

AI-Enabled Forward Prediction and Inverse Design of Composite Materials

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Composite materials offer exceptional opportunities for tailoring stiffness, strength, and failure resistance through microstructural and architectural design. At the same time, this flexibility creates a major challenge as the response of composites depends strongly on heterogeneity, spatial arrangement, weave architecture, and damage evolution, making design exploration computationally expensive when based solely on high-fidelity simulations. For a composites community increasingly interested in AI, the key question is not simply whether AI can fit simulation data, but how it can be used in a way that remains mechanically meaningful and useful for design.

In this talk, I will address that question across several classes of composite materials. I will start with deep learning frameworks for predicting full-field stress distributions in heterogeneous composites, showing how image-based surrogates can capture the influence of volume fraction and spatial randomness while retaining more mechanistic information than scalar property predictions alone. We will then move to learning richer mechanical responses from composite geometry, including parameterized representations of constitutive behavior. Building on these forward models, we will next address inverse design of woven composite architectures, with emphasis on the challenges of non-unique structure–property mappings and the role of interpretable texture-based features in guiding design. Finally, I will extend these ideas to failure-aware design through convolutional neural network surrogates for phase-field fracture simulations, enabling efficient optimization of composite microstructures for improved tensile strength.

The central message of my talk is that AI has the potential to become a practical tool for composite materials research when it is coupled with mechanics, informed representations, and design objectives. Rather than replacing established modeling approaches, AI frameworks complement simulation by accelerating prediction, enabling inverse exploration of large design spaces, and providing new pathways toward data-driven composite design.