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Effect Of Constraint On The Tensile Behavior Of An AZ91 Magnesium Alloy

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ABSTRACT: The deformation and failure behaviour of a cast AZ91 alloy was investigated using circumferentially-notched tensile specimens with different notch radii. The break strength corresponding to various constraint levels were estimated. The fracture surface was observed using scanning electron microscopy (SEM). The results indicated that deformation and failure of the AZ91 magnesium alloy are very sensitive to the constraint (stress triaxiality). The fracture mechanisms change from typical ductile tearing to quasi cleavage with increasing constraint level.

1 INTRODUCTION

Magnesium alloys are attractive for applications in automobile, aerospace, communication and computer industry because of their very low density, high specific strength and good machineability and availability as compared to other structural materials. Mg has a low density of 1.74g/cm^3, which is approximately 35% lighter than Al alloys and 65% lighter than Ti alloys. It also has a good conductivity and high damping capacity. However, the disadvantages of magnesium are low elastic modulus and limited toughness due to the few slip systems which are available in a hexagonal close-packed structure. Many investigations have shown that failure of metallic materials is highly dependent on the constraint condition (stress triaxiality) ahead of a crack or notch. A high constraint level can prompt brittle fracture and lead to a low fracture toughness. Normally, ductile tearing is controlled by nucleation, growth and coalescence of microvoids. It has been observed experimentally that the crack tip opening displacement (CTOD) or J-integral at the initiation of ductile fracture is higher for specimens with low constraint than those with high constraint [Cotterell et al, 1985; Matsoukas et al, 1986; Wu et al, 1991]. Yan and Mai [1997, 1998, and 2000] indicated the both brittle and ductile fracture are strongly dependent on constraint level at crack tip. Unfortunately, few studies have been carried out to understand the effect of constraint on deformation and fracture of magnesium alloys. In this study, the effect of constraint on deformation and failure of an AZ91 magnesium alloy in tensile test was investigated.

2 EXPERIMENTAL PROCEDURE

AZ91 magnesium alloy (about 9% Al, 1% Zn and 0.21% Mn added) was used in this work, which is one of the most popular magnesium alloys with a great potential for applications in automotive industry. The microstructure is shown in Fig. 1, which mainly consists of α-Mg matrix and second phases ($Mg_{17}Al_{12}$).

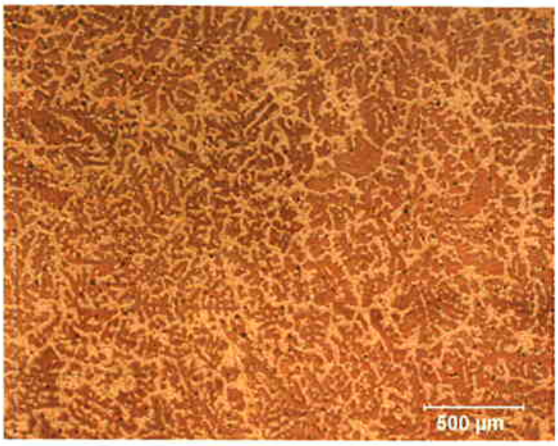


Figure 1 Microstructure of the Mg alloy

In order to vary the constraint condition, tests were carried out on circumferentially-notched tensile specimens with different notch radii, whose dimensions are shown in Fig. 2.

