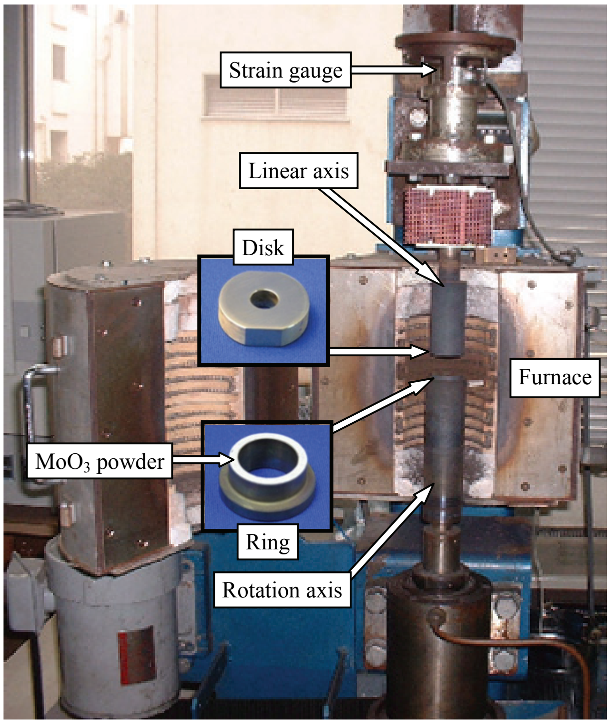

Fig.1 Ring-on-disk tribometer with furnace

3. Results and discussion

3.1 Friction and wear of materials

Figure 2 shows the friction coefficient. The friction coefficient for the uncoated specimen increased from 0.27 to 0.72 with increase of temperature from R.T. to 600 °C. The friction test was aborted at 700 °C because friction force exceeded the upper limit of this tribometer in a moment. On the other hand, the friction coefficient of MoO_3 coated specimen increased from 0.19 to 0.56 with increase of the temperature from R.T. to 400 °C, and then it decreased to 0.44 with increase of the temperature up to 600 °C. Although the friction coefficient increased again to 0.57 by increasing temperature to 700 °C, it was small enough comparing with that of uncoated specimen and friction test was accomplished at this temperature.

Figure 3(a) and 3(b) show the wear amount of aluminum bronze disk specimen and the wear amount of stainless steel ring specimen, respectively. The negative value in Fig.3(b) means that the weight of ring specimen increased after friction test because the material of disk specimen adhered on the ring specimen.The wear amount of uncoated specimen was smaller than that of MoO_3 coated specimen tested at R.T. and 200 °C for both of the disk and ring. At the temperature of over 400 °C, the wear amount of uncoated specimen was larger than that of MoO_3 coated specimen. Though the wear amount of the uncoated specimen at 700 °C cannot be directly compared with the results for other temperatures, it is obvious that the wear amount of the specimen at 700 °C is larger than

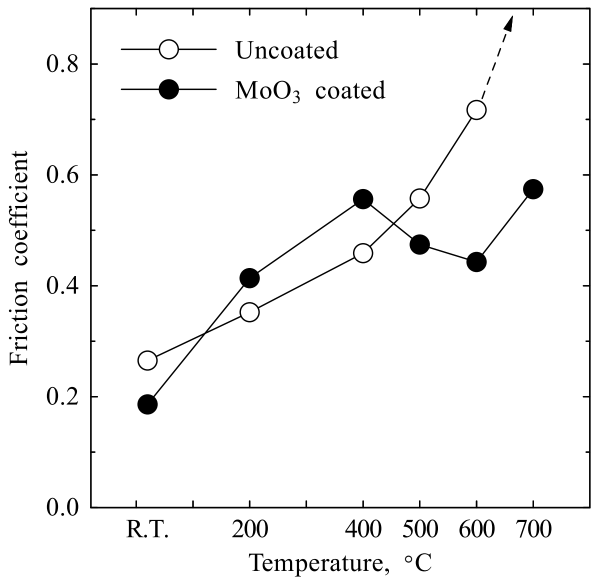

Fig.2 Friction coefficient for the pair of aluminum bronze disk and uncoated / MoO_3 coated stainless steel ring.

that for the temperature less than 600 °C. MoO_3 coating showed remarkable wear reducing effect especially at the temperature from 500 to 700 °C.

