Superposition of Cohesive Elements to Account for R-Curve Toughening in the Fracture of Composites

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Abstract: *The relationships between a resistance curve (R-curve), the corresponding fracture process zone length, the shape of the traction/displacement softening law, and the propagation of fracture are examined in the context of the through-the-thickness fracture of composite laminates. A procedure that accounts for R-curve toughening mechanisms by superposing bilinear cohesive elements is proposed. Simple equations are developed for determining the separation of the critical energy release rates and the strengths that define the independent contributions of each bilinear softening law in the superposition. It is shown that the R-curve measured with a Compact Tension specimen test can be reproduced by superposing two bilinear softening laws. It is also shown that an accurate representation of the R-curve is essential for predicting the initiation and propagation of fracture in composite laminates.*

Keywords: *Composites, Crack Propagation, Damage, Fracture, Failure, Cohesive Elements.*

1. Introduction

To predict the propagation of damage in quasi-brittle materials such as composites, it is necessary to define damage evolution laws that account for the fracture energy dissipated in each damage mode. Thermodynamic consistency based on fracture toughness is necessary to ensure objectivity of the solution with respect to finite element mesh choice, to predict scale effects, and to determine the proper internal load redistributions. Most damage models, such as the Progressive Damage Model for Composites provided in Abaqus and typical cohesive elements, represent the evolution of damage with bilinear softening laws that are described by a maximum traction and a critical energy release rate. The shape of the softening law, e.g., bilinear or exponential, is assumed to be inconsequential for the prediction of fracture.

The objective of the present work is to examine the relationships between the assumed shape of the traction/displacement softening law, the R-curve, its fracture process zone length, and their effects on the propagation of fracture. In Section 2, it is shown that material softening and R-curve are directly related to each other and that bilinear laws cannot accurately represent toughening mechanisms that cause an R-curve response. To address this difficulty, a procedure based on the superposition of bilinear softening laws is proposed that can account for all the mechanisms that