

Effects of MoO₃ Powder on the Wear and Frictional Properties of Aluminum Bronze at High Temperature

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Abstract

The effect of MoO₃ (molybdenum trioxide) powder on the wear and frictional properties of aluminum bronze was studied at the temperature up to 700 °C. MoO₃ 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. Unknown material was generated on the friction track of aluminum bronze slid at high temperature. As the result of X-ray diffraction analysis of friction track, the generated material was supposed to be Cu₃Mo₂O₉. 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

Aluminum bronze is one of the conventional bearing materials which can be applied 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 wear of aluminum bronze especially at high temperature¹⁾. On the other hand, the lubricity of many kinds of metal oxide at high temperature has been studied. It was reported that MoO₃ showed superior lubricity at high temperature of about 700 °C²⁾. It was expected that MoO₃ enhances wear resistance of aluminum bronze at high temperature. In this paper, the effects of MoO₃ powder accumulated on the sliding surface on the friction and wear of aluminum bronze under high temperature conditions are reported.

2. Samples and experiments

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.

Table 1 Compositions of aluminum bronze C6191

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

Generally speaking, oxide powders are difficult to adhere to metal surface. Therefore, in this sample preparation, oxide 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 $1.0 \mu\text{m}$ (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.

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.

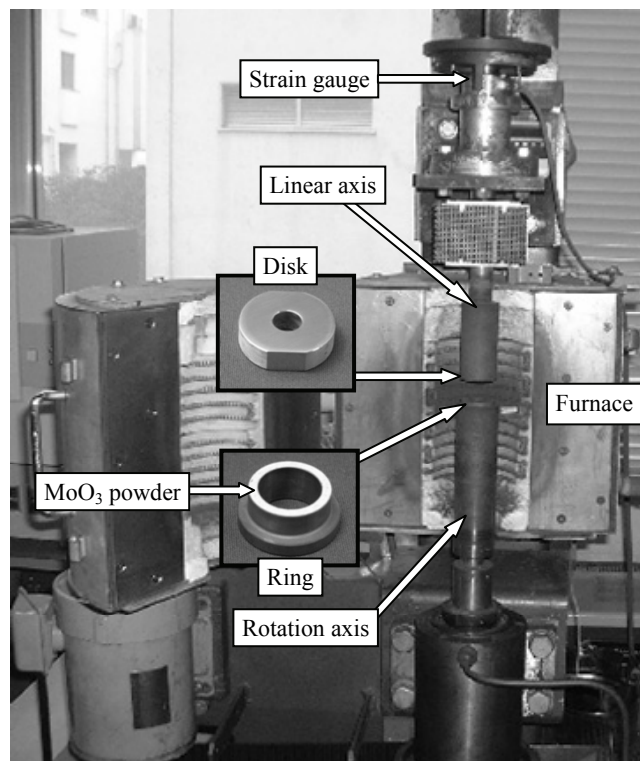


Fig.1 Ring-on-disk tribometer with furnace

3. Results and discussions

3.1 Friction and wear of materials

Figure 2(a), 2(b) and 2(c) show the friction coefficient, the wear amount of aluminum bronze disk specimen and the wear amount of stainless steel ring specimen, respectively. The negative value in Fig.2(c) means that the weight of ring specimen increased after friction test because the material of disk specimen adhered on the ring specimen.

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.

The wear amount of uncoated specimen was smaller than that of MoO₃ 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 MoO₃ 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 that for the temperature less than 600 °C. MoO₃ coating showed remarkable wear reducing effect especially at the temperature from 500 to 700 °C.

