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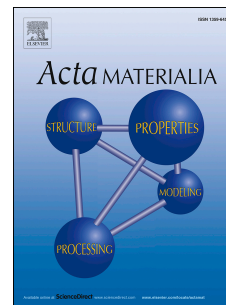
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The microstructural origin of work hardening stages

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Abstract

The strain evolution of the flow stress and work hardening rate in stages III and IV is explored by utilizing a fully described deformation microstructure. Extensive measurements by transmission electron microscopy reveal a hierarchical subdivision of grains by low angle incidental dislocation boundaries (IDBs) and medium to high angle geometrically necessary boundaries (GNBs). This universal evolution is demonstrated for nickel, copper, and aluminum deformed by cold rolling from strains of 0.05 to 5.5. Microstructural morphology evolves with increasing strain through a transition resulting in a lamellar cell-block structure aligned with the deformation. This transition is caused by the emergence of new slip systems and a stable texture. Four parameters describe the microstructure, the misorientation angle across each boundary type and their respective spacing. Universal scaling characterizes the normalized distributions of three separate parameters. A new scaling law connects the strain evolution of two strength parameters: the dislocation density of IDBs and the spacing between GNBs. Strengthening mechanisms and strength contributions for those two parameters are expressed respectively as a linear addition of the classical Taylor and Hall-Petch formulations. Model predictions agree closely with experimental values of flow stress and work hardening rate in stages III and IV. Strong connections between the evolutionary stages of the deformation microstructure and work hardening rates create a new (modern) basis for the classic problem of work hardening in metals and alloys. These connections lead the way for the future development of ultra high strength ductile metals produced via plastic deformation.

Key words: Work hardening; Dislocations; Deformation microstructure; Mechanical properties;

Transmission electron microscopy

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