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The effect of morphology on ductile failure in multi-phase materials

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

Introduction

Multi-phase materials are frequently being applied in engineering applications because of their typical high strength and ductility, e.g. to design light-weight but crash resistant cars. In contrast to the overall hardening response, the failure mechanisms are not well understood. We identify the microstructural morphology (i.e. distribution of phases) responsible for the initiation of ductile failure; i.e. the morphology that governs the location where the damage D is maximum in Fig. 1.

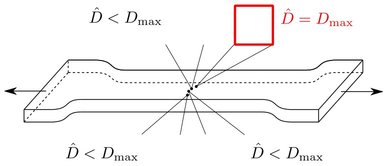

Figure 1. Sketch of the failure location (microstructure taken from [1]).

Model

A Representative Volume Element is used in which the microstructure is modelled in a highly idealised fashion. The hard inclusion phase is randomly distributed in a soft matrix. The 'worst-case' distribution (the 'RVE' highlighted in Fig. 1) is identified by comparing a large number of randomly generated RVEs.

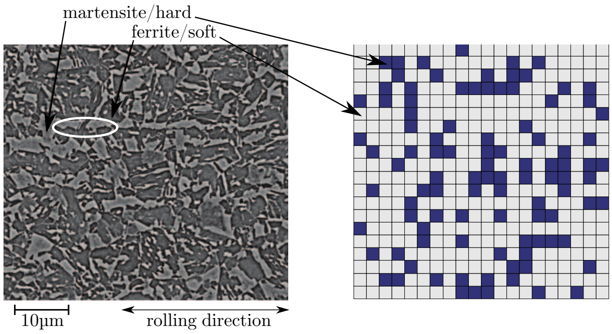

Figure 2. Microstructure of a multi-phase material: (left) microscopic image of a dual-phase steel, adapted from [2]; (right) a randomly generated RVE. The critical feature of Fig. 3 is highlighted in white (left).

Result

The RVEs are compared in terms of damage, defined as the product of hydrostatic stress and plastic strain. Three examples are shown in Fig. 3 where the damage increases from left to right. The highest level of damage is consistently observed in a critical feature such as sketched. A similar feature is observed experimentally (highlighted in white in Fig. 2(left)). Closer investigation reveals that the feature's orientation with respect to the load is essential. The level of damage is influenced by the microstructure in the vicinity of the feature. Indeed similar features are found where damage is low (Fig. 3(left)).

The hardness, characterized by the factor χ^{hard}, and the volume fraction, f^{hard}, of the inclusion phase are varied for the most critical microstructure. Fig. 4 shows that the overall hardness increases with both, however failure initiation occurs at a lower applied strain.

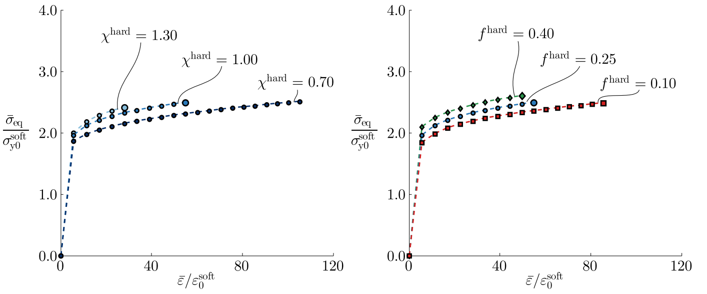

Figure 4. The overall equivalent stress $\bar{\sigma}_{\text{eq}}$ for different hardening factors χ^{hard} (left) and volume fractions f^{hard} (right) of the inclusion phase.

The combined effect is studied by comparing the failure initiation at constant overall hardness. It is observed that the ductility is increased by increasing the volume fraction of the inclusion phase while at the same time decreasing its hardness.

Conclusion

The influence of the load and microstructure on the damage in the critical morphological feature is understood, simplifying the a-priory identification of critical locations inside the microstructure. Also the effect of hard phase volume fraction and hardness on the ductility is identified.

References:

[1] Y. Hu, X. Zuo, R. Li, Z. Zhang, *Mater. Res.*, 15(2):317–322, 2012.
[2] X. Sun, K.S. Choi, W.L. Liu, M.A. Khaleel, *Int. J. Plasticity*, 25(10):1888–1909, 2009.

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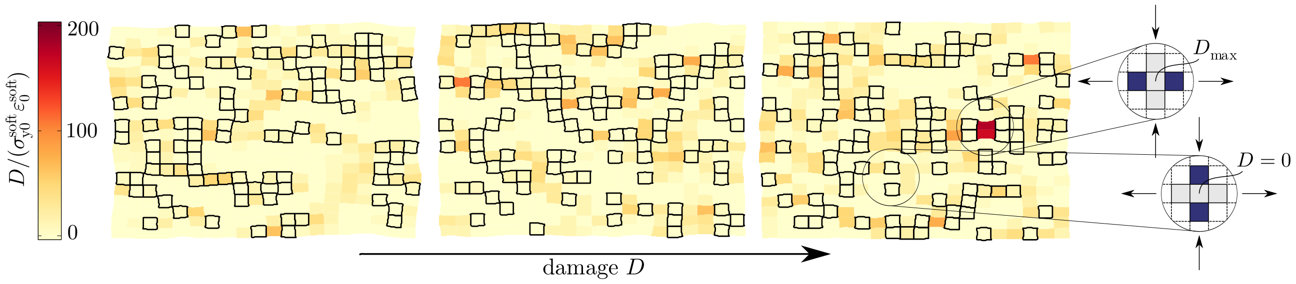

Figure 3. The normalized damage D of RVEs characterized by the lowest, intermediate, and the highest level of damage. The critical feature is highlighted, in which the hard inclusion phase is dark.

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