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EFFECT OF HETEROGENEITY IN SHAPE MEMORY ALLOYS

J. S. OLSEN*, Z. L. ZHANG* AND C.VAN DER EIJK†

*Department of Structural Engineering
Norwegian University of Science and Technology
N-7491 Trondheim, Norway
e-mail: Jim.Stian.Olsen@ntnu.no, Zhiliang.Zhang@ntnu.no

† SINTEF Materials and Chemistry)
N-7465 Trondheim, Norway
e-mail: Casper.v.Eijk@sintef.ntnu.no

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Summary. In this study the behaviour of a superelastic NiTi-alloy containing micro-voids has been investigated. The effect of different sized micro-voids was analysed by employing axisymmetric unit-cell models. It is shown that the critical stress for starting forward phase transformation is strongly affected by the presence of micro-voids. The finite element results indicate that the existence of micro-voids can reduce the re-centring capabilities in NiTi-alloys and that this effect should be taken into consideration of constitutive equations.

1 INTRODUCTION

Constitutive models describing the behaviour of shape memory alloys have been focused to account for the unique features shape memory effect (SME) and superelasticity (SE). Recently models that account for plasticity in addition to SME and SE have been developed.[1,2] This gives the opportunity to investigate what role plasticity has on SMA behaviour both for homogeneous materials, and, as in this study, in-homogeneous materials.

An axisymmetric unit-cell model introduced by Koplik and Needleman[3] has been used to investigate the effect of micro-voids on NiTi-alloys. Auricchio's model[4,5] for SMA, extended by Rebelo et al.[6] to include plasticity, was used as a UMAT subroutine in the finite element analysis software ABAQUS.

2 RESULTS AND DISCUSSION

In this study the focus has been on an axisymmetric unit-cell containing micro-voids with initial void volume fraction f_0 in the range 0.0 - 0.127 subjected to various stress triaxiality levels (T=0.33 - 1.33). The stress triaxiality is defined as

$$T = \frac{\sigma_{hydrostatic}}{\sigma_{equivalent}}. \tag{1}$$

Fig. 1(a) shows the equivalent stress-strain curves for a unit-cell with different initial void volume fractions subjected to uniaxial loading, while Fig. 1(b) shows the effect of stress triaxiality on a unit-cell with initial void volume fraction f_0=0.0104. There is a clear indication in the results that the critical stress for forward transformation initiation is affected by both the presence of micro-voids and the stress state. The reduction can be as large as 40 % (See Fig. 1). (The narrow hystereses in Fig. 1(b) are due to convergence problems in ABAQUS when certain levels of initial void volume fraction and stress triaxiality are combined. The results, however, still depicts the effect of the stress triaxiality on the critical stress for initiation of forward phase transformation, and are therefore included). Yan et al.[1] reported that for shape memory alloys with no, or very small, initial void volume fraction, there was little effect on the critical stress due to varying stress triaxiality. A heterogeneous shape memory alloy will experience in-homogeneous phase transformations. This can explain the strong effect that f_0 and T have on the critical transformation stress. Early initiation of phase transformation close to the micro-void due to stress concentrations, leads to a reduction in the macroscopic stiffness. Increasing triaxiality will lead to early transformation in a larger part of the material, hence; the macroscopic stiffness is further reduced. The same reasoning can be made about the initiation of plastic deformation in the material. From Fig. 1(a) it can be seen that the homogeneous material (f_0=0.0) has a pronounced shift in the stress curve as the phase transformation ends and elastic deformation of twinned martensite starts. For the heterogeneous materials (f_0=0.0013 - 0.127) the shift is less pronounced and this effect is enhanced by increasing the initial void volume fraction. The degree of plastic deformation increases with the void size, which leads to a reduction in the macroscopic stiffness. Fig. 3 shows contour plots of the local equivalent plastic strains in three unit-cells with different initial void volume fraction (f_0=0.0013, f_0=0.0352, f_0=0.083). The unit-cells are subjected to uniaxial load and the plots show the local equivalent plastic strains at E_e=0.08. The assumption made by Olsen et al.,[7] that imperfections in the material can be detrimental to the re-centring capabilities of shape memory alloys are supported by the micromechanical analyses made in this study. Due to high stress levels close to the micro-void there will be an early onset of plastic deformation leading to residual strain. This is clearly seen in Fig. 1(a) where it can be seen that residual strains can reach levels as high as 1 %, depending on the initial void volume fraction.

