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Origin of the twinning to slip transition with grain size refinement, with decreasing strain rate and with increasing temperature in magnesium

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Abstract—The aim of this paper is to elucidate the origin of the transition from twinning to slip dominated flow in pure Mg. With that purpose, two polycrystals with average grain sizes of 19 and 5 μm were prepared by rolling and annealing and they were tested in compression along the rolling direction at strain rates ranging from 10^{-3} to 10^{-5} s^{-1} and at temperatures comprised between 50 and 250 °C. Twinning was evaluated by conventional electron backscatter diffraction (EBSD) and the activity of different slip systems was measured by an exhaustive EBSD-assisted slip trace analysis. A transition from twinning to basal slip, localized along deformation bands, was found to take place with decreasing grain size, with decreasing strain rate and with increasing temperature. The emergence of basal slip as the dominant deformation mechanism is promoted in all three cases by increasing levels of connectivity between favorably oriented grains, which facilitate slip transfer across grain boundaries. Such connectivity is related to the fraction of grain boundaries (GBs) with misorientations smaller than a threshold value ($f_{\theta < \theta th}$) as well as to their local arrangement. Since processing for grain refinement results in larger $f_{\theta < \theta th}$ values and both decreasing strain rate and increasing temperature increase θ_{th}, in all cases twinning is eventually replaced by basal slip.

Keywords: Twinning; Grain size; Temperature; Strain rate; Trace analysis

1. Introduction

Mechanical twinning has been recognized as a key deformation mechanism in metallic materials [1]. Its role is especially important in hexagonal closed packed (hcp) polycrystals in which, at low temperatures, dislocation slip alone might not provide the five independent systems required for intergranular strain compatibility [2].

Furthermore, in hcp metals in which the c/a ratio is larger than the ideal value of 1.633, such as magnesium and its alloys, the room temperature critical resolved shear stress (CRSS) of tensile twinning is commonly lower than that of non-basal slip systems [3–5] and, thus, strain accommodation by twinning might be preferred even when a sufficient number of slip systems are potentially available. Despite the intense efforts devoted over the years to understand this intriguing deformation mechanism, many fundamental issues remain, to date, unclear. For example, the influence on twinning of microstructural parameters such as the average grain size (d), as well as of testing conditions like strain rate and temperature, are still not well understood. This paper focuses, in particular, on tensile twinning, which will be hereafter referred to as “twinning”.

The effect of grain size on twinning in magnesium at room temperature and quasi-static rates is still under debate [5–20]. First, although it is generally accepted that grain refinement gives rise to larger increases in the yield stress (σ_y) when twinning is the main deformation mechanism than when dislocation slip prevails [6–8], several conflicting views have been put forth regarding the nature of such grain size dependence. On the one hand, the grain size effect on yielding during twin-dominated straining has been modeled using a Hall–Petch (HP) type relation ($\sigma_y = \sigma_0 + kd^n$), where σ_0, the lattice friction stress, and k, the HP slope, vary widely with composition, texture, temperature and processing method [6–15]. This approach has, however, been recently called into question by a systematic statistical analysis of a large number of crystallites in a rolled high purity Mg polycrystal by Beyerlein et al. [16], who found no influence of grain size on whether or not at least one twin appeared in a specific grain. Second, the effect of d on the room temperature twinning activity is also still controversial. Some studies report a decrease of the twinning activity with grain refinement [7,17,18] as well as the occurrence of a twin to slip-dominated flow transition at a sufficiently low d value [7,19–21]. Different transition grain sizes have indeed been reported for Mg polycrystals processed using different methods. For example, Li et al. [19] observed the suppression of twinning for d values smaller than 2.7 μm in pure Mg processed by equal channel angular

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