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PREDICTION OF FAILURE ENVELOPES OF COMPOSITE LAMINATES BASED ON FINITE-VOLUME MICROMECHANICS

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ABSTRACT

The multiscale prediction of biaxial failure envelopes of symmetric composite laminates using lamination theory and micromechanics models called Parametric Finite-Volume Direct Micromechanics (FVDAM) theory and Generalized Method of Cells (GMC). The micromechanics models are used to predict the degraded properties of individual plies due to local fiber, matrix and interfacial damage. Initial and final failure surface predictions using FVDAM and GMC-based analyses are then compared. The FVDAM has the detailed stress field predictive capability, and the FVDAM-based predictions are conservative relative to the GMC-based predictions.

Keywords: multiscale, GMC, FVDAM, failure envelope.

INTRODUCTION

While prediction of laminate failure envelopes based on macroscopic ply-level failure events is commonly employed in design calculations, it masks the various micro-level damage events that provide insight into the design of superior laminates. The multiscale laminate failure envelope approach developed by Tang and Zhang based on the generalized method of cells micromechanics (GMC) model and lamination theory has proved a viable tool in predicting failure envelopes of symmetric laminates under biaxial loading relative to the phenomenological approach. Herein, we incorporate an advanced homogenization model called finite-volume direct averaging micromechanics (FVDAM) theory into the multiscale laminate failure approach in order to mitigate poor GMC predictive capabilities when transverse shear is an important ply-level stress component. Comparison of the GMC-based and FVDAM-based laminate failure envelopes is carried out for several laminate configurations in order to delineate the limits of applicability of simple, yet efficient, spring-like models such as GMC.

RESULTS AND CONCLUSIONS

Failure envelopes were generated for [0], [90/0]s, [0/±60]s and [90/±45/0]s laminates. For the unidirectional laminates the loading was applied in the σ_{22}-σ_{12} and σ_{22}-σ_{23} stress spaces, while for the multidirectional laminates the loading was applied in the laminate σ_{xx}-σ_{yy} stress space. In the case of unidirectional laminates, initial failure envelopes corresponded to the maximum failure envelopes due to the rapid propagation of matrix-dominated failure accompanied by the loss of load-bearing capability. The FVDAM-based predictions were

conservative relative to the GMC-based predictions, and the largest differences between the two micromechanics predictions occurred along the negative σ_{22} axis and positive and negative σ_{23} axes. This is illustrated in Fig. 1 for the [0/±60]s laminate where large differences in the initial failure envelopes are observed along the negative σ_{xx} and σ_{yy} directions. Axial shear stress fields in the principal material coordinate system of the 60 deg plies just before and after failure initiation are shown in Fig. 2 for the vertical load path, demonstrating the important differences between local GMC and FVDAM stress predictions.

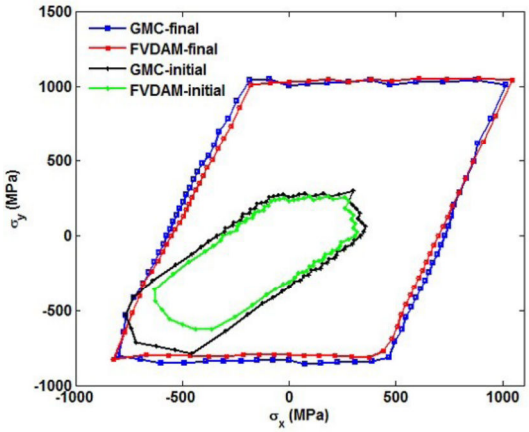

Fig. 1 - Homogenized failure envelopes obtained from GMC and FVDAM calculations for the [0 /±60]s laminate.

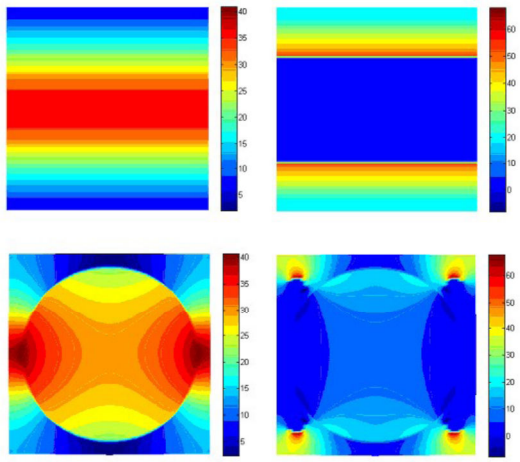

Fig. 2 - Local axial shear stress fields (σ_{12}) obtained from GMC (top) and FVDAM (bottom) calculations just before initial failure (left) and after (right).

While GMC and FVDAM-based predictions of initial failure surfaces of unidirectional and multidirectional laminates differ due to FVDAM's detailed stress field capability, differences in the final failure envelopes are small. Failure in unidirectional laminates under off-axis inplane loading is matrix and fiber/matrix interface dominated - this requires detailed stress field predictive capability. In contrast, multidirectional laminates exhibit progressive ply-level failure evolution which ultimately involves fiber breakage. Hence spring-like models such as GMC are adequate for this purpose.

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