Tribology International 59 (2013) 17–22

Contents lists available at SciVerse ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Friction and wear properties of lead-free aluminum alloy bearing material with molybdenum disulfide layer by a reciprocating test

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ARTICLE INFO

Article history:
Received 1 August 2011
Received in revised form
18 July 2012
Accepted 20 July 2012
Available online 31 July 2012

Keywords:
Plain bearing materials
Solid lubricant
Friction coefficient
Wear

ABSTRACT

Friction and wear behavior of Al–Sn–Si alloy with MoS_2 layer under lubricated condition was investigated by a reciprocating friction tester. It became clear that the Al–Sn–Si alloy with MoS_2 layer showed about 70% lower friction and about 1/10 lower wear depth compared to the Al–Sn–Si alloy. The worn surfaces of the Al–Sn–Si alloy with MoS_2 layer were observed and analyzed by a SEM, a TEM and an EDX. It indicated that the sliding surface of the counterface had larger area of Mo than the area of Al which was transferred from the Al–Sn–Si alloy with MoS_2 layer by sliding, resulting in low friction and high wear resistance.

1. Introduction

In recent years, automotive engines are required to have environmental concerns, better fuel economy, lower friction, reduction of mechanical loss, and to be more lightweight and compact. The combination of these factors result in a demand for engine bearing systems to operate under higher specific load; to be operated with lower friction; and to be composed of lead-free material. Lead-free aluminum bearings have been widely available. Since these engine operating conditions produce several different lubrication regimes, different methods of reducing friction for bearings are required in different regimes [1,2], such as mixed or even boundary lubrication regimes for an extended part of their normal duty cycle. They are the engine designs with small bearings and low viscosity lubricants. This occasionally leads to increase of friction.

Based upon these requirements, a lead-free aluminum alloy bearing with low friction layer of molybdenum disulfide (MoS_2) of sub-micrometer thicknesses on the plain bearing inner surface was developed focusing on the reduction of friction [3,4]. The MoS_2 layer was adhered by a shot peening process [5]. Kagohara et al. showed that friction coefficient of the lead-free aluminum alloy bearing with MoS_2 layer was lower than that of a lead-free aluminum alloy bearing using a bearing test machine. In addition, the lead-free aluminum alloy bearing with MoS_2 layer did not cause adhesion of Al to a counterface [4].

MoS_2 coatings have been used in the industry as a soft lubricant since 1940s. For the research, the friction and wear behavior of MoS_2 coated material has been reported [6–10]. However, there was little research of the friction and wear behavior of MoS_2 layer adhered by a shot peening process [11]. Therefore, the mechanism of the low friction behavior is further required to clarify in detail, together with the wear behavior of MoS_2 layer adhered by a shot peening process on the aluminum alloy bearing material.

In this research, fundamental friction and wear tests of the lead-free aluminum alloy bearing material with MoS_2 layer under lubricated condition was conducted using a reciprocating friction tester, and then their mechanisms were discussed by the observation and analysis of the worn surfaces.

2. Experiment

2.1. Test apparatus

Fig. 1 shows a schematic view of the reciprocating friction tester. The test material was rubbed against a bearing steel ball with a diameter of 6 mm in oil. The frictional force was measured by the load cell attached to the ball holder. As the wear behavior of MoS_2 coated materials are affected by environment [7,8], the apparatus was set in a room with controlled temperature and humidity with an air conditioner, i.e., temperature was 20–25 °C, relative humidity was 40–55%. The friction test was carried out under a 2 N load at a sliding speed of 100 mm/min. The stroke of sliding was 10 mm. In this case, the Hertzian maximum contact pressure was about 560 MPa, so it might become high contact

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http://dx.doi.org/10.1016/j.triboint.2012.07.017

pressure rather than the contact pressure in the plain bearing of actual working. Nevertheless, this contact load was chosen in order to do the accelerated wear test of the specimens. Before the friction test, the additive-free paraffinic base oil of 10 µL was dropped onto the sliding surface. The oil viscosity was 77 mm^2/s at 20 °C.

2.2. Test materials

The test materials were the currently used lead-free Al–Sn–Si alloy bearing material (designated as Al–Sn–Si alloy) and the newly developed lead-free Al–Sn–Si alloy bearing with low friction MoS_2 layer (designated as Al–Sn–Si alloy with MoS_2 layer, see Table 1). The MoS_2 powder was adhered by a shot peening process to the surface of the Al–Sn–Si alloy without using a resin binder [5]. The specimen was cut from an actual half plain bearing, whose size was 17 mm in width, 18 mm in length and 1.5 mm in thickness (Fig. 1). The surface roughness (R_a) of the specimen was about 0.65 µm.

The counterface material was a steel bearing ball (composition in mass%: 0.95–1.10C, 1.30–1.60Cr, 0.15–0.35Si, under 0.50Mn, under 0.025P, under 0.025S, the rest Fe) designated as SUJ 2 in the Japanese Industrial Standards.

