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Micromechanical modelling of magnesium alloy and its experimental verification

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Abstract

Micromechanical modelling of magnesium alloys is presented. The applied model combines the crystal plasticity framework accounting for twinning with the self-consistent grain-to-polycrystal scale transition scheme. The mechanical response of the material in the experiments involving the strain path changes is studied, together with the prediction of the accompanying texture evolution. It is demonstrated that the evolution of microstructure has an important impact on the overall material behaviour. The model predictions will be verified in experiments performed on the rolled sheets made of AZ31B alloy.

Keywords: micromechanics, crystal plasticity, twinning, texture evolution

1. Introduction

For magnesium alloys, materials of hexagonal (hcp) lattice symmetry, the group of easy slip systems provides only two independent systems per grain. At room temperature, the lack of five independent slip systems, required for a general shape change of volume elements, is compensated by twinning. Activity of this mechanism of plastic deformation is thus beneficial in view of the stress reduction and enhancement of ductility. However, as a result, the development of strong crystallographic textures upon mechanical processing, e.g. rolling or extrusion is observed. The pronounced texture is the source of the strong anisotropy of mechanical properties of the produced components such as, for example, strong asymmetry between in-plane tension and compression for AZ31B sheets. This asymmetry is explained by the activity of different mechanisms of plastic deformation depending on the loading direction. In view of the above observations micromechanics seems to provide a natural tool enabling understanding and description of a relation between the microstructure of the above materials and their macroscopic (overall) properties, cf. [2].

In the contribution, with the use of the recently developed micromechanical model [1, 2], the AZ31B response and associated texture evolution are investigated in tension-compression cycles in view of the experimental results reported in [3]. Additionally, the results of own experimental studies on the material will be reported that will serve for further identification of microstructure-property relationship for this Mg alloy and validation of the proposed model.

2. Micromechanical model

2.1. Crystal plasticity framework

The constitutive model was formulated in [1, 2]. The large-strain crystal plasticity framework accounting for twinning is used. The vital components of the approach are presented below.

Twinning is described as a unidirectional slip mode, so that the shear rate on a twin system is calculated as

$$\dot{\gamma}^l = \gamma^{TW} \dot{f}^l , \tag{1}$$

where $\dot{f}^l$ is the rate of volume fraction of the twinned part created by the twin system l and γ^{TW} is the characteristic twin shear specified by the lattice geometry. Appearance of twin-related orientations in the texture image is accounted for by using the probabilistic twin volume consistent (PTVC) scheme. The method preserves consistency of twinning activity and the reorientation probability, so that the volume effect of twins on texture image is well reproduced. valid textures are predicted.

The rate of shear on the slip or twin system and the nonnegative resolved shear stress are related by the classical viscoplastic power law. The evolution of the critical shear stress (τ_c) for the subsequent modes follows the hardening law encompassing four types of interactions: slip-slip, slip-twin, twin-slip and twin-twin. In particular, it differentiates between impact of accumulated slip or twinning on the increment of τ_c. The impact of slip activity is described by the Voce-type law that accounts for the athermal statistical storage of moving dislocations and dynamic recovery. The impact of twinning activity is related to the geometrical effect of twin boundaries on deformation modes activity. The modification of mechanical properties of twins with respect to the matrix is also included in the model. More details concerning the formulation and its physical background can be found in [2].

The overall response of a polycrystal is determined by the self-consistent averaging procedure applied to a representative aggregate composed of individual grains. The self-consistent method makes use of the Eshelby solution obtained for linear elastic materials, therefore linearization of the material response is required. The results presented in the work are obtained with the use of the VPSC model of Lebensohn and Tome, in which the PTVC reorientation scheme and the hardening model have been incorporated.

2.2. Application to AZ31B alloy

Magnesium is a hcp material with $c/a = 1.624$. Following previous studies, cf. [2], three types of slip systems: basal, prismatic and pyramidal $\langle c + a \rangle$, as well as tensile twinning are assumed to be active. Among slip systems the pyramidal $\langle c + a \rangle$ system is the hardest mode, while basal slip and tensile twinning are easier to initiate. Material parameters of the model for AZ31B were identified in [2]. Experiments indicate that the rolled magnesium sheets exhibit the basal texture of axial symmetry in the

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sheet plane, e.g. [3]. Since strain along **c**-axis can only be accommodated by pyramidal $\langle c + a \rangle$ slip (a hard mode) or unidirectional twinning (only for extension along **c** axis), magnesium alloys show high asymmetry and anisotropy in mechanical properties. Such asymmetry has been observed in uniaxial tension-compression tests reported in [3]. The proposed model can be used to explain the observed material behaviour in light of the predicted active mechanism of plastic deformation. The selected results are presented in Figs 1-2. They concern samples loaded in the direction normal to the sheet plane.

