# TENSILE TWINNING: BANE OR BOON FOR FRACTURE OF MAGNESIUM ALLOYS

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**Abstract**
In this paper, an overview of recent experiments and some simulations aimed at understanding the fracture behavior of magnesium is presented. The effects of crystallographic orientation, notch acuity, temperature and strain rate are examined. The results show that tensile twins critically influence the fracture mechanism operative near a crack or notch tip. On the other hand, they contribute significantly to plastic dissipation and toughening. Also, they impart hardening which can retard micro-void growth.

## 1. Introduction

Magnesium alloys, which are attractive from the standpoint of light-weight structural applications, exhibit plastic deformation due to slip as well as twinning. The former involves basal and non-basal systems, while the latter includes tensile or $(10\bar{1}2)$ twins and contraction or $(10\bar{1}1)$ twins, which lead to extension and contraction, respectively, along the c-axis of the HCP lattice. Tensile twins (TTs) can widen rapidly and cause large lattice rotation. Also, there is a pronounced variation in critical resolved shear stress values amongst the various slip and twin systems. Consequently, based on the stress state, different deformation mechanisms can get triggered, which in turn, influence the failure behavior. In this paper, recent experiments and some simulations aimed at clearly understanding the role of TTs on the fracture response of Mg will be described.

## 2. Crack initiation and growth in Mg single crystals

Mode I fracture experiments were conducted [1] using notched Mg single crystal specimens under three point bending pertaining to three crystallographic orientations. Profuse tensile twinning was noticed around the notch tip for all orientations (see image quality (IQ) map, Fig.1(a)) leading to significant dissipation. From the optical metallograph shown in Fig.1(b), twin traces pertaining to two variants can be noted with the crack growing along twin boundaries and deflecting at twin-twin intersections (see MNO in detailed view, Fig,1(c)). Basal and prismatic slip traces labeled as S1 and S2 are also seen in Fig.1(b) with the former deflecting by about 86° inside a twin (refer KJIH in Fig.1(c)).

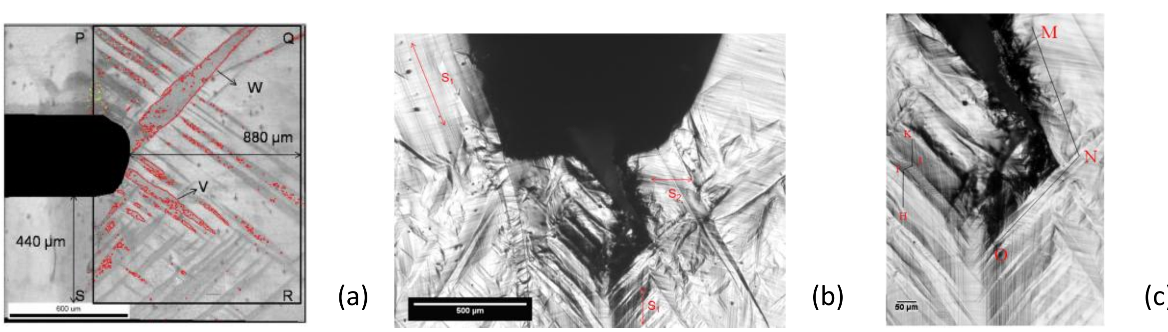


Fig.1 (a) IQ map showing numerous TTs near notch tip in Mg single crystal; (b), (c) Optical metallographs depicting traces of two TT variants, slip traces and extended crack (reproduced from [1]).

## 3. Effect of notch acuity, temperature and loading rate on fracture response of Mg alloys

In [2], fracture tests were carried out using four-point bend (4PB) specimens with notches and fatigue pre-cracks (FPC) of a rolled (basal-textured) AZ31 Mg alloy. Numerous TTs were observed in the grains around the notch / crack tip, with higher density in FPC specimens (Fig.2(a)). While quasi-brittle fracture surface features were noticed in FPC specimens (Fig.2(b)), dimples were seen in notched samples (Fig.2(c)) giving rise to strong increase in the toughness $J_c$. The former are attributed to twin induced micro-cracks (for example, *W* in Fig.2(a)). However, in both CT and 4PB specimens, TTs were perceived in the ligament, irrespective of notch size. Brittle-ductile transition (BDT) in fracture mechanism (due to retarded TT development near the tip) with increase in loading rate $\dot{J}$ and temperature $T$ (to 100°C) was reported in [3,4]. By contrast, at crack initiation stage, more TT-induced dissipation in the far-edge of the ligament occurs with elevation in both $\dot{J}$ and $T$, which along with the BDT, leads to dramatic enhancement in $J_c$.

