

# FATIGUE BEHAVIOUR OF A ROLLED AZ31 MAGNESIUM ALLOYS PREPARED BY EP AND BB CONDITIONS

Y. Fouad

@iust.ac.ir

Received: January 2010

Accepted: July 2010

Faculty of Engineering and Materials Science, German University in Cairo, Cairo.

**Abstract:** Rotating bending fatigue tests have been performed using smooth specimens of a rolled AZ31 magnesium alloy in laboratory air at ambient temperature. Fatigue strength and characteristic was evaluated and fracture mechanism was discussed on the basis fracture surface analysis. Electrical polishing (EP) as well as deep rolling (ball burnishing (BB)) U-notched specimens were performed on two groups of samples, to evaluate optimum conditions for fatigue life. The microstructure and tensile properties of roll cast (RC) Mg- 3% Al- 1% Zn (AZ31) was investigated. The fatigue strength of 107 cycles around 100 MPa for deep rolling while it was around 40 MPa for Electrical polishing. It was very important to understand the effect of (ball burnishing (BB)) conditions on the hardness of the surface through to the core. The two procedures improved the fatigue performance, but better improve in results were found in ball burnishing. The growth of small cracks initiated at the surface coincided with the FCP characteristic after allowing for crack closure for large cracks, but the operative fracture mechanisms were different between small and large cracks. At the subsurface crack initiation site, smooth facets were always present regardless of applied stress level.

**Keywords:** AZ31, Fatigue, Surface treatment, Ball burnishing, Electrical Polishing.

## 1. INTRODUCTION

Mg alloys are very attractive materials in order to achieve high performance and energy saving of machines and structures, because of their advantages such as light weight, high strength-to-weight ratio and high specific stiffness. On the other hand, there is a lack of competitive wrought Mg alloy products, especially sheet materials, which are much needed for numerous weight-sensitive applications. Therefore, they have recently been increasing interest as structural materials in many applications, in particular, they are considered to be replacing aluminum alloys with a concomitant saving in weight in automotive industries. For applications to load-bearing components, it is necessary to evaluate various fatigue properties. A large number of studies on magnesium alloys has been carried out since the "second renaissance" of these alloys in the beginning of the 1990's, however, most of them have been concerned with the mechanical properties and the development of new alloys [1]. Most wrought magnesium alloys are processed at high temperature because of their poor ductility at low temperature. Despite several previous publications concerning dynamic and static recrystallization in magnesium alloys [2-4], there

is still lack of insight into the appropriate mechanisms and the accompanying properties. Ogarrevic and Stephens have reviewed the fatigue data of Mg alloys published between 1923 and 1990 and indicated that a significant amount of fatigue strength data existed, but most of it was not recent [7]. When considered such situation of fatigue research and the recent development of Mg alloys, the accumulation of various fatigue data is now of particular importance. Mg alloys can be classified into two categories, casting and wrought alloys. In casting alloys, defects such as casting porosity and cavity are usually present and the fatigue properties are affected significantly by their shape and dimension [8, 9]. In the present study, axial fatigue tests have been performed using smooth specimens of a rolled AZ31 Mg alloy in laboratory air at ambient temperature. Fatigue strength was evaluated.

## 2. EXPERIMENTAL PROCEDURES

### 2. 1. Material

The material used is a commercial AZ31 Mg alloy rolled plate with a thickness of 10 mm. The chemical composition of the present alloy is

**Table.1.** Chemical composition of the materials (wt %)

Al%	Ca%	Cu%	Fe%	Mn%	Ni%	Pb%	Si%	Sn%
3.078	0.0573	0.0065	0.0054	0.3647	0.002	0.0075	0.0204	<0.002
Zn%	Zr%	Mg%						
1.337	<0.01	95.1						

analysis by using Spectro Analytical instruments according to DIN 31051. The chemical composition of the material is shown in Table 1. The material was provided in as-rolled condition and no heat treatment was applied to fatigue specimen before experiment.

## 2. 2. Specimens

As shown in Fig. 1. Mechanical testing tensile and fatigue specimens with 5 mm diameter, 14 mm gauge length was machined from as-received so that their axis is parallel to the rolling direction. BB condition prepared with the following preparation condition on ECOROLL instrument using tool type (HG6) at 100 bar (246 N) with feed rate of 0.17 mm/min at 30 rpm.

**Fig. 1.** Shape and dimension of mechanical testing specimens

## 2.3. Procedures

Fatigue strength data were obtained at a stress ratio,  $R$ , of -1 using the fatigue experiments were carried out in laboratory air at room temperature using a rotating bending fatigue machine. Its cyclic speed was 50 Hz during the fatigue tests,

the temperature and humidity of the atmosphere was not strictly controlled. After the experiment, fracture surfaces were exam in detail by scanning electron microscope (SEM) The fatigue cracked surfaces were investigated by scanning electron microscope (SEM) HITACHI X-650 at different magnifications no preparation carried out to specimens before scanning. Microhardness test was procedure carried out on specimens as tensile test.

