Material instability in ductile multiphase materials – a computational micromechanics study

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Abstract

Man-made materials tend to be either strong or ductile. Many applications, however, require strength and ductility. Materials producers attempt to meet these conflicting requirements by developing materials with microstructures which consist of two or more phases — often hard but brittle particles embedded in a soft and ductile matrix. Whereas multiphase microstructures show promising properties, the full potential of this concept to have 'the best of both' cannot yet be exploited because of an incomplete understanding of their failure properties. Given their intrinsically complex microstructure, the failure mechanisms of multiphase materials are also complex. Microcracks and microvoids may be nucleated in the hard or soft phase, or at their interface. They subsequently show a tendency to propagate and coalesce via the soft phase, ultimately resulting in the initiation of a macroscopic crack. All of these stages have been observed to depend heavily on the properties of the phases, their volume fractions and their morphology — as well as on the precise, local loading conditions. The objective our study is to provide some clarity in this overwhelming picture of competing, heavily interdependent candidate mechanisms and paradoxical experimental observations.

We approach the problem at an abstract level, using a highly idealised micromechanical model which includes only the key features of the microstructure, including the key microstructural failure mechanisms. The model assumes the phases to be randomly distributed in a square grid and defines two competing failure mechanisms – one for each phase. Its simplicity serves multiple purposes, as it (i) greatly facilitates the interpretation of results, (ii) allows one to run many (hundreds of) realisations, thus generating statistically meaningful datasets, and (iii) enables a wide range of parameter variations, in order to study the influence of the parameters of the system on the outcome of the competition. Despite its simplicity, the model captures, and helps to explain, the trends predicted by much more complex models as well as observations made in experiments.
Specific questions which we aim to answer in this study are: (i) How do pre-existing defects affect the strength and ductility of multiphase materials? (ii) What determines the outcome of the competition between global and local ductility? (iii) How does formability of these materials depend on stress state – in particular on stress triaxiality and Lode angle?

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