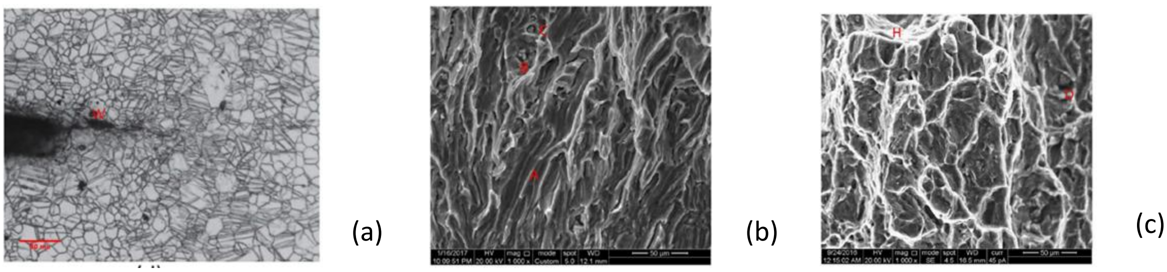


Fig.2(a) Optical metallograph displaying TTs in grains around crack tip in a rolled AZ31 Mg alloy. SEM fractographs of (b) a FPC and (b) a notched specimen (reproduced from Ref.[2]).

## 4. Effect of crystallographic orientation and TTs on void growth and coalescence

Plane strain (unit cell) finite element simulations of cylindrical void growth in Mg single crystals pertaining to two lattice orientations and several biaxial stress ratios λ were performed in [5]. Profuse tensile twinning occurs in the orientation where c-axis coincides with major principal stress axis leading to void coalescence by shear localization (Fig.3(a)). Also, it causes texture hardening and retardation in void growth prioir to lattice reorientation, which can be noted from variations of mean stress $\Sigma_m$ and void volume fraction $v_f$ with macroscopic strain $E_2$ (for $E_2 < 0.06$) displayed in Figs.3(b) and (c), respectively.

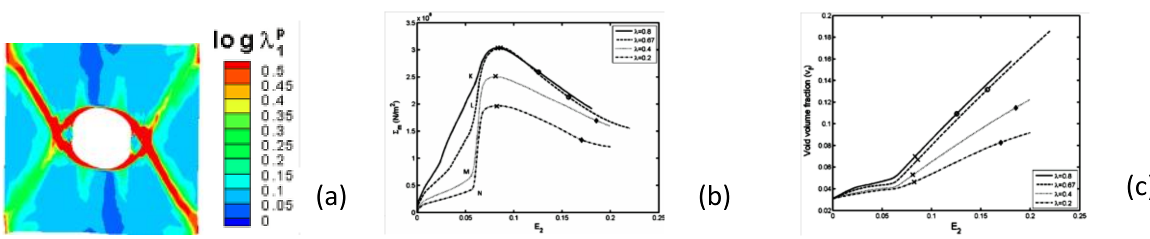


Fig.3(a) Contours of log( $\lambda_1^p$ ) corresponding to λ=0.2 and variation with strain $E_2$ of (b) $\Sigma_m$ and (c) $v_f$ for lattice orientation where c-axis is along major principal stress axis $X_2$ (reproduced from Ref.[5]).

## 5. Conclusions

Rapid evolution of TTs near the crack tip leads to quasi-brittle failure. However, it is impeded due to reduction in near-tip stress levels caused by increase in notch size, loading rate and temperature giving rise to BDT. This coupled with enhanced background dissipation and retardation in near-tip void growth rate by TTs can significantly enhance $J_c$. Thus, TTs have contrasting effects on fracture response of Mg.

## References

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