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Wear Characteristics of AZ91D Magnesium Alloy under Dry Sliding Condition against Hardened Alloy EN31 Steel Disc

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Abstract

Magnesium alloys are very interesting materials used for engineering applications such as automotive, and aerospace industries. Wear is a degradation of material from surface of the workpiece when it is subjected to sliding motion. Also, coefficient of friction is important factor which affects the rate of wear and application of engineering materials. Wear and friction are important characteristics for making the mechanical components subjected to sliding motion. Hence study of wear and friction phenomenon of engineering materials like magnesium alloy is necessary. In this article tribological characteristics of magnesium alloy AZ91D against hardened alloy EN31 steel as counter disc has been studied. The pin-on-disc (POD) wear and friction test had been used for the analysis of failure of materials under sliding motion. The wear test was performed on 10N, 20N, 30N, and 40 N loads with sliding velocities of 0.42m/s, 0.52m/s, 0.63m/s and 0.73m/s. The effect of the sliding distance and the normal load on the wear rate, wear depth and the coefficient of friction has been investigated. The main wear mechanism was found to be plastic deformation and thermal softening.

Keywords: Friction Coefficient, Magnesium Alloy, Wear Characteristics

1.0 Introduction

Magnesium alloy has very interesting properties such as low density, good machinability, good castability and high Young's modulus. Due to these reasons magnesium alloys are extensively used in manufacturing of components used in mechanical industry like automotive and aerospace industries[1-4]. AZ91D is an interesting materials among the group of magnesium alloys which possess very good physical and mechanical characteristics, which leads to its application in engineering field. Hence degradation of this material in service environment is common. In service environment materials fails in four ways such as oxidation, corrosion, wear and fatigue. Hence in this study the wear failure of AZ91D alloy has been investigated to know about the harsh environment applicability of this alloy. During operation while in sliding motion the surface of materials gets damaged. Hence surface properties of materials should be known before use in engineering application. Wear and friction is surface related properties. So, study on wear and friction properties is desirable before use of materials in automotive and aerospace industries. It is also well known that the most of the mechanical engineering components are made of alloy steel. Hence, the wear characteristics of AZ91D Mg alloy against the alloy steel is necessary, when it is used in automobile industry or the components subjected to wear and friction. In this study the tribological characteristics of AZ91D magnesium alloy under different normal loading conditions and sliding velocities has been studied. The wear of materials occur in different way of mechanism like as adhesive wear, abrasive wear, diffusion wear, oxidative

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wear, corrosive wear and plastic deformation[5]. An *et al.* had tested the tribological behaviour of two magnesium alloys such as Mg_{97}-Zn_1-Y_2 and AZ91D magnesium alloy against the steel counter face[6]. It has been observed that the five wear mechanism were found during the wear test such as abrasion, oxidation wear, delamination wear, plastic deformation due to thermal softening and surface melting. It has been reported that Mg-Zn-Y showed higher wear resistance at higher load than 80N. Chen *et al.* had investigated tribological behaviour of AZ91D against AISI5200 steel as counter face[7]. It was reported that the two types of wear regime was observed such as regime of the mild wear and regime of severe wear. In regime of the mild wear, mechanism was reported as wear due to oxidation and wear due to delamination where as in severe wear regime, the mechanism of wear was reported as plastic deformation and thermal softening. Krishnan *et al.* had investigated the wear properties of AZ91D with different load and different temperature conditions against hardened steel counter face[5]. It was reported that the wear rate of the AZ91D alloy was low at high temperature state and the wear value was high at higher loading conditions. Wang *et al.* had experimented the dry sliding wear characteristics of AZ91D magnesium alloy at different load and temperature condition against commercial 10 steel counter face[8]. It was reported that the wear rate at high temperature about 200℃ was low. Aung *et al.* had tested the tribological behaviour of AZ91D magnesium alloy against counterface of stainless steel with low sliding speed under dry sliding condition[9]. It was reported that the main reason for wear mechanism was wear due to adhesion and wear due to oxidation.

