Strain rate and temperature sensitive multi-level crystal plasticity model for large plastic deformation behavior: Application to AZ31 magnesium alloy

Milan Ardeljan, Irene J. Beyerlein, Brandon A. McWilliams, Marko Knezevic

PII: S0749-6419(16)30048-1

DOI: 10.1016/j.ijplas.2016.04.005

Reference: INTPLA 2042

To appear in: *International Journal of Plasticity*

Received Date: 28 November 2015

Revised Date: 5 April 2016

Accepted Date: 9 April 2016

Please cite this article as: Ardeljan, M., Beyerlein, I.J., McWilliams, B.A., Knezevic, M., Strain rate and temperature sensitive multi-level crystal plasticity model for large plastic deformation behavior: Application to AZ31 magnesium alloy, *International Journal of Plasticity* (2016), doi: 10.1016/j.ijplas.2016.04.005.

Strain rate and temperature sensitive multi-level crystal plasticity model for large plastic deformation behavior: Application to AZ31 magnesium alloy

Milan Ardeljan[a], Irene J. Beyerlein[b], Brandon A. McWilliams[c], Marko Knezevic[a, *]

[a]Department of Mechanical Engineering, University of New Hampshire, Durham, NH 03824, USA
[b]Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA
[c]Weapons and Materials Research Directorate, US Army Research Laboratory, Aberdeen Proving Ground, MD 21005, USA

Abstract

In this work, we develop a multi-level constitutive model for polycrystalline metals that deform by a combination of elasticity, slip and deformation twinning. It involves a two-level homogenization scheme, where the first level uses an upper bound Taylor-type crystal plasticity (T-CP) theory to relate the single-crystal scale to the polycrystal meso-scale and the second level employs an implicit finite elements (FE) approach to relate the meso-scale to the macro-scale. The latter relaxes the iso-strain constraints imposed by the Taylor model. As such, we name the model T-CPFE. At the single crystal level, the model features a dislocation-based hardening law providing the activation stresses that governs slip activity within the single crystals. For deformation twinning, it contains an advancement of a composite grain model that retains the total Lagrangian formulation. Here we use the T-CPFE model to analyze the mechanical response and microstructure evolution of extruded AZ31 Mg alloy samples in simple compression, tension, and torsion under strain rates ranging from 10^{-4} s^{-1} to 3000 s^{-1} and temperatures ranging from 77 K to 423 K reported in (Kabirian et al., 2015). Taking the experimentally measured initial texture and average grain size as inputs, the model successfully captures stress-strain responses, deformation texture evolution and twin volume fraction using a single set of material parameters associated with the thermally activated rate laws for dislocation density. The distinctions in flow stress evolution among the loading conditions result from differing relative amounts of slip and twinning activity, which the model internally adjusts based on evolution of slip and twin resistances in the response to the imposed loading conditions. Finally, we show that the T-CPFE model predictions of geometrical changes during compression compare favorably with corresponding geometry of samples deformed experimentally. For this application, it predicts the anisotropy and asymmetry of the material flow resulting from crystallographically soft-to-deform extension twinning and basal slip and hard-to-deform contraction twinning and pyramidal slip. The formulation developed is sufficiently general that the T-CPFE model can be applied to other materials that slip and twin.

Keywords: A. Microstructures; A. Twinning; B. Crystal plasticity; B. Anisotropic material; C. Finite elements; T-CPFE UMAT

* Corresponding author at: University of New Hampshire, Department of Mechanical Engineering, 33 Academic Way, Kingsbury Hall, W119, Durham, New Hampshire 03824, United States. Tel.: 603 862 5179; fax: 603 862 1865.
E-*mail address*: marko.knezevic@unh.edu (M. Knezevic).