3.2 X-ray diffraction analysis

The results of XRD (X-ray diffraction) analysis of the friction track on the aluminum bronze disk specimen, which was slid against MoO_3 coated stainless steel ring, are shown in Fig.4. The diffraction peaks obtained from MoO_3 powder and CuO powder are also shown in the same figure as reference. These data were obtained by using cobalt target X-ray source because aluminum bronze contains a few % iron as shown in Table 1. In this range of diffraction angle, aluminum bronze shows no peak. Several peaks with certain intensity were observed from the specimens tested at 500 and 600 °C. The similar peaks are obtained also from the specimens tested at 700 °C, though the diffraction intensity is small. By comparing with the diffraction peaks obtained from MoO_3 and CuO powder, it can be concluded that the peaks obtained from the friction track on the aluminum bronze are not from MoO_3 or CuO.

We conducted peak identification with the diffraction peak intensity in the database. The XRD spectra obtained from the friction track of aluminum bronze slid against MoO_3 coated ring at 600 °C and the diffraction peak intensity of $Cu_3Mo_2O_9$ in the database (JCPDS 01-070-1495) are shown in Fig.5. Taking into account the difference between the wavelength of X-ray from cobalt target and that from copper target, the diffraction angles for $Cu_3Mo_2O_9$ in the database was shifted in this figure. It can be suggested that the generated material on the friction track of aluminum bronze is $Cu_3Mo_2O_9$ because the diffraction peak position and intensity of database

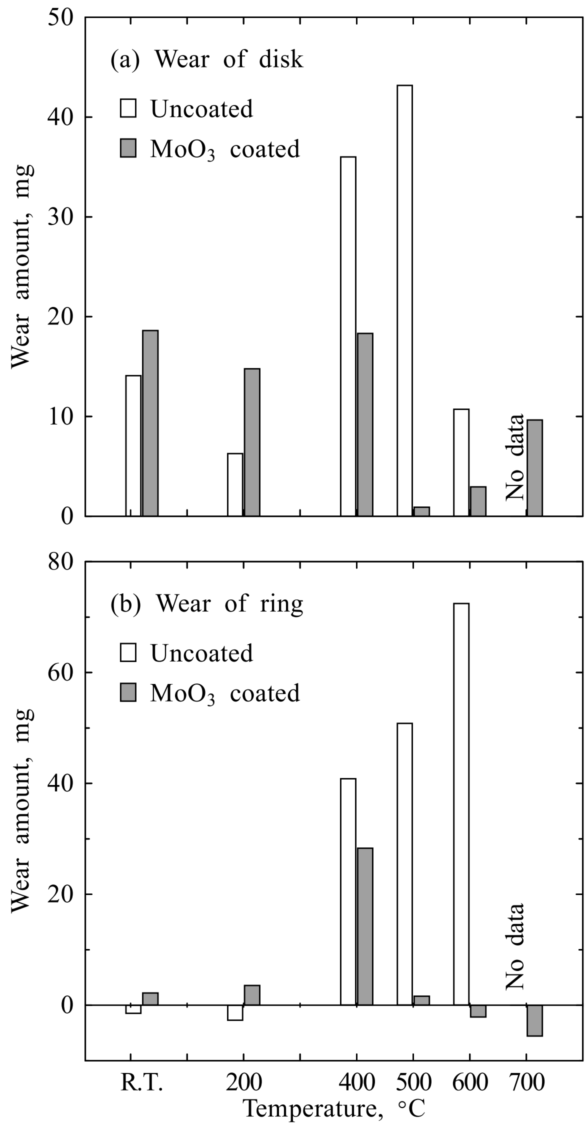

Fig.3 Wear amount of (a) the aluminum bronze disk and (b) the stainless steel ring for uncoated and MoO_3 coated specimens

are in good agreement with the obtained XRD spectrum. In the case of friction between aluminum bronze and stainless steel, it can be considered that MoO_3 didn't work directly as a lubricant at high temperature but it reduced friction and wear by changing into $Cu_3Mo_2O_9$. Copper contained in the aluminum bronze is easily oxidized especially at the surface by heating in air. $Cu_3Mo_2O_9$ was generated during sliding at high temperature under high pressure by the reaction of MoO_3 powder and copper oxide. Wahl et al. reported that the ion-beam deposited amorphous Cu-Mo coating on alumina substrates showed low friction coefficient at 530 and 650 °C [3]. They suggested that the amorphous Cu-Mo coating changed to crystalline oxide $CuMoO_4$ and that the softened oxides worked as high temperature lubricant. Though $Cu_3Mo_2O_9$ has different crystal structure from $CuMoO_4$, it is possible that $Cu_3Mo_2O_9$ which has similar ingredient with $CuMoO_4$ is softened and shows superior lubricity at high temperature.

