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Effect of extension {1012} twins on texture evolution at elevated temperature deformation accompanied by dynamic recrystallization

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ABSTRACT

High temperature deformation processing of magnesium and its alloys is often accompanied by dynamic recrystallization (DRX). Deformation twinning is one of the main deformation mechanisms in HCP metals, but very few works are available in literature (experimental or modelling) which investigate the effect of the deformation twinning on dynamic recrystallization. The current study provides insights regarding the deformation mechanisms of magnesium alloy during compression test at elevated temperatures. The role of the extension twins in DRX is examined using a previously developed dynamic recrystallization model based on the crystal plasticity finite element approach. In order to consider extension twins, an EBSD IPF map with reoriented twinning elements is used as input. An entire element is reoriented into twin orientation and DRX proceeds within the new microstructure. This way, twins can serve as a nucleation site because they provide high angle grain boundaries. The results of compression simulations for extruded AZ31 Mg alloy are presented and validated with the experimental data available in the literature. The results show twinning when present affects the resultant texture as most of the new nucleating grains are clos eto the twin matrix interface and have twin orientation.

1. Introduction

The limited formability of magnesium and its alloys at room temperature leads to the need in high temperature deformation processing. High temperature forming of cast alloys is inevitably accompanied by dynamic recrystallization (DRX) driven by the stored energy associated with dislocations [15]. Magnesium has a hexagonal close-packed crystal structure, and limited slip systems available at room temperature. Deformation twinning is one of the main deformation mechanisms at room temperature and beyond. Extension twins appear when grains' c-axes are placed under tensile loading. While at room temperature extension twinning is a major deformation mechanism, elevated temperature tests reveal very few twinning [32,21,5]. This can be explained by thermal activation of non-basal slip systems, namely, pyramidal $\langle c+a\rangle$ slip system [9,16,4]. Since dynamic recrystallization in magnesium alloys was reported at temperatures as low as 150 °C [15], it is important to study the effect of the deformation twinning on DRX.

There are limited works available on deformation twinning behaviour and its effect on texture evolution during DRX. Martin et al. [27] assumed that extension twin boundaries are highly mobile, and therefore, they thicken rather than serve as a recrystallization site. The same assumption was made in the work by Ma et al. [25], where EBSD analysis showed the presence of twins during an extrusion of Mg AZ61 alloy at 450 °C, emphasizing the possibility of twins at high temperatures. The major suggestion was that at the elevated temperature in extrusion, $\langle c+a\rangle$ type dislocations are generated, which can also be favourable for deformation twinning [28]. In the work by Al-Samman and Gottstein [4] it was assumed that the deformation twinning can be a potential nucleation site for DRX, since the stored energy of twinning is higher than in the matrix. However, recrystallization that occurs inside twin lamellae was restricted within twin area, which was observed in the experimental studies of the single crystal, as in the work by Al-Samman et al. [6] for example. This observation was also confirmed by the other studies of single crystals under compression and tension at different temperatures [39,18,19]. Although in the same work by Al-Samman and Gottstein [4] it was also observed extension twins without recrystallization at the end of the deformation, and the reason why twins were left unrecrystallized was unknown, however, the authors suggested that they might have appeared during unloading of the sample.

The strain rate has bigger effect on the activation of twinning during high temperature deformation. Thus, at the strain rates $\dot{\varepsilon}<10^{-1}s^{-1}$, the effect of twinning was negligible at high temperature deformation [26], and some elevated temperature tests also revealed very few twins [32,4,21]. However, Dudamell et al. [11] reported high amount

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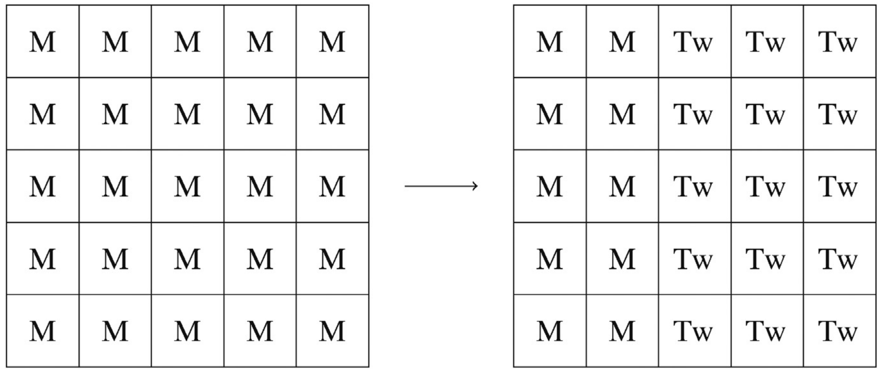

Fig. 1. Schematic representation of the twin incorporation into the mesh.

