

Twinning-Induced Mechanical Anomalies in Magnesium Wrought Alloy AZ31

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Introduction

Twinning is an important deformation mechanism in hexagonal close-packed (hcp) metals which possess an insufficient number of slip systems. Thus, mechanical behaviors of hcp metals are significantly affected by the activation of twinning. For example, the low stress required for the activation of tension twinning on {1012} plane in Mg alloys results in strong yield asymmetry [1]. Since twinning mechanism is different from that involved with slip (e.g., polarities of the required shear stress and resultant shear strain, atomic shuffles and radical reorientation of crystal), twinning-dominant deformation or that mixed with twinning and slip may result in interesting mechanical properties which could not be expected in slip-dominant deformation. Here, we report two mechanical anomalies we have found in textured AZ31: one is negative strain rate sensitivity (nSRS) and the other is auxeticity (i.e., contracts laterally when compressed).

Experimental Procedures

Samples for tension (rod type: 6mm and 25 mm in diameter and gage length, respectively) and compression (cylindrical type: 12 mm and 18 mm in diameter and height, respectively) tests were machined from the AZ31 plate with strong basal texture (Fig. 1(a)) in three different ways (Fig. 1(b)) in order to investigate orientation effects on mechanical properties. Monotonic tension and compression tests were conducted at room temperature at strain rate of 0.001/s while strain rates were changed from (to) 0.0005/s to (from) 0.005/s for strain rate jump up/down tests. Interrupt tests were also conducted in order to measure the lateral strains and to characterize the microstructures developed at the strains of interest.

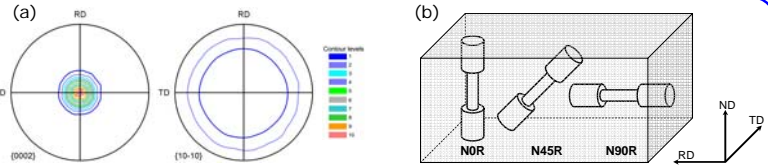


Figure 1. (a) Texture, represented by basal and prism pole figures, of as-received AZ31 plate from which samples for tension and compression tests were machined in three different ways: the majority of c-axes of the materials are parallel to the ND, and to the direction tilted from the ND to the RD by 45° and to the RD, respectively, in NOR, N45R and N90R samples.

Results

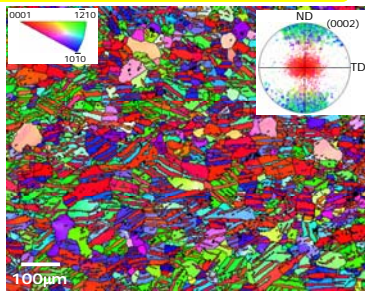


Figure 2. EBSD microstructure of N90R(c) sample which was deformed in compression to true strain of 0.025. (0002) pole figure (inset) reveals that ~40% of microstructure is twinned (appeared as red in pole figure).

Table 1. Summary of variations of twinning activity in AZ31 alloy with starting orientation and strain.

	True strain, ϵ				
	0	0.04	0.08	0.12	0.16
NOR (t)	tt (+++)	tt (+)	ct (+)	ct (++)	
NOR (c)	ct (+)	ct (+++)			
N45R (t)	tt (++)	ct (o)	ct (o)	ct (o)	
N45R (c)	tt (++)	ct (o)	ct (+)	ct (++)	
N90R (t)	ct (o)	ct (+)	ct (++)		
N90R (c)	tt (++)	tt (+)	ct (+)		

(+++): very high; ++high; +: moderate, o: weak

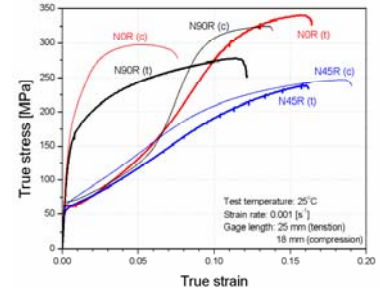


Figure 3. Orientation effects on yield asymmetry between tension and compression and on hardening behavior of AZ31. The NOR and N90R samples exhibit high asymmetry which is, however, not pronounced in the N45R sample.

