11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20–25, 2014, Barcelona, Spain

COUPLED GLIDE-CLIMB DIFFUSION-ENHANCED CRYSTAL PLASTICITY

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Key words: *Crystal plasticity, dislocation climb, vacancy diffusion, multi-scale*

Many metallic systems are nowadays operated in a regime where the evolving mechanical properties are not simply dependent on dislocation glide mechanisms within the underlying crystals only. This is typically the case for climb-assisted deformation and creep mechanisms, which are known to contribute significantly at higher temperatures in pure metals, solid solution alloys, particle strengthened and multi-phase metals. Moreover, in modern thin film systems for micro-electronics or micro-electro-mechanical systems (MEMS), climb mechanisms already contribute to a significant extent at only mildly elevated temperatures or even room temperature.

The role of climb in plasticity has been addressed in several papers in a purely phenomenological manner, where constitutive equations incorporate the contribution of climb. The focus of this contribution is to break through the phenomenological nature of these approaches at the crystal plasticity level, by coupling deformation to dislocation motion assisted by glide and diffusional climb. For this purpose, a state-of-the-art crystal plasticity model needs to be used, which properly incorporates short-range dislocation-dislocation interactions. The backbone of the crystal plasticity framework is based on a strain gradient crystal plasticity model [1], enriched with dislocation transport physics [2].

For the coupling with vacancy diffusion at the local scale, reference is made to the work of Gao and Cocks [3], which presents a thermodynamically based variational framework that links the climb of a single edge dislocation to the diffusion of vacancies. Attention is given to the governing equations and physics of the vacancy diffusion process, the driving forces acting on a dislocation to climb and the intrinsic coupling between both. The climb law is therefore diffusion-controlled. The problem is studied at the meso-scale, where pile-ups against particles can be resolved explicitly, i.e. a scale at which it is meaningful to preserve a direct coupling between the mean vacancy flux and the dislocation climb process. A rate-dependent strain gradient crystal plasticity formulation is adopted, which accounts for the net sign of the dislocation population. The dislocation problem can be described in a fully conservative manner with transport equations. Since the analysis is carried out at the meso-scale, all dislocations are assumed to be able to participate in the climbing process. The corresponding transport equations for the dislocations are updated to incorporate climb. In order to incorporate the effect of the dislocation climb on the plastic deformation tensor, the crystallographic split of the plastic velocity gradient tensor is extended for the climb kinematics associated to each slip system.

The innovative aspects of this contribution are: (1) a fully coupled crystal plasticity model through which climb is controlled by the diffusion of vacancies; (2) an extended strain crystal plasticity model, that incorporates the climbing dislocations in the governing transport equations; (3) a global-local approach to separate the scales and assess the influence of the local diffusion problem on the global plasticity problem; (4) a kinematically enriched crystal plasticity model, which directly incorporates the climb kinematics in the crystallographic split of the plastic velocity gradient.

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