EFFECT OF TEMPERATURE ON THE MODE I FRACTURE BEHAVIOR OF A ROLLED MAGNESIUM ALLOY

S Arjun Sreedhar[1*] and R Narasimhan[1]

[1]Department of Mechanical Engineering, Indian Institute of Sceince, Bangalore, India
** Presenting Author email: arjunss@iisc.ac.in*

Abstract
The temperature dependence of the mode I fracture behavior of a rolled Mg AZ31 alloy having near basal texture is studied in this work through four-point bend fracture experiments in the temperature range from 25°C to 100^0C. It is found that the operative fracture mechanism changes from twin-induced quasi-brittle cracking to one mediated by ductile void growth and coalescence as temperature is raised above 65^0C. A concomitant reduction in tensile twin development near the crack-tip is observed with enhancement in temperature, while at the specimen far-edge it increases, resulting in pronounced texture changes at higher temperature. The reduction in tensile twin evolution with energy release rate and enhancement in micro-void growth rate near the crack-tip over the above temperature range are rationalized through simplified analyses. The change in fracture mechanism from brittle to ductile and higher dissipation due to tensile twinning at the specimen far-edge as temperature increases results in significant enhancement in fracture toughness.

1. Introduction

Magnesium alloys, due to their high strength to weight ratio, are being considered for automotive power train applications like transmission case and engine blocks. The operating temperatures of these components can be between 100^0C to 200^0C. Although, several experimental studies have been conducted with Mg alloys based on uniaxial loading or homogeneous states of stress at higher temperatures, no fracture tests have been reported. Hence, in this paper, recent mode I fracture experiments at 25^0C (room temperature or RT), 65^0C and 100^0C, performed using fatigue pre-cracked four-point bend specimens of a rolled Mg AZ31 alloy [1], are described. The results show brittle to ductile transition in fracture mechanism and strong elevation in toughness over the above temperature range.

2. Effect of temperature on fracture mechanism

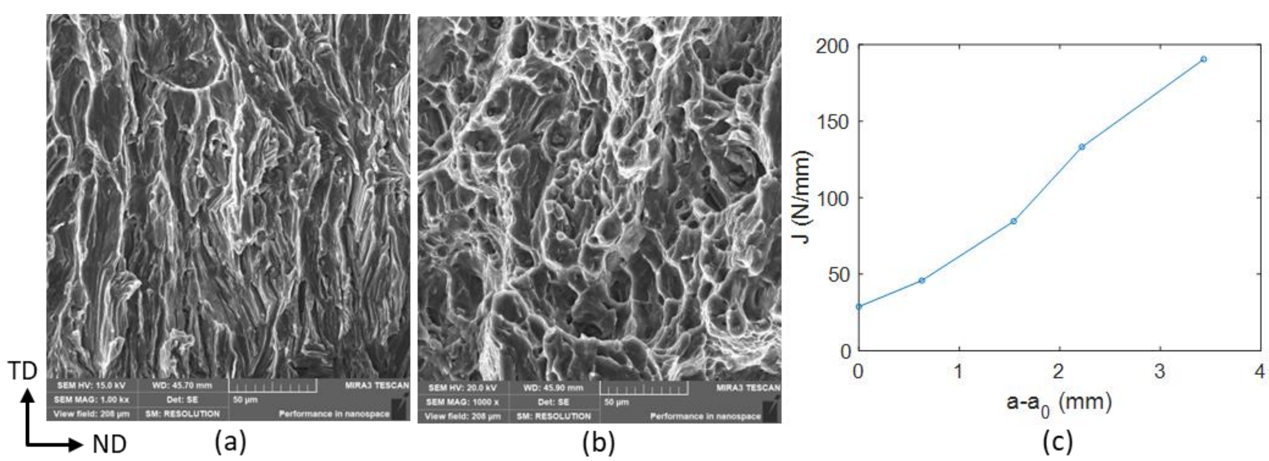

Fig. 1 SEM fractographs near fatigue pre-crack tip corresponding to experiments conducted at (a) RT and (b) 100^0C. (c) Crack growth resistance curve corresponding to RT (reproduced from [1]).

