Combined effects of graphite and sulfide on the tribological properties of bronze under dry conditions

Yoshimasa Hirai*a, Tomohiro Satob, Hatsuhiko Usamic

a Technology Development Division, Kurimoto, Ltd., 2-8-45, Shibatani, Suminoe-ku, Osaka 559-0021, Japan.
b Department of Mechanical Engineering, Kansai University, 3-3-35 Yamate, Suita, Osaka 564-8680, Japan.
c Department of Materials Science and Engineering, Meijo University, 1-501, Shiogamaguchi, Tenpaku-ku, Nagoya 468-8502, Japan.
a*Corresponding author: y_hirai@kurimoto.co.jp

HIGHLIGHTS
➢ Friction surface was penetrated graphite using the shot peening and roller burnishing.
➢ No seizure occurred with sulfide bronze.
➢ Combined effect of graphite and sulfide prevents the transfer of counterpart elements.

ABSTRACT

The present study describes the tribological properties of penetrated-graphite bronze containing micro-sized sulfide under dry conditions. The graphite penetration was carried out by means of roller burnishing. Micro shot peening was also applied in order to fabricate micro dimples in the penetrated graphite. The graphite area fraction was approximately 50%. The tribological properties were evaluated using a face-to-face type testing apparatus under dry conditions. The results showed that the friction coefficient of the sulfide-containing bronze decreased and the seizure resistance properties significantly increased. The friction distance until seizure occurrence was improved to more than 2.5 times. Furthermore, the friction coefficient was low and stable until the end of the experiment. It was inferred that the friction resistance was decreased and stabilized when the transfer layer was without Fe content.

Keywords:
| Dry friction | Bronze | Sulfide | Graphite | Combined effect | Seizure |
1.0 INTRODUCTION

With copper alloys, it is possible to adjust the mechanical properties of alloy composition control, and they are among the materials that have been used for a long time as bearing materials. Among them, tin bronze has excellent initial conformability and seizure resistance, and is manufactured by casting or sintering. Lead bronze has particularly good anti-seize properties, because lead is a solid lubricant. However, in recent years, use of lead has been limited by environmental regulations (Directive 2011/65/EU, 2011). MoS$_2$ or graphite is used as a substitute material for lead. Therefore, in order to improve initial conformability and seizure resistance, a solid lubricant such as MoS$_2$ (Kovalchenko et al., 2012), Pb or graphite is used (Liu et al., 2011; Juszczyk et al., 2014; Ghorbani et al., 2005). In addition to these, the frictional properties of copper alloy dispersed sulfide (Cu-S-Fe system) in bronze (called “sulfide bronze”) have been reported (Hirai et al., 2013). The sulfide bronze was good seizure resistance than bronze for journal friction test under dry conditions (Sato et al., 2015). Furthermore, friction characteristics have been improved by using two kinds of solid lubricant, MoS$_2$ and graphite (Kato et al., 2003). The friction characteristics of sulfide bronze using graphite have been indicated by means of a ring-on-disc experiment under dry conditions (Sato et al., 2012). Penetration of graphite was achieved by means of pressing against a rotating specimen surface using condensed graphite. Graphite was made to penetrate into shot peening dimples and sintering pores. The sliding distance was 300 m, and the friction coefficient of the dimple specimen was lower than that of the sintering pores specimen. In this study, the friction characteristics were, compared to bronze, an improved graphite penetration method for industry, and increased friction distance and load in the experiment. Moreover, the effects of the combination of sulfide and graphite as a solid lubricant were evaluated. On the other hand, one of the methods for blending graphite into copper alloy is a powder metallurgy method. With casting, it is difficult to disperse the graphite. Therefore, a method is applied in which bulk graphite is made to penetrate into casting copper alloy. In this study, the sulfide (Cu-S-Fe system) was crystallized and dispersed in the solidification process. The graphite was dispersed only on the friction surface, without special treatment for the material production process. Penetration of the graphite was carried out using a mechanical method, and was applied to the friction surface only. The self-lubricant penetration was carried out using micro shot peening and roller burnishing (Usami 2015; Usami et al 2014; Ishihara et al., 2015). The micro shot peening was applied in order to fabricate micro dimples to be filled with graphite. The roller burnishing was applied in order to make the graphite penetrate and flatten the bulges of the dimple lips. The tribological properties were evaluated using a face-to-face-type testing apparatus under dry conditions. The specimens were sulfide bronze and bronze without a solid lubricant, prepared by each of casting and sintering. The counter specimen was three chromium alloy steel balls with a flat surface geometry. The
tribological properties of the sulfide-bronze pair with the chromium steel balls were studied with penetrating graphite using a mechanical method, and the friction surfaces were investigated.

