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Relationship of wear properties to basal-plane texture of worn surface of Mg alloys

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ABSTRACT

The wear properties of pure-Mg, AZ31 extruded alloy, AZ91 cast alloy, and $Mg_{90.5}Cu_{3.25}Y_{6.25}$ (at.%) cast alloy consisting of Mg and long-period-ordered (LPO) phases were investigated by pin-on-disk-type wear tests under dry sliding. The wear loss of the $Mg_{90.5}Cu_{3.25}Y_{6.25}$ cast alloy at high-applied loads over 147 N was less than those of AZ Mg alloys, and about two-thirds of the AZ31 extruded alloy, which indicated that the $Mg_{90.5}Cu_{3.25}Y_{6.25}$ cast alloy has superior wear-resistance. The basal planes (0 0 0 2) and (1 0 $\bar{1}$ 1) were apparent in the X-ray diffraction patterns of worn surfaces of pure-Mg and Mg alloys. This XRD result indicated that basal planes in both the Mg and LPO phases were aligned to worn surfaces for the pure-Mg and Mg alloys, and this result was also supported by EBSD analysis. Because slip deformation tends to easily occur on the Mg basal plane at a low critical resolved shear stress (CRSS), formation of the basal-plane alignment on the wear surface negatively affects the wear-resistance properties. After the wear test of the $Mg_{90.5}Cu_{3.25}Y_{6.25}$ cast alloy, a kink deformation in the LPO phase was frequently observed in the worn edge section. The kink deformation in the LPO phase contributes to improve wear-resistance properties by suppression of the basal-plane alignment.

1. Introduction

In the automotive parts industry, the use of lightweight Al alloys as alternative materials to steel is steadily increasing, and Mg alloys, which are even lighter than Al alloys, offer significant promise in this area [1–3]. The use of lighter pistons, valves, or other sliding engine parts on which inertial force act is effective in improving fuel consumption, in part because lightening these moving parts reduces friction. In fact, sliding parts such as connecting rods or valve lifters made of aluminum have already contributed to improved fuel consumption. Therefore, it is desirable to develop Mg-alloy parts with good wear-resistance properties. Several studies have reported the wear properties of Mg alloys in terms of load dependence, variations in sliding speed, and microstructure examinations of worn surfaces [4–10]. For example, Matsuoka et al. investigated the effect of grain size on the wear-resistance properties of the AZ60 alloy and found that wear-resistance improved for increased grain sizes [11]. For the AZ91 cast alloy, it was reported that the wear rate tends to rapidly increase at a given point during the wear process. This phenomenon is believed to occur because the temperature at the worn or abraded surface of AZ91cast alloy rises during wear, and when it reaches about 347 K the wear mode changes from mild wear (oxidation wear and delamination wear) to severe wear accompanied by plastic deformation [12]. Moreover, several studies not only classify the above wear regimes, but they also clarify the wear mechanisms through observations of the worn-surface microstructure that develops because of severe wear and by making crystallographic investigations focused on the basal-plane texture. Farhat performed pin-on-disk-type friction tests on pure Al and Ti metals (disk specimen) against AISI 304 stainless steel (pin specimen) and reported (1 1 1) alignment for pure-Al and (0 0 0 1) alignment for pure-Ti. Thus, the slip plane is aligned parallel to the worn surface during the wear test, which indicates that the wear progresses easily within the sample material [13]. This results from a high interest in elucidating the essential wear-resistance properties.

Although such studies exist involving the wear-resistance properties of Mg alloy, there is still little research dealing with its wear properties, which contrasts starkly with the numerous studies available on the use of Al alloys or steels for sliding automobile parts. Moreover, although there has been much discussion on wear regimes, the issue of how deformation microstructure relates to grains is still not sufficiently understood in crystallographic terms. Thus, inducing excellent wear-resistance properties in Mg alloys continues to remain unclear.

This paper investigated the wear properties of pure-Mg, AZ31 extruded alloy, AZ91 cast alloy, and $Mg_{90.5}Cu_{3.25}Y_{6.25}$ (at.%) cast alloy composed of Mg and LPO phases. Furthermore, this paper discussed X-ray diffraction investigations of the texture that devel-

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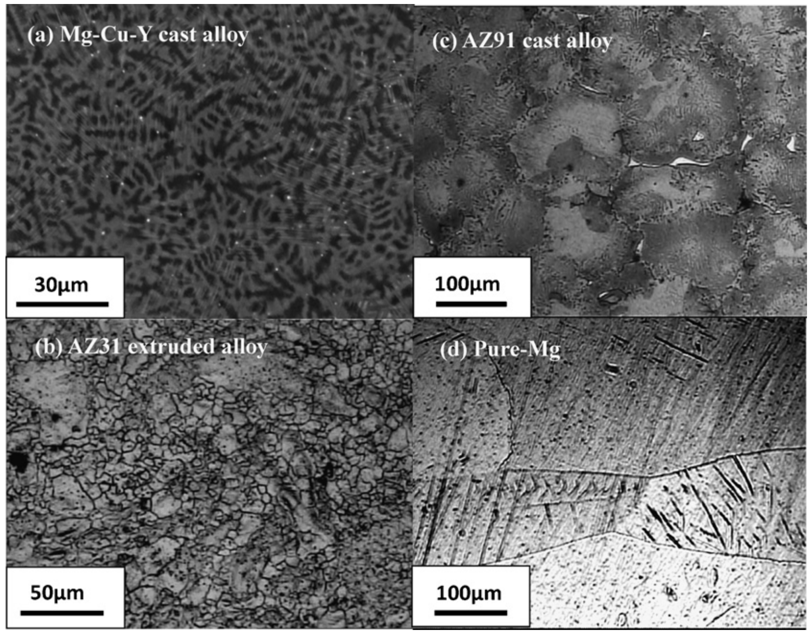

Fig. 1. (a) SEM (BEI) image of Mg–Cu–Y cast alloy. OM images of (b) cross section of AZ31 extruded alloy, (c) AZ91 cast alloy, and (d) pure-Mg.

oped on the wear surface upon wear testing and also suggested how wear properties relate to texture.

