Forest + Precipitate Hardening in 2.5d Discrete Dislocation Modeling of Plasticity and Fracture

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The key phenomenon of forest hardening in dislocation plasticity is inherently three dimensional. Yet, fully 3d discrete dislocation (DD) models of fracture and fatigue, for instance, remain computational challenging while 2d DD models have provided a number of insights into these problems. To bridge this gap, here we present a new "2.5d" DD model that includes the evolution of forest hardening within a material with pre-existing obstacles to dislocation motion, such as precipitates. The new model captures forest hardening by introducing new forest obstacles on one slip system based on the local dislocation density on other slip systems, and also includes the combined strengthening due to the new forest dislocations and the pre-existing precipitates. The model introduces only parameters that come from 3d DD studies, namely the forest junction strength and the dislocation mean-free path, and satisfies a number of limiting cases. In simple tension tests, the new model predicts an initial yield stress that is controlled by the precipitate obstacles followed by a linear work hardening at a rate that depends on the mean-free path and which can be estimated from input material parameters. The model is then used to study the growth of cracks as a function of the initial yield stress and the hardening rate. As expected from continuum models, materials with forest hardening are less tough than materials without forest hardening.

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