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COMPUTATIONAL ANALYSIS OF SIZE EFFECTS USING ADVANCED CRYSTAL PLASTICITY MODELS

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ABSTRACT

In the past decade, industry is increasingly focused on the behaviour of materials in micro- and nanosystems. At the level of many microsystems, metallic structures and films are used ranging from sizes of a few microns to hundreds of microns. The scientific community has given a lot of attention to this subject, in particular in the range where size effects have a dominating contribution.

This presentation focuses on a full classification and computational modelling of different size effects, related to different underlying physical mechanisms in the crystalline microstructure. To this purpose, size effects in the plastic response of thin Al structures and films have been measured and modelled accordingly. Within this context, the following aspects will be shortly addressed:

- first-order size effects, highlighting the influence of the ratio between the size of grains and the characteristic dimensions of micro-components [1, 2]:
  - processing-induced size effects, studied on the basis of mechanical cutting and laser cutting of small scale specimens
  - grain boundary induced size effects
  - surface-induced size effects, related to the presence of an outer free surface
  - statistical size effects, related to the statistical variation of the number of grains in miniaturized specimens [3]
- second-order size effects, studied by a strain gradient crystal plasticity approach, which accounts for essential short-range dislocation interactions [4, 5, 6, 7].

The computational description of the FCC behaviour relies on a recently developed strain gradient dependent crystal plasticity approach, which incorporates an intrinsic scale dependence [8, 9, 10, 11]. The heterogeneous deformation-induced evolution and distribution of geometrically-necessary dislocations (GND's) are incorporated into a physically based continuum theory of crystal plasticity, which is briefly

presented. Additional boundary conditions are formulated at the grain boundaries, obstructing the slip at the slip system level in the direction perpendicular to those boundaries. At the free (external) surfaces, the GND densities are prescribed to be zero, which allows to capture an intrinsic size dependence upon varying grain size and/or sample size.

Comments on the physical justification and interpretation of the higher-order terms will be presented. An idealized dislocation pile-up configuration is considered, for which a sharp comparison between discrete and continuum solutions can be made. The most rigorous connection in this context has been established by Groma et al. [12] on the basis of statistical arguments. The resulting higher-order theory has been demonstrated to correlate well with discrete dislocation simulations [13]. In the present contribution we demonstrate how a virtually identical theory can be formulated on a purely deterministic basis thus providing additional insight into the origin of the nonstandard terms in crystal plasticity.

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