VIRTUAL EXPERIMENTS FOR STRUCTURAL COMPOSITES THROUGH MULTI-SCALE MODELING

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Keywords: *composites, multiscale modeling, cohesive models, failure*

Abstract

Predicting the failure of materials is one of the oldest problems of engineering and one of the least perfectly solved. Even in modern times, after a century of the formal study of fracture mechanics and the advent of computational stress analysis, predictions remain closely tied to empirical data gathering. In the current state of art of composite structural design, the burden of testing to prove safety is so immense that it becomes a major bottle-neck for fast materials insertion (a typical large airframe, for example, currently requires about 10,000 tests to achieve safety certification). While stress analysis is an excellent tool for predicting the distribution of loads throughout the structure when its behavior is linear-elastic, once damage begins, prediction becomes problematic. The fundamental difficulty is that damage in tough engineering materials (excluding brittle materials such as glass) involves extremely complicated nonlinear processes acting from the atomic scale (e.g., dislocations and bond rupture), through the microscale (e.g., microcracking, crazing in polymers, plasticity in metals), and on up to the scale of the structure itself (e.g., large cracks and buckling modes).

Conceptual and computational advances in fracture modeling made over the last decade have at last brought computer simulations to the point of being able to replicate the details of damage evolution in tough structural composites. Contributing successes include the refinement of cohesive models of fracture and the formulation of mixed stress-strain and traction-displacement models that combine continuum (spatially averaged) and discrete damage representations in a single calculation. In this presentation, we will discuss practical strategies to set up multiscale models using top-down approaches that utilize hierarchical formulations to invoke increasingly complex models of damage mechanisms, cascading down to the necessary materials scales that have dominant influences on structural composites integrity. It will be shown, through direct comparison of multiscale simulations to some long-standing unresolved composite failure problems, that such a multiscale modeling approach offers faithful predictions to the failure/damage evolution in structural composites. Thus it is able to render a potentially revolutionary approach to the design and certification of composite structures: through the use of such high-fidelity models for prediction of composite testing, or, virtual experiments. Furthermore, simulations that are sufficiently realistic to act as virtual experiments could relax the need for simplicity by vastly increasing the number of tests that can be rapidly and cheaply executed, thus allowing for materials optimization at the structural design stage.

References

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