## 3. RESULTS AND DISCUSSION

**3.1.** In Table 2 Shows the mechanical properties of specimens. Tensile tests were performed using specimens with gauge length of 14 mm and gauge diameter of 5 mm for the EP and BB specimens.

### 3. 2. S/N curves

S/N curves for the EP and the BB specimens in laboratory at a stress ratio of -1 and frequency of 50 Hz (rolled magnesium alloy) in laboratory air is shown in Fig. 2. In this figure, for comparison purposes, the S–N curves of the EP and BB specimens are shown respectively. As seen from the figure, the fatigue life of the rolled magnesium alloy of EP specimen is relatively shorter than that of BB specimen. The extent bending in the S–N curve is gentler in the BB specimens than in the EP specimen. Next let us compare the S–N characteristics of the EP and BB specimens. There are great differences in the fatigue lives and in the fatigue limits, especially at higher stress amplitudes, there are differences in the fatigue lives.

**Table. 2.** Mechanical properties of the material

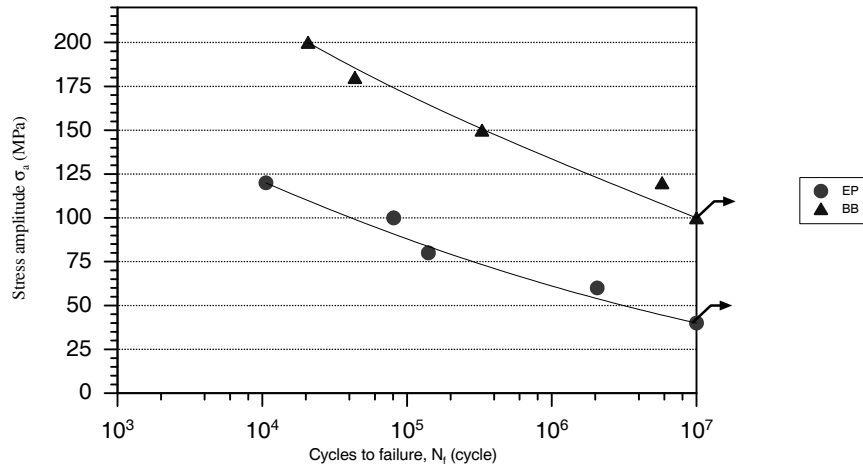
Material	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Young's modulus (GPa)
AZ31	154.8	232	23.67	45

**3. 3.** A different experiment were used to investigate the best condition for BB (pressure, feed rate, speed) as example for tool HG3 200 bar (123 N) for 50, 100 and 150 rpm. The microhardness measurement from the surface in Fig. 3. Shows that the suitable condition for using 200 bars is 100 rpm for AZ31 as the hardness decreased from the circumference gradually to the center.

### 3. 4. SEM

The fracture surface of AZ31 for EP condition and BB condition at different stress is shown in Fig.

4. Subsurface crack initiation occurred at applied stresses at 60 MPa. At BB condition but it can be seen for both 80 and 100 MPa stress for EP condition. The S-N diagram is shown in Fig. 2. It is well known that fatigue limit does not exist in non-ferrous alloys, thus fatigue tests were continued until  $10^7$  cycles. At EP condition  $\sigma = 40$  MPa, fatigue failure did not occur, but non-propagating cracks were observed on the specimen surface. As can be seen in the figure, the present Mg alloy seems to possess a definite fatigue limit, which may be related to the existence of non-propagating cracks. The fracture mode depending



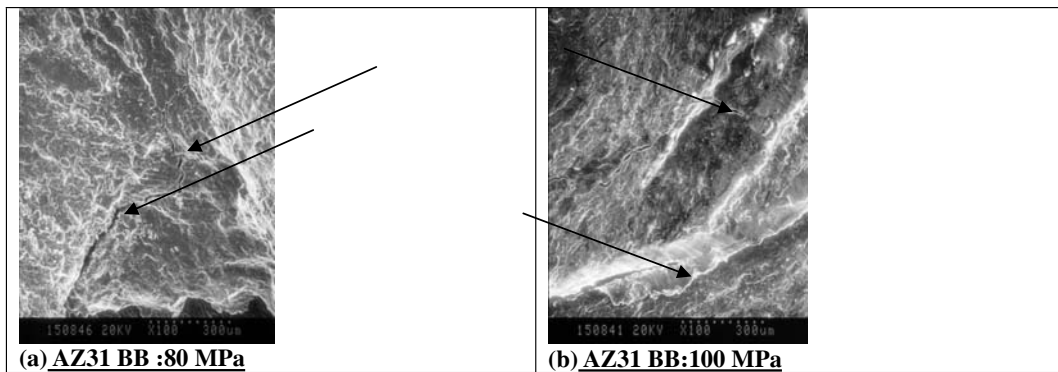
**Fig.2.** S-N curve for rolled AZ31 at EP,BB conditions, rotating beam, R=-1, 50Hz.



