The Use of Cohesive-Zone Models to Analyze the Behavior of Adhesive Joints

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The use of adhesives in structural automotive applications will rely on an effective understanding of how they behave under crash conditions, and how to model their performance. Historically, the strengths of adhesive joints have been modeled by two distinctly different approaches - strength-based criteria and energy-based criteria. Cohesive-zone models form a natural and self-consistent approach to bridge these two approaches within a single framework. In systems for which the adherends remain elastic, cohesive-zone models allow many well-known concepts of interfacial fracture mechanics, and its energy-based failure criteria of toughness to evolve. In systems for which the adherends deform in a plastic fashion, cohesive-zone models provide a framework for analysis in a regime that cannot be addressed by fracture mechanics. Under these conditions, the behavior of a joint may be controlled by the strength of the adhesive, the toughness of the adhesive, or by a combination of the two parameters, depending on the details of the geometry and properties of the materials. An practical issue is then how to determine, in a relatively simple fashion, the two cohesive parameters that can be used in mixed-mode applications. This is of particular interest for automotive applications where a methodology for designing adhesive joints for energy-management during crashes needs to be developed.

Traditional approaches that have been developed from fracture mechanics are not applicable for automotive applications, because of the extensive amounts of plasticity in the adherends that needs to accompany fracture so as to enhance energy absorption. Cohesive-zone models provide an approach that permit quantitative analysis of the fracture and deformation of adhesive joints under a broad range of conditions.

As a particular example, the failure of joints between steel sheet and a commercial adhesive has been examined at different loading rates. Two fracture modes were observed: quasi-static crack growth and dynamic crack growth. The quasi-static crack growth was associated with a toughened mode of failure; the dynamic crack growth was associated with a more brittle mode of failure. A cohesive-zone model was used to analyze the experiments, with comparisons between the experimental conditions and the numerical predictions being used to evaluate the cohesive parameters of strength and toughness for the adhesive.

The results of the experiments and analyses indicated that the fracture parameters for quasi-static crack growth were essentially rate independent, and that quasi-static crack growth could occur even at the highest crack velocities. Effects of rate appeared to be limited to the ease with which a transition to dynamic fracture could be triggered. This transition appeared to be stochastic in nature, it did not appear to be associated with the attainment of any critical value for crack velocity or loading rate.