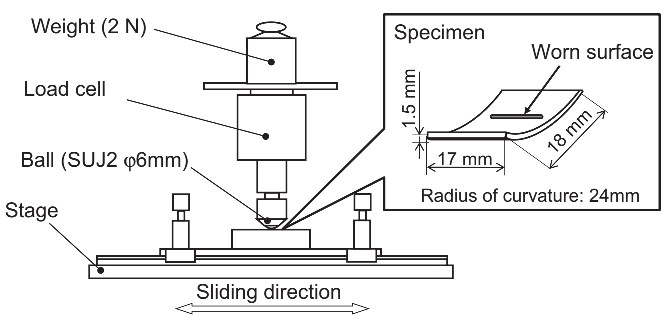

Fig. 1. Schematic view of the reciprocating friction tester.

Table 1
Construction of bearing material.

Currently used material (Al–Sn–Si alloy)	Lead-free Al–Sn–Si alloy bearing material currently used in engine
Newly developed material (Al–Sn–Si alloy with MoS_2 layer)	Bearing material with directly adhered MoS_2 on the surface currently used bearing material

3. Results and discussion

3.1. Morphology of Al–Sn–Si alloy with MoS_2 layer

Fig. 2 shows the Scanning Electron Microscope (SEM) images and the Energy Dispersive X-ray spectroscopy (EDX) mapping images of the specimen. There are remaining tool marks that exist with a depth of about 1 µm on the surfaces. EDX images show the existence of the MoS_2 present on the surface of Al–Sn–Si alloy with MoS_2 layer. The cross-sectional structure of the fabricated layer was observed using a Scanning Transmission Electron Microscope (STEM) system to verify the formation of the layers. The TEM cross-section was prepared using a FIB processing system. STEM-EDX mapping of the cross-section microstructure of Al–Sn–Si alloy with MoS_2 layer is shown in Fig. 3. The MoS_2 layer was formed on the surface of aluminum alloy, but the thickness of the MoS_2 layer was not uniform. Furthermore, in order to observe the morphology of the MoS_2 layer, the cross-section microstructure was observed using TEM with high magnification (Fig. 4). Thickness of the MoS_2 layer was about 4–70 nm on the aluminum alloy surface. The lattice fringe parallel to the interface was observed in the inner part of the MoS_2 layer. The interval of the lattice fringe was about 0.6 nm near spacing of the (002) MoS_2. The aluminum oxide layer, whose thickness was about 5–8 nm, was formed in the interface of the MoS_2 layer and the aluminum alloy.

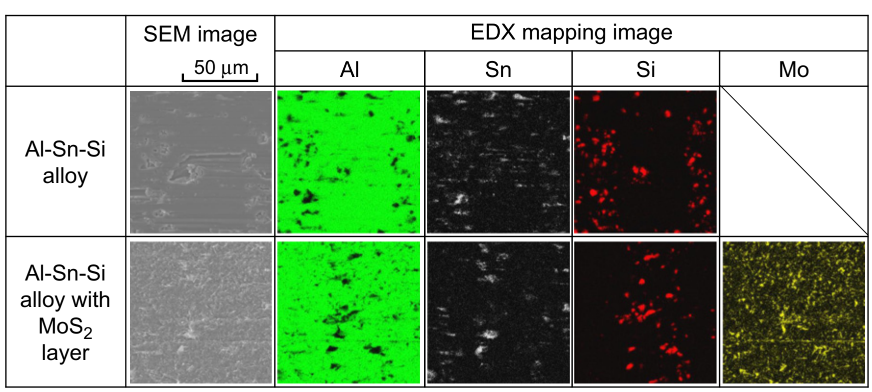

Fig. 2. SEM images and EDX mapping images of the original surface of the specimens.

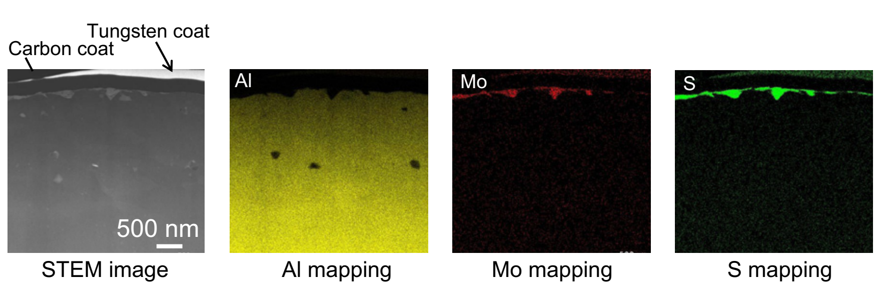

Fig. 3. STEM-EDX mapping images of cross-section microstructure of the Al–Sn–Si alloy with MoS_2 layer.