A MICROMECHANICS ANALYSIS FOR THE MICROSTRUCTURE DESIGN OF A TWO-PHASE PSEUDELASTIC COMPOSITE

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ABSTRACT: A micromechanics analysis on the possibility of designing a two-phase pseudoelastic composite is made for the case where ductile transformable shape memory alloy plastic particles are imbedded coherently in an elastic matrix. It is demonstrated that a pseudoelastic stress-strain loop in a macroscopic loading-unloading cycle can be obtained by microscopically stress induced forward and reverse martensitic transformations in the SMA particles. The relation between the macroscopic stress-strain response and the material parameters of the constituents of this composite is quantified through the micromechanics calculations, which reveals that the best ductility and thus the greatest energy absorption capacity of this novel microstructure can be obtained by the optimum material design.

KEY WORDS: composite, optimum material design, two-phase pseudoelastic composite, microstructure design

I. INTRODUCTION

Advanced composites, due to their combined advantage in various physical and mechanical properties, see ever increasing applications in areas of modern high technology. Examples are: the shock-resistant composites applied in space platforms and hypersonic vehicles, smart composites used in automatic control and robot, etc.. Many of these applications require materials that will survive the impact loading and have high capacity of energy absorption and resilient property after inelastic deformation. In developing such materials, modelling their properties and predicting their behavior poses challenging theoretical problems to the scientists of both materials and mechanics due to the fact that these composites are often manufactured and synthesized under the guidance of material design. They are generally constituted by two or more materials with unequal elastic constants and stress-strain responses, etc.. They suffer from highly inhomogeneous stress and strain fields when loaded either thermally or mechanically. The characteristic length scale of the inhomogeneity of the stresses and strains is determined by the geometry of the microstructure. For the composite studied here, it is about 1–100 microns. Successful, fundamental research into the properties and reliability of the composite therefore requires theoretical models that treat the materials as discontinuous on the same microscopic scale and predict the macroscopic behavior correctly. In doing so, micromechanics approach will play a dominant role. In this paper, as a first step toward such a goal, it is demonstrated that the macroscopic
pseudoeastic stress-strain loop with hysteresis can be obtained if the temperature, extent of deformation and the material parameters of the constituents is properly selected and controlled. The quantitative analysis is based on the self-consistent Mori-Tanaka's average field theory[1-3] which has been widely used in mechanics of composite materials. Unlike most other approximate methods which require solving implicit equations numerically, the Mori-Tanaka method has the advantage of yielding explicit, closed-form analytical relations for the effective macroscopic properties (behaviors). In the present study, the macroscopic yielding function and the incremental stress strain relation in stress space is derived and the deformation characteristics are analysed. The implication of the pseudoeastic behavior to the crack-tip shielding is briefly discussed in the final part.

II. DERIVATION OF THE CONSTITUTIVE RELATIONS

1. Deformation Characteristics of the Two Phases

![Fig.1 (a) Pseudoeastic stress-strain curves and (b) the associated forward and reverse transformation yielding surfaces](image)

The two-phase composite considered in this paper consists of an isotropic elastic matrix phase denoted by the index $M$ and an isotropic elastic-plastic particulate phase as inclusions denoted by the index $I$. Perfect bonding is assumed between the two constituents which have different isotropic elastic constants denoted by $\mu, K, \nu$ and $\bar{\mu}, \bar{K}, \bar{\nu}$ for matrix and particulates, respectively. For simplicity, the shape memory alloy particles (usually monocrystal grains) are assumed to have a random distribution, a spherical shape and an equal size. The volume fraction of the SMA particles is $\gamma$. The matrix obeys the Hook's law. In general, SMA particles may display different mechanical behavior, i.e., pseudoeasticity and shape memory effect at high and low temperatures where austenite and martensite, respectively, are stable or metastable. In the present work only pseudoeastic behavior at high temperature ($T > A_f$) is considered. This kind of behavior is caused microstructurally by a mechanism called stress-induced forward and reverse transformations. A lot of work has been done on the constitutive relations of pseudoeasticity in both theory and experiment. The main deformation features of the pseudoeasticity in uniaxial tension and compression are shown in Fig.1(a), where the inelastic deformations are associated with two yielding surfaces (in temperature and stress space, the terminology “yielding” in classical plasticity is employed) which microscopically correspond to the forward and reverse transformation conditions, respectively. The two-dimensional illustration of the two yielding surfaces are