It can be observed from the above literature review that few researchers had tested the wear properties of AZ91D Mg alloy against the steel disc as counter body. No any researcher has investigated the wear properties of AZ91D alloy against hardened alloy EN 31 steel under different normal load and sliding velocities conditions. Hence further research in this area is necessary. Keeping in view of the above things author has investigated the wear behaviour of AZ91D alloy against the EN31 hardened alloy counter disc. In this present investigation, tribological behaviour of magnesium alloy against EN31 hardened alloy steel has been investigated under different variable conditions. The EN 31 hardened steel are taken as counter body because most of the machinery components are made of steel, hence the wear behaviour of magnesium alloy against hardened steel is important for investigation. The main variables which are taken for this experimental analysis are sliding velocity and normal load. The sliding velocities taken are 0.42m/s, 0.52 m/s, 0.63m/s and 0.73 m/s and normal loads taken for this wear investigation are 10N, 20N, 30N, and 40N. Four level of normal loads and four level of sliding speeds are taken as parameters and other parameters are kept as constant. In this way 16 experiments were performed.

2.0 Experimental Planning and Procedure

The AZ91D magnesium alloy is taken as the wear test material in the present investigation. The elemental content of AZ91D magnesium alloy is shown below in the Table 1. The Table 2 shows the physical and the mechanical properties of the Mg alloy AZ91D. The thickness of Mg alloy AZ91D was taken as 8 mm. The samples of magnesium alloy are cut into size of 8 mm x 8 mm x 8 mm by abrasive cutter. The wear and friction test was conducted on Pin-On-Disc (POD) tribometer (Make: Magnum Engineers Pvt. Ltd.). Four types of load such as 10N, 20N, 30N, 40N are applied. And four sliding distances are used 251 m, 314m, 377m and 440m. In this way 16 experiments were conducted to test the wear characteristics of the magnesium alloy. Before wear testing samples are abraded with 600 grades emery paper and after that cleaned with acetone. All the sixteen samples are weighed before wear testing. After wear testing samples are cleaned with acetone and weighed again. The difference in weight loss before wear testing and after wear testing are done. The weight of all samples are taken with the help of analytical weighing balance having the accuracy level of 10^{-4}g. The wear rate has been calculated by the following equation (1). The wear depth can be directly measured by the data acquisition system attached to the pin-on-disc tribometer. The friction coefficient are also recorded from the computer assisted data acquisition system connected to the POD tribometer. The experimental procedure set-up diagram of POD wear tester is presented below in Figure 1. The Table 3 presents the wear test parameters.

Wear Rate (g/Nm) =

$$\frac{Weight\ Loss(g)}{Normal\ Load\ (N) x\ Sliding\ Distance(m)} \quad (1)$$

Table 1. Elemental composition (by wt. %) of AZ91 D Mg alloy substrate

Chemical composition	Al	Mn	Zn	Si	Cu	Fe	Ni	Mg
AZ91 D Mg alloy	8.30	0.20	1	0.10	0.03	0.01	0.00	Remaining

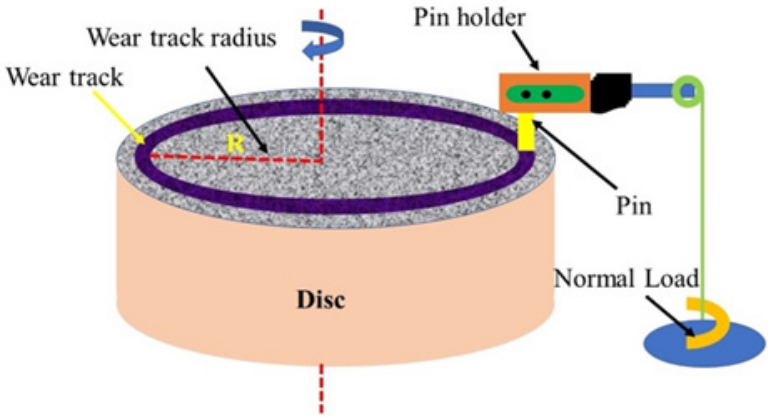


Figure 1. Schematic line diagram of POD type wear testing apparatus.

