Improved Formability of Magnesium and Magnesium Alloy AZ31 by Texture and Microstructure Control
by
Petra Backx

Abstract

During the last few decades the world has seen a growing demand for magnesium alloys in almost every field of today’s metals consuming industry. The largest consumer is the automotive industry, driven by the commitment to reduce the emission of a car and thus the weight of car components. However, the number of possible applications of magnesium alloys is strongly reduced by the limited ductility and the mechanical anisotropy of this material, mainly caused by its hexagonal crystal structure. Magnesium research nowadays focuses on attempts to improve the ductility and reduce the anisotropy by alloy development, changes in process steps or the development of innovative forming processes.

First, a literature review is presented concerning the different deformation mechanisms, observed in magnesium and AZ31, and the influence of these mechanisms on texture, microstructure and mechanical properties after deformation. This review shows that one way to reduce the mechanical anisotropy is the create a material with a random texture. Apart from the anisotropy, ductility is also influenced by this texture. Improving the ductility can be obtained by both texture control and grain refinement. It is noticed, however, that there is a lack of accurate data concerning the activation of the different deformation mechanisms, in particular no data can be found on the CRSS (= Critical Resolved Shear Stress) as a function of temperature, strain rate and alloy composition. These data are necessary to get a better insight in the deformation behaviour of magnesium.

This research aims at improving the formability of the currently most used wrought magnesium alloy, namely AZ31. The two main alloying elements, aluminium (3wt%) and zinc (1wt%), cause solid-solution hardening and grain refinement, causing an improved strength and ductility in comparison with pure magnesium. In a first stage, experimental techniques as well as modelling were used to obtain critical values for the initiation of twinning, basal slip, c+a slip, DRX (= Dynamic Recrystallization) and the formation of microcracks. In a next stage, the obtained knowledge was applied in an attempt to improve the deformation behaviour of AZ31 at room temperature.

Experimental stress-strain curves were recorded, showing the behaviour of pure magnesium and AZ31 at different temperatures and strain rates during uniaxial compression. These data were used to calculate the strain hardening rate $\theta$ as a function of strain $\epsilon$. Critical stress and strain values were obtained from the inflection points in these $\theta$-$\epsilon$ curves. By comparing these data with optical microstructures and texture measurements of samples deformed to the obtained critical strains, it was shown that the inflection points
coincide with the activation of twinning and DRX and the formation of microcracks in the samples. In both materials, the critical stress values for twinning are found to be independent of temperature and strain rate. The obtained critical stress values for the formation of microcracks are seen to be a function of temperature in pure magnesium. Not enough data are available to determine the temperature dependence of this critical stress in AZ31. The critical stress for the initiation of DRX in both pure magnesium and AZ31, shows an exponential behaviour as a function of strain rate and a linear behaviour as a function of temperature. The described method for the determination of critical stresses can in the future easily be applied to other materials.

In a subsequent stage of this work, the VPSC (= Visco-Plastic Self-Consistent) code of C. Tomé was employed. This code allows to simulate the stress-strain behaviour and hardening observed during uniaxial compression, as well as the texture evolution during deformation. A very good agreement was obtained between experimental and modelled stress-strain curves. The texture evolution during deformation was modelled correctly, but modelled textures were seen to evolve faster, leading to correct textures at lower stresses and strains compared to the experimental data. This modelling work has resulted in a description of the CRSS for both twinning and basal slip in pure magnesium and AZ31. The obtained CRSS values for basal slip are found to depend on the strain rate and the accumulated shear strain. Application of the VPSC code also resulted in an estimate for the CRSS for the initiation of $\mathbf{c+a}$ slip.

During this research, both twinning and DRX were seen to play an important role in the deformation of AZ31. Both deformation mechanisms were studied in detail.

The evolution of twins in AZ31 during compression and subsequent annealing was examined. Increasing the strain during uniaxial compression at room temperature was seen to result in the expansion of twins. Annealing treatments resulted in both shrinking and expanding twins. Grains containing multiple twin variants and a high slip deformation after the formation of twins, were seen to cause shrinking of twins. It was also observed that the amount of strain prior to annealing, has an influence on the annealing behaviour of twins.

The progress of DRX was studied as a function of strain and the influence of strain rate and temperature were assessed. Optimal conditions were determined, in terms of strain rate and temperature, required to generate a fully recrystallized material with a low texture index (i.e. a texture as close as possible to a random texture). This random texture is important, as this will strongly reduce anisotropy and contribute to an enhanced ductility. A completely recrystallized material will lead to grain refinement, causing an improved ductility. A balance between both a high fraction recrystallized and a low texture index thus has to be found.

The obtained optimal parameters were combined with annealing treatments to lead to
a material with an improved formability. The key factors giving rise to this improved formability are grain refinement through DRX and texture control through controlled pre-deformation. AZ31 samples were produced with a formability of over 40% at room temperature and only a limited reduction in strength compared with the reference material obtained from the extruded bar.