Materials and Design 32 (2011) 2923–2933

Contents lists available at ScienceDirect

Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Characterization of a shape memory alloy hybrid composite plate subject to static loading

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ARTICLE INFO

Article history:
Received 9 July 2010
Accepted 28 November 2010
Available online 21 December 2010

Keywords:
A. Polymer matrix composites
G. Coupon testing
H. Selection of components

ABSTRACT

In this manuscript the design process of a SMA wire-reinforced hybrid composite (SMAHC) plate is introduced in detail. The influence of various parameters on the overall behavior of the SMAHC plate is discussed. These parameters include: the mechanical behavior of the constituents (i.e. the host composite and SMA), the SMA volume fraction, the temperature dependent loading effects and the fabrication process. For that, a series of SMAHC plates were fabricated and tested under monotonic loading condition. The characteristics curves and formula for assessing the effect of the SMA at different temperatures are presented. It would be demonstrated that the embedment of SMA wires could improve the overall structural response of the host material in terms of stiffness and strength at elevated temperatures. Also capability of the one dimensional constitutive models in predicting the macroscopic stress–strain behavior of SMAHC plates is verified experimentally.

1. Introduction

Shape memory alloys (SMAs) are gaining interest in the aerospace, automotive, and medical industries due to their unique characteristics, which include the shape memory effect, pseudoelasticity, and improved material behavior upon heating. Unlike the extensive research into widely used applications of SMA as an actuator muscle, the investigation into structural enhancement via the use of SMA is relatively scarce. It should be noted that in all of the aforementioned applications, it is the shape memory effect of SMA that is utilized. This unique property that occurs by the crystalline transformation of the alloy from martensite phase (low stiffness) into austenite phase (high stiffness) upon heating induces high tensile force in SMA. However, the type of application addressed here, in the context of structural reinforcement by SMA, is different from the conventional applications that often use SMA as a miniature actuation muscle. The latter application takes advantage of SMA retraction (i.e. the shape memory effect). In contrast, through transformation between its two crystalline phases, the SMA reinforcement uses its higher thermally-induced stiffness as embedded within a separate host substrate to enhance the overall response. Knowing that SMA retraction is affected by the material deformation of the host substrate, the structural reinforcement would be achieved by the shape memory effect of SMA.

Characterization of shape memory alloys dates back to 1969, when the National Aeronautics and Space Administrative (NASA, USA) released a comprehensive report [1] that presented the constitutive thermo-mechanical behavior of Nickel Titanium Novel Ordinance Laboratory (NiTiNOL) wire. Since then, many researchers have addressed and formulated the SMA behavior based on the materials introduced within the aforementioned report [2–6].

A systematic study of thermo-mechanical behavior of NiTiNOL was conducted by Liang and Rogers [7], through which they presented a constitutive relationship for the formulation of crystalline transformation from martensite to austenite phases as well as the reverse process. Their proposed formulation is considered a basic mathematical model of the transient behavior of NiTiNOL upon heating or cooling between its two crystalline phases. Since then, the application of SMA in structural reinforcement via using its mitigating effect has been an extensively researched subject.

Among the various types of structural reinforcement, the use of SMA within composite structures is an interesting subject due to the many applications of composite materials in various industries. Numerous applications use the characteristic of greater stiffness induced in NiTiNOL alloys upon their transformation into the austenite phase. Many researchers [8–12] have proposed theoretical and numerical models to investigate the effect of SMA reinforcement in composite structures subject to different loadings; however, few of them have addressed this issue from a practical perspective.

The research into experimental characterization of shape memory alloy reinforced hybrid composite (SMAHC) is still continuing. Turner et al. [13], Turner [14,15] and Davis et al. [16], developed a manufacturing method for fabrication of SMAHC beams and characterized their behavior under thermo-mechanical loading. Their manufacturing method is very similar to the manufacturing

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0261-3069/$ - see front matter
doi:10.1016/j.matdes.2010.11.068