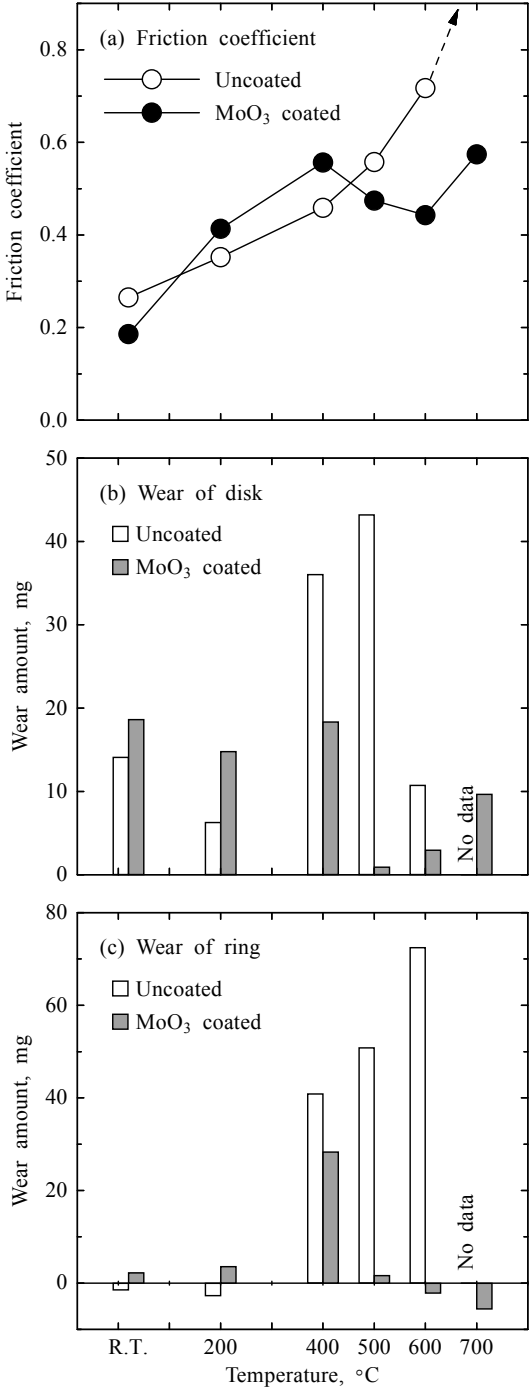


Fig.2 Results of the friction test for the pair of aluminum bronze disk and uncoated / MoO₃ coated stainless steel ring, (a) friction coefficient, (b) wear amount of disk specimen and (c) wear amount of ring specimen

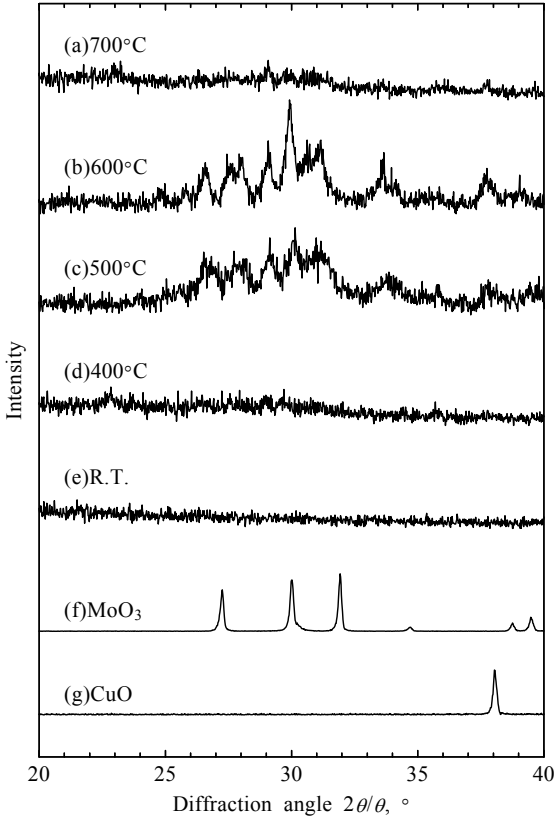


Fig.3 XRD spectra obtained from (a)-(e) the friction track of the aluminum bronze slid against MoO₃ coated stainless steel ring, (f) MoO₃ powder and (g) CuO powder

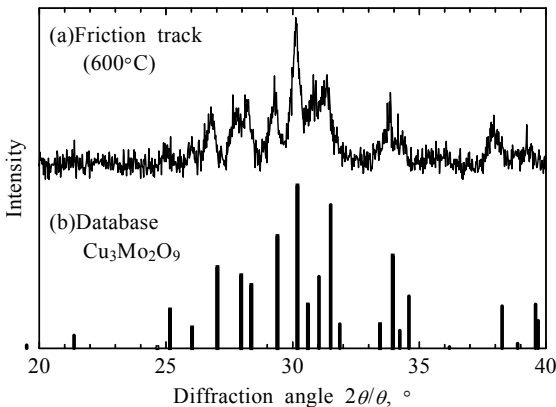


Fig.4 (a) XRD spectra obtained from the friction track of the aluminum bronze slid against MoO₃ coated stainless steel ring at 600 °C, (b) peak intensity of Cu₃Mo₂O₉ in the database (diffraction angle is corrected for Co target X-ray)

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 MoO₃ coated stainless steel ring, are shown in Fig.3. The diffraction peaks obtained from MoO₃ 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 MoO₃ and CuO powder, it can be concluded that the peaks obtained from the friction track on the aluminum bronze are not from MoO₃ 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 MoO₃ coated ring at 600 °C and the diffraction peak intensity of Cu₃Mo₂O₉ in the database (JCPDS 01-070-1495) are shown in Fig.4. Taking into account the difference between the wavelength of X-ray from cobalt target and that from copper target, the diffraction angles for Cu₃Mo₂O₉ in the database was shifted in this figure. It can be suggested that the generated material on the friction track of aluminum bronze is Cu₃Mo₂O₉ because the diffraction peak position and intensity of database 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 MoO₃ didn't work directly as a lubricant at high temperature but it reduced friction and wear by changing into Cu₃Mo₂O₉. Copper contained in the aluminum bronze is easily oxidized especially at the surface by heating in air. Cu₃Mo₂O₉ was generated during sliding at high temperature under high pressure by the reaction of MoO₃ 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 °C³⁾. They suggested that the amorphous Cu-Mo coating changed to crystalline oxide CuMoO₄ and that the softened oxides worked as high temperature lubricant. Though Cu₃Mo₂O₉ has different crystal structure from CuMoO₄, it is possible that Cu₃Mo₂O₉ which has similar ingredient with CuMoO₄ is softened and shows superior lubricity at high temperature.

4. Conclusions

MoO₃ 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 generated on the friction track of aluminum bronze and it was supposed to be Cu₃Mo₂O₉ from the results of XRD analysis. It was suggested that Cu₃Mo₂O₉ was generated during sliding at high temperature under high pressure by the reaction of MoO₃ powder and copper oxide, and then it worked as high temperature lubricant.

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