EFFECT OF TWINNING ON THE LARGE STRAIN TORSION OF EXTRUDED AZ31 BARS

P.D. Wu[*a)], H. Wang[*], K.W. Neale [**]
[*]*Department of Mechanical Engineering, McMaster University,*
Hamilton, Ontario, Canada
[**]*Faculty of Engineering, University of Sherbrooke*
Sherbrooke, Quebec, Canada

Summary We study the large strain torsion of magnesium alloy AZ31 extruded bars, with emphasis on the influence of twinning on the second-order axial effects. All the simulations are based on the recently developed EVPSC model for polycrystalline materials. It is demonstrated that twinning has a significant effect on large strain torsion of magnesium alloy AZ31 extruded bars.

Introduction

It has been noticed that most of the experimental and numerical research on the large strain behaviour of polycrystals with the hexagonal close packed (HCP) crystallographic structure have been restricted to tension and compression along different directions. However, it is expected that some important mechanical behaviours associated with shear might not be revealed by studying these tension and compression deformation processes. Although large strain shear can be obtained through a simple shear test, it seems that a torsion test provides an ideal means to study large strain behaviour dominated by shear deformation. Extensive experimental and numerical research has been performed on large strain torsion for polycrystals with the cubic crystallographic structures. However, there are rare investigations on the torsion of HCP polycrystals. Furthermore, all the numerical studies on large strain torsion of HCP polycrystals have excluded twinning.

In the present study, we numerically simulate large strain torsion of magnesium alloy AZ31 extruded bars by using the special purpose finite element designed by Wu and Van der Giessen [1]. All the simulations are based on the large strain elastic viscoplastic self-consistent (EVPSC) model for polycrystalline materials developed by Wang et al. [2], which includes both slip and twinning as plastic deformation mechanisms. The influence of twinning on the axial effects is emphasized.

Results and Discussions

We consider a solid circular bar with radius R_0 and length L_0 subjected to an angle of twist ψ due to an applied torque M. The lateral surface of the bar is stress free, and all properties are assumed to be axisymmetric and homogeneous along the axial direction. The end faces of the bar are constrained to the extent that they remain plane and perpendicular to the axial direction, so that we may assume that any cross-section of the bar remains planar. We further assume that the behavior remains axisymmetric and the bar remains circular cylindrical with current radius R and current length L. The results of large strain torsion of a circular solid bar are efficiently presented in terms of the following quantities:

$$\Gamma = \frac{R_0}{L_0}\psi, \quad \bar{\tau} = \frac{3M}{2\pi R_0^3}, \quad \bar{\sigma} = \frac{F}{\pi R_0^2}, \quad \bar{\varepsilon} = \ln\left(\frac{L}{L_0}\right) \tag{1}$$

Here, Γ represents the shear strain at the outer surface of the bar. $\bar{\tau}$, $\bar{\sigma}$ and $\bar{\varepsilon}$ are the normalized torque, axial force and axial strain, respectively.

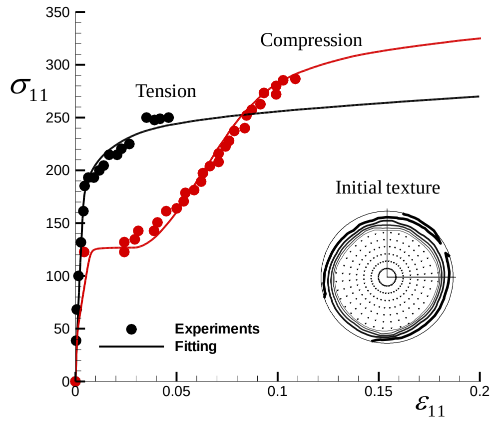


Fig. 1. Stress and strain response of AZ31 bar under uniaxial tension and compression along the ED. The insert is the initial texture represented in terms of the {0001} pole figure. The reflecting surface is normal to the ED.

