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Understanding the Micromechanical Behaviors of Particle-Reinforced Al Composite by Nonlocal Crystal Plasticity Modeling

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ABSTRACT

Particle-reinforced aluminum matrix composites (PRAMCs) have great potential for application in aerospace, automobile, defense, and electronics due to their high specific strength and stiffness and good resistance to wear and corrosion. Achieving a superior trade-off between the strength and ductility of PRAMCs necessitates an elaborative control of the microstructures, like the size and distribution of particles, as well as grain size, morphology, and texture of the matrix. The multiscale interaction between the particles and the matrix's microstructure is insufficiently understood due to the lagging of high-resolved in-situ characterization. This work proposes a nonlocal physically based crystal plasticity (CP) modeling approach to reveal the underlying micro-mechanisms of deformation and strengthening of a TiB2/Al-Zn-Mg-Cu composite with various microstructures. The CP constitutive model considers both the kinetics of statistically stored dislocations (SSDs) and the strain gradient effect in terms of the enhancement of geometrically necessary dislocations (GNDs). The spectral method based on the fast Fourier transform is employed to calculate the high-order gradient terms associated with updating GND density. Multiscale full-field CP simulations were conducted on high-resolved microstructural RVEs of PRAMCs. Results show that decreasing grain size and adding reinforced particles simultaneously accelerate the multiplication of SSDs and GNDs by promoting the formation of strain concentrations and high plastic strain gradients. Larger orientation scattering occurs and more slip systems are activated in the region close to the particles to accommodate the deformation compatibility. The interaction between the various-sized particles and the matrix was quantified in terms of the grain-level deformation heterogeneity and stress/strain partitioning, and local crystallographic orientation change.

KEYWORDS

Nonlocal crystal plasticity modeling; particle reinforced aluminum matrix composites; geometrically necessary dislocations (GNDs); spectral method

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