Quantifying the Role of Coarse Intermetallic Particles on Twinning Behavior

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Abstract

Deformation twinning is a mechanism of critical interest in magnesium alloys and other HCP metals, both due to its ability to accommodate strain and its tendency to contribute to failure by providing a preferential crack pathway along twin boundaries. This deleterious behavior is worsened by instances of twin transmission, where a twin impinging on a grain boundary nucleates an adjacent, connected twin in the neighboring grain due to intense local stresses. Many commercial Mg alloys feature coarse grain boundary intermetallic particles in their as-produced state which potentially impede or exacerbate the localized stresses that play a role in both twin transmission and twinning behavior. Combined EDS-EBSD is used to analyze grain boundary particles, deformation twins, and transmission events to determine how particle morphology, position, and grain orientation modify twinning behavior and transmission likelihood and how these findings compare to computational results from Crystal Plasticity—Fast Fourier Transform modeling.

Keywords

Deformation twinning • Twin transmission • Intermetallic phases

Extended Abstract

Deformation twinning is a mechanism of critical interest in magnesium alloys and other HCP metals as it provides both beneficial and deleterious effects. Twinning enables magnesium alloys to accommodate strain in crystallographic directions that are relatively difficult to achieve through slip alone such as along the **c**-axis [1]. At the same time, twin boundaries can serve as a preferential crack pathway which can contribute to premature failure of Mg parts during fabrication or service [2, 3]. Understanding and control of twinning behavior are thus crucial for producing tough and formable parts, as well as for broadening the application space of magnesium alloys.

This deleterious behavior of twinning is made worse by instances of twin transmission, where the intense local stresses caused by a twin impinging upon a grain boundary induce the nucleation of a new twin in the neighboring grain that can then propagate, grow, and potentially transmit across yet another grain boundary. Transmission results in a pair of adjoined twins that form a continuous twin boundary across the grain boundary, providing a longer pathway for a crack to follow. As twin transmission is more favorable across grain boundaries with low misorientation [4, 5], highly textured material is particularly susceptible to transmission events and the potential formation of long chains of twins across many grains, leading to a long, continuous twin boundary which can greatly contribute to premature brittle failure [6].

Many commercial Mg alloys feature intermetallic particles in their as-produced state, such as the β-$Mg_{17}Al_{12}$ phase in Mg–Al alloys [1, 7]. While the effects of the nanoscale intragranular precipitates on twinning behavior have been studied extensively [8], little research has been done on the coarse micron-scale particles that typically form at the grain boundaries in these alloys during solidification [9]. These coarse intermetallic particles are elastically harder than the matrix, and the backstresses due to mechanical mismatch can impede or exacerbate the localized stresses caused by twin impingement that play a role in both twin transmission and twinning behavior.

Previous computational studies by our group using Crystal Plasticity—Fast Fourier Transform (CP-FFT) modeling [10] indicated that certain microstructural cases, such

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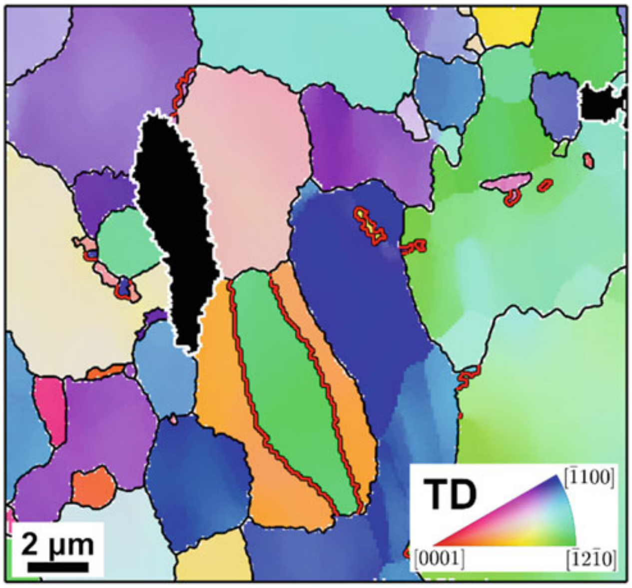

Fig. 1 Inverse pole figure map from combined EDS-EBSD of strained AM60 Mg alloy. Grain boundaries are highlighted in black, twin boundaries are highlighted in red, and particle phases are colored in black with white borders

as instances of a twin directly impinging upon an intermetallic particle of sufficient size, would reduce the likelihood of nucleating a new twin in the neighboring grain. However, other microstructures—such as a twin impinging upon the grain boundary nearby the particle without directly making contact—resulted in an increased likelihood of transmission. Additionally, the modification of stress states in the parent and neighboring grains due to the presence, size, and position of the particle was associated with changes in the twin thickness in the parent grain and the potential variant selection in the secondary grain. These simulation results for single twins and particles can help to interpret the statistical occurrence of twinning in real particle-containing magnesium microstructures.

Toward that goal, this work uses electron dispersive spectroscopy (EDS) and electron backscatter diffraction (EBSD) in tandem to simultaneously analyze grain boundary particles, deformation twins, and transmission events over a broad region of the microstructure. As shown in Fig. 1, the combined EDS-EBSD data is processed using automated algorithms designed to work with the MTEX [11] open-source toolbox for MATLAB to identify both intergranular particles and twin boundaries. Chemical information provided by EDS is combined with band contrast values from EBSD to segment particles, while orientation information from EBSD is used to automatically identify twin boundaries. Twinning statistics such as area fraction, thickness, and variant selection—including Schmid and non-Schmid variant identification—can be automatically calculated, and instances of adjoined twin pairs across grain boundaries determined. Similarly, instances of twin-particle contact can be identified or the distance between a twin and particle along a grain boundary (such as in Fig. 1) can be calculated. These automated segmentation and analytical methods using combined EDS-EBSD enable a statistical study of how particle morphology, position, and grain orientation modify twinning behavior and transmission likelihood, and allow for the findings to be compared to computational results from CP-FFT modeling.

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