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Transverse tensile and creep modeling of continuously reinforced titanium composites with local debonding

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Abstract

A new, widely applicable model for local interfacial debonding in composite materials is presented. Unlike its direct predecessors, the new model allows debonding to progress via unloading of interfacial stresses even as global loading of the composite continues. The primary advantages of this new model are its accuracy, simplicity, and efficiency. In order to apply the new debonding model to simulate the behavior of composite materials, it was implemented within the generalized method of cells (GMC) micromechanics model for general periodic multi-phased materials. The time- and history-dependent (viscoplastic) transverse tensile and creep behavior of SiC/Ti composites, which are known to be subject to internal fiber–matrix debonding, was then simulated. Results indicate that GMC's ability to simulate the transverse behavior of titanium matrix composites has been significantly improved by the new debonding model. Further, the present study has highlighted the need for a more accurate time, temperature, and rate dependent constitutive representation of the titanium matrix behavior in order to enable predictions of the composite transverse response, without resorting to recalibration of the debonding model parameters.

Keywords: Metal matrix composite; Debonding; Modeling; Micromechanics; Viscoplasticity; Tension; Creep; Method of cells

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1. Introduction

Accurate design and life prediction tools for advanced multi-phased materials are needed to facilitate the implementation of these developing materials. Although closure has not been reached regarding the best models for use in the design and life prediction tools, it has become clear that if a model is ever to serve a purpose beyond that of basic research, it must fulfill several primary requirements. These include a high level of accuracy on the macro and microscales, computational efficiency, and compatibility with the finite element method. Fulfillment of these requirements allows a model to serve materials scientists who design composite materials by enabling quick and easy variation of composite parameters for material

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development optimization purposes. Likewise, those who design structures with these materials are well served if the model is consistent with the finite element method. Though it is not perfect, the generalized method of cells (GMC), developed by Aboudi (1991, 1995), is an excellent choice for implementation into modeling tools for advanced composites, given the requirements described above.

GMC is an analytical micromechanics model for multi-phased materials with arbitrary periodic microstructures. It provides closed-form constitutive equations for such materials and allows easy incorporation of physically based viscoplastic deformation models, as well as arbitrary failure and damage models for each phase. Further, recent independent advances have simplified the utilization of GMC as an elemental constitutive model from within commercial nonlinear finite element analyses (Wilt et al., 1997; Arnold et al., 1999), and significantly increased the model's computational efficiency (Pindera and Bednarcyk, 1999).

In addition, GMC has been implemented within a comprehensive micromechanics analysis code, MAC/GMC by NASA Glenn Research Center (Arnold et al., 1999). The code has many features that render it useful for design, deformation modeling, and life prediction for a wide range of materials, and it is available (www.grc.nasa.gov/WWW/LPB/mac) to the general public within the United States (as it is export controlled). The present investigation extends the capabilities of MAC/GMC by incorporating a new physically based micro-level debonding model that allows local unloading to occur in the composite. The code, with this new debonding model, was employed to examine the longitudinal tensile deformation and failure behavior of SiC/Ti composites by Bednarcyk and Arnold (2000, 2001). Herein the new debonding model, as implemented in MAC/GMC, is applied to examine the *transverse* tensile deformation and creep behavior of SiC/Ti. The new debonding model is compared with several previous models that have been used to simulate interfacial debonding in titanium matrix composites (TMCs). Via comparison with experiment, it is shown that the new model, working in the context of the recently developed computationally efficient version of GMC, allows more accurate modeling of the composite behavior compared to previous methods.

2. The transverse response of SiC/Ti composites

In recent years, the pursuit of advanced aerospace systems has fueled research on TMCs. These materials, in particular continuously reinforced SiC/Ti, have demonstrated potential for high temperature propulsion and airframe application because of their excellent properties at elevated temperature *in the fiber direction*. Unfortunately, the transverse behavior of TMCs has proven to be the composite's Achilles' heel. Weak bonding at the fiber–matrix interface renders the composite inferior to monolithic titanium and superalloys in the transverse direction. Amelioration of SiC/Ti transverse properties through lamination of plies with different fiber orientations has proven largely ineffective because the transverse behavior of each ply is so poor. Thus realization of the potential demonstrated by TMCs will likely depend on future development of manufacturing processes that can reduce the effects of the weak bonding in the composite; one example being the hybridization of strong and weakly bonded fibers (Arnold et al., 1996a). In the meantime, modeling efforts, such as the present investigation, can help provide a better understanding of the interface and how the weak bonding affects the overall behavior of TMCs. Further, since the weak bonding in SiC/Ti is so pronounced and so well established, SiC/Ti can serve as a model system for development of interface modeling technology. This technology will then be employed for present and future composite systems that exhibit weak bonding, but are not rendered so ineffective by the weak bonding as TMCs have been thus far.

Fig. 1 shows the typical 650 °C tensile response of the SCS-6 fiber, the TIMETAL 21S [1] matrix, and SCS-6/TIMETAL 21S composites in the longitudinal and transverse directions. Evident in the composite

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[1] TIMETAL 21S is a registered trademark of TIMET, Titanium Metals Corporation, Toronto, OH.