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HIGH-PERFORMANCE IMAGE-BASED MODELING OF FAILURE IN HETEROGENEOUS MATERIALS WITH APPLICATION TO THIN LAYERS

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Heterogeneous materials in the form of composites are increasingly prevalent in engineering application. Furthermore, there is increased use of adhesives to bond structural members together, often forming thin adhesive layers, for reasons such as ease of assembly and reduction of stress concentrations. Many of these adhesive layers have reinforcing particles to enhance mechanical or secondary properties of the bonded joint. Predicting how the size, shape, orientation and distribution of the reinforcing particles change the failure response of the bonded system is important for design and safety assessment. We present an image-based multiscale cohesive modeling study of failure in thin heterogeneous layers that examines the effects of the size of the representative unit cell as well as the diameter and volume fraction of spherical particles on the macroscopic failure response.

We present three-dimensional simulations that resolve the large range of spatial scales, from the failure-zone thickness up to the size of the representative unit cell, in damage mechanics problems of particle reinforced adhesives. We show that resolving this wide range of scales in complex three-dimensional heterogeneous morphologies is essential in order to apprehend fracture characteristics such as strength and fracture toughness, as well as the shape of the softening profile. Moreover, we show that computations that resolve the essential physical length-scales of the problem capture the size-effect in fracture toughness, for example. In the vein of image-based computational material science, we construct statistically optimal unit cells containing hundreds to thousands of particles. We show that these statistically representative unit cells are capable of capturing the first- and second-order probability functions of a given data-source with better accuracy than traditional inclusion packing techniques. In order to accomplish these large computations, we present a parallel multiscale cohesive formulation and extend it to finite strains including damage mechanics. The high-performance parallel computational

framework is executed on thousands of processing cores. A mesh convergence and a representative unit cell study are performed. Quantifying the complex damage patterns in simulations consisting of tens of millions of computational cells and millions of highly nonlinear equations requires data-mining the parallel simulations, and we propose several damage metrics to quantify the damage patterns. The changes in the microscale failure features, as highlighted by the damage metrics, are related to changes in the macroscopic traction-separation response.