Gradient-Enhanced Crystal Plasticity Model with Micropolar Regularization: Prediction of the Indentation Size Effects

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In recent times of miniaturization and nanotechnology, the understanding of the behavior of materials at the micro- and nano-scales has attracted attention of many theoretical and experimental studies. Despite years of efforts, there are still challenges and unsolved theoretical dilemmas. In the case of crystal plasticity (CP), it is now accepted that the response of the material at the micro scale is influenced by the geometrically necessary dislocations (GNDs) which are associated with the incompatibility of plastic (or elastic) deformation. Notwithstanding the accepted concept of GNDs and a great variety of existing CP models, 3D indentation simulations with acceptable experimental validation are still scarce in the literature.

In the current work, we present a model of gradient crystal plasticity (GCP) which is based on the 'minimal' gradient enhancement of CP that involves a natural length scale in the hardening law. In its simplest form, the internal length scale coincides with the mean free path of dislocations – the well-known length-scale in the dislocation theory of plasticity – and therefore has a direct physical meaning [1]. In the present work, the Cosserat model is employed to encompass the gradient-enhanced model in the finite element setting. It is shown that the resulting computational model is capable of predicting the indentation size effect on nominal hardness of a Cu single crystal with a satisfactory accuracy [2].

References

[1] Petryk, H., Stupkiewicz, S., A minimal gradient-enhancement of the classical continuum theory of crystal plasticity. Part I: The hardening law, *Arch. Mech.* 68, 459–485 (2016).
[2] Ryś, M., Stupkiewicz, S., Petryk, H., Micropolar regularization of crystal plasticity with the gradient-enhanced incremental hardening law, *Int. J. Plasticity* (submitted).