Analytical Micromechanics Modeling Technique Developed for Ceramic Matrix Composites Analysis

Ceramic matrix composites (CMCs) promise many advantages for next-generation aerospace propulsion systems. Specifically, carbon-reinforced silicon carbide (C/SiC) CMCs enable higher operational temperatures and provide potential component weight savings by virtue of their high specific strength. These attributes may provide system-wide benefits. Higher operating temperatures lessen or eliminate the need for cooling, thereby reducing both fuel consumption and the complex hardware and plumbing required for heat management. This, in turn, lowers system weight, size, and complexity, while improving efficiency, reliability, and service life, resulting in overall lower operating costs (refs. 1 and 2).

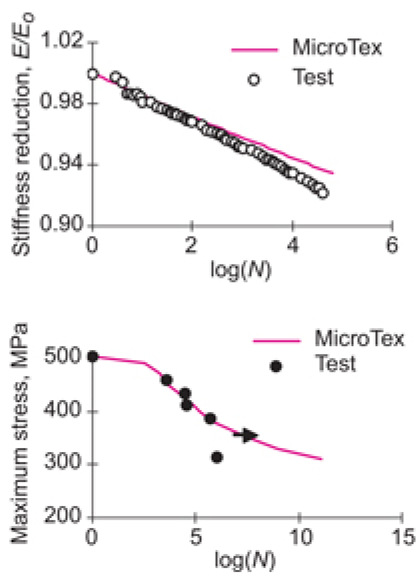
However, the fiber architectures of C/SiC CMCs are more complex because of the weaving, braiding, and knitting of fiber yarns over tape laminates. Thus, along with the development of fabrication processes and test methodologies, the development of analytical models to predict the mechanical properties and strength of textile composites is of increasing importance.

The micromechanics computer program for textile composites (MicroTex) analysis was developed at the NASA Glenn Research Center to provide a user-friendly tool for analyzing a wide variety of multilayered, oriented, fabric-reinforced woven and braided composites and laminated composites. Improved from a prior code (TEXCAD, refs. 3 and 4), MicroTex can calculate overall thermal and mechanical properties and make engineering estimates of damage progression and strength. This code discretely models the yarn centerline paths within the textile repeating unit cell by assuming sinusoidal undulations at yarn cross-over points, and it uses a yarn discretization scheme (which subdivides each yarn into smaller, piecewise straight yarn slices) together with either a three-dimensional strain-averaging procedure or a thin composite plate theory to calculate overall thermal and mechanical properties, stress distributions, and layer average strains (refs. 3 and 4).

For the failure analysis, the textile composite failure is defined as the loss of the loading capability of the repeating unit cell, which depends on the stiffness reduction due to material slice failure and nonlinear material properties. Two models, a fracture model and a continuum model, are employed for the failure analysis of material slices (matrix and yarn slices). In addition to the maximum strain and maximum stress criteria of TEXCAD (ref. 5), a statistical criterion based on the shear-lag model, fracture mechanics, and statistical principles is used to predict the tensile failure of yarn slices (ref. 6). Although the technique is applicable to any kind of composite material, it is particularly focused on CMCs in this article. A fatigue analysis modeling capability was also incorporated into this computer program to predict the fatigue life of the structural components on the basis of the overall stiffness reduction and the material (matrix and yarn) strengths decreasing with cyclic loads.

An experimental investigation was performed to determine the fatigue and static behavior of fiber architectures of [0°/90°] two-dimensional-layup C/SiC CMC specimens and to verify the analytical models through experiments. The specimens were loaded in static tension and in tension-tension fatigue under isothermal fixed-frequency conditions. Two temperature levels and a range of stress levels for fatigue were used to assess performance. The tests were conducted at 23 and 1000 °C. Modulus and cycles to failure were measured several times during the test.

The graphs present the methodologies and capabilities of the computer program by giving sample problems with comparisons to experimental data. This work was supported by the Ultra-Efficient Engine Technology (UEET) Project.



Top: Stiffness reduction for [0°/90°] plain weave for maximum stress at 410.60 MPa.
Bottom: S–N curve for [0°/90°] C/SiC plain-weave composite.

References

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