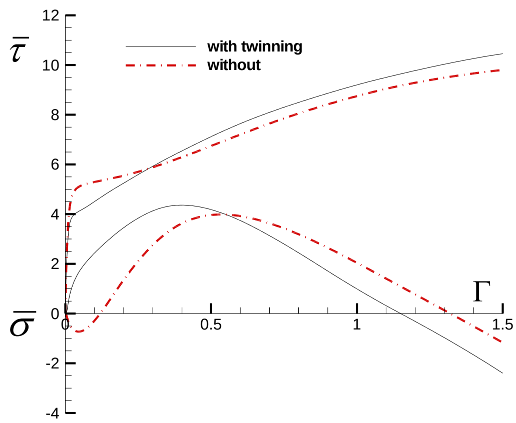
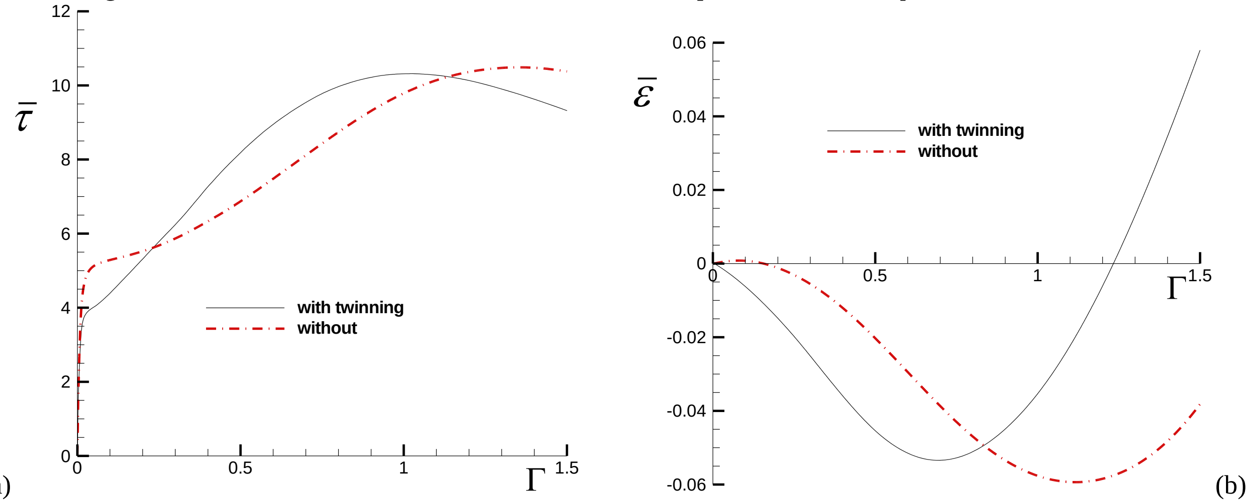


Fig. 2. Predicted effect of twinning on normalized shear stress $\bar{\tau}$ and axial stress $\bar{\sigma}$ under fixed-end torsion.

[a)] Corresponding author. Email: peidong@mcmaster.ca

The EVPSC model developed by Wang et al. [2] for polycrystalline materials is a completely general elastic visco-plastic, fully anisotropic, self-consistent polycrystal model, applicable to large strains and to any crystal symmetry. Recently, Wang et al. [3] found that the Affine self-consistent scheme gave the best overall performance among the self-consistent approaches examined. Therefore, the EVPSC model with the Affine self-consistent scheme is applied to numerically study large strain torsion of HCP polycrystals. The material considered here is the magnesium alloy AZ31 extruded bar, which has been experimentally studied by Agnew et al. [4]. The {0001} pole figure of the texture (Fig. 1) shows that the grains tend to have their basal planes oriented parallel to the extrusion direction (ED) of the bar. The basal slip, prismatic slip and pyramidal slip as well as extension twinning are selected as the deformation modes in AZ31. Values of the hardening parameters for each mode are estimated by fitting numerical simulations of uniaxial tension and compression along the ED to the corresponding experimental flow curves (Fig. 1). The values of these parameters will be used in subsequent simulations. From Fig. 1 it is clear that the characteristic S-shape of the compressive flow curve clearly reveals the importance of twinning in compression. The macroscopic yield stresses for uniaxial compression and tension are about 120 MPa and 190 MPa, respectively, showing the strong tension/compression asymmetry associated with twinning. The EVPSC model with the Affine scheme fits the experimental curves quite well.



(a) (b)

Figure 3. Predicted effect of twinning on (a) normalized shear stress $\bar{\tau}$, and (b) axial strain $\bar{\varepsilon}$ under free-end torsion.

The most significant difference in plastic deformation between HCP polycrystals and cubic polycrystals is that while most cubic polycrystals are deformed solely due to crystallographic slip, both slip and twinning contributes to plastic deformation in HCP polycrystals. Therefore, it is of great interest to assess the effects of twinning on large strain torsion of HCP polycrystals. Figure 2 shows the predicted effect of twinning on the normalized shear stress $\bar{\tau}$ and axial stress $\bar{\sigma}$ under fixed-end torsion. The fixed-end condition is imposed by invoking $\bar{\varepsilon} = 0$ and thus allows the development of an axial force F. A compressive axial stress is observed at very small strains when twinning is excluded, while a tensile axial stress is obtained when $\Gamma < 1.15$ if twinning is included. Figure 3 shows the predicted effect of twinning on the normalized shear stress $\bar{\tau}$ and axial strain $\bar{\varepsilon}$ under free-end torsion. The free-end condition is imposed by forcing $F = 0$ and thus allows for an axial strain $\bar{\varepsilon}$. The large tensile elongation at large strains is clearly due to twinning. Furthermore, excluding twinning significantly reduces the softening effect in the $\bar{\tau}$ vs. Γ curve. From Figs. 2 and 3 it is clear that twinning has a significant influence on the large strain torsion of HCP polycrystals. Therefore, in order to study the mechanical behaviour of HCP polycrystals under large strain torsion it is necessary to include both slip and twinning as deformation mechanisms.

References

[1] Wu P.D., Van der Giessen E.: *Archive of Applied Mechanics* 61: 89-103, 1991.

[2] Wang H., Wu P.D., Tomé C.N., Huang Y.: *Journal of the Mechanics and Physics of Solids* 58: 594-612, 2010.

[3] Wang H., Raeisinia B., Wu P.D., Agnew S.R., Tomé C.N.: *International Journal of Solids and Structures* 47: 2905-2917, 2010.

[4] Agnew S.R., Brown D.W., Tomé C.N.: *Acta Materialia* 54: 4841-4852, 2006.