2. Experimental procedure

The $Mg_{90.5}Cu_{3.25}Y_{6.25}$ (at.%) cast alloy (hereinafter designated as Mg–Cu–Y cast alloy) was prepared by melting Mg, Cu, and Y with a purity of 99.9% in a CO_2 atmosphere using an electric-furnace. After melting the alloy in an iron-crucible, it was cast into an iron mold 8 mm × 15 mm × 100 mm in size. The Mg–Cu–Y alloy was re-melted in the furnace at 973 K, and then rapidly solidified in a Cu-mold ϕ 8 mm × 100 mm^3 in size to avoid segregation of the solute elements. Wear properties were investigated using a pin-on-disk-type wear test machine (Takachiho TRI-100W-s) under dry conditions. The Mg–Cu–Y cast alloy, which is used as the pin specimen for the wear tests, was machined by lathe to ϕ 8 mm × 30 mm^3. Furthermore, 5 mm length from the end of the pin specimen was machined to ϕ 3 mm to serve as the contact surface for the wear test. To obtain the parallel condition between pin surface and pin end, pin specimen was fixed by a jig and pin-surface was polished by using a parallel grinder. The pure-Mg, the AZ31 extruded alloy, and the AZ91 cast alloy were prepared in the same manner. Compositions of AZ31 and AZ91 alloys are Mg–3Al–1Zn (mass %) and Mg–9Al–1Zn (mass %) respectively. The disc specimen was made of high chrome-bearing steel (980HV0.5) with a surface roughness of approximately 0.1 μm. Dry sliding tests were performed under applied loads from 49 to 294 N. The sliding speed and sliding distance were 0.21 m/s and 188 m, respectively. The microstructure observation was performed by scanning electron microscope (SEM, JSM-5300LV) and an optical microscope (OM, Olympus PMG-2). The worn surface was investigated by X-ray diffraction (XRD, JDX-3530). The grain orientation was studied using electron backscattering diffraction (EBSD) equipped with a SEM (JEM-7001F).

3. Results and discussions

Fig. 1(a) shows a SEM backscatter electron image (BEI) of the Mg–Cu–Y cast alloy. The BEI of the Mg–Cu–Y cast alloy shows two phases: an Mg phase observed as dark regions and an LPO phase observed as gray regions. The Mg phase of about 5–15 μm in size is observed between the grain boundary phases (LPO phase), which is about 2–15 μm thick. From the BEI, volume fraction of the LPO phase is estimated to be about 60%. The structure of the LPO phase formed in the Mg–Cu–Y cast alloy is confirmed from TEM observation to be an 18R-type structure. The LPO structure is not limited to this type; various LPO structures such as 10H-, 14H-, or 24R-type are observed in Mg–M–Y (M = Zn, Cu, or Ni) alloys [14–16]. Moreover, to develop high-strength Mg alloys from room temperature (R.T.) to high temperatures, the LPO phase is considered effective as a strengthening phase because it forms as a stable phase in Mg–M–Y alloys, which is indicative of high-strength within high temperature ranges [17–19]. Fig. 1(b) shows an optical microscope (OM) image of a cross-section of the AZ31 extruded alloy. An Mg phase with re-crystallized grains of about 5–20 μm in size results from the extrusion processing, and an Mg phase with non-re-crystallized grains of about 50–70 μm in size are apparent in the image. Fig. 1(c) shows an OM image of the AZ91 cast alloy and reveals that Mg grains of about 100–200 μm in size with $Mg_{17}Al_{12}$ phases at the grain boundary. Fig. 1(d) shows an OM image of the pure-Mg. The grain sizes of 300 μm to 1 mm are huge compared to the other Mg alloys. The Vickers hardness values for the materials in Fig. 1(a)–(d) are 98HV0.5, 55HV0.5, 69HV0.5, and 28HV0.5, respectively.

Fig. 2 shows the wear loss of the pure-Mg and Mg alloys plotted as a function of applied load. Wear progresses deformation of contact surface and grinding of the pin specimen (with generation of wear debris) as shown in Fig. 5, and consequently estimation of relative wear rate was difficult because contact surface area have been changed by deformation. Therefore, description of "wear loss" in this paper means differences of pin height along longitudinal axis before and after wear test. Relationship between wear loss and wear distance obtained by wear test of Mg alloys shows comparatively linear in these Mg alloys. So, it is considered that grinding of pin specimen affects wear loss compared with deformation of contact surface, and hence difference of pin height between before and after wear test indicates wear resistance.

It is found that the wear loss increases in all specimens as the applied load increases. Among these specimens, pure-Mg exhibits wear loss for applied loads of 49 N and 98 N, which is larger than those of the Mg alloys. Moreover, the wear loss exhibits a sud-