Unidirectional dry sliding wear analysis of ZE41 magnesium alloy

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Abstract. Magnesium alloys have many characteristics like good castability, high strength to-weight ratio and good amenability. The ZE41 magnesium alloy consists of zirconium (Zr), zinc (Zn) and rare earth elements. Magnesium alloys have many application in aerospace, automotive industries and biomedical implants. Microstructure is shown for ZE41 magnesium alloy Wear rates are measured for ZE41 magnesium alloy using pin-on-disk experiment setup. Rate of wear and coefficient of friction is measured for 10N-20N range at sliding velocity of 0.5 m/s with constant sliding distance of 300 meters. It is observed that load is not affecting coefficient of friction significantly but there is decrement in the value of CoF when load is increased from 10N to 15N. Wear behaviour in initial condition is different but it is converging to general which means more the load more will be the wear. Wear mechanism is abrasion for low loads then slightly changes to delamination.

1. Introduction

Magnesium alloys have many applications in industries where reduction of weight is the main concern such as automobile industries, aerospace industries and bio medical implants. Magnesium based alloys are used as degradable biomaterial implants in humans for temporary implants applications [1]. Magnesium alloys are suitable to these light weight applications due to its high strength-to-weight ratio. These alloys also have high corrosion resistance, low density, dimensional stability and castability. Casted product of ZE41 can be altered in grain size with controlled cooling method [2]. Magnesium ZE41 alloy is commonly used for gravity casting for limited creep resistance corrosion properties due to the rare earth elements in it. Composition of ZE41 magnesium alloy is mostly consist of Magnesium (Mg) while other parts are Zinc (Zn) as 3.12%, Zirconium (Zr) as 0.54%. Rare earth elements as Gadolinium (Gd), Neodymium (Nd) etc. are 0.75-1.75% (wt) [3].The rare earth elements helps in alloy melting, refining in microstructure and increase anti-oxidizing properties whereas Zinc(Zn) improves ductility and also strength at high temperature [4]. The tribological tests are carried out to understand the insight of wear behaviour of ZE41 magnesium alloy for constant sliding velocity and different load conditions. It should be noted that improving the surface properties are found to be effective way to wear resistance of the engineering materials particularly surface hardness. In this regard, several surface modification techniques were employed to improve the tribological performance of non-ferrous and ferrous alloys [5-12]. As in most of the application of magnesium alloys like in aircraft and automobile industries analysis of sliding wear behaviour is very important because of load and constant contact between two components. In the present work, effect of normal load on the friction curves and dynamic wear loss under unidirectional sliding wear mode is investigated.
2. Experimental methods

Wear experiments are performed on pin-on-disk tribology tester with ZE41 magnesium alloy as pin in 3mm X 3mm X 6mm size. The counter-body was EN-31 hardened to 58-62 HRC steel disk with 165mm diameter. For experiments different load condition of 10N, 15N and 20N. All the samples are run on test for 600 Sec with constant sliding velocity of 0.5m/s which results in sliding distance of 300 meters. Design of experiment See Table (1). All specimens and tribometer disk are cleaned with acetone for elimination of any undesired particles or debris.

| Sample No. | Load (N) | Time (sec) | Sliding Velocity (m/s) |
|------------|----------|------------|------------------------|
| Sample No. 1 | 10       | 600        | 0.5                    |
| Sample No. 2 | 15       | 600        | 0.5                    |
| Sample No. 3 | 20       | 600        | 0.5                    |

3. Results and Discussion

3.1 Microstructural Analysis

For microscopic analysis sample surface is grounded with 100 grit to 2000 grit emery paper. After that polished with diamond paste. To develop microstructure picric acid, acetic acid, ethanol, distilled water is used as an etchant for ZE41 Magnesium alloy. Observations are carried under optical microscope at optical magnification. Fig. 1 shows the microstructure was almost having an equiaxed grains with $\alpha$-Mg with eutectic precipitates boundaries of grains. Similar microstructure was observed in study [13].

