Crystal Plasticity Modeling of Deformation in Mg Alloy Bi-Crystal under Cyclic Loading

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Synopsis
A crystal plasticity finite element model (CPFEM) has been used to simulate fatigue loading of a bi-crystal, representing an idealized weld, of dissimilar magnesium alloys at room temperature. This study looks at the cyclic deformation behavior in terms of the stress-strain curves and slip and twinning activity for specific orientations of the crystals. Comparison of the stress-strain response of single crystal magnesium experiments and simulations are used to verify the model. Stress-strain curves and the evolution of the shear strain for the different slip and twin systems after 1000 cycles is presented. The effect of the orientations of the crystal on slip is discussed.

Introduction
Fatigue performance is important for any sort of structure that goes through tension-compression cycles. Fatigue strength after friction stir welding (FSW) in Mg alloys can be significantly different. Fatigue is highly affected by the deformation modes that are activated, which are dependent on factors such as grain size and texture. The FSW process results in a finer grained microstructure as well as an abrupt change in texture across the interface created between the stir zone and base material. Fig. 1, which may affect fatigue performance. Due to the inherent anisotropy of the HCP lattice the number of slip systems in magnesium is restricted. Twinning, which is the re-orientation of part of the crystal lattice, becomes an important additional mechanism to accommodate strain during plastic deformation. Slip and twinning activity also highly depends on the orientation of the crystal.

Improved understanding of the fatigue behavior of Mg requires a realistic description of the relation between the fatigue deformation and key microstructure attributes. The CPFEM has been developed to effectively model the anisotropic deformation and hardening of polycrystalline materials. The finite element code is implemented to model elastic and plastic deformation considering slip and twinning based plastic deformation where twinning is treated as pseudo-slip.

Methods and Results
The model is built upon previous code written by Hamidreza Abdolvand and Mark Daymond for polycrystalline Zr and Mg. The constitutive equations were coded into a user material subroutine (UMAT) which was executed in the finite element software package ABAQUS. In the present work the model simulations were compared to magnesium single crystal tension and compression data from the literature. The simulation data matched very well to experiment. To simulate fatigue of a dissimilar alloy interface, a bi-crystal composed of two different alloy cubic crystals (Figure 2) with different relative orientations was coded. One crystal was assigned the properties of Mg AZ31 and the other Mg AZ80. In total 7 simulations were done using a fully reversible load of 90% yield for 1000 cycles. The orientations used were combinations of the c-axis pointed 0°, 45°, and 90° to the tensile axis. These orientations were selected because they correlate to mechanically “hard” and “soft” orientations. The 0° and 90° orientations are particularly interesting because twinning is easily activated in certain loading directions. Figures 3 and 4 show the evolution of the shear strain for two different orientation combinations, 0°/45° and 90°/45°. This indicated that some cyclic plasticity did occur and that the magnitude of the shear strain evolution changes with orientation.

Fig. 1. Synchrotron data showing the intensity and orientation of the c-axis in the transverse plane of an Mg alloy FSW.5
Fig. 2. An idealized bi-crystal weld. Each color represents a different alloy.
Fig. 3. Evolution of shear strain in AZ31 (Red, 0°) and AZ80 (Blue, 45°).
Fig. 4. Evolution of shear strain in AZ31 (Red, 90°) and AZ80 (Blue, 45°).

References