# Probabilistic Thermomechanical Fatigue of Polymer Matrix Composites

Traditional computational approaches for predicting the life and long-term behavior of materials rely on empirical data and are neither generic nor unique in nature. Also, those approaches are not easy to implement in a design procedure in an effective, integrated manner. The focus of ongoing research at the NASA Lewis Research Center has been to develop advanced integrated computational methods and related computer codes for a complete reliability-based assessment of composite structures. These methods--which account for uncertainties in all the constituent properties, fabrication process variables, and loads to predict probabilistic micromechanics, ply, laminate, and structural responses-have already been implemented in the Integrated Probabilistic Assessment of Composite Structures (IPACS) (ref. 1) computer code. The main objective of this evaluation is to illustrate the effectiveness of the methodology to predict the long-term behavior of composites under combined mechanical and thermal cyclic loading conditions.

A unified time-, stress- and load-dependent Multifactor Interaction Equation (MFIE) model developed at NASA Lewis (ref. 2) has been used to simulate the long-term behavior of polymer matrix composites. The MFIE model evaluates the magnitude of degradation and properties of constituent materials (including possible impending failure modes) at every cycle step at the temperature that will be used for micromechanics and laminate analysis.

The deterministic part of the methodology has been implemented in the in-house computer code Integrated Composite Analyzer (ICAN) (ref. 3). NASA Lewis has demonstrated a methodology to compute the fatigue life for different applied-stress to laminate-strength ratios on the basis of first-ply failure criteria and thermal cyclic loads. (First-ply failure criteria assumes that a laminate has failed when any stress component in a ply exceeds its respective allowable.) Degradation effects due to long-term environmental exposure and thermomechanical cyclic loads are considered in the simulation process.
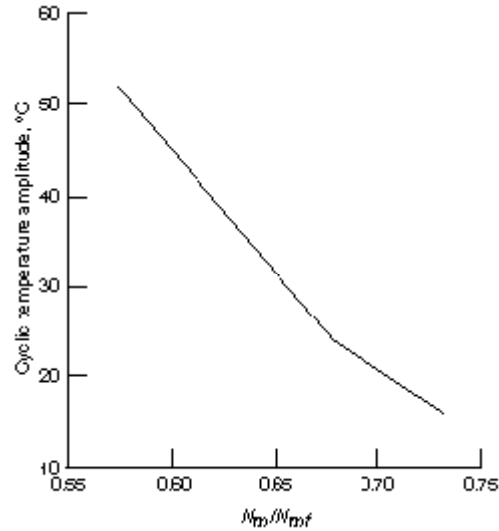
Fatigue life variation for 0.999 reliability of (0°/45°/90°)ₛ graphite/epoxy laminate. Ply thickness, 0.127 mm under thermal cyclic load; mean mechanical load, 0.5 static strength.

In reference 4, an application of MFIE is illustrated by considering a $[0°/\pm45°/90°]_s$ graphite fiber epoxy matrix composite. The fatigue life cycles were computed for different thermal cycles and for different magnitudes of applied-stress-to-laminate-strength ratios based on first-ply failure criteria (ref. 4). These curves can be used to assess the fatigue life of a component subjected to mechanical cyclic loading for a given reliability (as in the figure above). Cumulative probability distribution functions for mechanical fatigue due to different cyclic stress magnitudes and the respective sensitivity factors are shown in the following figure.[1]
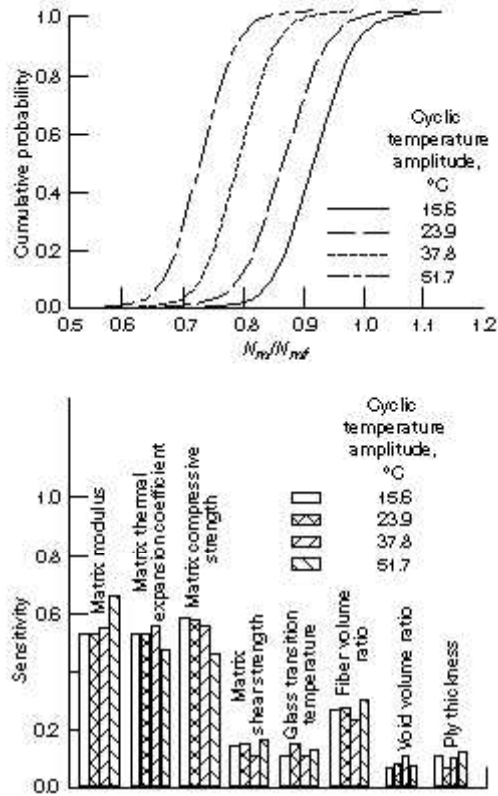
Cumulative distribution function and sensitivity of fatigue life for 0.999 reliability of (0/45/90)ₛ graphite/epoxy laminate. Ply thickness, 0.127 mm under thermal cyclic load; mean mechanical load, 0.5 static strength. Top: Cumulative distribution function. Bottom: Sensitivity of fatigue life for 0.999 reliability.

[1]Note that results similar to those in these figures can be developed for different stress ratios but constant temperatures (ref. 4).

References

1. Integrated Probabilistic Assessment of Composite Structures (IPACS) User's Manual: Ver. 1.0. NASA Contract No. NAS3-25266, Task Order No. 5209-02, Dec. 1991.

2. Boyce, L.; and Chamis, C.C.: Probabilistic Constitutive Relationships for Cyclic Material Strength Models. AIAA Paper 88-2376, 1988.

3. Murthy, P.L.N.; and Chamis, C.C.: Integrated Composite Analyzer (ICAN): Users and Programmers Manual. NASA TP-2515, 1986.

4. Shah, A.R.; Murthy, P.L.N.; and Chamis, C.C.: Effect of Cyclic Thermo-Mechanical Loads on Fatigue Reliability in Polymer Matrix Composites. NASA TM-107091, 1995.

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