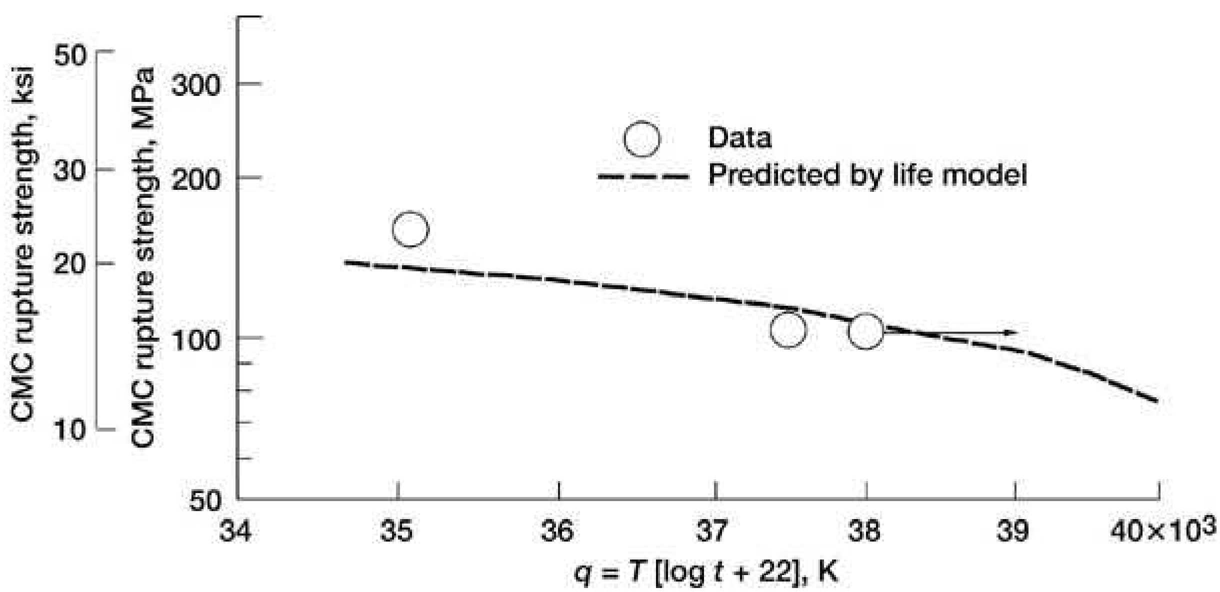
Constituent-Based Life Models Being Developed for SiC/SiC Composites

For the successful utilization of ceramic matrix composites (CMC) as hot-section components in advanced aeropropulsion engines, the CMC constituents will need to be tailored and optimized to meet all the critical property demands of each component. Under the High-Speed Research (HSR) and Advanced High-Temperature Engine Materials Technology (HITEMP) Programs, the NASA Glenn Research Center at Lewis Field initiated research to develop mechanistic models for key CMC thermostructural properties. These models would describe the effects of different constituent factors (composition, geometry, and volume fraction) and of potential application conditions (stress, time, temperature, and environment) on these properties. Particular focus was placed on both analytical and numerical modeling of state-of-the-art SiC/SiC composites where the primary load-bearing constituents are stoichiometric SiC fibers in a complex multiphase SiC matrix produced by chemical vapor infiltration and melt infiltration.

Recent studies have resulted in computer-based numerical models for the elastic modulus, thermal expansion, and thermal conductivity properties of the SiC/SiC system (ref. 1). Additional studies have generated analytical and empirical models for the time dependence of composite rupture strength at temperatures above 2200 °F (1200 °C), where CMC's have an important thermostructural advantage over current nickel-based superalloys. These life models utilize thermal activation theory and fiber stress-rupture results measured at Glenn to generate Larson-Miller (*L–M*) plots of fiber rupture strength versus *q*, a single time- and temperature-dependent parameter (ref. 2). Assuming a worse case in which the SiC matrix is cracked, rupture is then controlled by the time-dependent fracture characteristics of the fiber bundles bridging the matrix cracks. With this as the controlling mechanism, one can then use simple composite theory and the fiber *L–M* plots to predict CMC rupture strength versus the *q* parameter (ref. 3).



Time- and temperature-dependent rupture strength for a state-of-the-art SiC/SiC composite.

The dashed line shows the predicted rupture strength of a SiC/SiC composite that is reinforced by a state-of-the-art stoichiometric SiC fiber. For the *q* parameter, time is in hours and temperature in degrees kelvin. To generate these predictions, a two-dimensional 0°/90° composite with ~16 percent fiber in the applied stress direction and an air test environment were assumed. As such, it is possible to compare the model predictions against limited stress-rupture data for this CMC as shown by the data points. The good agreement confirms the rupture model at least for the selected CMC and test conditions. Thus for this particular SiC/SiC composite, one can estimate a 1000-hr rupture strength of ~12 ksi at 2400 °F (T = 1588 K and q = 39 700 K). At lower CMC application stresses, the SiC matrix is typically uncracked, so both the fiber and matrix constituents share the composite load. In this case, CMC rupture is controlled by the constituent with the longest rupture time based on the creep rate of the composite. Measured Monkman-Grant plots of rupture time versus creep rate for the two SiC constituents have been used to develop CMC life models for this important application condition (ref. 4). NASA and DOD are currently using this information to establish application and material goals for more advanced CMC’s that can be used at even higher temperatures.

References

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