Quantification of precipitate hardening of slip and twinning in Mg-5Zn using micro-pillar compression

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In magnesium-based alloys, the hexagonal close packed structure plastically deforms by both dislocation slip and mechanical twinning. This complex deformation behaviour controls yield asymmetry, texture development, ductility and work hardening rates. Understanding how each of these individual deformation modes behaves is therefore of critical importance for understanding the plastic flow of magnesium in engineering applications. Since polycrystalline deformation concurrently activates multiple deformation modes, in this work, we designed a micropillar compression test to activate only one deformation mode. These experiments are essentially single crystal tests, and were designed to develop a more fundamental understanding of the effect of precipitation on slip and on deformation twinning. The Mg-5%Zn alloy has been chosen for examination because it is known to exhibit significant precipitate strengthening, and this alloy was tested in the solution-treated and in the aged condition. It was found that precipitation causes moderate hardening of the basal slip system, and also significantly increases the work hardening rate. Precipitation had little effect on specimens compressed in the c-axis.

Examination of twinning posed an additional challenge, since twinning undergoes a well-defined nucleation event before twin growth occurs. In this work, we separated the nucleation stress and the growth stress of twinning by compression of micropillars containing a pre-existing twin through the centre of the specimen, see below. Micropillar compressions had a similar shape in their flow curve to macroscopic single crystals, but contrary to published literature, these samples showed a strong size effect. Taking this into account, the critical stress for growth of twins in magnesium is found to be ~7 MPa which is consistent with previously published measurements on macroscopic single crystals . These experiments have been used to deduce the precipitate hardening of twin growth, and for the present precipitate dispersion this has been measured to be 30 MPa. Backstress calculations based on elastic bending of the precipitates showed close agreement to the measured precipitate hardening, and this model therefore accounts well for the observed strengthening. Site specific atom probe tomography of the twin boundaries showed that room temperature ageing was sufficient to produce segregation of zinc to the twin boundary. This was found to immobilize the twin, and is believed to be the first report of solute locking of twins from room temperature exposure. Twin nucleation stresses were found to be unaffected by precipitates or solutes.