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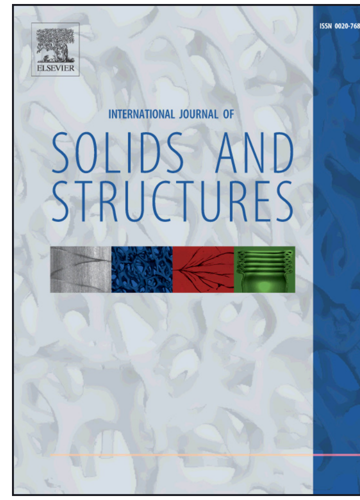

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T.W.J. de Geus, R.H.J. Peerlings, M.G.D. Geers

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Microstructural topology effects on the onset of ductile failure in multi-phase materials – a systematic computational approach

T.W.J. de Geus[a,b], R.H.J. Peerlings[a,*], M.G.D. Geers[a]

[a]Department of Mechanical Engineering, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
[b]Materials innovation institute (M2i), P.O. Box 5008, 2600 GA Delft, The Netherlands

Abstract

Multi-phase materials are key for modern engineering applications. They are generally characterized by a high strength and ductility. Many of these materials fail by ductile fracture of the, generally softer, matrix phase. In this work we systematically study the influence of the arrangement of the phases by correlating the microstructure of a two-phase material to the onset of ductile failure. A single topological feature is identified in which critical levels of damage are consistently indicated. It consists of a small region of the matrix phase with particles of the hard phase on both sides in a direction that depends on the applied deformation. Due to this configuration, a large tensile hydrostatic stress and plastic strain is observed inside the matrix, indicating high damage. This topological feature has, to some extent, been recognized before for certain multi-phase materials. This study however provides insight in the mechanics involved, including the influence of the loading conditions and the arrangement of the phases in the material surrounding the feature. Furthermore, a parameter study is performed to explore the influence of volume fraction and hardness of the inclusion phase. For the same macroscopic hardening response, the ductility is predicted to increase if the volume fraction of the hard phase increases while at the same time its hardness decreases.

Keywords: micromechanics, ductile failure, damage, multi-phase materials

1. Introduction

1.1. Background

Multi-phase materials are frequently used in engineering applications because they generally provide a good compromise between a high strength and a high ductility. Examples are dual-phase steels, metal matrix composites, and fiber-reinforced polymers. For many of these multi-phase materials the macroscopic response as a function of the microstructure has been reasonably well characterized, both experimentally and numerically [1–7]. Existing models range from simple phenomenological models to complex multi-scale simulations. So far, it is only partially understood which microstructural mechanisms govern the failure of these materials [8–12]. To better understand and characterize the failure of multi-phase materials one needs to consider the response at the microstructural level; the level at which the inhomogeneity between phases is clearly distinguishable, and damage initiates.

1.2. State of the art

Experimental evidence exists that suggests that failure often occurs by ductile fracture of the, generally relatively soft, matrix phase. This is substantiated for example by fractography, in-situ microstructural observations using Scanning Electron Microscopy (SEM), or X-ray tomography [11, 13–17]. Similar observations are made using models [13, 18, 19]. However, depending on the configuration and loading conditions considered, also brittle failure of the hard inclusion phase or decohesion of the interface between the two phases has been observed [14–16, 20].

To better understand the onset of failure in multi-phase materials, a wide variety of microstructural models are used. These models often use relatively simple material representation in which both phases are modeled using an elasto–plastic constitutive model and where failure is associated with large local permanent deformation (e.g. [1, 3, 7, 9, 19, 21]). Sometimes, more complicated models are used to quantify

*Corresponding author. Tel.: +31 40 247 2788; fax: +31 40 244 7355.
Email address: R.H.J.Peerlings@tue.nl (R.H.J. Peerlings)