Unraveling the three-dimensional fracture mechanisms of a multi-phase material

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ABSTRACT

Multi-phase materials are used in many modern engineering applications. For instance in the automotive industry many structural components are manufactured using dual-phase steel. In such applications a compromise is made between strength and ductility to maximize the structural integrity of the car body while minimizing the weight, but at the same time ensuring formability. Multi-phase materials provide both strength and ductility by combining two phases with distinct mechanical properties at the level of the microstructure (i.e. the level of individual grain in dual phase steel). Generally these materials consist of a comparatively hard but brittle inclusion phase embedded in a soft but ductile matrix.

The mechanical response (elasticity and plastic hardening) is reasonably well understood, and can be predicted using models with varying degrees of complexity ranging from the analytical rule of mixtures to numerical models. However the failure of such materials is less understood. Several authors have studied failure of multi-phase materials (for example [2-4]), but very few perform a systematic study. Kumar et al. [3] use a statistical reconstruction of the microstructure to identify the critical configuration for the onset of fracture. In addition, De Geus et al. [1] identify the average microstructure around the onset of fracture of the soft and ductile matrix phase.

This paper studies a two-phase material of which the microstructure comprises a hard, yet brittle, reinforcement phase embedded in a soft but ductile matrix. It addresses a crucial uncertainty in unraveling the fracture mechanisms of such materials: the three-dimensional nature of the microstructure. The goal is to identify the critical spatial arrangement of the phases around the fracture initiation sites. A structured, periodic, microstructure is used that models the individual grains of the two phases using equi-sized cubes. A large ensemble of individual microstructures allows the comparison of a large set of different morphologies. The mechanical response is calculated using the spectral method, which combines the Fast Fourier Transform with a fundamental solution. These two ingredients bring a systematic analysis on a statistically representative subset of microstructures within common computational limits. The results indicate that when the microstructure is subjected to a pure shear, planar, macroscopic deformation, the local morphology in that plane has the strongest correlation to the initiation of fracture. Indeed, when the microstructure is limited to two-dimensions and subjected to the same deformation mode, the average arrangement of phases around the fracture initiation sites remains similar to that of the three-dimensional model. It consists of a plate of the hard phase aligned with the tensile direction, intersected by regions of the soft phase in the shear directions. The observations are in line of the earlier work by De Geus et al. [1] and supports their conclusions.

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