Fatigue Behavior of Heat Treated AZ31 Magnesium Alloy

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Abstract—This research was done by using three groups, of heat treated AZ31 Magnesium alloy. First group was as received samples, second group was recrystallization annealing samples and third group was solution treated samples. Fatigue test are carried out for applying forces (5, 7.5, 10, 15, and 17.5N) these forces convert to stresses. The stress values are (50.4, 75.6, 100.9, 151.3 and 176.5 Mpa). Fatigue curves have been recorded for heat treated AZ31 Magnesium alloy, also one specimen from each fatigue test group is subjected to hardness and surface roughness test. The results show the as received group fatigue when compared to recrystallization annealing and solution treatment, the failure occur in high number of cycling because of the alloy made by hot extrusion process so it has high compressive stress in addition to high strain hardening.

Index Terms—AZ31 Magnesium Alloy; Fatigue Test; Roughness; Hardness; Recrystallization Annealing; Solution Treatments.

I. INTRODUCTION

Recently, interest in lightweight materials is raised to decrease greenhouse emissions and improving fuel economy in transportation industries. This increasing interest in lightweight materials has inspired research on both wrought and cast magnesium (Mg) products for their high strength-to-weight ratios and fatigue resistance [1]- [3]. In fact, wrought Mg alloys in general have higher fatigue resistance and mechanical strength than cast Mg alloys due to limited inclusion sizes and precipitation hardening after severe deformation during processing [2], [4]- [7]. As a result of their energy and weight saving characteristics, magnesium alloys are considered to be good candidates for material in, for example, auto parts, portable personal computers, and telephones. The request for magnesium alloys in such applications has increased rapidly in recent years. Understanding the fatigue characteristics of magnesium alloys is vital when they are used as structural members [8]. As magnesium is expanding into more critical applications in powertrain, chassis and body areas, there is a great need for developing wrought magnesium products such as AZ31 with improved mechanical properties including fatigue resistance. [9], [10]. There are many studies on fatigue behavior of Mg alloy. For example, Begum et al, [11] studied low cycle fatigue behavior of AZ31 magnesium alloy. They showed. With increasing total strain amplitude

both plastic strain amplitude and mean stress increased and the fatigue lifetime decreased. Tokaji and his colleagues studied Fatigue behavior and fracture mechanism of a rolled AZ31 magnesium alloy fatigue tests were continued until 3×10^7 cycles. At stress (50 MPa), fatigue failure didn't occur, but non-propagating cracks were observed on a specimen surface. As can be seen in the figure, the present Mg alloy seems to possess a definite fatigue limit and similar behavior is also recognized in extruded AZ61 alloy [12].

II. EXPERIMENTAL

A. Materials

The AZ31 Mg alloy samples chemical composition is list in Table I. The specimens are manufactured according to standard dimension of fatigue rig, as show in Fig. 1.

TABLE I: THE AZ31 MG ALLOY SAMPLES CHEMICAL COMPOSITION

Content	Result
Al	2.90
Zn	0.90
Mn	0.36
Si	0.0130
Fe	0.0024
Cu	0.0089
Mg	Balance

Fig. 1. Shape and dimensions of fatigue test sample

B. Heat treatments

The samples divided into three groups, first group as received samples, second group samples heat treated by recrystallization annealing, and third group samples heat treated by solution treatment. Recrystallization Annealing process are accomplished by heating the samples in furnace at (200°C) for 20 minutes and then cooled at furnace. Solution treatment process accomplished by heating the samples to (400°C) for 15 minutes, then quenching the samples in distilled water and aging at (110°C) for 15 minutes.

C. Roughness test

The surface roughness is measure of surface irregularities in surface texture. Surface roughness plays a significant role in determining and evaluating surface quality of a product. Because surface roughness affects functional characteristic

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of the products such as fatigue, light reflection, wearing, heat transmission, friction and lubrication, product quality is required to be at the high level. [13]. the results of roughness test are shown in Table II

TABLE II: SURFACE ROUGHNESS TEST RESULTS

Specimens state	Ra (μm)	Ra av. (μm)
As received specimen	1.751	1.797
	1.826	
	1.816	
	2.017	
Annealing specimen	2.019	2.022
	2.032	
	1.010	
	1.031	
Solution treated specimen	1.031	1.018
	1.015	

D. Hardness test

Hardness is property of a material that enables it for resisting plastic deformation [14], before microhardness test, samples were ground using silicon carbide papers 400, 800, and 1000 grit and polished with cloth paper and fine with diamond lapping compound. The hardness of the AZ31 magnesium alloys were determined to investigate the effect of heat treatment on the obtained value. Vickers microhardness test was conducted to three groups. The average of three reading was taken. The results demonstrate an improvement in hardness with solution treatment sample due to precipitating hardening while recrystallization annealing and as received samples has approximately similar hardness value . Table III shows the Vickers microhardness results.

TABLE III: VICKERS MICROHARDNESS TEST RESULTS

Specimens state	HV kg/cm ²	HV av. kg/cm ²
As received specimen	52.41	55.59
	59.61	
	54.77	
	56.18	
Annealing specimen	56.88	56.94
	57.77	
	77.62	
	82.00	
Solution treated specimen	68.19	75.93

E. Fatigue Test

Fatigue is a progressive, localized, permanent structural change that occurs in materials subjected to fluctuating stresses and strains that may result in cracks or fracture after a sufficient number of fluctuations. [15]. Fatigue test is carried out by (HSM19D rotating fatigue machine) shown Fig. 2.

