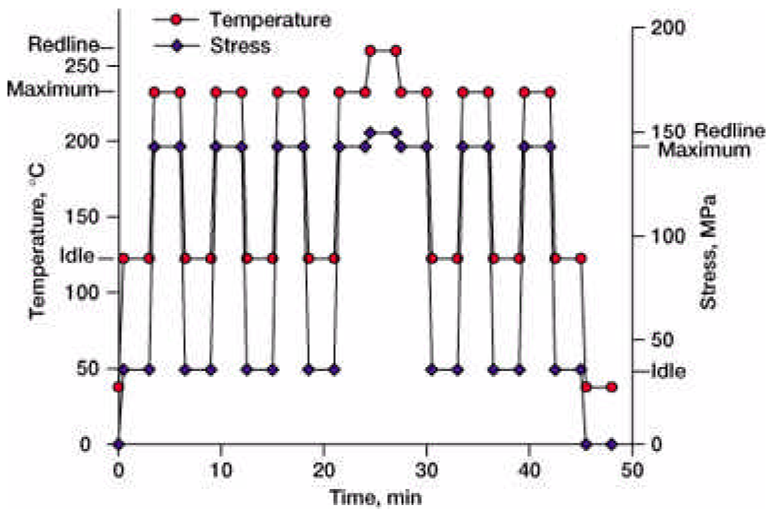
Thermomechanical Fatigue Durability of T650-35/PMR-15 Sheet-Molding Compound Evaluated

High-performance polymer matrix composites (PMC's) continue to be the focus of a number of research efforts aimed at developing cost-effective, lightweight material alternatives for advanced aerospace and aeropropulsion applications. These materials not only offer significant advantages in specific stiffness and strength over their current metal counterparts, but they can be designed and manufactured to eliminate joints and fasteners by combining individual components into integral subassemblies, thus making them extremely attractive for commercial applications. With much emphasis on the low-cost manufacturing aspects of advanced composite structures, there is heightened interest in high-performance sheet-molding compounds (SMC's). SMC's effectively reduce the costs associated with component production that uses prepregs, where variable costs are generally associated with labor, secondary processes, and scrap. With compression molding, SMC's can be fabricated into complex shapes facilitating the use of simple charge patterns, part consolidation, and molded-in inserts, which reduce labor, equipment, and operation costs for preparatory and secondary processes.

Researchers at the NASA Lewis Research Center, in cooperation with the Allison Advanced Development Company, completed an investigation examining the use of T650-35/PMR-15 SMC for a midstage inner-vane endwall application within a gas turbine engine compressor. This component resides in the engine flow path and is subjected not only to high airflow rates, but also to elevated temperatures and pressures. This application is unique in that it represents a very aggressive use of high-performance SMC's, raising obvious concerns related to durability and property retention in the presence of microstructural damage. Therefore, it was necessary to evaluate the fatigue behavior and damage tolerance of this material subjected to a representative thermomechanical fatigue (TMF) mission-cycle loading spectrum.

Damage progression was tracked through changes in the macroscopic deformation and elastic stiffness in the loading direction. Additional properties, such as the glass transition temperature and dynamic mechanical response also were examined. The fiber distribution orientation was characterized through a detailed quantitative image analysis, and material durability and damage tolerance were quantified on the basis of residual static tensile properties after a prescribed number of TMF missions. Detailed microstructural examinations used optical and scanning electron microscopy to characterize the local damage.



Thermomechanical fatigue mission cycle used for the T650-35/PMR-15 SMC inner-vane endwall application, showing idle, maximum, and redline (overload) conditions for temperature and stress.

Results indicate that the imposed TMF missions had only a modest effect on material durability as measured by the mechanical properties. Some microstructural damage was observed subsequent to 100 hours of TMF cycling. It consisted primarily of fiber debonding and transverse cracking local to predominantly transverse fiber bundles. No statistically significant degradation occurred in the residual tensile properties. Some of the more aggressive TMF scenarios examined, however, did promote notable creep damage and excessive strain accumulation that led to rupture. In some cases this creep behavior occurred at temperatures in excess of 150 °C below commonly cited values for the glass transition temperature. As a result, thermomechanical exploratory creep tests were conducted. These revealed that the SMC was subject to time-dependent deformation at stress/temperature thresholds of 150 MPa/230 °C and 170 MPa/180 °C.

Bibliography

Castelli, M.G.; Sutter, J.K.; and Benson, D.: Durability and Damage Tolerance of a Polyimide/Chopped Fiber Composite Subjected to Thermomechanical Fatigue Missions and Creep Loadings. Time Dependent and Nonlinear Effects in Polymers and Composites. ASTM STP-1357, R.A. Schapery and C.T. Sun, eds., American Society for Testing and Materials, 1999.

Lewis contacts: Michael G. Castelli, (216) 433-8464, Michael.G.Castelli@grc.nasa.gov; and Dr. James K. Sutter, (216) 433-3226, James.K.Sutter@grc.nasa.gov
Author: Michael G. Castelli
Headquarters program office: OAT
Programs/Projects: Propulsion Systems R&T, HITEMP