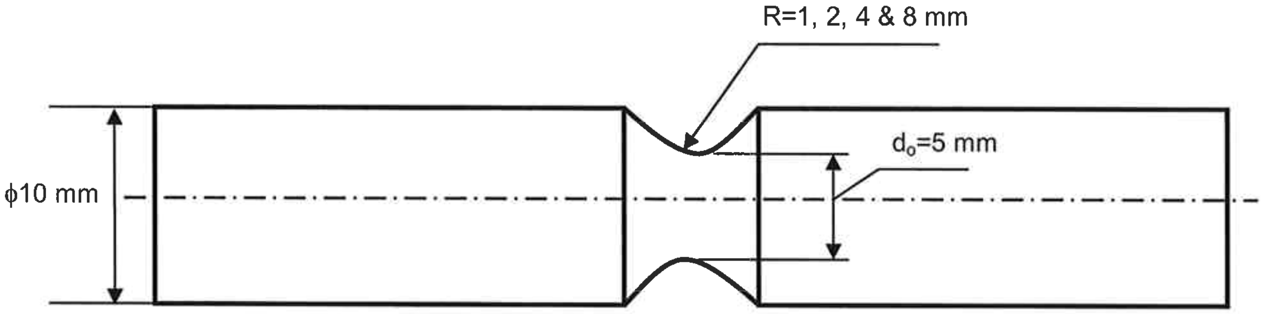


Figure 2 Schematic of the circumferentially-notched tensile specimen

Birdgman's analysis [1952] was used to evaluate the distributions of stress triaxiality (constraint) and strain in the minimum cross-section area of the notch. This analysis was originally applied for a smooth tensile bar after necking but it may be used as an approximation to pre-notched specimens. The maximum stress triaxiality (ratio between mean stress and effective stress) is estimated as,

$$(\sigma_m / \sigma_{eff})_{\max} = 1/3 + \ln(d/2R+1), \tag{1}$$

where R is the profile radius of the cirumferential notch and d is the diameter of the minimum cross-section. The effective plastic strain is

$$\varepsilon_p = 2\ln(d_o / d), \tag{2}$$

where d_0 is the initial value of d.

The specimens were machined from the longitudinal direction in a cast ingot. The tests were carried out in an Instron testing machine. The axial displacement was recorded using an extensometer mounted on the specimen surface. The continuous changes in the notch profile were monitored using a CCD camera. The fracture surfaces were examined using scanning electron microscopy (SEM).

3 RESULTS AND DISCUSSION

Fig. 3 shows the nominal stress-strain relationship for the tensile bars with different radii. The stress is calculated from the load divided by the original minimum cross-section area. It is expected the deformation is not uniform in the axial direction in the notched section. As a result, it is difficult to know the effective gauge length in a notched bar when recording the strain with an extensometer. The strain reported here is only the average value within the total gauge length of the extensometer (50 mm). For the smooth tensile specimen (without a notch), after the initial elastic response, the stress rises as a result of strain hardening and then drops. The tensile behavior of the notched specimens, however, differs from that of the smooth bars. There is less degree of strain hardening in the specimens with higher stress triaxiality (reduction of notch profile radius). Also, an apparent increase of break stress (σ_f) with stress triaxiality is observed, as shown in Fig. 4. This is very similar to the investigation of Hancock and Mackenzie [1976] on two low alloy steels where apparent increase of break strength with stress triaxiality was observed.

