Fracture Modeling of Fiber-Reinforced Polymer Composites with a Novel Mesh-Objective Method

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Many load bearing structures in the aerospace industry such as wing skin panels, fuselage panels have been designed with fiber-reinforced polymer composites (FRPC) to achieve advantageous structural properties of light weight and high strength. The effectiveness of these designs is strongly correlated with the understanding of damage tolerance response in FRPC. This necessitates the development of robust, validated, and time-effective computational models for analyzing complicated fracture mechanisms. Though various approaches [1-8] have been proposed, there are still many drawbacks that need to be resolved in order to develop an efficient, discrete and physical modeling technique for fracture in FRPC. For example, the requirement that crack-path is known a-priori in cohesive zone modeling method (CZM), virtual crack closure technique (VCCT) and some other methods [1-4] made them unable to analyze real-world fracture responses. This issue is addressed in the extended finite element method (X-FEM) and the variational multiscale cohesive method (VMCM) [5-7], but they are computationally expensive. Additionally, it is important that computational modeling of fracture associated with finite element analysis has to possess mesh-objectivity. In this work, these challenges are resolved through the development and implementation of a novel mesh-objective method for mixed-mode failure in FRPC. By merging the continuum approach with cohesive zone modeling (Figure 1), the method (also referred to as continuum-decohesive finite element method or CDFE [8]) offers many advantages. These include: (a) crack-path is not required to be pre-determined; (b) crack is modeled by incorporating a discrete, strong-discontinuity formulation; (c) mesh-objectivity is maintained; (d) the method is capable of modeling both stable and unstable crack growth; (e) computational efficiency is significantly improved as compared to strong-discontinuity methods such as X-FEM or VMCM. These features of the proposed technique are assessed through a systematic verification process using a combination of tests and modeling including elements tests, mesh-objectivity tests, and various structural tests such as single edged-notch tension (SENT) and open hole tensile test of a lamina (Figure 2). The proposed method and its computational implementation prove to be highly promising for analysis of a wide variety of fracture problems in FRPC.

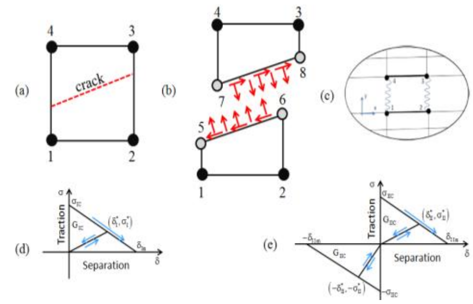

Figure 1: (a) Continuum element, (b) Element splitting due to crack, (c) Cohesive zone modeling, (d) Mode-I cohesive law, (e) Mode-II cohesive law

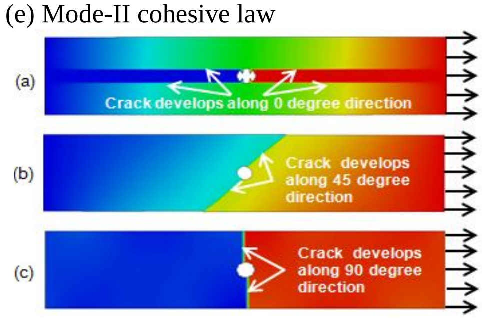

Figure 2: Sharp (strong-discontinuity) crack obtained with the novel method for open hole tensile loading of lamina for three cases of fiber orientation (a) 0 degree, (b) 45 degree, (c) 90 degree

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