Multiscale assesment of microstructurally-sensitive fatigue crack nucleation and growth and their mechanistic drivers

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ABSTRACT

Discrete dislocation studies have provided a quantitative measure of the dislocation structure and interactional *configurational energy density* (much of which is stored as GNDs) which is argued to be key to both crack nucleation and growth at the microstructural length scale. This quantity can be captured at the crystal plasticity level as a stored energy density [1].

Experimentally validated modelling provides knowledge of key microstructural quantities (accumulated slip, stress and GND density [2,3]) at experimentally observed fatigue crack nucleation sites and it is shown that while each of these quantities is potentially important in crack nucleation, none of them is in its own right is sufficient to be predictive. However, the local (elastic) critical stored energy density, measured over a length scale determined by the density of GNDs, has been shown to predict crack nucleation sites in single and oligocrystal tests. In addition, once primary nucleated cracks develop and are represented in the XFEM crystal model, the stored energy correctly identifies where secondary fatigue cracks are observed to nucleate in experiments [2]. Studies of R-ratio, non-proportionality and multi-axial stress states in nickel alloys and in 316 steel demonstrate that their effects on fatigue life can be captured with the critical stored energy density.

The dislocation configurational energy/stored energy density is also investgated as a mechanistic driver of microstructurally-sensitive fatigue crack growth in ductile metals employing the eXtended Finite Element Method (XFEM) to represent the crack. Microstructural fatigue crack growth is studied in single crystals, bicrystals and in polycrystals of cubic (fcc, bcc) and hexagonal (hcp) structure [4]. Along with the crystallographic slip, the stored energy density is shown to predict microstructurally-sensitive crack growth tortuosity, and to capture many features that have been observed experimentally, including crack deflection and retardation at the grain boundaries.

REFERENCES

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