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Investigation on mechanical behaviour of AM60 magnesium alloys

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Properties

ABSTRACT

Purpose: In this work, tension, impact, bend and fatigue tests were conducted in an AM60 magnesium alloy. The effects of environmental temperature and loading rates on impact and tension behavior of the alloy were also investigated.
Design/methodology/approach: The tests were conducted using an Instron universal testing machine. The loading speed was changed from 1 mm/min to 300 mm/min to gain a better understanding of the effect of strain rate. To understand the failure behavior of this alloy at different environmental temperatures, Charpy impact test was conducted in a range of temperatures (-40~35°C). Plane strain fracture toughness (K_{IC}) was evaluated using compact tension (CT) specimen. To gain a better understanding of the failure mechanisms, all fracture surfaces were observed using scanning electron microscopy (SEM). In addition, fatigue behavior of this alloy was estimated using tension test under tension-tension condition at 30 Hz. The stress amplitude was selected in the range of 20~50 MPa to obtain the S-N curve.
Findings: The tensile test indicated that the mechanical properties were not sensitive to the strain rates applied ($3.3x10^{-4}$~0.1) and the plastic deformation was dominated by twining mediated slip. The impact energy is not sensitive to the environmental temperature. The plane strain fracture toughness and fatigue limit were evaluated and the average values were 7.6 MPa.m1/2 and 25 MPa, respectively.
Practical implications: Tested materials AM60 Mg alloy can be applied among others in automotive industry aerospace, communication and computer industry.
Originality/value: Many investigations have been conducted to develop new Mg alloys with improved stiffness and ductility. On the other hand, relatively less attention has been paid to the failure mechanisms of Mg alloys, such as brittle fracture and fatigue, subjected to different environmental or loading conditions. In this work, tension, impact, bend and fatigue tests were conducted in an AM60 magnesium alloy.
Keywords: Magnesium alloy; Mechanical behaviour; Yield; Fracture; Fatigue

1. Introduction

Magnesium (Mg) alloys are attracting increasing attention due to potential applications in automobile, aerospace, communication and computer industry where light weight materials are desirable. Unfortunately, the disadvantage of Mg alloys is low strength, low ductility and low corrosion resistance. Many investigations have been conducted to develop new Mg alloys with improved stiffness and ductility [1-5]. On the other hand, relatively less attention has been paid to the failure mechanisms of Mg alloys, such as brittle fracture and fatigue, subjected to different environmental or loading conditions. In this work, tension, impact, bend and fatigue tests were conducted in an AM60 magnesium alloy. The effects of environmental temperature and loading rates on impact and tension behavior of the alloy were also investigated.

2. Experimental procedure

2.1. Materials

AM60 cast magnesium alloy (with 6% Al, 0.2% Zn and 0.21%) was used in this work, which is one of the most popular magnesium alloys with great potential for applications in automotive industry. The microstructure is composed of α-Mg matrix and a second phase ($Mg_{17}Al_{12}$), as shown in Fig. 1

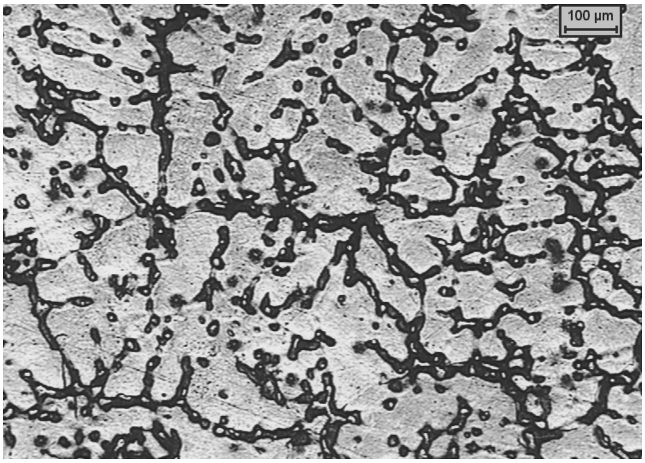

Fig. 1. Microstructure of the AM60 magnesium alloy

2.2. Mechanical tests

The tests were conducted using an Instron universal testing machine. The loading speed was changed from 1 mm/min to 300 mm/min to gain a better understanding of the effect of strain rate. To understand the failure behavior of this alloy at different environmental temperatures, Charpy impact test was conducted in a range of temperatures (-40~35°C). Plane strain fracture toughness (K_{IC}) was evaluated using compact tension (CT) specimen. To gain a better understanding of the failure mechanisms, all fracture surfaces were observed using scanning electron microscopy (SEM). In addition, fatigue behavior of this alloy was estimated using tension test under tension-tension condition at 30 Hz. The stress amplitude was selected in the range of 20~50 MPa to obtain the S-N curve.

3. Results and discussion

The results of impact test at different temperatures are shown in Table 1.

