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Dry sliding wear behavior of as-cast ZE41A magnesium alloy

S. Anbu selvan *, S. Ramanathan

Department of Manufacturing Engineering, Annamalai University, Annamalainagar, Chidambaram 608002, Tamil Nadu, India

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ABSTRACT

In present work, an attempt has been made to investigate the wear behavior of as-cast ZE41A magnesium alloy during dry sliding. The experiments were performed using pin-on-disc type wear apparatus against a EN32 steel counterface in a load range of 30–150 N, sliding velocity range of 0.5–2.5 m/s and at a constant sliding distance of 1500 m. Microstructural investigations on the worn surfaces were undertaken using a scanning electron microscope (SEM) equipped with an energy dispersive spectrometer (EDS) for determination of type of damage and nature of distortion at the surface. Wear mechanisms such as abrasion, oxidation, delamination, plastic deformation and melting were identified. Wear maps were drawn for the test result data. Mild wear, severe wear and ultra severe wear regimes were identified using wear transition map through microstructural observations.

1. Introduction

Magnesium alloys, the lightest among structural materials, have become alternative candidate for applications in automotive, aerospace, audio and electronic industries. These alloys have earned reputation owing to their high specific strength, which leads to the weight reduction resulting in a considerable economic advantage. The density of magnesium is about 35% less than that of aluminium and is about 77% less than that of steel [1]. Magnesium alloys are attractive materials for use in aircraft structures due to their low densities and good casting properties [2]. Despite the growing interest in magnesium alloys, very little data exist on their friction and wear behavior. While magnesium alloys would normally not be candidates for bearings, sliding seals or gears, there are situations in which their surfaces could come into contact with other materials so as to make their friction and wear behavior of interest. In certain applications, light weight alloys and composites are subjected to sliding motion including automotive brakes, engine components (piston and cylinder bores). Sliding wear is also an important consideration in material processing by rolling, forging, etc. [3]. Tribological properties of a sliding system for the materials depend on the properties of the specimen materials [4,5] and counterface materials [6,7], their interaction with the environment [8,9] as well as the experimental conditions, including the applied load and sliding velocity [10].

Published work on the wear behavior of magnesium alloy is quite limited. An et al. [3] investigated the dry sliding wear behavior of as-cast magnesium alloys $Mg_{97}Zn_1Y_2$ and AZ91 using pin-on-disc configuration. Tests were done at a normal load range of 20–380 N and 20–240 N respectively and at a sliding velocity of 0.785 m/s. They revealed that $Mg_{97}Zn_1Y_2$ exhibited good wear resistance compared with AZ91 for applied loads in excess of 80 N. Zhang et al. [11] investigated the dry sliding wear of as-cast Mg–Zn–Y magnesium alloy against Gcr15 steel (HRC65 ± 5) using block-on-wheel system. Wear tests were conducted with in a load range of 10–70 N, sliding time range of 10–40 min and at a sliding velocity of 0.42 m/s. They revealed that Mg–25Zn–2Y quasicrystal material exhibited better wear resistance at all applied loads. El-Morsy [12] investigated the dry sliding wear behavior of hot deformed magnesium AZ61 alloy against stainless steel counterface with 63 RC surface hardness using pin-on-ring system. The tests were carried out in a sliding velocity range of 0.2–1.8 m/s, load range of 50–350 N and at a sliding distance was about 1500 m. The results revealed that the sliding wear behavior can be classified into two main wear regimes, mild wear regime and severe wear regime. In mild wear region, the wear rates increased linearly with the sliding velocity and the applied load (steady state). In the severe wear region, the wear has been found to increase almost proportionally with applied load and sliding velocity.

Blau and Walukas [13] investigated the sliding friction and wear of magnesium alloy AZ91D produced by die-cast (DC) and Thixomolded (ThM) in both unidirectional and reciprocating sliding motion, using stainless steel type 440C as a counterface. Test results indicated that the average wear rate of the ThM alloys in reciprocating sliding was approximately 25% lower than that for DC alloys. Hiratsuka et al. [8] investigated dry sliding wear of pure magnesium against an alumina counterface using a pin-on-disc apparatus. Tests were done at a normal load of 9.8 N, a sliding velocity of 1.6 m/s and at a total sliding distance of 25,000 m. They observed two different wear mechanisms depending on the testing environment. Magnesium exhibited on oxidation wear mechanism

* Corresponding author. Tel.: +91 9865387907; fax: +91 4144 239734.
E-mail address: anbushankari@yahoo.co.in (S. Anbu selvan).

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when tested in air. When the wear tests under the same load and velocity conditions were repeated in vacuum (2.5×10^{-4} Pa), magnesium showed metallic wear. Chen and Alpas [14] also reported the dry sliding wear of AZ91 magnesium alloy against a steel counterface using a pin-on-disc apparatus. Tests were done with in a load of 1–350 N and a sliding velocity range of 0.1–2.0 m/s. They revealed that a transition from mild to severe wear occurred was controlled by the contact surface temperature of the alloy and that the on set of the severe was coincided with a surface temperature of 74 °C. They also established a sliding wear map for AZ91, in which the mild wear regime consisted of two sub-wear regimes, namely an oxidational wear regime and a delamination wear regime; the severe wear regime comprised a severe plastic deformation wear regime and a melt wear regime. Zhang and Alpas [15] have shown that mild to severe wear transition that occurs at a certain combination of load, velocity and sliding distance and controlled by a surface temperature criterion which coincided with the threshold temperature at which thermally activated processes, such as dynamic recrystallization initiated.