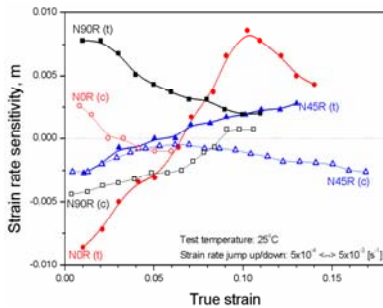


Figure 4. Effects of strain and orientation on SRS. Note that except N90R (t) sample, all the samples exhibit nSRS at least within a limited ranges of strain and that strains at which nSRS appear correspond to where extensive twinning takes place.

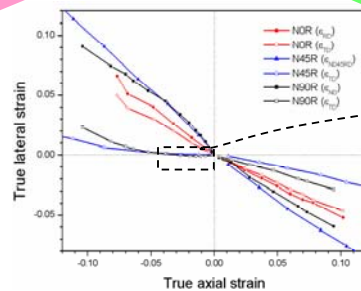


Figure 5. Variations of lateral strains with axial strain. Except N90R(c) sample, all the samples exhibit linearity.

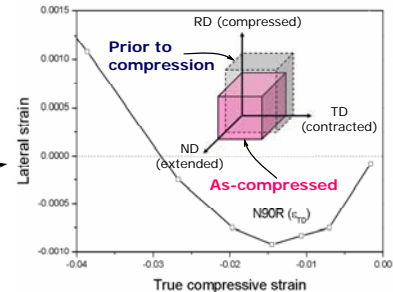


Figure 6. Variation of lateral strain along the TD with increasing compressive strain in N90R (c) sample. The lateral strain increases negatively with compressive strain, peaking at $\epsilon = -0.015$, and shows transition to positive value at $\epsilon = -0.03$. The lateral strain along the ND, on the other hand, increases much rapidly in order to maintain volume constancy.

Discussion

All deformed AZ31 samples exhibited twins (Fig. 2) although the extents and types of twinning varied depending on starting texture, deformation mode and strain (Table 1). Activation of twinning, especially tension twin on {1012}, led to significant yield asymmetry between in tension and compression and to different work hardening behaviors (Fig. 3) as reported previously [1]. Strain rate jump tests revealed that some of the samples exhibit nSRS and that the strain regimes where nSRS is found correspond to the regimes of extensive twinning (Table 1 and Fig. 4), which hints an involvement of twinning in nSRS. Although an attempt has been made to model the effect of twinning on SRS [2], the fundamental mechanism involved has not been clearly understood. A possible explanation for twinning-induced nSRS is that slip requires the higher stress at higher strain rate so that the imposed strain is accommodated more by twinning that has the lower resolved shear stress. In addition, auxeticity was observed in AZ31 sample (N90R) deformed in compression (Fig. 6). This counter-intuitive behavior is found to be a direct result of extensive tension twinning, which is proved by a theoretical calculation in which tension twinning in Mg single crystal is assumed to be a sole mechanism responsible for deformation (Fig. 7). Since the extent of auxeticity is proportional to the extent of twinning, the auxeticity is expected to increase with decreasing temperature.

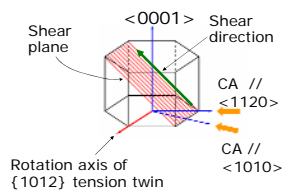
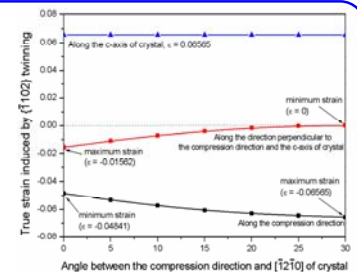


Figure 7. Twinning-induced lateral strains in Mg single crystal. Depending on the crystallographic planes {hkil} on which external compression is applied, the lateral strain varies between -0.01562 and 0. This calculation proves the fact that auxeticity in AZ31 is caused by extensive twinning.



Conclusions

Extensive twinning in AZ31 results in various mechanical anomalies including yield asymmetry between in tension and compression, anomalous hardening behavior, negative strain rate sensitivity and auxeticity. The twinning-induced nSRS implies that when deformation twinning is involved, changes in deformation behavior under varying strain rate cannot be explained based solely on dislocation model in which measurements of SRS provide a key link. Accordingly, dislocation model based explanation for SRS in the metals where twinning can be involved with deformation might be misleading, which thus needs to be revisited. Auxeticity found in AZ31 is a direct result of extensive tension twinning and, thus, is the first finding of *plastically* auxetic behavior. This counter-intuitive property in Mg may expand its application to functional devices such as robust shock-absorbing materials, fastener or strain amplifier [3].

References

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