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Stress distributions in single shape memory alloy fiber composites

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ABSTRACT

Shape memory alloy (SMA) in the form of wires or short fibers can be embedded into host materials to form SMA composites that can satisfy a wide variety of engineering requirements. The recovery action of SMA inclusions induced by elevated temperature can change the modal properties and hence the mechanical responses of entire composite structures. Due to the weak interface strength between the SMA wire and the matrix, interface debonding often occurs when the SMA composites act through an external force or through actuation temperature or combination of the two. Thus the function of SMAs inside the matrix cannot be fully utilized. To improve the properties and hence the functionality of SMA composites it is therefore very important to understand the stress transfers between SMA fibers and matrix and the distributions of internal stresses in the SMA composite. In this paper, a theoretical model incorporating Brinson's constitutive law of SMA for the prediction of internal stresses is successfully developed for SMA composites, based on the principle of minimum complementary energy. A typical two-cylinder model consisting of a single SMA fiber surrounded by epoxy matrix is employed to analyze the stress distributions in the SMA fiber, the matrix, and at the interface, with important contributions of the thermo-mechanical effect and the shape memory effect. Assumed stress functions that satisfy equilibrium equations in the fiber and matrix respectively are utilized, as well as the principle of minimum complementary energy, to analyze the internal stress distributions during fiber pull-out and the thermal loading process. The entire range of axisymmetric states of stresses in the SMA fiber and matrix are developed. The results indicate substantial variation in stress distribution profiles for different activation and loading scenarios.

1. Introduction

Shape memory alloys (SMAs), a kind of smart material that is often used in sensors and strain actuators, have been investigated extensively over the past two decades. Unlike traditional materials or even most engineering material systems, SMAs can undergo a reversible solid–solid phase transformation between a martensitic phase and an austenitic phase under proper thermo-mechanical loading. By virtue of this transformation SMAs possess some unique properties, such as shape memory effect, super elasticity, high damping capabilities, and bio-compatibility, which lead to their wide use in civil engineering [1,2], the aviation industry [3], and medical devices [4].

SMA composite, fabricated by embedding SMA fibers or particles into a host material, is a new type of adaptive material that can achieve vibration control [5], structural reinforcement [6], shape change [3,7], and damage repair [8]. Therefore, many analytical, numerical, and experimental studies of SMA fiber reinforced composites have been conducted. James and Lagoudas [9] developed a micromechanics method to evaluate the effective thermo-mechanical properties of composites reinforced with SMA fibers. The thermo-mechanical responses of SMA hybrid composites subjected to combined thermal and mechanical loads have been studied [10] using a finite element method. Experimental studies [11] of the deformation behavior of a NiTi SMA composite have been conducted by Murasawa et al. All this research has concentrated on the properties of the SMA composites. However, the interface between the NiTi fiber/particle and the matrix must be very well bonded to ensure continuity of stress and strain. Furthermore, the interface not only transfers stress from NiTi SMA to the matrix, it is also a potential source of cracks. Interfacial debonding failure of SMA composites, caused by embedded prestrained SMA fibers in some host materials, may occur as a result of over-actuation of temperature or some kind of thermo-mechanical loading. Lau et al. carried out some experimental work [12] on interfacial

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