Fig. 2. Fatigue Testing Apparatus

Fatigue test is performed with constant temperature (room temperature) and variable amplitude load. Specimen is exposed to an auto load by display unit; this load generates a bending moment. Therefore, the surface of specimen is under tension and compression stress effect when it rotates. The magnitude of the load (p) is measured by Newton (N) applied to the specimen for a known magnitude σ (MPa) and obtained from applying the equation as below:

$$\sigma = (p \times l \times 32) / (\pi \times d^3) \quad (1)$$

Where:

P= force (variable) (N)

L= the length of the fatigue test specimen (mm)

D= minimum diameter of the fatigue test specimen (mm)

III. RESULTS AND DISCUSSION

The results for each test have been recorded and then discuss to evaluate its effect. Fatigue tests are performed for three groups; each group has fifteen samples, as previously mentioned. These tests are carried out at applied forces (5, 7.5, 10, 15, and 17.5N) these forces convert to stress. The stress values are (50.4, 75.6, 100.9, 151.3 and 176.5 Mpa). Three tests are performed at each of these stress levels and the number of cycles until failure is recorded by an auto display unit which is coupled directly to the drive shaft of the D.C. motor. Fatigue test is performed at room temperature and the load remains constant until the failure of the specimen occurs. When specimen fails, the fatigue testing automatically stops.

A. As Received Group

The results of this test are shown in Table IV, and the fatigue test diagram S-N curves shows in Fig. 3.

TABLE IV: AS RECEIVED FATIGUE TEST RESULTS

Specimens No.	Applied load (N)	Applied Stress (MPa)	Failure Cycles (Nf)	Average Cycles (Nav.)
1,2,3	5	50.4	169116,214 311,163197	182208
4,5,6	7.5	75.6	35585,6201 8,32969	43524
7,8,9	10	100.9	7544,11446 .5712	8234
10,11,12	15	151.3	4710,8096, 4432	5746
13,14,15	17.5	176.5	3347,4519, 1962	3276

Fig. 3. As received fatigue test diagram

B. Recrystallization Annealing Group

The results of this test are shown in Table V. And the fatigue test diagram S-N curves shows in Fig. 4.

TABLE V: RECRYSTALLIZATION ANNEALING FATIGUE TEST RESULTS

Specimens No.	Applied load (N)	Applied Stress (MPa)	Failure Cycles (Nf)	Average Cycles (Nav.)
1,2,3	5	50.4	54254,1249 30,56259	78481
4,5,6	7.5	75.6	23144,3523 3,12522	23633
7,8,9	10	100.9	3613,13756 ,7018	8129
10,11,12	15	151.3	3325,5834, 2913	4024
13,14,15	17.5	176.5	836,2882,2 426	2048

Fig. 4. Recrystallization annealing fatigue test diagram

C. Solution Treatment Group

The results of this test are shown in Table VI. And the fatigue test diagram S-N curves shows in Fig. 5

TABLE VI: SOLUTION TREATMENT FATIGUE TEST RESULTS

Specimens No.	Applied load (N)	Applied Stress (MPa)	Failure Cycles (Nf)	Average Cycles (Nav.)
1,2,3	5	50.4	10003,1560 0,11135	12246
4,5,6	7.5	75.6	5746,9912, 7496	7718
7,8,9	10	100.9	4472,2073, 2440	2995
10,11,12	15	151.3	749,1170,6 22	847
13,14,15	17.5	176.5	420,148,25 1	273

Fig. 5. Solution Treatment fatigue test diagram

The results of three different S-N curves data are now plotted in Fig. 6.

Fig. 6. Comparison between Three Cases of Fatigue Testing

From figure 6. show the as received group fatigue result as comparison to recrystallization annealing and solution treatment result, the failure occur in high number of cycling because of the alloy made by hot extrusion process so it has high compressive stress in addition to high strain hardening. While in recrystallization annealing the failure occur at number of cycling lower than as received group, due to stress relieve process and nucleation new grain, this group will fractured at lower number of cycles because of HCP structure of magnesium alloy. Finally in solution treatment group the failure occur at number of cycling lower than the two groups because of precipitate particles; the grain bounders will be the region of intergranular fracture because of the particles precipitate on grain bounders that will be the region of crack initiation and propagation.

In as received group the fracture type is rough in general and in recrystallization annealing group the type of fracture is seem some smooth and in solution treatment group it is brittle fracture. The regions of fracture samples are shown in Fig. 7.

a-as received sample b-annealing sample c-solution treatment
Fig. 7. Region of fracture

IV. CONCLUSION

1. The as received AZ31 specimen has high fatigue endurance comparing to other groups.
2. The fatigue fracture views of recrystallized specimens are less brittle than others because of fine grains.
3. The hardness of solution treated specimens are the higher values, leads to lower fatigue cycling.
4. There is little difference in fatigue equations recorded for all types of AZ31 Mg alloy samples.

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