2.0 MATERIALS AND METHODS

2.1 Specimen preparation

The specimens were bronze and sulfide bronze prepared by both casting and sintering. Surface modification was based on a plastic deformation process consisting of micro shot peening and roller burnishing after machining. The micro shot peening was used to fabricate micro dimples by using glass beads of average particle size 90 µm. After the shot peening, graphite was supplied to the specimen surface by penetration into the dimples during the roller burnishing. Another effect that the burnishing was used for was to flatten the projections around the dimples, because there were projections at the edges of the dimples after the shot peening. The roller burnishing was carried out in a lathe machine using a carbide alloy roller. The resulting surface morphologies are shown Figure 1. The graphite area ratio of all of the specimens was approximately 50%. The surface roughness of the casting specimen was Ra 0.15 and of the sintering specimen was Ra 0.2, after the roller burnishing.

Figure 1: Optical microscope image of graphite-penetrated disc surfaces
2.1 Experimental Procedure

Tribological properties were evaluated with a 3-balls-on-disc type testing apparatus under dry conditions and in an air atmosphere. A schematic of the testing apparatus is shown in Figure 2. The three balls had a flat surface 3.0 mm in diameter with a roughness of Ra 0.07, which was finished by grinding using No.400 sandpaper. The balls used were a high-carbon chromium material for bearing steel (SUJ2, Ø6.35 mm), and were installed at equal intervals (=120 degrees) around the same circumference on a ball-setting jig in the testing apparatus. The disc specimens had a penetrated-graphite surface of size Ø44 mm, Ø28 mm and 5 mm. The applied load was 10 N and was increased every 1000 m, and the sliding speed was 1.0 m/s. The experiment was interrupted when seizure occurred as a result of a rapid increase in friction coefficient.

![Schematic of testing apparatus](image)

Figure 2: Schematic of testing apparatus

3.0 RESULTS AND DISCUSSION

3.1 Results

The friction experiment results for the casting specimens are shown in Figure 3. Seizure occurred with the bronze specimen immediately after the 2000-m sliding distance, when the load was at the beginning of 30 N. The friction coefficient was 0.1 to 0.15 until seizure. On the other hand, seizure did not occur with the sulfide bronze specimen at the 5000-m sliding distance, when the load was at 50 N. The friction coefficient was less than 0.1, but it increased before the 5000-m sliding distance. The friction experiment results for the sintering specimens are shown in Figure 4. Seizure occurred with the bronze specimen before the 2000-m sliding distance, before the load was 30 N. The friction coefficient was 0.1 to 0.2 until seizure. On the other hand, seizure did not occur with the sulfide bronze specimen at the 5000-m sliding distance, when the load was at 50 N. The friction coefficient was approximately 0.1, and was stable until the end of the experiment.
Figure 3: Friction coefficient as a function of sliding distance, for casting specimens

Figure 4: Friction coefficient as a function of sliding distance, for sintering specimens