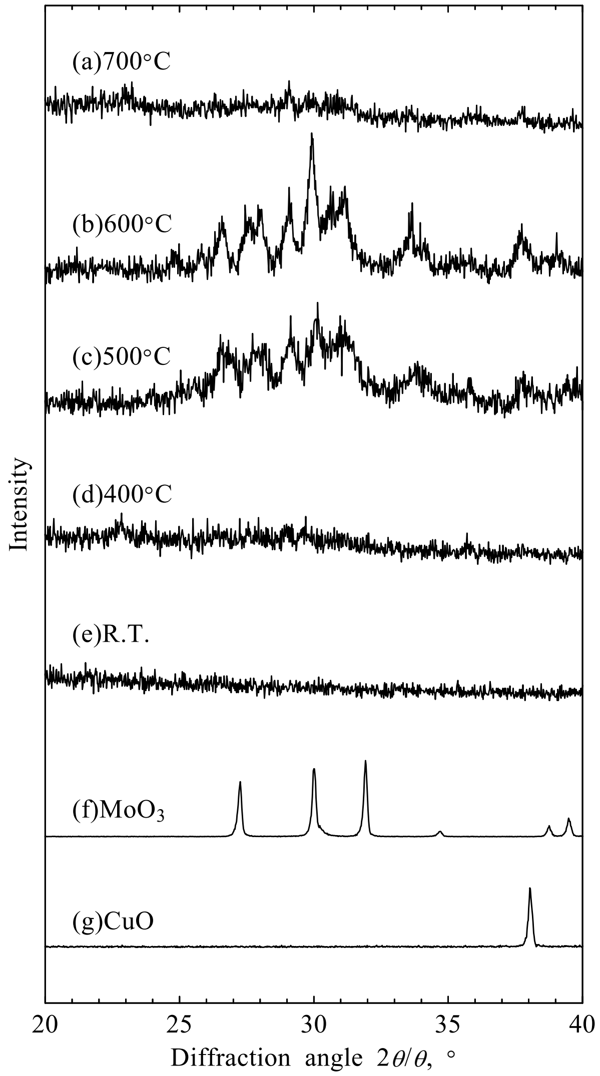

Fig.4 XRD spectra obtained from (a)-(e) the friction track of the aluminum bronze slid against MoO_3 coated stainless steel ring, (f) MoO_3 powder and (g) CuO powder

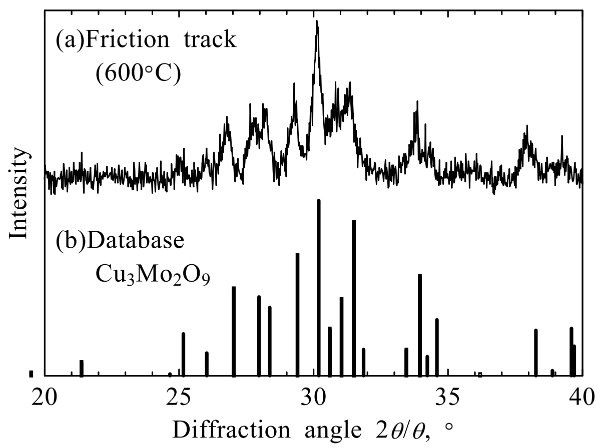

Fig.5 (a) XRD spectra obtained from the friction track of the aluminum bronze slid against MoO_3 coated stainless steel ring at 600 °C, (b) peak intensity of $Cu_3Mo_2O_9$ in the database (diffraction angle is corrected for Co X-ray)

4. Conclusions

MoO_3 powder supplied to the sliding interface between aluminum bronze and stainless steel reduced friction coefficient and wear of both materials at high temperature. Unknown material was genereted on the friction track of aluminum bronze and it was supposed to be $Cu_3Mo_2O_9$ from the results of XRD analysis. It was suggested that $Cu_3Mo_2O_9$ was generated during sliding at high temperature under high pressure by the reaction of MoO_3 powder and copper oxide, and then it worked as high tempereture lubricant.

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