Table 1.
Variation of impact energy with temperature

Temperature (°C)	Impact energy (J)
-40	5.23
-25	5.25
-10	5.32
5	5.33
20	5.35
35	5.52

It can be seen from Table 1 that the impact energy is not sensitive to the change of environment temperature. Therefore, no ductile to brittle transition can be expected in this alloy, in contrast to many carbon steels. The typical fracture surface of the impact samples is shown in Fig. 2. Ridge shaped morphology can be observed in the region close to the notch, indicating a relatively higher energy dissipation corresponding to the initiation of crack. The other areas on the fracture surface are featured by flat and river like patterns, as a result of rapid crack propagation. Overall, the absorbed energy is very low.

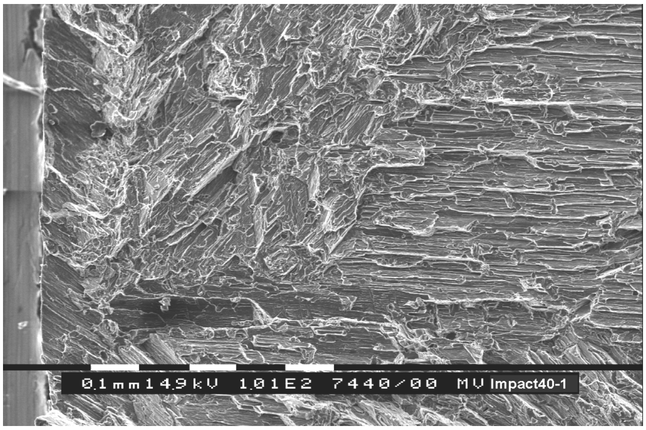

Fig. 2. Typical fracture surface of the impact specimen

The tensile test was conducted at different loading rates. Fig. 3 gives the stress-strain curves subjected to the loading speed in the range of 1mm/min to 300 mm/min.

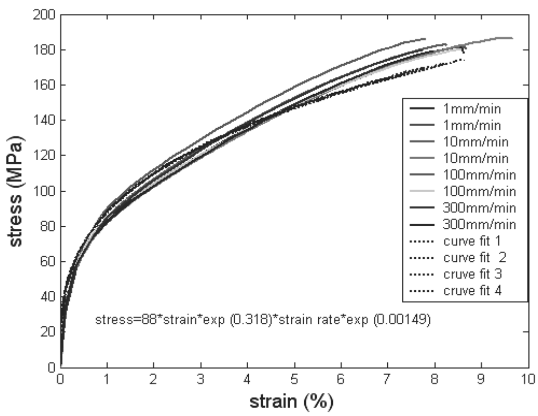

Fig. 3. Stress-strain curves at different loading speeds

Table 2.
Result of the tensile test

Loading speed (mm/min)	Young's modulus (GPa)	Yield strength (MPa)	Fracture strength (MPa)
1	45.2	58.2	182.3
10	48.6	53.7	177.6
100	-	63.4	183.6
300	-	60.7	180.4

The result of tensile test is summarized in Table 2.

From both Table 2 and Fig. 3, it can be seen that the yield and fracture strength increase slightly with the loading speed. For a HCP metal, such as Mg, high strain rate may lead to increased ductility due to high working hardening rate. On the other hand, dynamic recovery may decrease the working hardening rates by lowering defect density. In average, these two effects may offset each other and result in an almost constant tension behavior at different strain rates. It is interesting to note the apparent slip steps on the surface of the tensile samples, as shown in Fig. 4. This is due to the motion of dislocations along the slip planes. Some broken tensile specimens were sectioned perpendicular to the fracture surfaces to observe the microstructure. As shown in Fig. 5, some deformation twins are developed in the elongated microstructure. This is consistent with the observation of Gartnerova et al [6] in an Mg alloy. In fact, it is possible to observe deformation twins in Mg alloy with HCP crystal structure. Due to the development of extensive slip steps via motion of dislocations along the slip planes, small amount of twining are required to change the basal planes to more favorable directions relative to the stress axis so that the slip can be accommodated, as confirmed by Zhang et al [7].

The fracture surface of the tensile specimen was also examined using SEM and the typical morphology is shown in Fig. 6.

The mixed tearing ridges and quasi cleavage like facets indicate the plastic deformation during tension. This is why a certain amount of elongation (about 9%) can be achieved in this alloy (Fig. 3)

Compact tension (CT) specimens were employed to evaluate the plane strain fracture toughness (K_{IC}). The pre-crack was created in the CT specimens using fatigue method. In line with the ASTM standard, the fracture toughness can be evaluated using the failure load with the equation below,

$$K_{IC} = \frac{P_Q}{BW} f(a/W) \quad (1)$$

where P_Q is the failure load, B and W are the thickness and height of the specimen, and $f(a/W)$ is the correction factor of the crack length. The average fracture toughness is 7.3 MPa.m$^{1/2}$. Obviously, the fracture toughness is similar to another Mg alloy (AZ91) but lower than most aluminum and titanium alloys. The fracture surface of the CT specimen is shown in Fig. 7. It can be seen in Fig. 7 that the fracture surface is flat and dominated by river like ridges, indicating low energy dissipation during the brittle fracture. The fatigue limit of this alloy can be evaluated using the stress amplitude-cycles to failure (S-N) curve. The fatigue limit was found as 25 MPa.

