

Micromechanical Modelling of Small Scale Plasticity: Strain Gradient and Field Dislocation Mechanics Approaches

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In the recent decades, miniaturization of technology has invoked an intensive research in the field of scale dependent mechanical behaviour which is directly associated with scale dependent plasticity. Ample of experimental studies performed in the past displayed the existence of several size effects with the common feature of “smaller is stronger”. For example, increased hardness values with decreasing indenter size, fine grained metals are stronger than coarse grained ones, and thinner the sheet higher is the bending moment. Theoretical investigations conducted to capture this size dependent strengthening made it clear that experimentally observed size effect cannot be predicted via conventional plasticity model due to the fact that these theories do not include any internal material length scale. In the present work, two modelling approaches are put forward to capture the size dependent mechanical behaviour.

The first one is strain gradient crystal plasticity approach which is absolutely phenomenological and includes both isotropic and kinematic hardening provided by the strain gradients (GNDs). Larger magnitude of strain gradients at smaller length scale provides “smaller is stronger” effect to the model. Model is implemented in finite element framework and the proper working of the model is validated against experimental findings related to different kind of size effects. Moreover, adaptability of the crystal plasticity formulation has been demonstrated by adding phase transformation as one more deformation mechanism in addition to elastic and plastic deformation. The model is primarily used to explain the experimentally observed transformation kinetics and deformation behaviour of TRIP-assisted maraging steel.

Phenomenological mesoscopic field dislocation mechanics (PMFDM) is another modelling approach to capture the deformation behaviour of the materials at smaller length scale. The model is formulated in terms of dislocation density and a clear distinction is made between excess dislocations (GNDs caused by strain gradients) and statistical dislocations (SSDs). FDM explains the transport of polar dislocations under the influence of its own elastic stress field and stress field caused by applied boundary condition. Crystal plasticity is used as a closure for the model and formulated in terms of the mobile and forest dislocations. Capability and flexibility of the model is examined in sense of capturing the events related to different length scale such as reproducing the classical solution of stress field caused by discrete dislocations, capturing the stress field around a sharp crack and grain size effect. Model is primarily used to investigate the negative strain rate sensitivity (NSRS) in aluminium alloy AA2024. Finite element simulations are performed by using an extended version of the model where dynamic strain aging (DSA) effect is embedded in the crystal plasticity framework.