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Brittle-tough transitions during crack growth in toughened adhesives

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The use of structural adhesives in automotive applications relies on an effective understanding of their performance under crash conditions. In particular, there is considerable potential for mechanics-based modeling of the interaction between an adhesive layer and the adherends, to replace current empirical approaches to design. Since energy dissipation during a crash, mediated by plastic deformation of the structure, is a primary consideration for automotive applications, traditional approaches of fracture mechanics are not appropriate. Cohesive-zone models that use two fracture parameters - cohesive strength and toughness - have been shown to provide a method for quantitative mechanics analysis. Combined numerical and experimental techniques have been developed to deduce the toughness and strength parameters of adhesive layers, allowing qualitative modeling of the performance of adhesive joints. These techniques have been used to study the failure of joints, formed from a toughened adhesive and sheet metal, over a wide range of loading rates. Two fracture modes are observed: quasi-static crack growth and dynamic crack growth. The quasi-static crack growth is associated with a toughened mode of failure; the dynamic crack growth is associated with a more brittle mode of failure. The results of the experiments and analyses indicate that the fracture parameters for quasi-static crack growth in this toughened system are essentially rate independent, and that quasi-static crack growth can occur even at the highest crack velocities. Effects of rate appear to be limited to the ease with which a transition to dynamic fracture could be triggered. This transition appears to be stochastic in nature, and it does not appear to be associated with the attainment of any critical value for crack velocity or loading rate. Fracture-mechanics models exist in the literature for brittle-ductile transitions in rate-dependent polymers, which rely on rate dependent values of toughness with unstable branches. The present observations do not appear to follow the type of behavior that would be expected from these models, but are consistent with prior observations of fracture instabilities in bulk model rubber-toughened epoxies. Some alternative models for the transitions in fracture mode will be discussed.