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Microstructural and Micromechanical Evolution during Dynamic Recrystallization

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Abstract

Dynamic recrystallization (DRX) can in principle serve as an alternative way of controlling grain structure via a single route of hot working instead of the traditional cold working followed by annealing at elevated temperatures; in reality, its widespread application is hindered by the lack of quantitative understanding and prediction of the process. Using a recently developed model (Zhao et al., 2016) that integrates a fast Fourier transform-based elasto-viscoplastic model and a phase-field recrystallization model, we investigate the evolution of both microstructural and micromechanical fields in polycrystal copper during uniaxial compression at various elevated temperatures. Quantitative analysis based on the simulation results confirms that stress redistribution upon the formation of a new grain can significantly lower the dislocation density of neighboring grains, leading the so-called "DRX-enhanced recovery", while the new grain itself undergoes accelerated work hardening as compared to the matrix. Numerical analysis using current simulation data reveals a macroscopic kinetic equation describing the average dislocation density evolution during DRX softening. The critical strain for the onset of DRX and the Zener–Hollomon parameter are found to obey a power law, with the model predicted exponent being consistent with that found in experiments. Temperature-dependence of the Avrami exponents have also been predicted using the simulation data, which agrees with the experimental finding. The population of grain boundaries and triple and quadruple junctions are shown to evolve with deformation and be temperature-dependent.

Keywords: Dynamic recrystallization, Thermomechanical processes, Crystal plasticity, Phase-field, Microstructures

1. Introduction

The application of thermomechanical processing (TMP) for grain refinement and control of microstructure and texture in structural metals has continuously been advanced in industry and has been an active area of scientific research since the 1940's. In terms of both industrial application and scientific understanding, the combination of cold working followed by annealing at elevated temperatures, to induce nucleation and growth of new grains that replace the deformed materials via static recrystallization (SRX), is the most developed. In contrast, dynamic recrystallization (DRX) involves the nucleation and growth of new grains during deformation at elevated temperature ($> 0.5T_m$), which plays critical roles in processing many engineering metals such as steels, Mg-alloys and Ni-base superalloys to name a few, but remains poorly understood, with the lack of both fundamental knowledge and rigorous physics-based

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