Table 2. The Mechanical and the Physical properties of AZ91 D Mg alloy substrate

Density	1.81 g/cm^3
Tensile	240-250 MPa
Yield strength	160 MPa
Melting point	421 ℃

Table 3. Main experimental parameters of POD wear test

Normal load (N)	10, 20, 30, 40
Track Radius	20 mm
Test duration	10 min
Disc speed (RPM)	200, 250, 300, and 350
Relative humidity	44 %
Temperature ℃	27
Sliding distance (m)	251,314, 377, and 440
Sliding velocity (m/sec)	0.42, 0.52, 0.63, and 0.73

3.0 Results and Discussions

3.1 Wear Study

Figure 2(a) indicates the variation of wear rate with respect to the normal load. It has been found that the wear rate of AZ91D magnesium alloy falls with rise in normal load and also, similar trend has been observed that the rate of wear falls with rise in sliding velocity/ sliding distance. The reason for decrease in rate of wear is that at high normal load, plastic deformation of materials and thermal softening occurs and materials does not detached from the surface of test material[7]. Due to generation of high friction temperature during wear test at high loads thermal softening and melting of test materials occurs, which increases the rate of plastic deformation. Also, other possible reason for fall in rate of wear is due to formation of oxide layer of MgO_2, which behaves like protective layer from wear or loss of materials from the surface[9]. Due to excessive pressure generated at high normal loads the plastic deformation of materials occurs. From Figure 2(b) it has been found that the wear rate decreases with rise in sliding distance. This phenomenon is owing to the plastic deformation and thermal softening of materials and non-detachment

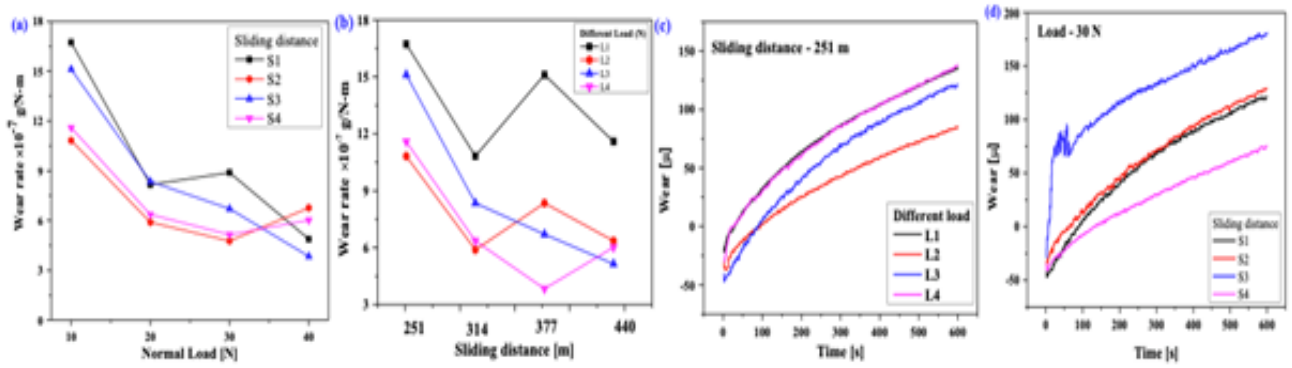


Figure 2. Variation in the wear rate.