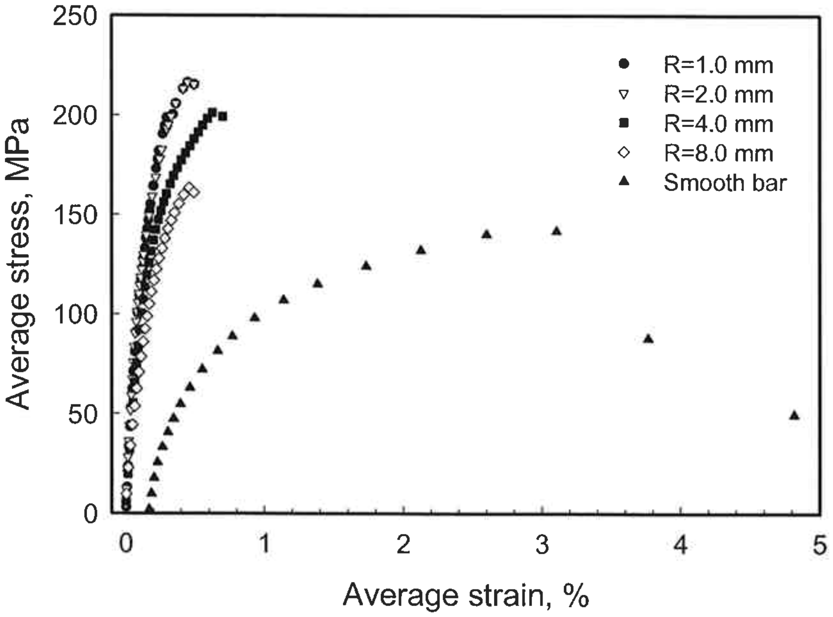


Figure 3 Nominal stress-strain relationships for the AZ91 Mg alloy

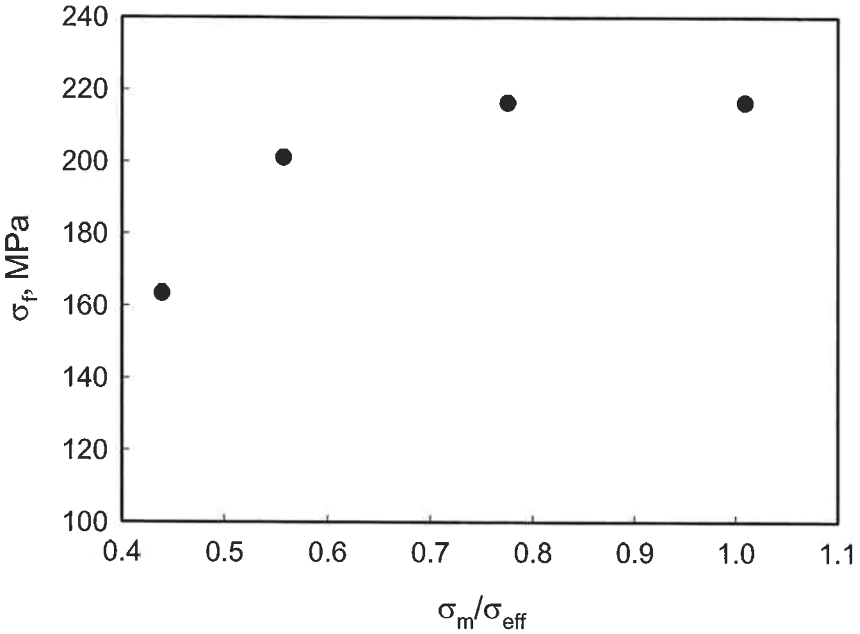
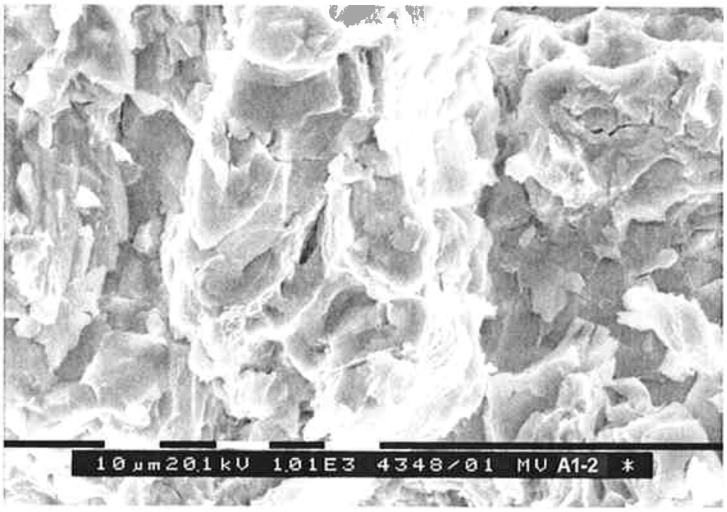
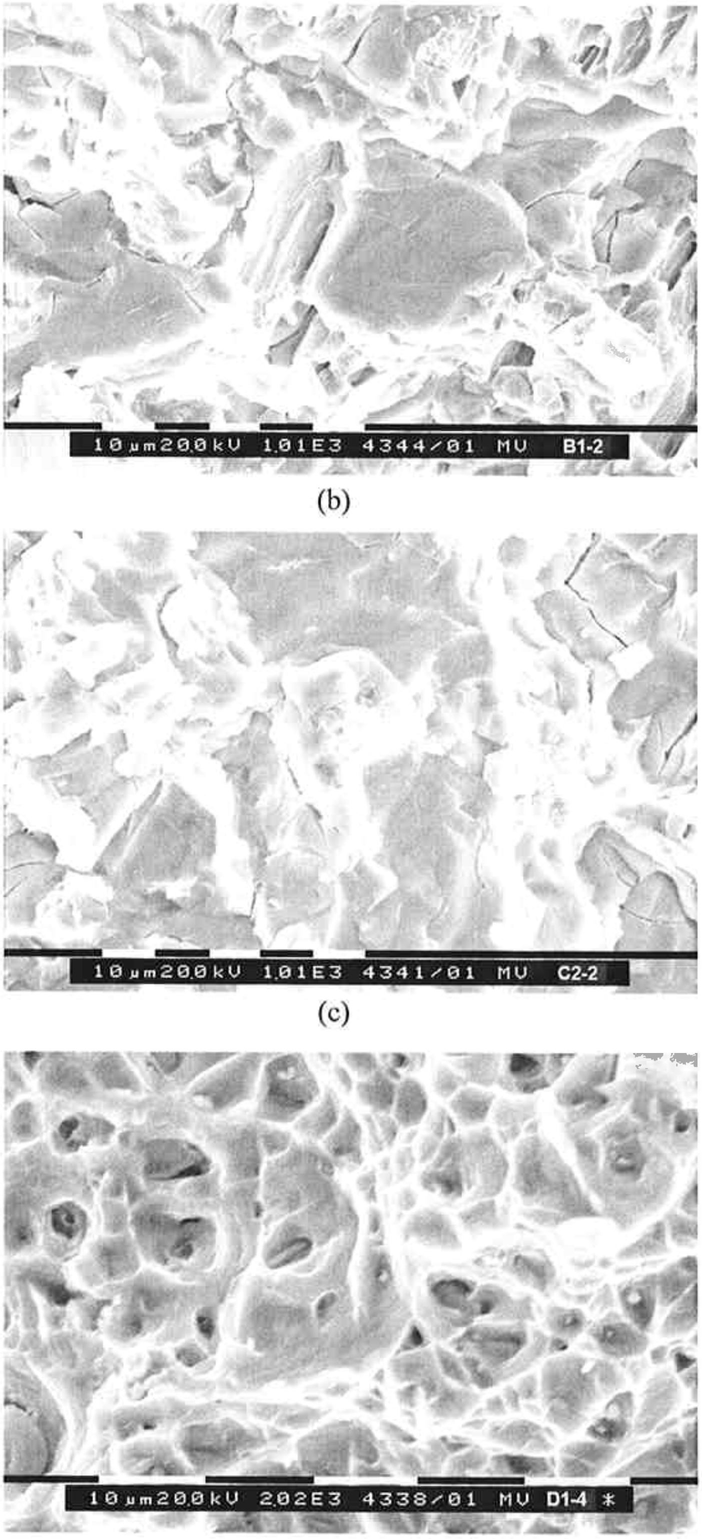


