SPATIAL STATISTICS OF CRYSTALLOGRAPHIC ORIENTATIONS: ANALYSIS WITHOUT THE TAYLOR ASSUMPTION

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Ductile metals consist of microscopic grains, each of which have a crystalline structure with a well-defined orientation. The orientations are random, but can be observed using electron microscopy. The probability density of these orientations, known as the orientation distribution function (ODF), has been found to be important in characterizing polycrystalline microstructure. Moreover, using dimension reduction methods, the ODF has been successfully used to study the relationships between microstructural and macroscopic material properties [1].

The ODF can be significantly altered when the material undergoes inelastic deformations during material processing. Due to the complexity of crystal plasticity, the Taylor assumption is commonly used when analyzing the evolution of material microstructure during inelastic deformations [2]. In this assumption, the material strain rate is uniform, with microstructural strain rate set equal to the macrostructural applied strain rate. From the mechanics point of view, the kinematics at the grain boundaries are trivially satisfied, but equilibrium is not, although the errors are tolerable for most applications. From the statistics point of view, the evolution of the ODF during processing can be predicted [1,3], again with errors that are tolerable for most applications. The limitation here is that the Taylor assumption can introduce significant errors in two-point statistics such as those that describe the orientations at neighboring grains.

There are several methods for predicting the evolution of the ODF during inelastic deformations without the Taylor assumption. The most straightforward is through the finite element method, using appropriate crystalline-based elements. While this is attractive in many aspects, there is a loss of insight associated with the use of purely computational methods. An alternate approach is through more transparent analytical methods based on the plasticity of single crystalline inclusions embedded in an equivalent homogeneous medium [4].

Here we investigate the evolution of one- and two-point statistical properties of the orientation angle during inelastic deformation. We focus specifically on the ODF and on the probability density of the difference in orientation angles at grain boundaries. To obtain this information, we use the aforementioned semi-analytical approach for crystalline plasticity with one notable extension. We use a self-consistent approach [5] to average only over the neighboring grains rather than averaging over the macroscale. To illustrate our results, we examine a 2-D problem with hexagonal-shaped grains.

This work is part of a larger project [6] of analysis of random microstructure using Bayes classifiers.

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