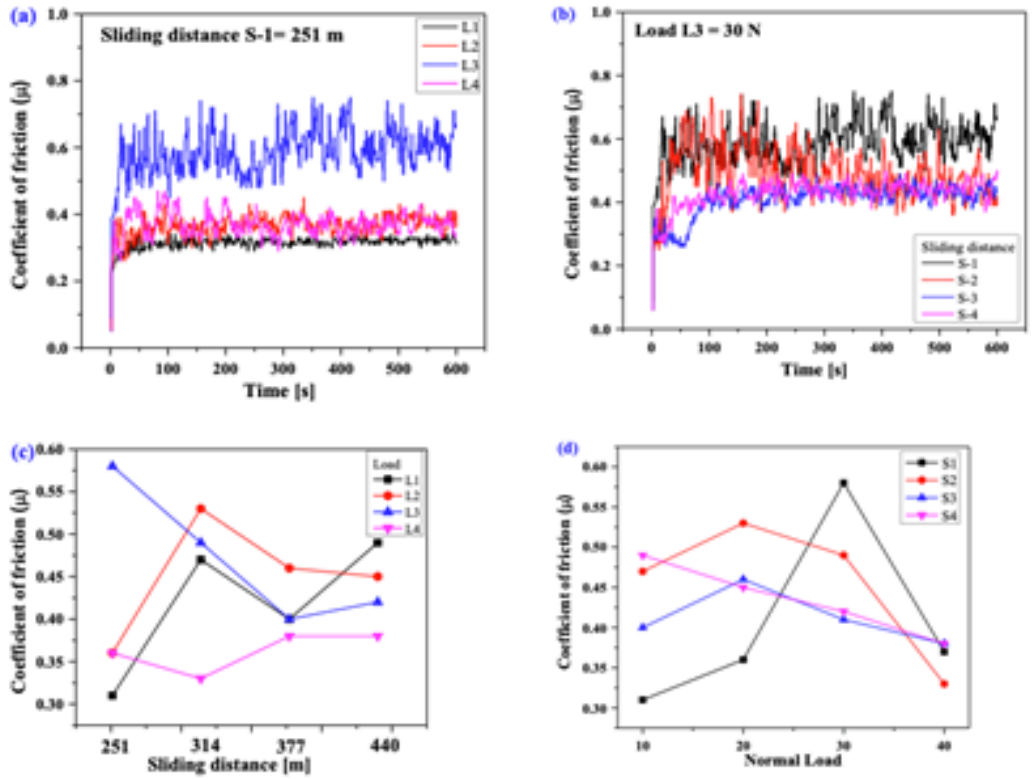


Figure 3. Variation in the coefficient of friction.

of materials from the surface of magnesium alloy. This is also due to the generation of high friction temperature at the mating surface, which leads to melting. Therefore the wear particle do not detach from the surface of the magnesium alloy. Which indicated decrease in wear rate at high sliding velocity or the sliding distance. Figure 2(c)

expresses the variation in depth of wear with variation in time at constant sliding distance and variation in normal loads. It has been seen from the figure that depth of wear increases with the increase in time duration of sliding. At all the normal loads it has been observed that the depth of wear increases with respect to time of sliding. Figure 2(d) shows the variation in the depth of the wear with respect to time at constant load and variation in the sliding distance. Again it has been seen that the depth of wear rises with increase in time duration of sliding. At all the sliding speed/sliding distance the wear depth increases. It can be observed that the depth of wear is lower at high sliding distance, which is due to high frictional temperature at high sliding velocity. Figure 2 shows the variation in the wear rate and Figure 3 shows the variation in the coefficient of friction.

4.0 Conclusions

After studying the tribological behaviour of magnesium alloy AZ91D against hardened alloy EN31 steel disc as the counter body on POD friction and wear tester, the main conclusions drawn are as follows:

1. The wear rate of Mg alloy against EN 31 hardened alloy steel counter face decreases with increase in normal load due to severe plastic deformation and high thermal softening of materials and non-detachment of worn out materials from the test material.
2. The rate of wear of magnesium alloy falls with rise in sliding distance due to high plastic deformation and non-detachment of worn out materials from the surface.
3. With increase in the sliding distance and normal load the depth of wear increases.
4. The friction coefficient decreases at higher sliding distance and the friction coefficient increases at the higher normal load up to 30N and after that it falls with further rise in normal load.

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