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Cyclic behavior of extruded magnesium: Experimental, microstructural and numerical approach

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ABSTRACT

The present study aims at determining the influence of cyclic straining on the behavior of pure extruded magnesium. For this purpose, tensile, compressive and cyclic tests are performed (small plastic strains are applied ($\Delta\varepsilon^p/2$ = 0.1% and 0.4%). Deformation mechanisms (slip and twin systems) have been observed by TEM and the different critical resolved shear stress (CRSS) have been determined. Based on microscopic observations, a crystal-plasticity-based constitutive model has been developed. The asymmetry between tensile and compressive loadings mainly results from the activation of hard slip systems in tension (such as $\langle a\rangle$ pyramidal and prismatic and $\langle c+a\rangle$ pyramidal glides) and twinning in compression. It is shown that basal slip is very easy to activate even for small Schmid factors. Numerical simulations reveal that untwinning in tension subsequent to compression must be considered to correctly fit the experimental S-shaped hysteresis curves. TEM observations indicate also intense secondary slips or twins inside the mother twins under cyclic conditions, so that twinning in compression and dislocation glide in tension are affected by cycling. The polycrystalline model allows to predict slip activities and twin volume fraction evolutions.

1. Introduction

Magnesium alloys are increasingly used for lightweight structural components in automotive industry. Vibrations in moving vehicle lead to cyclic loading of the components and necessitate focusing on fatigue behavior of magnesium alloys. Although cast alloys are more generally used, cast defects tend to limit ductility. Wrought alloys offer better mechanical properties but the strong crystallographic texture inherited from the deformation process leads to strong anisotropic properties. More particularly in terms of cyclic loading, hysteresis loops are asymmetric under strain-controlled tests (Zenner and Renner, 2002; Nobre et al., 2002; Noster and Scholtes, 2003; Lou et al., 2007) and compressive ratcheting is observed under symmetric stress-controlled tests (Lamark et al., 2002).

Previous works do not agree on the activated slips to accommodate deformation at room temperature in the hexagonal close packed (HCP) magnesium and Mg alloys. HCP magnesium presents a limited number of slip systems. Five independent slip systems are needed to accommodate a general isochoric plastic strain rate tensor that can be found during the deformation of a polycrystalline material. Due to very low critical resolved shear stress (CRSS), of the order of 1 MPa, basal slip, i.e. slip on the (0001) plane with $\langle 11\bar{2}0\rangle$ Burgers vector, is unanimously reported as the easiest to be activated. Prismatic $(10\bar{1}0)$ $\langle 11\bar{2}0\rangle$ and pyramidal $(10\bar{1}1)\langle 11\bar{2}0\rangle$ slips are also reported (Couret and Caillard, 1985) although their CRSS are 40–100 times larger than for basal slip (Partridge, 1967; Reed-Hill and Robertson, 1957; Reed-Hill and Robertson, 1957) and although some

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