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BOUNDING THE PLASTIC STRENGTH OF POLYCRYSTALLINE SOLIDS

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Abstract. The macroscopic elasto-plastic response of polycrystalline solids like engineering metals and many geological materials is to a great extent dictated by the morphology, lattice orientation and elasto-plastic response of each individual single-crystal grain composing the aggregate. The relationship between these macroscopic and microscopic properties is necessary to estimate the deformation-induced plastic anisotropy that develops in polycrystalline solids undergoing large deformations, a problem relevant to various engineering applications such as metal forming processes. Very often the response of these materials is idealized as elastically rigid and plastically non-hardening. Within this so-called rigid-perfectly plastic model, the above problem reduces then to finding the macroscopic yield surface of the polycrystalline aggregate given the yield surface at the single-crystal level and the statistics of the morphology and orientation distributions of the grains. Due to their inherent microstructural randomness, cognate polycrystalline solids will not exhibit a single response but a ---hopefully small--- range of responses. Therefore, one can either develop estimates that yield a single representative response or derive bounds for the entire range of possible responses. This work is concerned with bounds. Bounds are also useful for two reasons: they provide benchmarks to test estimates and they can be used as estimates themselves.

Several methods are by now available to determine bounds for the macroscopic plastic strength of polycrystalline solids. A nonlinear homogenization method has been recently proposed by Idiart and Ponte Castañeda (Idiart & Ponte Castañeda 2007 Proc. R. Soc. A 463, 907–924) with the potential to deliver improved bounds at the expense of increased computational complexity. The method is applied here to various types of cubic and hexagonal solids with varying degrees of crystal anisotropy. The resulting bounds incorporate up to second-order microstructural statistics. Improvements over earlier bounds are found to be modest for highly symmetric materials but for low-symmetry materials the new bounds become appreciably sharper when the constituent crystals have more than five slip systems with less than five of them linearly independent.