Size effects predicted by the minimal gradient-enhacement of crystal plasticity

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ABSTRACT

Several strain-gradient theories of crystal plasticity have been proposed over the last two decades to describe the size effects that accompany plastic slip at small length scales. Recently, we have proposed a minimal gradient-enhancement [1,2] of the classical theory of plasticity of single crystals with the aim to describe the most essential size effects in a possibly simple manner. The essence of the proposed modification is in extending only the evolution equations for critical resolved shear stresses by a single non-conventional term involving slip-rate gradients. An internal length scale has been derived for that purpose, which is expressed through standard quantities that appear in a non-gradient hardening law. This length scale possesses a direct physical interpretation that is frequently missing is other gradient-plasticity models.

The model has been formulated in the framework of classical continua, and as such it does not involve any additional balance equations. As shown in [2], an analytical solution describing the boundary layer in a constrained half-space can be found directly with no additional treatment. At the same time, direct finite element implementation of the model is not straightforward, and the present implementation relies on introducing non-local slip rates that provide a global continuous approximation of the corresponding local slip rates. The model has been applied to three-dimensional simlations of fcc single crystals. It has been found [2] that the experimentally observed indentation size effect in a Cu single crystal is captured correctly even though there is no adjustable length-scale parameter. The analytical solution mentioned above has also been used to show that the finite-element solution converges to the analytical one as the mesh is refined.

REFERENCES

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[2] S. Stupkiewicz and H. Petryk, A minimal gradient-enhancement of the classical continuum theory of crystal plasticity. Part II: Size effects, *Arch. Mech.* **68**, 487-513 (2016).