

Mechanical Engineering Doctoral Defense

High-fidelity Multiscale Modeling and In-situ Experiments of Advanced Aerospace Composites in Extreme Environments

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Abstract

Advanced fibrous composite materials exhibit outstanding thermomechanical performance under extreme environments, which make them ideal for structural components that are used in a wide range of aerospace, nuclear, and defense applications. The integrity and residual useful life of these components, however, are strongly influenced by their inherent material flaws and defects resulting from the complex fabrication processes. These defects exist across multiple length scales and govern several scale-dependent inelastic deformation mechanisms of each of the constituents as well as their composite damage anisotropy. Tailoring structural components for optimal performance requires addressing the knowledge gap regarding the microstructural material morphology that governs the structural scale damage and failure response. Therefore, there is a need for a high-fidelity multiscale modeling framework and scale-specific in-situ experimental characterization that can capture complex inelastic mechanisms, including damage initiation and propagation across multiple length scales.

This dissertation presents a novel multiscale computational framework that accounts for experimental information pertinent to microstructure morphology and architectural variabilities to investigate the response of ceramic matrix composites (CMCs) with manufacturing-induced defects. First, a three-dimensional orthotropic viscoplasticity creep formulation is developed to capture the complex temperature- and time-dependent constituent load transfer mechanisms in different CMC material systems. The framework also accounts for a reformulated fracture mechanics-informed matrix damage model and the Curtin progressive fiber damage model to capture the complex scale-dependent damage and failure mechanisms through crack kinetics and porosity growth. Next, in-situ experiments using digital image correlation (DIC) are performed to capture the damage and failure mechanisms in CMCs and to validate the high-fidelity modeling results.

The dissertation also presents an exhaustive experimental investigation into the effects of temperature and manufacturing-induced defects on toughened epoxy adhesives and hybrid composite-metallic bonded joints. Nondestructive evaluation techniques are utilized to characterize the inherent defects morphology of the bulk adhesives and bonded interface. This is followed by quasi-static tensile tests conducted at extreme hot and cold temperature conditions. The damage mechanisms and failure modes are investigated using in-situ DIC and a high-resolution camera. The information from the morphology characterization studies is used to reconstruct high-fidelity geometries of the test specimens for finite element analysis.

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Zoom Link: <https://asu.zoom.us/j/89586311113>