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Multiaxial Failure Envelopes and Uncertainty Quantification of Nuclear-Grade SiCf/SiC Woven Ceramic Matrix Tubular Composites

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ABSTRACT:

A comprehensive experimental and computational approach for determination of constitutive relations and **multiaxial failure envelopes** of nuclear-grade continuous silicon fiber (SiC_f) and SiC matrix woven tubular composites is proposed. **2D and 3D woven composites with two different weave architectures** ($\pm 30^o$ and $\pm 45^o$) will be manufactured and tested under a variety of loading configurations to develop **multiaxial failure criteria**. A recently developed **Direct Micromechanics Method (DMM), pioneered by one of the co-PIs,** will be used for analyzing the failure behavior of SiC_f/SiC ceramic composites and establish a **phenomenological multiaxial failure criterion** for generalized complex loading conditions. The failure envelopes will be **validated** at static (10^{-3}/s) and dynamic (10^3/s) strain rates, and at two temperatures (25 ^{o}C and 150 ^{o}C) using a variety of experiments and characterization methods. Unique to this proposal is the use of **instrumented dynamic test** methods coupled with **high speed (up to million frames per second) digital photography to visualize failure modes in real time** and identify the corresponding failure load for validation of failure envelopes. Realizing that SiC_f/SiC ceramic composites exhibit inherent microstructural heterogeneity (fibers, tow, matrix, porosity, etc.), **vast variability** in their brittle behavior and microstructural features (variations in matrix phase thickness, porosity distribution, imperfections in tube wall thickness and weave angles, etc.), and hence variability in properties and performance, we embark on **uncertainty quantification** of the influence of these variables on fracture strength, constitutive relationships and the failure envelopes. The uncertainties in the material properties are propagated through the DMM, the failure criterion and the failure envelopes to quantify uncertainty in the strength for a variety of loading conditions through **Monte Carlo simulations**.

The proposal effort at **University of Florida (UF)** is led by three PIs with extensive experience and expertise in experimental mechanics on ceramics and composites, computational modeling of composites, and uncertainty quantification. The composite tubes for testing will be manufactured and supplied by **General Atomics** who has extensive experience in fabrication of these tubes for nuclear industry. Two PhD students will be advised at UF. One student will focus on DMM, failure envelopes, multiaxial failure criterion, and uncertainty quantification. The second student will focus on characterization of microstructural heterogeneity, experimental determination of failure strength at various strain rates, temperatures and loading conditions, and validation of failure envelopes.

The DMM and the resulting multiaxial failure envelopes can be used for in-depth analysis of any woven composite under complex loading scenarios. The quantification of the influence of heterogeneity and the variability in performance is crucial to the successful prediction of failure and reliable operation of tubular structures under extreme environments. Finally, the resulting phenomenological multiaxial failure criterion with uncertainty quantification can be **easily adopted in industry** for design refinement, optimization of performance under the desired operating conditions, and reliable prediction of failure under unforeseen accidental scenarios.