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Dual-stage nested homogenization for rate-dependent anisotropic elasto-plasticity model of dendritic cast aluminum alloys

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ABSTRACT

This paper proposes a nested dual-stage homogenization method for developing microstructure based continuum elasto-viscoplastic models for large secondary dendrite arm spacing or SDAS cast aluminum alloys. Microstructures of these alloys are characterized by extremely inhomogeneous distribution of inclusions along the dendrite cell boundaries. Traditional single-step homogenization methods are not suitable for this type of microstructure due to the size of the representative volume element (RVE) and the associated computations required for micromechanical analyses. To circumvent this limitation, two distinct RVE's or statistically equivalent RVE's are identified, corresponding to the inherent scales of inhomogeneity in the microstructure. The homogenization is performed in multiple stages for each of the RVE's identified. The macroscopic behavior is described by a rate-dependent, anisotropic homogenization based continuum plasticity (HCP) model. Anisotropy and viscoplastic parameters in the HCP model are calibrated from homogenization of micro-variables for the different RVE's. These parameters are dependent on microstructural features such as morphology and distribution of different phases. The uniqueness of the nested two-stage homogenization is that it enables evaluation of the overall homogenized model parameters of the cast alloy from limited experimental data, but also material parameters of constituents like inter-dendritic phase and pure aluminum matrix. The capabilities of the HCP model are demonstrated for a cast aluminum alloy AS7GU having a SDAS of 30 μm.

1. Introduction

Metals and alloys containing heterogeneities e.g. particulates, precipitates, intermetallics, or voids in the microstructure are widely used in automotive, aerospace among other engineering systems. The micrograph in Fig. 1 depicts the microstructure of a Al–Si–Mg hypoeutectic cast aluminum alloy (AS7GU) used in the automotive industry. The microstructure comprises of (i) age-hardened aluminum matrix, strengthened by Mg/Si and Si precipitates, and (ii) a dispersion of brittle silicon particulates in the matrix. The spatial distribution of the silicon inclusions and their morphology depends on the casting procedure used, and especially on the rate of heat extraction (Ghosh et al., 2006). The solidification process tends to push particulates into the regions between the evolving secondary dendrite arms. Once the eutectic temperature is reached, the silicon inclusions are pinned in location. This process results in a very inhomogeneous distribution of the Si inclusions in the microstructure as seen in Fig. 1(a). The distribution of silicon inclusions along the dendrite cell boundaries results in the delineation of two different material phases in Fig. 1(a), viz. (i) a heterogeneity-free pure aluminum matrix, and (ii) an inter-dendritic phase (IDP) in which silicon inclusions are dispersed in the aluminum matrix. The spatial distribution

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