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Grain-Scale Surface Roughness in Ductile Polycrystals

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ABSTRACT

The main scope of this study is concerned with the origin of plastic strain localization and surface roughening in polycrystals. The specific case study is an oligocrystal aluminum sample with a single quasi-2D layer of coarse grains which is plastically deformed under uniaxial tensile loading. This study presents a one-to-one comparison of crystal plasticity finite element simulation with the experimental uniaxial tensile test on a dogbone specimen. During the deformation process, the evolution of strain localization, surface roughening, microstructure and in-grain orientation fragmentation are carefully recorded. Thereafter, high-resolution simulations using crystal plasticity finite element models are conducted. The *vis-a-vis* comparison between model predictions and experiments allows for the direct assessment of quality of the agreement. Particular attention is given to the ability of the model to capture surface roughening, strain localization and the pattern of activation of slip systems in the grains. For example, as shown in Figure 1, in grain-6 the deformation localizes during the tensile test, experiencing internal orientation fragmentation. In addition, the boundaries among grains-6, 7, 8 and 9 are less visible after straining. Most of the other grains still preserve a relatively uniform orientation distribution with a smooth orientation gradient as seen in grain-13.

The study suggests that the grain topology and microtexture have a significant influence on the origin of strain heterogeneity. Moreover, it suggests that the final surface roughening profiles are related both to the macro strain localization and to the intra-grain interaction. Finally slip lines observed on the surface of the samples are used to probe the activation of slip systems in detail. This study allows to conclude that:

(i) The grain stretching over the whole width of the dogbone specimen is remarkably soft. The absence of dislocation barriers provided by grain boundaries is conducive to strain localization. Due to the significant thickness reduction, a severe surface roughening can be observed in that region of the sample.

(ii) Inclined grain boundaries in otherwise columnar grains can introduce additional shear tendency and a valley-like roughening profile along grain boundaries which leads to discrepancies with the model.

(iii) The appearance of slip lines on the surface at a lower strain level normally arises from the slip systems with maximum Schmid factor. Due to its continuum nature, the crystal plasticity finite element model requires the activation of additional slip systems, besides the one with maximum Schmid factor. An increasing strain can produce a laminate structure which is beyond the capabilities of CPFEM models.

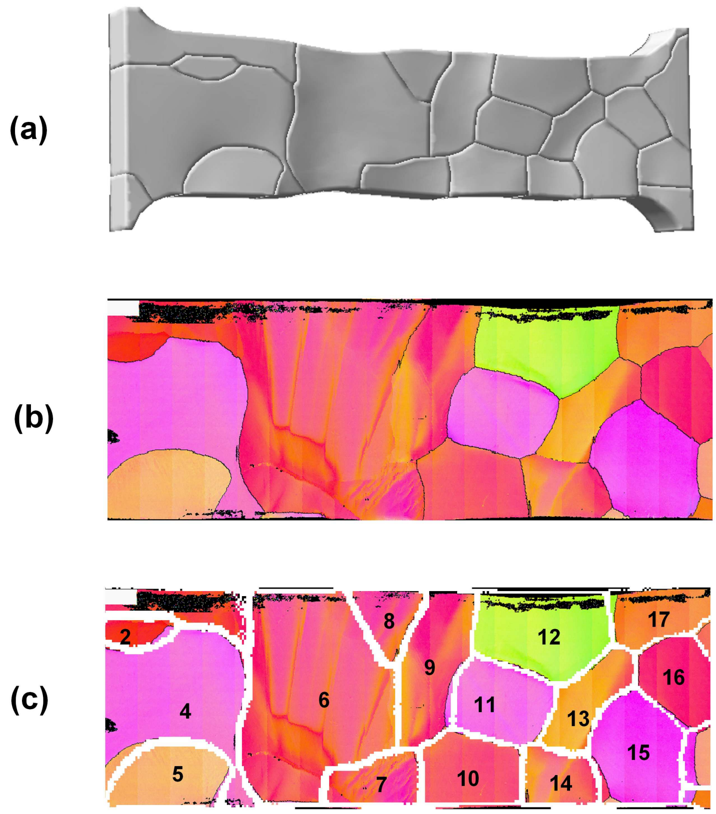

Figure 1: Comparison of the deformed grain shapes between the simulation and experiments of a deformed ligocrystal aluminum sample after 10.50% elongation. A perspective view of the simulated specimen is given to emphasize the three-dimensional character of the simulation. (a) Numerical simulations. A net of grooves is added to the simulated sample to reveal the deformed grain boundaries. (b) Corresponding EBSD observation. (c) Simulation-Experiment. A good match can be found after overlapping both results.