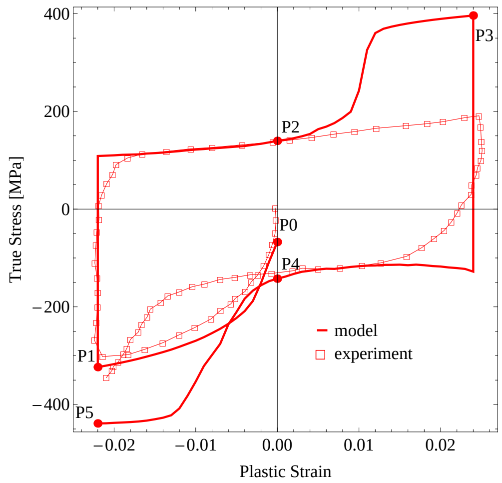

Figure 1: Compression-tension cycle in the direction normal to the AZ31B sheet plane - comparison of the model predictions and experiment [3]

Let us shortly analyze the results. For the initial compression (P0-P1), the strain is accommodated by basal and pyramidal $\langle c + a \rangle$ slip, next during subsequent tension (P1-P3) twinning is active. Its activity has a marked effect on texture: all the grains have been reoriented due to twinning, so that at the end (P3) all basal planes are perpendicular to the sheet plane. It enables activity of twinning mechanisms in the reoriented grains (i.e. detwinning) during subsequent compression (P3-P5). Again almost all the grains are reoriented, so that the texture returns to the original basal texture (P5). It is expected that such behaviour will be repeated during subsequent cycles. The simulated textures reproduce well experimental ones reported in [3]. The observed discrepancy between the experimental and simulated stress-strain curves stems from the fact that in the model twinning activity stops earlier than in the experiments.

3. Experimental verification

In order to verify the model the uniaxial tension tests will be performed on samples prepared form AZ31B sheet of 1 mm thickness. The preliminary result of tension tests is shown in Fig. 3, together with the microstructure of the as-received material obtained using Scanning Electron Microscope (SEM). The presence of initial twins is observed. In order to reduce the presence of mechanical twins in the initial state the samples were annealed at 350^{o}C for 2h and cooled slowly in the furnace.

Two-step tension tests will be performed. First the large sample will be pre-strained up to the pre-defined strain level in order to induce an asymmetry of the initial texture in the sample plane, as expected on the basis of modelling predictions [2]. Next, the smaller samples will be cut from the prestrained material at the selected angles with respect to the loading direction. The experiments will be performed till rupture and up to the specified strain with the proceeding unloading of the sample. The initial and final texture will be measured. The next step will be the study of the samples response in tension-compression cycles.

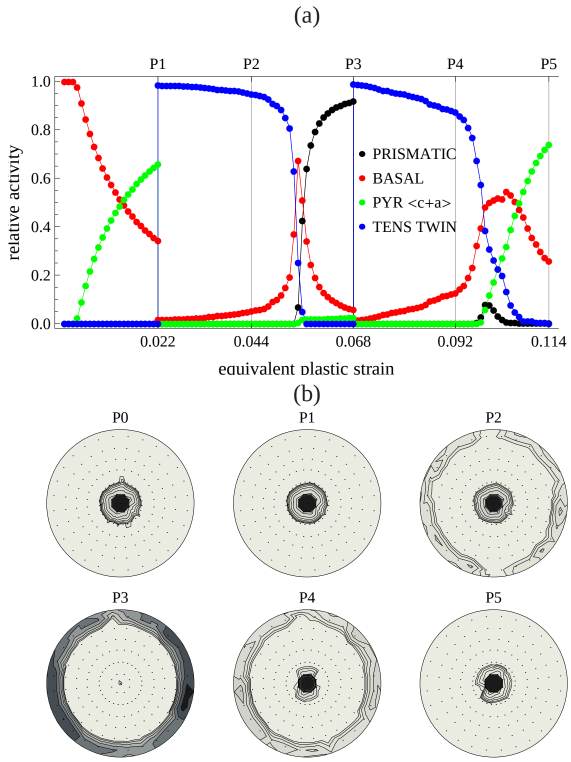

Figure 2: (a) Relative activities of the deformation modes and (b) texture evolution (the (0001) pole figure with a sheet plane as a projection plane) predicted by the model for the compression-tension cycle in Fig. 1

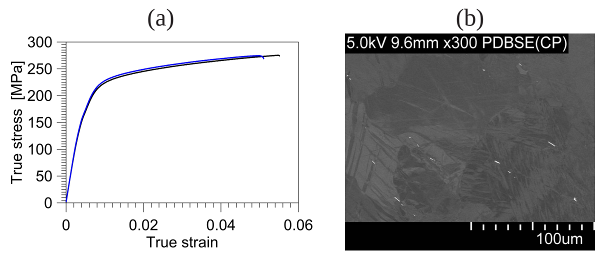

Figure 3: Preliminary in-plane tension test of AZ31B sheet: (a) stress-strain curve, (b) initial microstructure (SEM)

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