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A 'stack' model of rate-independent polycrystals

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ABSTRACT

A novel 'stack' model of a rate-independent polycrystal, which extends the 'ALAMEL' model of Van Houtte et al. (2005) is proposed. In the 'stack' model, stacks of *N* neighboring 'ALAMEL' domains collectively accommodate the imposed macroscopic deformation while deforming such that velocity and traction continuity with their neighbors is maintained. The flow law and consistency conditions are derived and an efficient solution methodology based on the linear programming technique is given. The present model is applied to study plastic deformation of an idealized two-dimensional polycrystal under macroscopically imposed plane-strain tension and simple shear constraints. Qualitative and quantitative variations in the predicted macroscopic and microscopic response with *N* are presented. The constraint on individual 'ALAMEL' domains diminishes with stack size *N* but saturates for large *N*. Computational effort associated with the present model is analyzed and found to be well within one order of magnitude greater than that required to solve the classical Taylor model. Furthermore, implementation of the consistency conditions is found to reduce computation time by at least 50%.

1. Introduction

In numerical simulations of polycrystal plastic deformation (Mathur and Dawson, 1989; Beaudoin et al., 1993, 1995; Mika and Dawson, 1998; Barbe et al., 2001; Ganapathysubramanian and Zabaras, 2005; Logé and Chastel, 2006; Van Houtte et al., 2006; Guan et al., 2006; Haddadi et al., 2006; Amirkhizi and Nemat-Nasser, 2007; Barton et al., 2008), microstructure-based prediction of material point response offer advantages over phenomenology-based predictions (Kim et al., 2008; Wang et al., 2008; Van Houtte et al., 2009, and references therein), albeit at greater computational cost. One advantage is that microstructure-based methods are applicable without restrictions for all loading histories, and also typically over a wider range of strain-rates and temperatures than phenomenological methods. Also, microstructure-based models predict material response at both macro and micro-scales. They are therefore amenable to experimental verification at both scales (Peeters et al., 2001a,b; Mahesh et al., 2004).

Microstructure-based polycrystal plasticity models evolve the lattice orientation and anisotropic hardening of grains in response to macroscopically imposed constraints on the material point. A number of microstructure-based models are presently available. These range from the simple, yet qualitatively successful Taylor model (Taylor, 1938; Hirsch and Lucke, 1988a,b) to the crystal plasticity finite element method (Kalidindi et al., 1992, 2006; Kalidindi and Duvvuru, 2005; Knezevic et al., 2008). While the former assumes that each grain of the polycrystal deforms according to the macroscopic constraint (Taylor hypothesis), the latter resolves spatial variations of deformation down to the sub-granular scale. The greater resolution comes at a cost: computationally, the former is typically two to three orders of magnitude less expensive than the latter.

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