Figure 4 Variation of break stress with stress triaxiality

To gain a better understanding of the fracture mechanisms, the fracture surfaces for the specimens with various notch profile radii were observed using SEM and typical fracture surfaces are shown in Fig. 5.



(a)



(b)

(c)

(d)

Figure 5 Typical fracture surfaces for specimens with different notch profile radii: (a) R=1mm, (b) R=2 mm, (c) R=4 mm and (d) R=8 mm.

For the samples with notch profile radii of 1, 2 and 4 mm, the fracture surfaces are featured as quasi cleavage. There are many cleavage facets and small tearing ridges on the fracture surface. The average size of these facets decreases with decreasing the profile radius (increase of constraint).

Some secondary cracks perpendicular to the fracture surface are also observed. On the other hand, the fracture surface of the specimen with a larger notch profile radius (8 mm) is featured as a typical ductile fracture, evidenced by the existence of dimples due to the growth and coalescence of microvoids, Fig. 5 (d). It can be also observed that many inclusion particles are located in the bottom of these dimples. Therefore, there is an apparent transition from ductile tearing to cleavage with increase the constraint level. Further work on the ductile-brittle transition mechanism is required.

4 CONCLUSIONS

The results of the circumferentially-notched tensile test indicated that deformation and failure of the AZ91 magnesium alloy are very sensitive to constraint (stress triaxiality) level. Higher break strength is associated with the specimens with higher stress triaxiality. With increasing the stress triaxiality, the fracture mechanisms change from typical ductile tearing to quasi cleavage. Therefore, apparent embrittlement takes place in this alloy under a high constraint condition.

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