![Microstructure of ZE41 magnesium alloy](image)

(a) At 139x total magnification  (b) At 693x total magnification

3.2 Hardness Analysis

Hardness measurement was carried out using micro hardness tester for 500g load and dwell time of 10 seconds using diamond indenter. A total of 5 hardness measurements are performed at different locations on the sample. The averaged value of hardness for ZE41 magnesium alloy is $68.788 \pm 6.032$ HV$\text{a}_0.5$. Rare earth elements such as Neodymium(Nd) has highest solid solubility in magnesium and helps in the improvement of strength with increase in (Nd) as it contributes to both solid solution hardening capabilities as well as for precipitation hardening whereas Gadolinium(Gd) helps in elongation to fracture compared to other metallic alloys [14].

![Hardness measurement](image)
3.3. Coefficient of Friction Analysis

Coefficient of friction is calculated for each data point of friction force value using formula (CoF = Friction Force/Load Applied) and plotted against time for each load condition as mentioned in Table 1. All the plots are shown in the Fig. 2.

The effect of normal load on coefficient of friction shown figure 2d. It shows similar values of coefficient of friction for all load conditions. In a study on magnesium alloy AZ71E investigated by Huang Weijiu [15] shows that the coefficient of friction decreases as the load is increased. This same is observed in the present study for ZE41 magnesium alloy in which coefficient of friction is decreased on the increment of load from 10N to 15N.

![Graphs of Coefficient of Friction vs Time for various load conditions](image)

(a) Graph of 10N Load for CoF vs Time  
(b) Graph of 15N Load for CoF vs Time  
(c) Graph of 20N Load for CoF vs Time  
(d) Combined graph of Load for CoF vs Time

Figure 2: Graphs of Coefficient of Friction vs Time for various load conditions

| Sample No.  | Load (N) | Time (sec) | Sliding Velocity (m/s) | CoF (Mean) |
|-------------|----------|------------|------------------------|------------|
| Sample No. 1| 10       | 600        | 0.5                    | 0.345      |
| Sample No. 2| 15       | 600        | 0.5                    | 0.316      |
| Sample No. 3| 20       | 600        | 0.5                    | 0.319      |

3.4. Wear Analysis

Wear behaviour for different load is shown in Fig. 3. In initial stage sliding wear rate is highest for 10N load compared with 15N and 20N (See Table 2). As sliding distance increase which means time increase it shows similar slopes as of 15N and 20N. It is interesting to note that in beginning of the experiment
20N load sample shows least wear rate but it crosses 15N sample at 257 sec roughly also crosses 10N sample at the end of the experiment. Huang weijiu [15] found that sliding mechanism changes on the application of load, with increase in load the mechanism changes to delamination and melting from abrasion. Wear rate comparison is performed by using slope analysis (See Table 3). It shows maximum wear rate in the beginning is for 10N load but as sliding distance increases, wear rate is maximum for 20N load compared to 10N load. This behaviour is also observed by A.J Lopez [16] for sliding velocity 0.5m/s wear rate shown as mass loss/sliding (g/m) increases with increase in load. Similar wear rate trend is also observed in study performed by Chiranth [13] that on increase of load wear rate increased.

Table 3: Data of Wear with slope change in linearly fitted data

| Time (Sec) | 10N     | 15N     | 20N     |
|-----------|---------|---------|---------|
| 0-15      | 5.3823  | 1.5981  | 1.0205  |
| 100-600   | 0.2906  | 0.3736  | 0.4481  |

Figure 3: Graph of Sliding Wear vs Time of Loads

4. Conclusion

In the present study, the material ZE41 magnesium alloy investigated has equiaxed grains and grain boundaries are precipitates of rare earth elements. It observed that at constant sliding velocity condition for different loads, the coefficients of friction shows decrease in the value on increment of load suddenly for 10N to 15N but for 15N and 20N almost similar value is observed. Sliding wear in the initial stage is different, but in the steady state, it observed a progressive trend of wear, which is more the load more the wear rate. It is presumed that at sliding velocity used in the present study mainly abrasion wear mechanism could have played as key role however wear mechanism slightly changes from abrasion toward delamination and melting when load is increased.

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