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AUGMENTED FINITE ELEMENT METHOD FOR VIRTUAL TESTING OF HIGH TEMPERATURE CMCS

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Ceramic matrix composites (CMCs) have been increasingly used in high heat flux applications due to their ultra-high temperature resisting capabilities. However, CMCs are prone to processing-induced or in-serve cracking due to the large thermal stresses. Thermally-induced cracking are dangerous because they provide pathways for further damaging processes such as oxidation and vapor-assisted corrosion, which may lead to catastrophic failure [1]. High-fidelity thermal-mechanical analyses to CMCs with consideration of arbitrary cracking are very challenging because the heterogeneous nature makes it impossible to know the cracking locations *a priori*. Yet correct and efficient treatment of crack coalescence and bifurcation is critical for simulating the complex, multiple crack damage states in these materials.

In the past years we have been developing a new simulation method named augmented finite element method (A-FEM) with temperature DoFs that can efficiently and faithfully account for the arbitrary cracking and the post-crack material damage accumulation in CMCs [2, 3]. The high accuracy and efficiency of the A-FEM is enabled by three key numerical capabilities developed in recent years: 1) a novel condensation method that enables mesh insensitive and accurate fracture predictions with mesh sizes 10~50 times larger, and computational times 100x~1000x times shorter, than other methods such as X-FEM, G-FEM, and PNM; 2) a unified cohesive zone model (CZM) that can predict static, fatigue, or dynamic crack initiation in general heterogeneous materials, followed by coupled crack propagation until final failure; and 3) a novel and very fast method to avoid numerical divergence due to unstable crack growth. The high-fidelity simulation capabilities pave the way for achieving virtual testing of complex CMCs at various scales from microscopic fiber/matrix interaction to structural integrity, all with explicit consideration of multiple cracking and crack interactions.

In this study, the concept and procedure of a top-down virtual testing strategy will be first introduced, with emphases on the needs for novel experimental methods for basic property characterizing and results validation and advanced numerical methods for high-fidelity predictions at all important scales. The virtual testing scheme will then be demonstrated by a detailed review of a recent exercise on a high-temperature textile CMC, including the use of micro-computer-tomography (μCT) for material heterogeneity characterization, the generation of virtual test specimens with the statistic tow/matrix information from the μCT characterization, full 3D A-FEM modeling of the virtual specimen for material and structural performance evaluation, and validation of the A-FEM simulated results against independent experimental testing results. The presentation will conclude with key lessons learned from this exercise and important future needs to make the virtual testing for routine engineering design practice.

References

1. B. N. Cox, H. Bale, et al. *Annu. Rev. Mater. Res*., 2014. **44**: p. 17.1-17.51.
2. W. Liu, Q. D. Yang, et al. *Inter. J. Numer. Meth. Engin*. 2014. **99**: p. 438-468.
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