PROGRESSIVE DAMAGE IN CMC MINICOMPOSITES WITH THICK INTERPHASES UNDER TENSILE LOADING

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Abstract
In this work, a composite cylinder assemblage (CCA) model has been used to model the progressive damage behavior under tensile loading of a three-phase ceramic matrix single-tow mini-composite composed of carbon fiber, silicon carbide (SiC) matrix and boron nitride (BN) interphase. A 3-phase shear lag model has been used to capture the matrix crack-driven stress redistribution in the presence of a finite thickness interphase. A probabilistic progressive modeling approach has been proposed to predict the tensile response of ceramic matrix composite (CMC) minicomposites. Multiple matrix cracking, interfacial debonding, and fiber failure have been considered as the damage modes. The predicted tensile response of CMCs from the progressive damage modeling approach agrees with experimental results obtained with C/BN/SiC minicomposites. Finally, the influence of volume fractions, constituent properties, and interfacial properties on the mechanical behavior of CMC minicomposites has been presented.

1. Introduction

Toughness enhancement in CMCs occurs due to an 'engineered' finite thickness weak fiber matrix interphase. In a previous study by the authors, the effect of varying BN interphase thicknesses on the tensile response of C/BN/SiC mini-composites under tensile loading was examined [1]. The present work proposes an idealized CCA model to investigate the progressive damage behavior in these mini-composites allowing for probabilistic matrix cracking in SiC and probabilistic fiber breaking in C-bundle. A three-phase CCA model with a generalized shear lag model for stress redistribution has been proposed (see figure 1). Weibull statistics have been adopted in the matrix and fiber to capture the failure statistics in these brittle phases. Additionally, interactions between the location of matrix cracks, interfacial debonding, and fiber breaks have also been captured.

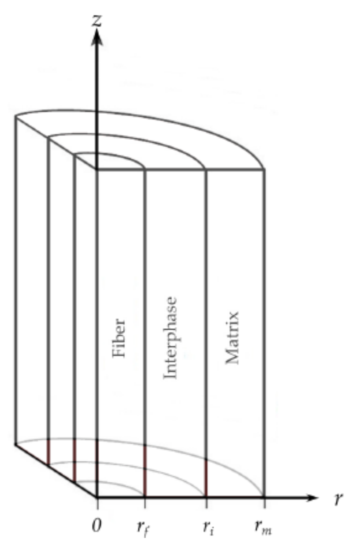

Fig. 1: 3-phase shear lag model

2. Results

Figure 2 depicts representative plots of axial stress versus axial strain predictions for a C/BN/SiC minicomposite that has been extensively investigated for tensile strength behavior [1], porosity distribution behavior [2], and constituent property determination using nanoindentation [3]. As discussed, the composite's matrix and fiber phases have been modeled using Weibull statistics, allowing for multiple matrix cracking, matrix-interphase debonding, and fiber breaks to occur progressively. In the current model, the volume effects have been explicitly accounted for – a strength value is assigned based on the distance between two matrix cracks while a new crack is introduced using a uniform distribution. Depending on the debond length at each matrix crack-interphase location, the possibility of an additional crack within neighboring cracks is ascertained (type I versus type II cracks). The local stress redistribution as a function of matrix crack evolution is accomplished using the 3-phase shear lag model, while a global load-sharing model has been used for fiber breaks wherein the stress is assumed to be shared uniformly amongst all the remaining fibers as the density of fiber breaks increases. As can be observed in Figure 2, matrix crack density evolution is closely followed by a 'lagging' fiber break density. The entire composite fails when the fiber break density reaches a critical value. In the future, Gaussian random fields will be explored to simulate the strength statistics.

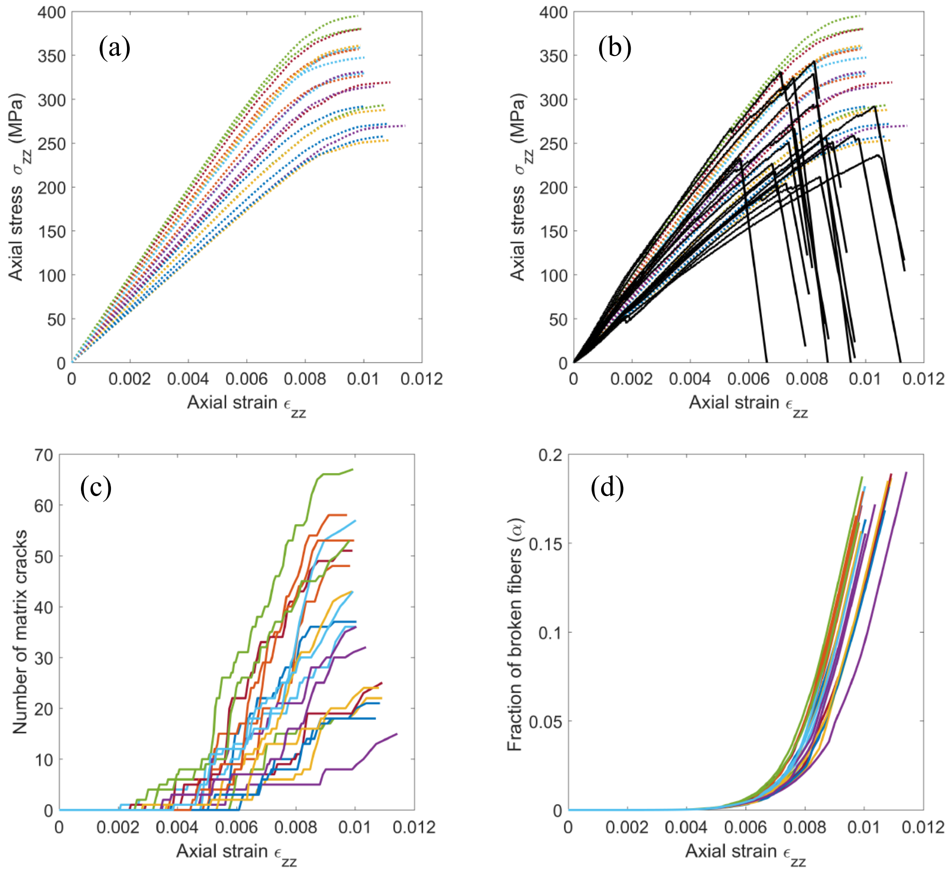

Fig. 2: Stress-strain response and progression of microscale damage for a C/BN/SiC minicomposite (a) predicted tensile response from multiple analysis runs, (b) predicted tensile response compared with the experimentally determined tensile response, (c) progression of matrix cracking that can be quantified by the number of cracks, and (d) progression of fiber breaks as a fraction of failed fibers.

3. Conclusions

While the presented model provides insight into the progressive damage in three-phase CMCs, the biggest challenge is accurately capturing the inherent defect distribution in CMCs. These defects act as damage onset locations that affect the overall load-carrying capability of the composite.

Acknowledgments

The financial support of Pratt and Whitney is gratefully acknowledged.

References

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