4th Polish Congress of Mechanics and
23rd International Conference on Computer Methods in Mechanics
PCM-CMM-2019, Kraków, Poland, September 8-12, 2019

MICROSTRUCTURALLY-SENSITIVE FATIGUE CRACK NUCLEATION AND GROWTH: DISLOCATION CONFIGURATIONAL ENERGY AND CRYSTAL PLASTICITY APPROACHES

Fionn Dunne[1*], David Wilson[1], Zebang Zheng, Bo Chen[1]

[1] Imperial College London, UK

An integrated experimental, characterization and computational discrete and crystal plasticity study of microstructurally-sensitive fatigue crack nucleation and growth is presented in order to assess their mechanistic drivers.

Discrete dislocation studies provide a quantitative measure of the dislocation structure and interaction 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 [1,2].

Experimentally validated modelling provides knowledge of key microstructural quantities (accumulated slip, stress and GND density [3,4]) 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 [3]. Studies of R-ratio, nonproportionality 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 [5] and in polycrystals of cubic (fcc, bcc) and hexagonal (hcp) structure [6]. Along with the crystallographic slip, the stored energy density is shown to predict microstructurallysensitive crack growth tortuosity, and to capture many features that have been observed experimentally, including crack deflection and retardation at the grain boundaries.

References

[1] Zebang Zheng et al. The dislocation configurational energy density in discrete dislocation plasticity. *Jnl. Mech. Phys. Solids.* 129, 39-60, 2019.

[2] David Wilson et al. A microstructure-sensitive driving force for crack growth. *Jnl. Mech. Phys. Solids.* 121, 147-174, 2018.

[3] Bo Chen et al. Microstructurally-sensitive fatigue crack nucleation in Ni-based single and oligo crystals. *Jnl. Mech. Phys. Solids.* 106, 15-33, 2017.

[4] Bo Chen, et al. Is Stored Energy Density the Primary Meso-scale Mechanistic Driver for Fatigue Crack Nucleation? *Intl. Jnl. Plas.* 101, 213-229, 2018.

[5] David Wilson et al. A mechanistic modelling methodology for microstructurally-sensitive fatigue crack growth. *Jnl. Mech. Phys. Solids.* 124, 827-848, 2019.

[6] David Wilson et al. Microstructurally-sensitive fatigue crack growth in HCP, BCC and FCC polycrystals. *Jnl. Mech. Phys. Solids.* 126, 204-225, 2019.