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MULTISCALE MODELLING OF FATIGUE CRACK INITIATION AND PROPAGATION IN METAL SINGLE AND POLYCRYSTALS

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Crystal plasticity finite element simulations will be presented showing the development of strain heterogeneities inside the grains of a polycrystalline aggregate made of Tantalum and subjected to cyclic loading [4]. The unique feature of the computation is that 1000 cycles could be simulated for a 250–grain aggregate under uniaxial overall strain $E_{33} = \pm 0.2\%$. Periodic boundary conditions are prescribed to the lateral faces whereas the two remaining parallel surfaces are free of forces, as done in [6]. A ratcheting phenomenon is observed at several places at the free surfaces, i.e. the accumulation of plasticity on some definite slip systems. A local amount of ratcheting is found to saturate after 300 cycles and reaches a non-zero value indicating that plastic strain will accumulate until a crack initiates. The phenomenon is not found in the bulk of the material even though plastic strain remains strongly heterogeneous from grain to grain. The surface effect in crystal plasticity has been explored in the past in the references [8, 3]. The ratcheting effect is regarded as a precursor of fatigue crack initiation [9]. A lifetime assessment method is then proposed to determine the number of cycle for intragranular crack initiation.

Once a crack has been initiated in a single crystal, ratcheting phenomena still play a significant role in the plastic activity around the crack tip and on further crack propagation. Following [5], we will show that strain localization bands can form at the crack tip in single crystals and that non-symmetric stress–strain loops are observed in the localization bands leading to ratcheting with respect to the activated slip systems. The accumulation of plastic slip is thought to promote crack propagation due to plasticity induced surface creation.

Finally crack propagation in single crystal is modelled by means of an anisotropic continuum damage model combining crystal plasticity and damage mechanisms associated with the opening and sliding of crystallographic planes (quasi–cleavage). The driving force for damage is the normal stress on these crystallographic planes. The damage threshold is decreased when plastic slip accumulates leading to a coupling between plasticity and damage. Mesh–independent simulations are obtained by introducing a characteristic length within a micromorphic extension of the model [1, 7]. The model accounts for crack initiation, propagation, bifurcation and branching. The material parameters are calibrated so as to reproduce the crack growth rate in single crystal superalloys [2].

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