**Fig. 3.** Microhardness profile of AZ31 after BB at 200 bars, 0.17 mm/min at different BB rotation speed.



**Fig.4.** SEM micrographs showing fracture surfaces at difference stress for EP at (a) 60MPa; (b) 80 MPa; (c) 100 MPa and BB at (d) 60MPa; (e) 80 MPa; (f) 100 MPa.



**Fig. 5.** SEM micrographs showing cracked surfaces at difference stress for BB at (a) 80MPa; (b) 100 MPa

on applied stress level, above 60 MPa cracks initiate at the surface (surface fracture), while below that stress at the interior of the specimen (subsurface fracture). Subsurface fracture is a very interesting finding, which has not been recognized in Mg alloys, for both EP and BB conditions.

The cracked line could be seen easily for higher stress for BB condition as fracture occurs in internal surface not at the outer surface as in the EP condition in Fig. 5.

#### 4. CONCLUSIONS

Rotating beam, bending fatigue tests have been performed using smooth specimens EP and BB methods for rolled AZ31 Mg alloy in laboratory air at ambient temperature. Fatigue strength characteristic were evaluated and discussed. The conclusions can be made as follows:

1. Fatigue strength at  $10^7$  cycles was 100 MPa

for BB condition with the following preparation condition on ECOROLL instrument using tool type (HG6) at 100 bar (246 N) with feed rate of 0.17 mm/min at 30 rpm. While the fatigue strength at 107 cycles was 40 MPa for EP condition.

2. Fatigue lives and the fatigue limit of BB specimens were higher than those of EP specimens with similar profiles.
3. Electrical polishing and ball burnishing preparation are very sensitive to working procedure of choosing temperature for EP or in choosing (Feed, Speed and tool head) for BB condition. After many trails to find out the good combination of the three parameters.
4. As a result of crack initiate from the surface for EP condition it fails under lower stress than in BB condition which crack initiate internally ( as surface treated by BB).
5. It could be investigate the best condition of BB by examine the surface up to 500  $\mu$ m for microhardness value, to choice best values for BB treatment.

This work was supported by Prof. Lothar Wagner at the Institute of Materials Science and Engineering, Clausthal University of Technology, Clausthal-Zellerfeld, Germany.

## 5. ACKNOWLEDGEMENTS

The authors express their thanks to Prof. Lothar Wagner at the Institute of Materials Science and Engineering, Clausthal University of Technology, Clausthal-Zellerfeld, Germany. For there valuable discussions, support and facility of instruments during this study.

## REFERENCES

1. Bronfin, B., Aghion, E., von Buch, F., Schumann, S., Friedrich, H. "Development of New Magnesium Alloys for Advanced Applications" Magnesium: Proceedings of the 6th International Conference Magnesium Alloys and Their Applications, 2005, 55-61.
2. Mackenzie, L. W. F., Lorimer, G. W., Humphreys, F. J. and Wilks., T. Recrystallization Behaviour of Two Magnesium Alloys. *Mater. Sci. Forum* , 2004, 467-482.
3. Yi, S. B., Zaefferer, S. and Brokmeier, H.- G. Mechanical behaviour and microstructural evolution of magnesium alloy AZ31 in tension at different temperatures, *Materials Science and Engineering: A*, 2006, 275-281, 424,
4. Del Valle, J. A. and Ruano, O. A. Influence of texture on dynamic recrystallization and deformation mechanisms in rolled or ECAPed AZ31 magnesium alloy, *Materials Science and Engineering: A*, 2008,473-480, 487.
5. Hakamada, M., Watazu, A., Saito, N., and e Iwasaki, H., Dynamic recrystallization behavior during compressive deformation in Mg-Al-Ca-RE alloy, *Journal of Materials Science*, 2008, 2066-2068, 43.
6. Jiang, J., Godfrey, A. and Liu, Q. Effect of Temperature on Microstructure and Texture during Compression of AZ31, *Materials Science Forum* , 2007, 245-248, 546 - 549.
7. Tokaji, K., Kamakura, M., Ishiizumi, Y. and Hasegawa, N. Fatigue behaviour and fracture mechanism of a rolled AZ31 magnesium alloy, *International Journal of Fatigue*, 2004, 1217-1224, 26.
8. Tokaji K, Ogawa T and Kameyama Y., The effects of stress ratio on the growth behaviour of small fatigue cracks in an aluminum alloy 7075-T6 (with special interest in stage I crack growth) *fatigue frat Eng Mater Struct*; 1990, 411-21,13.
9. Tokaji K, goshima Y., Fatigue behaviour of 6063 aluminium alloy in corrosive environments *J soc Mater Sci Jpn*; 2002,1441-6,51.