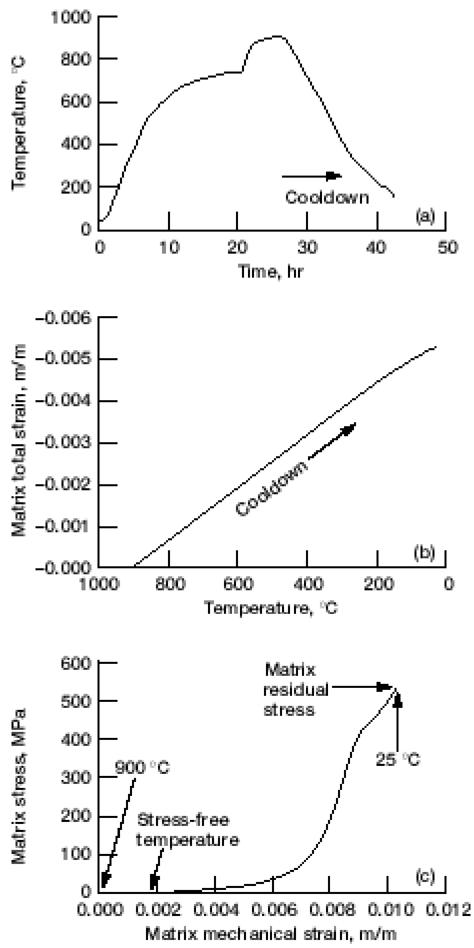
Mechanical Characterization of Thermomechanical Matrix Residual Stresses Incurred During MMC Processing

In recent years, much effort has been spent examining the residual stress-strain states of advanced composites. Such examinations are motivated by a number of significant concerns that affect composite development, processing, and analysis. The room-temperature residual stress states incurred in many advanced composite systems are often quite large and can introduce damage even prior to the first external mechanical loading of the material. These stresses, which are induced during the cooldown following high-temperature consolidation, result from the coefficient of thermal expansion mismatch between the fiber and matrix.

Experimental techniques commonly used to evaluate composite internal residual stress states are nonmechanical in nature and generally include forms of x-ray and neutron diffraction. Such approaches are usually complex, involving a number of assumptions and limitations associated with a wide range of issues, including the depth of penetration, the volume of material being assessed, and erroneous effects associated with oriented grains. Furthermore, and more important to the present research, these techniques can assess only "single time" stress in the composite. That is, little, if any, information is obtained that addresses the time-dependent point at which internal stresses begin to accumulate, the manner in which the accumulation occurs, and the presiding relationships between thermoelastic, thermoplastic, and thermoviscous behaviors. To address these critical issues, researchers at the NASA Lewis Research Center developed and implemented an innovative mechanical test technique to examine in real time, the time-dependent thermomechanical stress behavior of a matrix alloy as it went through a consolidation cycle.



Thermomechanical test technique to simulate in situ metal matrix composite HIP cycle conditions on a standalone matrix. (a) Step 1--Measure composite cooldown strain. (b) Step 2--Enforce composite strain on matrix. (c) Step 3--Measure thermomechanical matrix response in terms of stress-free temperature; thermoelastic, thermoplastic, and thermoviscous behavior; and residual stress.

In general, a standalone matrix material is subjected to the strain-temperature history experienced by the in situ matrix material during a uniaxially simulated hot isostatic pressing (HIP), or hot press cycle. First, the identical temperature time history experienced during the HIP cycle is imposed on the composite coupon while the composite cooldown thermal strain response is measured in a load-controlled environment. Employing the concept of fiber/matrix strain compatibility, we assume that the measured macroscopic strain history is identical to that experienced by the individual constituents. With this information, the measured composite cooldown thermal strain response is "enforced" on the standalone matrix material during an identical cooldown cycle in a strain-controlled environment. This allows the thermomechanical matrix stress response to be explicitly measured in real time without presupposing a given material behavior. From this technique, several critical measurements can be made, including (1) the time-dependent, stress-free temperature, (2) the degree of thermoelastic, thermoplastic, and thermoviscous behavior, (3) the real-time points within the HIP cycle where the respective behaviors occur, and (4) the residual stress locked into the matrix subsequent to the HIP cycle cooldown. Such results have been generated for several SiC-reinforced titanium matrix composites.

Bibliography

Castelli, M.G.: Mechanical Characterization of the Thermomechanical Matrix Residual Stresses Incurred During MMC Processing. HITEMP Review 1997. NASA CP-10192, 1997, paper 29, pp, 1-12. (Permission to cite this material was granted by Carol A. Ginty, February 19, 1998.)

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