On examining the fractographs, pertaining to RT and 100°C taken near the pre-crack tip, shown in Fig.1(a) and (b), respectively, it can be seen that the former exhibits elongated ridges or grooves, while the latter displays dimples. The fracture surface pertaining to 65°C is also similar to Fig.1(a), which is attributed to twin-induced brittle cracking [1]. This establishes that brittle-ductile transition (BDT) happens near the crack tip for this Mg alloy above 65°C. Interestingly, as the crack grows, the fracture mechanism changes to ductile even at RT, resulting in dimple features as in Fig.1(b). This gives rise to strong crack growth resistance as can be observed from fig. 1(c). Thus, the energy release rate, *J*, almost doubles as the crack grows by about 1 mm, and the tearing modulus calculated over the range of crack extension, (a-a_0), from 0 to 2.2 mm is about 91, which is considerably high.

3. Effect of temperature on fracture toughness

Fig. 2(a), shows variations of *J* with applied load per unit thickness for the three temperatures. The value of *J* at crack initiation, J_c, at RT, 65 and 100^{0}C are 32, 39 and 108 N/mm, respectively (marked by solid circles on the respective curves). The above dramatic increase in J_c is attributed to the BDT in fracture mechanism as well as higher dissipation in the background due to tensile twins (TTs). This can be noted from more pronounced TT development at the specimen far-edge corresponding to crack initiation stage at 100°C as compared to RT (see figs.2(c) and (b)). Simplified analyses performed using the structure of elastic-plastic crack tip fields predicts a strong decrease in TT evolution rate with respect to *J* near the tip as temperature is raised from RT to 100°C, similar to experiments, which gives rise to the BDT.

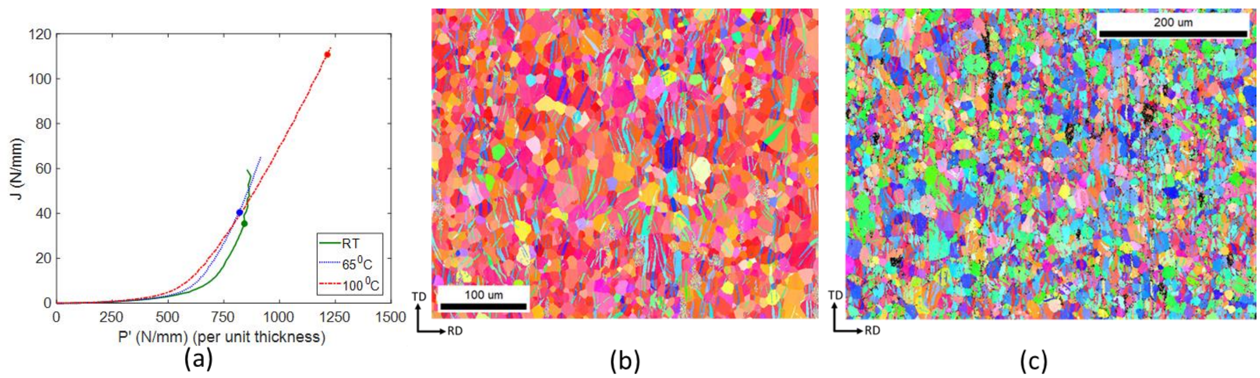

Fig. 2 (a) Energy release rate, *J* versus load per unit thickness, P'. Inverse pole figure (IPF) maps taken near specimen far-edge at crack initiation stage for (b) RT and (c) 100°C (reproduced from [1]).

4. Conclusions

Tensile twinning is found to play a pivotal role in the temperature dependent mode I fracture behavior of this Mg alloy. As the temperature is increased, tensile twin evolution near the tip is retarded while void growth and coalescence is promoted leading to ductile fracture. On the other hand, profuse tensile twinning at elevated temperature is observed at the ligament far-edge corresponding to crack initiation stage leading to more dissipation. Consequently, as the temperature changes from RT to 65^{0}C, J_c increases by about 22%, while a further elevation from 65^{0}C to 100^{0}C enhances it by a factor of 2.8.

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References

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