Figure 5 shows optical microscope images of the friction surfaces after the experiment. Friction tracks were observed on all disc specimens. With regard to the casting bronze specimen, fresh matrix was exposed on the worn disc surface during the sliding process. Furthermore, the worn ball surface was partially discolored to the disc color. It appears that the bronze component was transferred to the worn ball surface. In the same way, the worn ball surface for the casting sulfide bronze was partially discolored to the disc color. The sintering disc specimens showed gray-colored friction tracks. The surface roughness of the friction tracks was Ra 0.16 for the casting bronze disc, Ra 0.16 for the casting sulfide bronze, Ra 0.4 for the sintering bronze, and Ra 0.4 for the sintering sulfide bronze. The casting specimen roughness was unchanged compared to before the experiment, and the sintering specimens were rougher compared to before the experiment, because the sliding distance was longer than for the casting specimens.
The worn ball surface of the bronze counterpart was slightly discolored, that is, it indicated a slight transfer layer despite the fact that seizure occurred. The worn ball surface of the sulfide bronze counterpart was discolored to a weak sulfide bronze color along the friction tracks. It appears that the graphite and sulfide was squeezed out from the subsurface and spread over the worn surface during the sliding process. As a result, seizure did not occur with the sulfide bronze, because of combined effects of this graphite and sulfide.

Figure 5: Optical microscope images after experiment

Casting bronze: Disc (above) and ball (below)
Casting sulfide bronze: Disc (above) and ball (below)
Sintering bronze: Disc (above) and ball (below)
Sintering sulfide bronze: Disc (above) and ball (below)
Figure 6 shows the X-ray diffraction (XRD) pattern of the sintering sulfide disc surface after the friction experiment. The main phase consists of $\alpha$Cu, graphite, and Cu$_5$FeS$_4$ phases. It can be seen that the phase consists of fresh matrix. The Fe and S elements form Cu$_5$FeS$_4$ with the copper in the specimen in the atomization process for the powder material. It was found that the phase after the experiment had not changed as a result of friction heat or pressure.

![Figure 6: X-ray diffraction pattern of disc friction surface](image)

3.2 Discussion

The penetrated-graphite sulfide bronze demonstrated better seizure resistance than the penetrated-graphite non-sulfide bronze. It was speculated that the transfer state of the specimen had an effect on the seizure resistance. In the previous study (Sato et al., 2012), it was improved seizure resistance when Cu,S, were detected in the contact surface of the sulfide bronze under dry sliding conditions were confirmed. In this study, the effects of transfer state on seizure resistance of the sintering specimen were therefore investigated using an electron probe microanalyzer (EPMA). Figure 7 shows the EPMA analysis results for the disc friction surface after the experiment. For sintering bronze, the results were as follows: C, Fe, and O were detected in the disc friction tracks. C, Cu, and O were detected on the ball surface. Cu was detected slightly on the ball surface, while Fe was detected on the disc surface. The results indicated that there was a transfer of a ball element to the disc, and that the disc surface was oxidized. The contact surface of graphite-composite bronze and steel counterpart was oxidized under dry sliding conditions (Cui et al., 2012). For sintering sulfide bronze, the results were as follows: C, Fe, and S were detected in the disc friction tracks. C, O, Cu, and S were detected on the ball surface. The disc friction tracks were oxidized and Cu was detected slightly on the ball surface. Although the ball and disc did not transfer to each other, the disc friction tracks were oxidized and Cu was detected slightly on the ball surface. Even though the sliding distance was longer than for the bronze, no Fe element was detected. The results
indicated that sulfide had an effect of preventing transfer of the Fe element. Seizure occurred with the bronze specimen even though it was penetrated with graphite. The results indicated that the combined effect of graphite and sulfide was improved seizure resistance as a result of the prevention of transfer.

CONCLUSION

The tribological properties of a sulfide-bronze pair with chromium-steel balls were studied with penetrating graphite using a mechanical method, and the friction surfaces were investigated. Seizure occurred with the non-sulfide bronze despite the fact that the friction surface was penetrated with graphite, because the Fe element of the ball
was transferred to the disc. The sulfide bronze was given improved seizure resistance by penetrating the friction surface with graphite by means of micro shot peening and roller burnishing. It was possible to obtain a combined effect of graphite and sulfide in terms of preventing the transfer of counterpart elements.

REFERENCES


