Hardening and Strain Localisation in Irradiated Materials

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For irradiated annealed materials, radiation damage results in hardening due to the production of dislocation loops that impede dislocation motion. Failure then only occurs at elevated stresses (higher than the yield and ultimate tensile stress exhibited by unirradiated material) and is often associated with the clearing of the dislocation loops creating softer channels along which most of the deformation is localized. In cold-worked materials, hardening also occurs due to dislocation loop formation. In addition, helical climb of non-edge dislocations restricts the mobility of the dislocation network.

The strengthening effect of radiation damage in cold-worked materials by dislocation loop formation and helical climb is demonstrated by transmission electron microscopy and molecular dynamics simulations. The effect of radiation damage in promoting strain softening through the removal of radiation damage in isolated channels in annealed materials is also demonstrated.

The interaction of localised slip channels with grain boundaries can translate across the boundary by inducing dislocation sources close to the boundary in a neighbouring grain. The stress induced by dislocation pile-up has been investigated following the method outlined by Eshelby et al. (J.D. Eshelby, F.C. Frank, F.R.N. Nabarro, Philosophical Magazine 42 (1951) 351–364). The classical problem of a linear pile-up of $n + 1$ identical straight dislocations with the Burgers vector $\mathbf{b}$ stressed against a lock at the grain boundary is considered. In the original Cottrell treatment for pile-up (A.H. Cottrell, A.H., Trans. Met. Soc. AIME (1958) 212) it was assumed that there were no frictional stresses acting on the dislocations in the pile-up and the stress intensity was deemed to be $n\tau$, where τ is the applied shear stress. A more rigorous analysis in which the dislocation positions are calculated based on the force balance in the slip plane shows that the stress intensification from pile-up gives good agreement with the combined superposition of the stress fields from the dislocations provided both the applied shear stress and a frictional stress are factored in to the calculation. The stress intensity is then given by $n(\tau-\sigma)$, where σ is the frictional stress acting on the dislocations in the pile-up.