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Multiscale Investigation of SiC/SiC Composite Degradation in Helium Coolant Operating Environment

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ABSTRACT:

Silicon carbide fiber reinforced, silicon carbide matrix (SiC/SiC) composites are proposed for use in nuclear reactors due to their superior chemical and mechanical stability at high temperatures; however, SiC/SiC composites and other ceramic matrix composites (CMCs) exhibit degraded strength under sustained loads due to slow crack growth (SCG). There exists substantial literature evidence that SCG results in widespread matrix microcracking and composite embrittlement, and that the process environment can substantially affect the crack growth rate. This is particularly relevant for He and other gas-cooled reactor designs in which the process gas is often contaminated with oxygen levels too low to form protective oxide layers on the composite surface yet high enough to attack the composite interior by penetrating through networks of microcracks. Therefore, we believe there exist nonlinear chemical/mechanical interactions which may accelerate the degradation of SiC/SiC composites during environmental SCG and operational conditions; this is the central ***hypothesis*** of the proposed research.

To better understand these effects, the proposed research will investigate the fundamental environment-assisted SCG degradation mechanisms via multiscale, *in situ* and *ex situ* experimental techniques. The **specific research approaches** are: (1) to unveil environmental SCG mechanisms via *in situ* high temperature mechanical testing; (2) to isolate SCG effects on composite hermeticity via a novel *in situ* mechanical testing device coupled with digital image correlation and He leak detector; (3) to derive predictive, multiscale models of environment-assisted SCG; and (4) to harness the unique perspectives and experiences from university, national laboratory, and industrial team members to synthesize project findings into new ASTM/ASME standards. Results from experiments will be integrated into a predictive finite element simulation framework to model and predict degradation in operational conditions. This approach leverages unique *in situ* testing capabilities that can **assess SCG in the relevant coolant environments at temperatures to 1200°C** and exploits proven crack-detection methods based on digital image correlation, micro X-ray Computed Tomography, and acoustic emissions. Tests will be performed on both single-tow and full-scale composites to assess the roles of environment, composite structure, size, and mechanical loading on SCG behavior. The tested samples will be mechanically and structurally characterized at both constituent and bulk length scales to reveal the basic SCG mechanisms.

This proposed research will establish a new scientific understanding of environment-assisted SCG and predictive capabilities for degradation of SiC/SiC structural composites, which will expedite their introduction to the nuclear reactors. Furthermore, the results of this study are anticipated to benefit the design and inspection of ceramic nuclear materials. The developed experimental and modeling efforts can easily be extended to other ceramic matrix composite and coolant systems.