The Effect of Long-Term Thermal Cycling on the Microcracking Behavior and Dimensional Stability of Composite Materials

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Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of
Doctor of Philosophy
in
Engineering Mechanics

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December 1,1997
Blacksburg, Virginia

Keywords: Graphite-Epoxy, Cyanate Ester, Coefficient of Thermal Expansion, Stiffness, Thermal Fatigue, Cryogenic, Fizeau Interferometry, Space, Shear Lag

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(ABSTRACT)

The effect of thermal-cycling-induced microcracking in fiber-reinforced polymer matrix composites is studied. Specific attention is focused on microcrack density as a function of the number of thermal cycles, and the effect of microcracking on the dimensional stability of composite materials. Changes in laminate coefficient of thermal expansion (CTE) and laminate stiffness are of primary concern. Included in the study are materials containing four different Thornel fiber types: a PAN-based T50 fiber and three pitch-based fibers, P55, P75, and P120. The fiber stiffnesses range from 55 Msi to 120 Msi. The fiber CTE's range from $-0.50x10^{-6}$/°F to $-0.80x10^{-6}$/°F. Also included are three matrix types: Fiberite's 934 epoxy, Amoco's ERL1962 toughened epoxy, and YLA's RS3 cyanate ester. The lamination sequences of the materials considered include a cross-ply configuration, $[0/90]_{2s}$, and two quasi-isotropic configurations, $[0/+45/-45/90]_s$ and $[0/+45/90/-45]_s$. The layer thickness of the materials range from a nominal 0.001 in. to 0.005 in. In addition to the variety of materials considered, three different thermal cycling temperature ranges are considered. These temperature ranges are ±250°F, ±150°F, and ±50°F. The combination of these material and geometric parameters and temperature ranges, combined with thermal cycling to thousands of cycles, makes this one of the most comprehensive studies of thermal-cycling-induced microcracking to date.

Experimental comparisons are presented by examining the effect of layer thickness, fiber type, matrix type, and thermal cycling temperature range on microcracking and its influence on the laminates. Results regarding layer thickness effects indicate that thin-layer laminates microcrack more severely than identical laminates with thick layers. For some specimens in this study, the number of microcracks in thin-layer specimens exceeds that in thick-layer specimens by more than a factor of two. Despite the higher number of microcracks in the thin-layer specimens, small changes in CTE after thousands of cycles indicate that the thin-layer specimens are relatively unaffected by the presence of these cracks compared to the thick-layer specimens. Results regarding fiber type indicate that the number of microcracks and the change in CTE after thousands of cycles in the specimens containing PAN-based fibers are less than in the specimens containing comparable stiffness pitch-based fibers. Results for specimens containing the different

pitch-based fibers indicate that after thousands of cycles, the number of microcracks in the specimens does not depend on the modulus or CTE of the fiber. The change in *laminate* CTE does, however, depend highly on the stiffness and CTE of the fiber. Fibers with higher stiffness and more negative CTE exhibit the lowest change in laminate CTE as a result of thermal cycling. The overall CTE of these specimens is, however, more negative as a result of the more negative CTE of the fiber. Results regarding matrix type based on the ±250°F temperature range indicate that the RS3 cyanate ester resin system exhibits the greatest resistance to microcracking and the least change in CTE, particularly for cycles numbering 3000 and less. Extrapolations to higher numbers of cycles indicate, however, that the margin of increased performance is expected to decrease with additional thermal cycling. Results regarding thermal cycling temperature range depend on the matrix type considered and the layer thickness of the specimens. For the ERL1962 resin system, microcrack saturation is expected to occur in all specimens, regardless of the temperature range to which the specimens are exposed. By contrast, the RS3 resin system demonstrates a threshold effect such that cycled to less severe temperature ranges, microcracking does not occur. For the RS3 specimens with 0.005 in. layer thickness, no microcracking or changes in CTE are observed in specimens cycled between ±150°F or ±50°F. For the RS3 specimens with 0.002 in. layer thickness, no microcracking or changes in CTE are observed in specimens cycled between ±50°F. Results regarding laminate stiffness indicate negligible change in laminate stiffness due to thermal cycling for the materials and geometries considered in this investigation. The study includes X-ray examination of the specimens, showing that cracks observed at the edge of the specimens penetrate the entire width of the specimen. Glass transition temperatures of the specimens are measured, showing that resin chemistry is not altered as a result of thermal cycling.

Results are also presented based on a one-dimensional shear lag analysis developed in the literature. The analysis requires material property information that is difficult to obtain experimentally. Using limited data from the present investigation, material properties associated with the analysis are modified to obtain reasonable agreement with measured microcrack densities. Based on these derived material properties, the analysis generally overpredicts the change in laminate CTE. Predicted changes in laminate stiffness show reasonable correlation with experimentally measured values.

ACKNOWLEDGEMENTS

The author would like to gratefully acknowledge Professor Michael W. Hyer for his dedication to this project. I have worked with him for over seven years in my graduate education and his unending drive and dedication to the field of composite materials never ceases to amaze me. I am also grateful for the technical support of my Ph.D. committee members, Profs. Scott L. Hendricks, John J. Lesko, Brian J. Love, and Kenneth L. Reifsnider. I would like to thank Profs. Ron G. Kander and Don H. Morris, who served on my committee during the preliminary stages of my degree but had to withdraw in the end due to scheduling conflicts.

The technical support and advice I received during my residency at NASA Langley Research Center is gratefully acknowledged. Specifically, I would like to thank Dr. Stephen Tompkins, Dr. David Bowles, Dr. Wallace Vaughn, Dr. Howard Maahs, Craig Ohlhorst, and James Shen. Additional technical support was provided by Teresa O'Neil, Craig Leggette, Ron Penner, and Sandy Branham, to whom I am also grateful. A special thanks is given to Ashley Predith who helped tremendously with some of the experimental testing phases of this work.

I would also like to acknowledge Prof. Hugh McManus of M.I.T. for his help and advice with the analysis portion of the project. He was very willing to share his analysis code with me, for which I am most grateful.

Finally, I would like to thank my wife, Dr. Nicole L. Breivik, for her support throughout the completion of this degree. The final preparation of this dissertation coincided with the arrival of our son, Patrick Steven Brown, born on Oct. 17, 1997. I would like to thank my parents, Peter and Carol Brown, for their help and support during this momentous time in our lives.

This work was funded by the Environmental Interactions Branch of NASA Langley Research Center through the NASA-Virginia Tech Composites Program, grants NAG-1-343 and NAG-1-1912.

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