of twins during uniaxial tension and compression at dynamic strain rates, and it was shown in the work of Li et al. [22] that the texture evolution is more sensitive to strain rate at 400°C in AZ31 Mg alloy. Galiyev et al. [12] in their work reported active twinning, basal and $\langle c+a\rangle$ slip systems during deformation at <200°C in ZK60 Mg alloy. Twins were observed in TEM analysis after hot torsion at temperatures between 180 and 360 °C and strain rates $10^{-2}s^{-1}$ and $1.0s^{-1}$ [29]. As the temperature decreased, the twin boundaries became less sharp and resulted in serrated boundaries, which are often the precursors of DRX. Spigarelli et al. [33] studied high temperature formability of AZ31 between 200 °C and 400 °C. They found that at lower temperatures there was very little DRX and twinning is observed. While at higher temperatures that there was recrystallization but little twinning was observed.

Commercial magnesium alloy *AZ*31, the main material discussed in this work, has a strong basal texture, and therefore, different slip and twinning systems are active depending on the loading direction. The DRX behaviour of *AZ*31 Mg alloy has been studied at different temperatures and strain rates via experiments [29,4,34]. The experimental results showed that the initial texture has a significant effect on the stress-strain response as well as on the twinning behaviour at different temperatures and strain rates [8,38,11,22]. In the work by Srinivasarao et al. [35], it was concluded that {1012} twins appeared at the initial stage of the deformation before DRX started, and twinning was not a dominant deformation mechanism above 200°C. Tension and compression tests at the temperature range of 200°C and 400°C and strain rates $10^{-2}s^{-1}$ and $10^{-4}s^{-1}$ of *AZ*31 showed that during 200°C compression test along extrusion direction (ED), most of the grains undergo twinning [5]. The *c*-axis of HCP crystal was perpendicular to the compressive loading direction, which is favourable for the activation of twinning. A sign of active deformation twinning in the flow curves (plateau-type behaviour and rapid hardening) was present during the channel die compression of pure Mg and AZ31 alloy at 200°C and 300°C and the strain rate $10^{-4}s^{-1}$ [14,13]. Li et al. [23] presented experimental analysis that showed the relationship between twinning and DRX. They showed that the $<c + a>$ slip enhanced the DRX when twinning is active.

Based upon the review of the aforementioned works on the effect of the deformation twinning on dynamic recrystallization in magnesium alloys, it is concluded that there is a need in a research study of the effect of twinning during high temperature deformation to provide insights of the role of twinning during DRX.

Crystal plasticity models already have been an established tool to model grain level behaviour of the material. Since dynamic recrystallization is a grain scale problem, crystal plasticity is an ideal model to be utilized. The DRX-CPFE model presented in Popova et al. [30] showed a great potential in capturing the flow curve as well as texture evolution

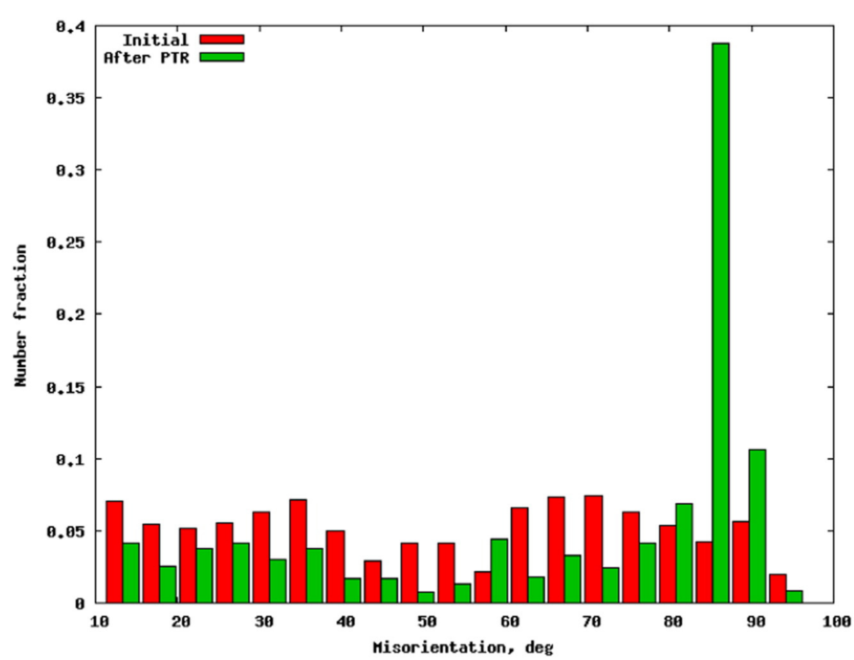

Fig. 2. Misorientation angle distribution: initial and after reorientation (degrees <10 are excluded).