3 CONCLUDING REMARKS

The effect of micro-voids and plasticity on the behaviour of superelastic NiTi-alloys has been studied. Micro-voids strongly affect the critical stress for initiation of phase transformation in the alloy; an effect that is enhanced by imposing triaxial loading. Early onset of plastic deformation due to the micro-voids has a detrimental effect on the materials re-centring capabilities. The main conclusion is that micro-voids and stress triaxiality affects the overall behaviour of NiTi-alloys and need to be considered when modelling superelastic behaviour.

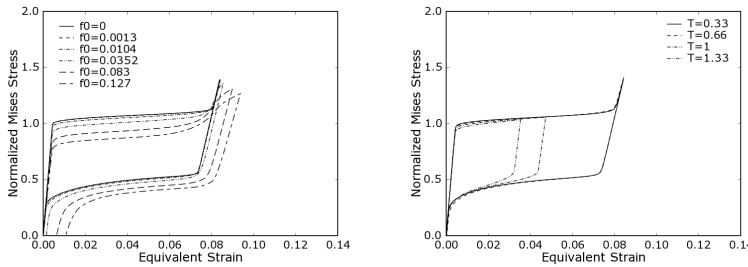

Figure 1: Effect of (a) initial void volume fraction on the equivalent stress-strain response in a unit-cell subjected to uniaxial loading, and (b) stress triaxiality in a unit-cell with $f_0 = 0.0104$.

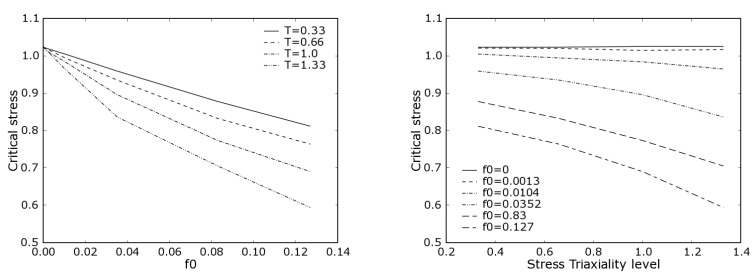

Figure 2: Critical stress for forward transformation as a function of (a) initial void volume fraction and (b) stress triaxiality level.

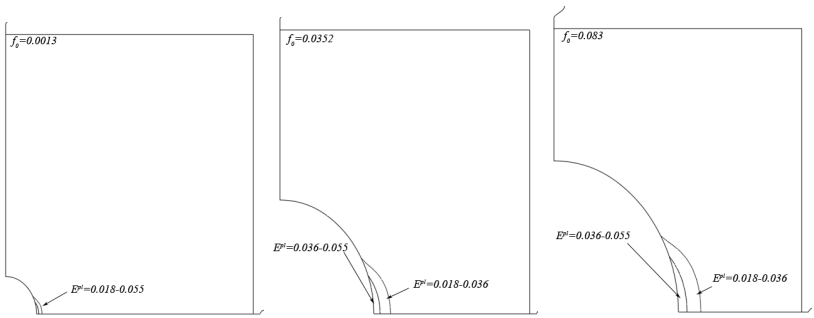

Figure 3: Contour plots of local equivalent plastic strain, E^{pl}, at E_e=0.08 in unit-cells subjected to uniaxial load. (a) f_0=0.0013, (b) f_0=0.0352, (c) f_0=0.083.

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