In view of its potential applications in helicopter rotor gear box and engine components, it is essential to understand the tribological behavior of the alloy. In the present work, dry sliding wear behavior of as-cast ZE41A magnesium alloy has been investigated using a pin-on-disc type wear apparatus against EN32 steel counterface. The effect of the sliding wear conditions, including the applied load and the sliding velocity on the wear transitions was examined. A wear mapping approach has been under taken to represent the wear regimes and the main mechanism of wear in each regime.

2. Experimental procedure

2.1. Testing materials

The material studied was as-cast ZE41A magnesium alloy. The chemical composition (wt.%) of the alloy used in this investigation was Zn, 3.85; Ce, 1.27; Zr, 0.53; Cu, 0.002; Al, 0.006; Mn, 0.008; Fe, 0.004; Si, 0.003; Ni, 0.002 and balance Mg. The initial microstructure of as-cast ZE41A magnesium alloy is shown in Fig. 1. The brinell hardness of the alloy was 62 (500 kg load) and its density was 1.84 g/cm^3.

2.2. Wear tests

The wear tests were carried out under dry sliding condition in accordance with the ASTM G-99 standard using a pin-on-disc wear testing machine. In the present study, pins of Mg alloys under investigation were machined to 6 mm in diameter and 30 mm in length. The surface preparation procedure of the wear test samples consisted of grinding surfaces manually by 240, 320, 400 and 600 grit sic papers, respectively and then polished them with 1.0 and 0.05 μm alumina power slurry using a low speed polishing machine. The polished surfaces were cleaned ultrasonically in a methanol solution. The counterface was EN32 steel disc (HRC 65) of 160 mm diameter and 8 mm width having surface roughness of 0.02 μm on which the test specimen slide. The steel disc was cleaned in a methanol solution before each wear test.

The tests were carried out in a sliding velocity range of 0.5–2.5 m/s and a load range of 30–150 N with a constant sliding distance of 1500 m. The mass losses were calculated from the differences in weight of specimens measured before and after the sliding test (after removing any loose debris) using a precision balance (0.001 g). Volumetric wear loss was estimated by dividing the mass loss by the density of the alloy (1.84 g/cm^3). Volumetric wear rate was calculated by dividing the volumetric wear loss by sliding distance. Each test was carried out twice in order to check the reproducibility and average of two tests was taken to determine the wear rate. The deviation between two tests was with in 2%. The worn surfaces were examined using scanning electron microscope (SEM) (Model JSM 5610 LV) equipped with energy-dispersive spectrum (EDS). Since the hardness of the counter face was far higher than that of the specimens and its wear volume was very small, the wear properties of the steel disc are not studied in the present paper.

3. Results and discussion

3.1. Wear behavior

The volumetric wear rates for as-cast ZE41A magnesium alloy are plotted against sliding velocity at a constant applied load of 30, 60, 90, 120, 150 N is shown in Fig. 2. At all applied load, the wear rates increased with increasing sliding velocity. This observation is consistent with the earlier investigation [2]. If sliding velocity increases, the contact temperature also increases due to higher frictional heat and will cause increase in wear rate. The wear rates increased linearly with the sliding velocity up to 1.0 m/s. The linear relationship indicates that steady state has been achieved. Further increases in the sliding velocity more than 1.0 m/s, large changes in the slope of the wear rate occurred for higher applied loads (120, 150 N). This indicates that transition from mild to severe wear. The effect of applied load on volumetric wear rate at constant

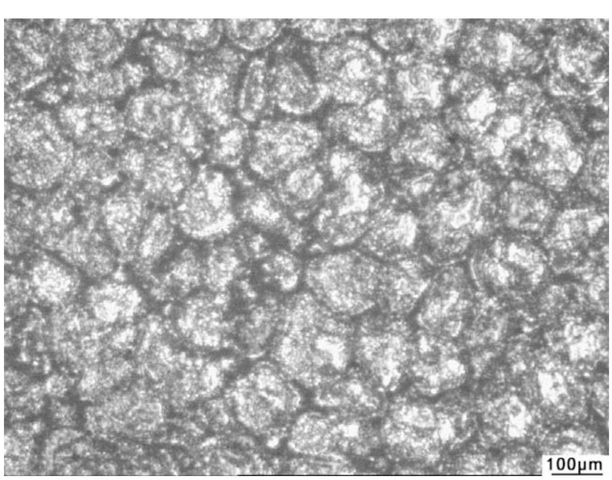

Fig. 1. Optical micrograph of ZE41A magnesium alloy.

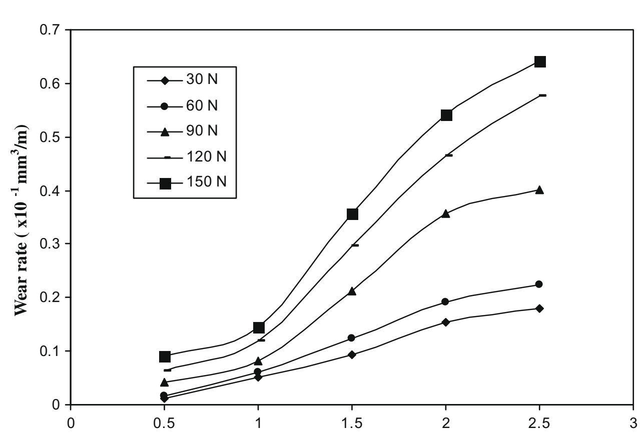

Fig. 2. Effect of sliding velocity on the wear rate at different applied loads.