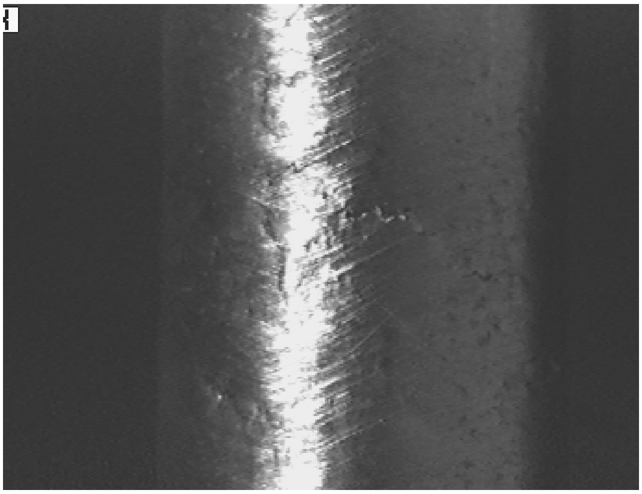

Fig. 4. Slip steps on the surface of tensile specimen

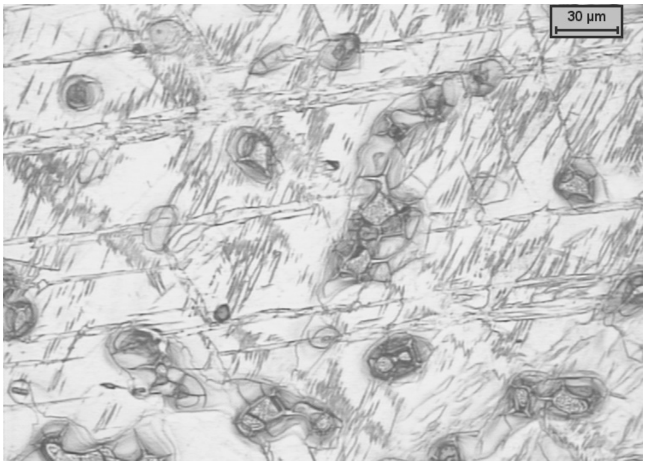

Fig. 5. Deformation twins developed near the fracture surface

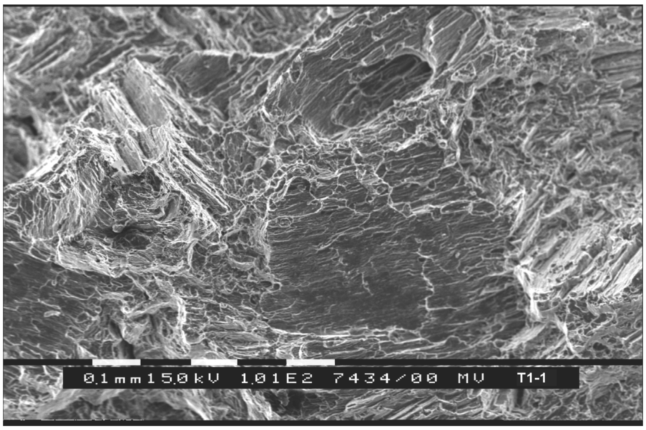

Fig. 6. Fracture surface of the tensile specimen

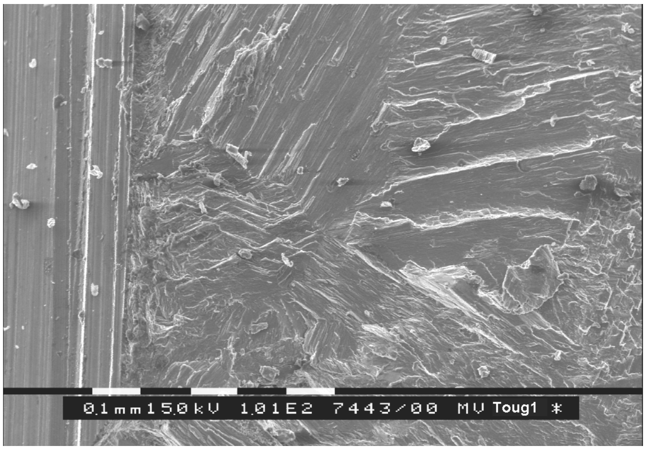

Fig. 7. Fracture surface of the CT specimen

4. Conclusions

Tensile, Charpy impact, compact tension and fatigue tests were conducted to investigate the deformation and failure behavior of an AM60 Mg alloy. The tensile test indicated that the mechanical properties were not sensitive to the strain rates applied ($3.3x10^{-4}$~0.1) and the plastic deformation was dominated by twining mediated slip. The impact energy is not sensitive to the environmental temperature. The plane strain fracture toughness and fatigue limit were evaluated and the average values were 7.6 MPa.m1/2 and 25 MPa, respectively.

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