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A COMPUTATIONAL STUDY OF PLASTIC FLOW BY DISLOCATION TRANSPORT IN A TWO-PHASE MICROSTRUCTURE

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Plastic deformation in metallic materials is governed by the glide and interaction of dislocations. Microstructure, e.g. the presence of grain and phase boundaries, generally restricts the glide of dislocations and thus results in a harder material. In this study we aim to develop a deeper understanding of the effect of such heterogeneities in the material's microstructure – and in particular of the interactions between dislocations associated with them – on the material's macroscopically observed plastic response.
We model the glide of dislocations in a single slip system by formulating continuum transport equations for the total dislocation density as well as the excess density – cf. the work of Groma and co-workers [1]. Short-range interactions between the dislocations are accounted for by interaction terms which depend on the gradients of these densities along the slip system. This results in nonstandard, nonlocal governing equations [2].
The microstructure which we consider is a periodic laminate of two phases. They have identical elastic properties, but different resistance against plastic deformation, which is modelled by a different drag resistance. An additional resistance against dislocation motion is introduced at the interface between the two phases, thus modelling the effect of a phase boundary. Dislocation glide is assumed to occur on a slip system which is perpendicular to the microstructure's lamellae and this allows us to treat the problem as a one-dimensional initial-boundary value problem.
The governing equations are solved numerically by the finite element method. A typical result is shown in Figure 1. It illustrates how the pile-up of dislocations of a certain sign against the phase boundary between the two phases results in a significant hardening during the initial stages of plasticity. As a result, the steady-state flow stress exceeds the Taylor average of the response of the two individual phases – which normally acts as an upper bound. The harder response observed here is due to the combined effect of boundary layers (pile-ups) and a redistribution of dislocations between the soft and the hard phase.
Studying the effect of parameter variations on the observed response allows us to develop a deeper understanding of the influence of the microstructure on the dislocation transport, and thus on the observed macroscopic response. Changing the period of the microstructure, i.e. the

grain size, for instance gives rise to a Hall–Petch type of size effect, which switches to an inverse size effect for extremely small grain sizes.

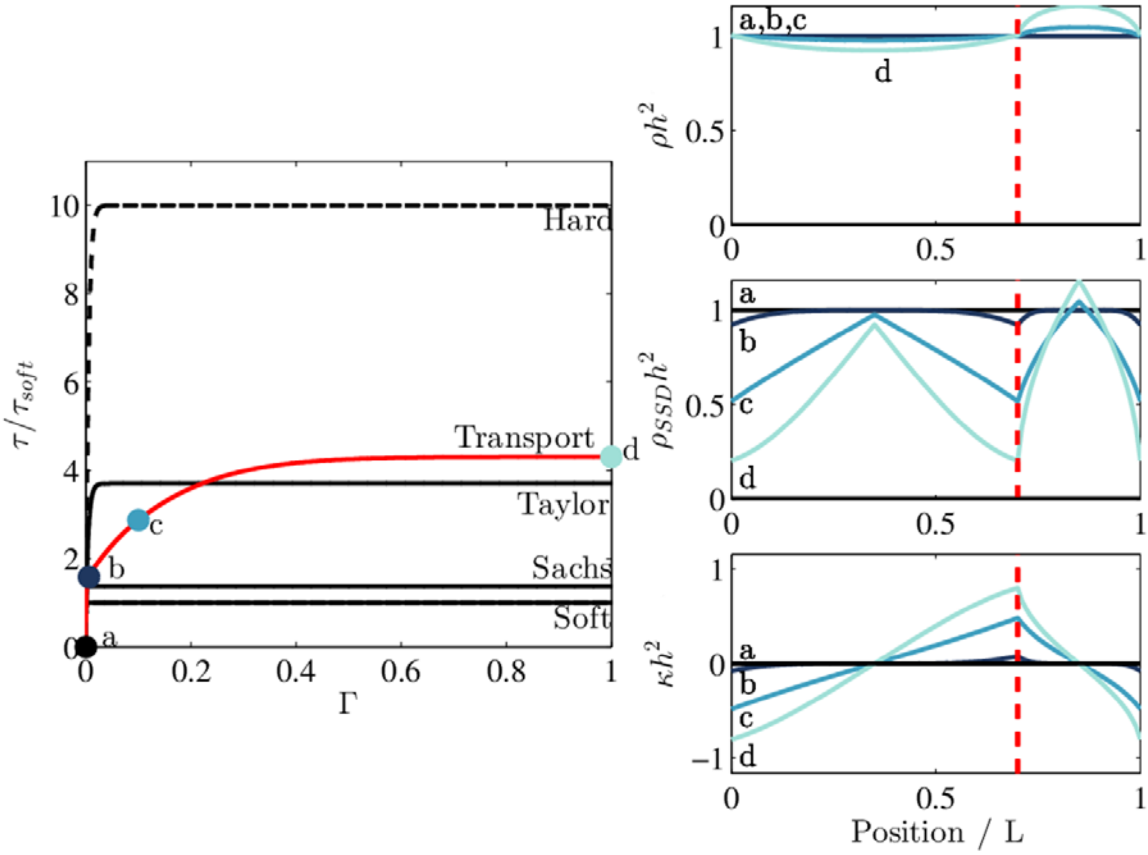

Figure 1: Numerical solution of the dislocation transport problem for a two-phase material. Left: overall stress–strain response (marked 'Transport'); right: evolution of the distributions of total, statistically stored and geometrically necessary dislocation densities.

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