Probabilistic Failure Criterion of SiC/SiC Composites Under Multi-Axial Loading

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ABSTRACT:

Silicon carbide (SiC) fiber-reinforced SiC matrix composites (a.k.a. SiC/SiC composites) have been shown to possess attractive material properties under both unirradiated and neutron radiated conditions. This finding has stimulated many applications of SiC/SiC composites in various nuclear structures including the light water reactors (LWR), gas-cooled high-temperature reactors, and fluoride-salt-cooled high-temperature reactors. Since the Fukushima-Daiichi accident, there has been a particular interest in the application of SiC/SiC composites for LWR fuel cladding.

There has been clear evidence that in LWR fuel cladding the SiC/SiC composites will experience a multi-axial stress state. Furthermore, it has also been acknowledged that the design of nuclear structural components must guarantee a tolerable failure risk, which requires the knowledge of the probabilistic failure behavior of the material. So far, the failure statistics of SiC/SiC composites under multi-axial loading has not been systematically studied. The lack of a probabilistic failure model of SiC/SiC composites hinders the development a mechanistic reliability-based design approach for LWR SiC/SiC composite fuel cladding. The proposed research is motivated by the imperative need for filling this knowledge gap.

The goal of the proposed research is to develop a probabilistic failure criterion of SiC/SiC composites under multi-axial loading, and to incorporate the criterion into a reliability analysis of the structural integrity of LWR SiC/SiC fuel cladding. This research will be anchored by a seamless integration of novel experimental and analytical tools, which will lead to a robust methodology for reliability analysis of SiC/SiC composite structures. It should be emphasized that, though this research will focus on the LWR fuel cladding, the proposed framework can be applied to SiC/SiC composite structures for other nuclear applications.

To accomplish the proposed goal, the research will consist of three primary tasks performed by a joint effort between one university and one national laboratory. Task 1 will focus on the design of a new testing system, which is capable of producing different multi-axial stress states. The system will be used to test SiC/SiC composites under different stress states. For each loading case, a sufficient number of specimens will be tested to investigate the probabilistic failure behavior. Task 2 will use acoustic emission and X-ray tomography analyses to examine the damage status of the specimens, and together with the results of multi-axial tests, a probabilistic failure criterion will be formulated. In Task 3, a finite weakest-link statistical model will be developed for SiC/SiC composites under multi-axial loading. The model will be calibrated and validated by the proposed multi-axial tests. With recent results of thermomechanical stress analysis of LWR SiC/SiC composite fuel cladding, the finite weakest-link model will be used to evaluate the failure risk of the fuel cladding. The proposed risk analysis lays a foundation for the future development of reliability-based design of LWR SiC/SiC composite fuel cladding.