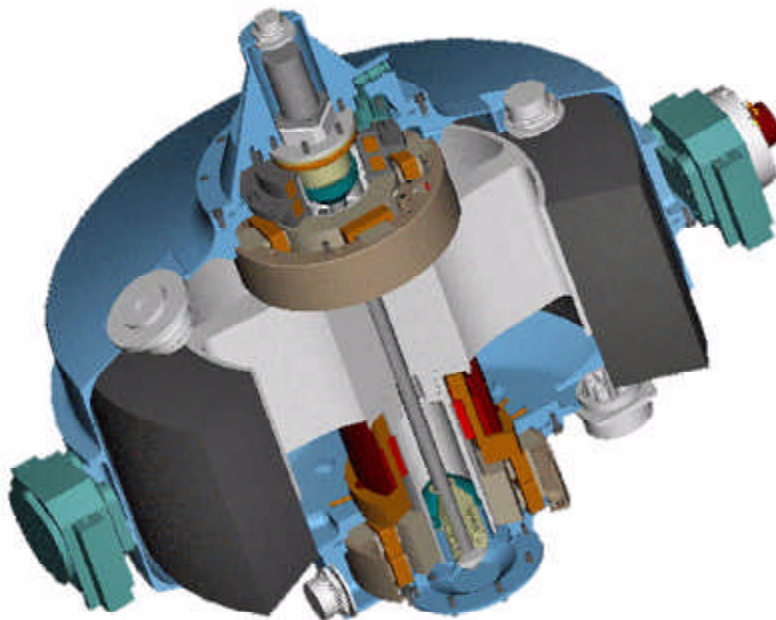# Time-Dependent Material Data Essential for the Durability Analysis of Composite Flywheels Provided by Compressive Experiments


Filament-wound composite flywheel rotor for space applications.

Successful spaceflight operations require onboard power management systems that reliably achieve mission objectives for a minimal launch weight. Because of their high specific energies and potential for reduced maintenance and logistics, composite flywheels (see the preceding figure) are an attractive alternative to electrochemical batteries. The Rotor Durability Team, which comprises members from the Ohio Aerospace Institute (OAI) and the NASA Glenn Research Center, completed a program of elevated temperature testing at Glenn's Life Prediction Branch's Fatigue Laboratory. The experiments provided unique design data essential to the safety and durability of flywheel energy storage systems for the International Space Station and other manned spaceflight applications. Analysis of the experimental data (ref. 1) demonstrated that the compressive stress relaxation of composite flywheel rotor material is significantly greater than the commonly available tensile stress relaxation data. Durability analysis of compression preloaded flywheel rotors is required for accurate safe-life predictions for use in the International Space Station.

The high operational speeds and specific energies of composite flywheel rotors are

attained by using the substantial load-carrying capacity of carbon fibers wound in the hoop direction. In contrast, the long-term durability of such rotors may actually be limited by the time- and temperature-dependent behavior of the polymer constituent of the composite: the epoxy matrix. The behavior of the epoxy dominates the uniaxial properties transverse to the fiber in the radial direction and the shear properties. This proposition was investigated for the prototypical rotor material, IM7/8552. Flat-filament wound panels were manufactured by the University of Texas Center for Electro Mechanics using the same process as for composite rotors. Coupon specimens, sectioned normal and parallel to the winding axis, were tested in compression and tension at room temperature, 95 °C, and 135 °C for strain rates from 5×10^{-6}/s to 5×10^{-3}/s. Creep and stress relaxation testing ran 72 hr, followed by a 72-hr recovery. Time-, temperature-, and load-sign-(compressive/tensile) dependent effects were significant transverse to the fiber. Under a fixed deformation of -0.5 percent strain for 72 hr, compressive stresses relaxed 16.4 percent at 135 °C and 13 percent at 95 °C. Tensile stresses relaxed only 7 percent in 72 hr at 135 °C for 0.5 percent strain. A graph showing the remarkable difference between the tensile and compressive stress relaxation response follows.
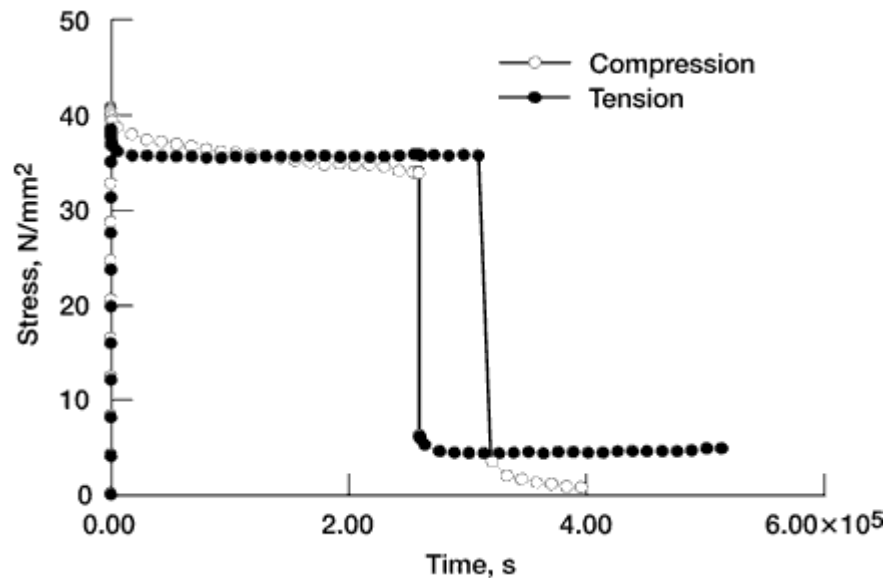
Comparison of the absolute compressive and tensile stress relaxation response at 135 °C at a constant applied strain of ±0.5 percent.

Long description of figure 2 Graph comparing the absolute compressive and tensile stress relaxation response at 135 °C at a constant applied strain of ±0.5 percent. The data depict decreasing stress magnitude with time that is greater in rate for a compressive load than for a tensile load. When the enforced deformation is removed from the specimen, the sign of the stress changes in each case. During the recovery phase, the material previously in compression recovers toward zero stress.

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In conclusion, the definition of a linear hereditary material response and the application of Boltzman's principle of superposition to describe the behavior observed here is problematic if not intractable. Undoubtedly, microstuctural analysis including the influence

of residual stresses due to processing will be needed to resolve the observed paradoxes. Within the scope of these experiments, uniaxial compressive stress relaxation data may be used to bound the amount of relaxation with the time of radial preload stresses in flywheel rotors. These experimental results are now being used in simulations of the long-term performance of composite rotors (ref. 2), demonstrating the importance and implications of having the appropriate material representation when predicting the durability of current and future rotor designs.

References

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2. Saleeb, A.F.; Arnold, S.M.; and Al-Zoubi, N.R.: A Study of Time Dependent and Anisotropic Effects on the Deformation Response of Two Flywheel Rotor Designs. Composite Materials: Testing and Design Fourteenth Volume, ASTM STP-1436, C.E. Bakis, ed., ASTM International, West Conshohocken, PA, 2003.

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