Lode angle effects on damage initiation in multiphase alloys

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Ductile fracture of engineering alloys is governed by a process of nucleation, growth and coalescence of microvoids. The process is commonly considered to be driven by (equivalent) plastic straining, with a significant dependence on the stress triaxiality ratio, i.e. the first invariant of the stress tensor over the second invariant of the deviatoric stress tensor. However, experimental studies carried out over the past two decades have shown that for many alloys there is also a significant influence of the third invariant of the deviatoric stress tensor, which is usually characterised via the so-called Lode angle – see e.g. [1].

In single phase materials, the Lode angle dependence has been explained by the anisotropic growth of voids. In our study we consider multiphase microstructures with a significant hardness contrast between the phases. In particular, our interest is in dual phase steels, which typically employ comparatively hard martensite particles as a reinforcement in a softer ferrite matrix. The contrast in properties in such microstructures results in strongly heterogeneous microscale stress and strain distributions. The main questions which we aim to address are (i) how this heterogeneity influences the dependence of deformability on the Lode angle (or, more generally, on the stress state) and (ii) whether it might in itself introduce a macroscale Lode angle dependence, even if the microscale constituent phases were Lode angle independent.

To answer these questions, we adopt a highly idealised microstructural model of a two-phase material which proved to be a highly effective vehicle for systematic study in earlier work [2, 3]. It consists of an ensemble of three-dimensional periodic cells containing cube-shaped grains which are randomly assigned the properties of the hard and soft phase according to pre-set volume fractions. Both phases are modelled as isotropic and elasto-viscoplastic. Their failure is characterised by the Johnson–Cook damage criterion, based on the grain averaged stress and strain evolution only. This criterion in its original form is Lode angle independent; however, we also consider a Lode angle dependent extension [4]. Each realisation of the random microstructure, i.e. each periodic cell, is subjected to a range of macroscopic (i.e. average) strain paths which induce different Lode angles until failure of the microstructure is predicted. The effect of stress triaxiality is also probed by superimposing a hydrostatic stress in evaluating the damage criterion.

The simulation results show a pronounced effect of the applied Lode angle on the predicted fracture strain, even for the, Lode angle independent, conventional Johnson–Cook criterion. The effect is consistent with experimental observations. Careful statistical analysis reveals that the macroscopic Lode angle dependence stems from its influence on the local stress triaxiality in damage-sensitive features ('hot spots') in the microstructure.

References

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