Fracture characterization of composite using high dimensional model representation based cohesive zone model

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1. INTRODUCTION

One of the main reasons for using composite material as a structural material is high strength to weight ratios. Military and commercial aircraft industries are now using composites to reduce structural weight while meeting the necessary strength requirements. Failure of composite materials involves evolution of various damage mechanisms, such as fibre breakage and matrix cracks, debonding of adjacent laminate layers, also known as delamination. Due to delamination, structural stiffness, load carrying capacity, instability and early structural failures will occur under loading. To understand the failure in composites, it is necessary to predict the crack initiation and propagation. For providing valuable insights in the prediction of crack initiation and propagation, the computational models used are called cohesive zone models (CZM). Cohesive elements have proven to be an excellent approach in computational fracture mechanics. Nevertheless, massively parallel computations are required to capture damage patterns and evolution meticulously in composites. The present study is to improve the CZM, rendering it into a computational tool that will be able to capture steady state energy release rate variations of a double cantilever beam (DCB) specimens based on unidirectional composite (IM7/977-3) test data. Based on path independent *J*-integral approach, the bridging law parameters are measured for finding the fibre bridging characteristics of unidirectional fiber composites of a DCB. In this work, to capture the steady state energy release rate variation, a response surface model (RSM) using high dimensional model representation (HDMR) technique[1] is developed to represent the load and crack length distribution in terms of adjusted bridging law parameters. The study shows how the cohesive parameters affect both the accuracy and the computational cost of the analyses, and contributes to establish guidelines for an effective use of cohesive elements in simulations.

2. COHESIVE ZONE MODEL

The concept behind this model considers the process of fracture as a gradual phenomenon in which separation takes place between two adjacent virtual surfaces across an extended crack tip. Nonlinear fracture process is approximated by traction separation law. Cohesive models have been used in the literature as a modelling tool to represent the physical processes occurring near a propagating crack by a simplified traction–displacement relationship, and to isolate the fracture process from the surrounding continuum constitutive model[2]. The CZM can be applied to both linear and nonlinear fracture mechanics. There are different types of traction separation laws, and an appropriate traction-separation law can be selected based on the failure mechanisms. These traction separation laws should be defined using selected parameters. Figure 1 shows bilinear traction-separation law which is defined using three parameters (i.e., peak traction, energy and

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stiffness)[3]. In Fig. 1, X-axis represents displacement, Y-axis represents stress, and the area under the curve signifies the fracture energy.

The failure mechanism of a traction–separation law involves a three-step process: (i) damage initiation, (ii) damage evolution, and (iii) element removal. Damage initiation indicates when the degradation of the element begins, which is after it reaches the peak traction. Damage evolution implies the rate at which the stiffness of the element is degrading after reaching the damage initiation criteria. And element removal is done after the traction approaches zero at a critical normal separation value[4]. In the traction–separation law (i.e., adjusted bridging law) developed by Feih (2006)[5], both crack initiation and propagation energy were accounted. Also, it was shown that the experimental data such as crack length and crack profiles were found to give very good agreement with the adjusted law. This adjusted bridging CZM is helpful for the present study, because the parameters can be directly linked to the delamination process. To define the element ahead of crack tip, the cohesive elements are embedded by the traction separation law. Initial crack and cohesive zone of a DCB are shown in Fig. 2. Based on traction-separation law, the cohesive model which signifies fracture zone, starts separation as the load increases, and this separation will continue till it reaches the critical limit.

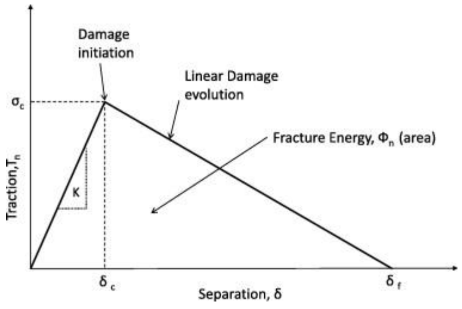


Figure 1. Bilinear traction separation law[3]

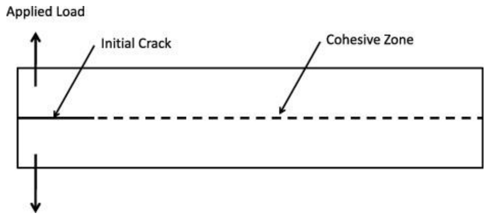


Figure 2. DCB with initial crack and cohesive zone[3]

3. METHOD FOR CAPTURING THE STEADY STATE ENERGY

In this work, to capture the steady state energy release rate (J_{ss}) variation, following procedure is adopted.

i). Estimate steady state energy release rate, load and crack length distribution from test data, and represent energy in Cumulative Distribution Function format.

ii). Use the test data to estimate the upper and lower bounds of each of the adjusted bridging law parameters.

iii). Develop response surface functions using HDMR technique to represent the load and crack length distribution in terms of adjusted bridging law parameters.

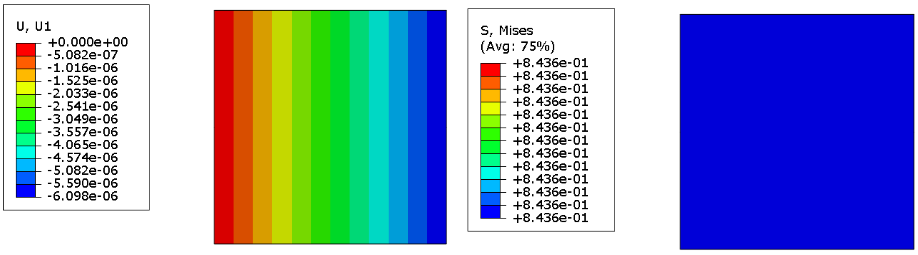
iv). Apply Monte Carlo Simulation (MCS) to the above functions using Pearson Distribution and calculate, J.

v). Perform optimization by minimizing the error between calculated $J\left(J_{CAL}\right)$ and test $J\left(J_{TEST}\right)$ to determine the statistical characteristics of the adjusted bridging law parameters.

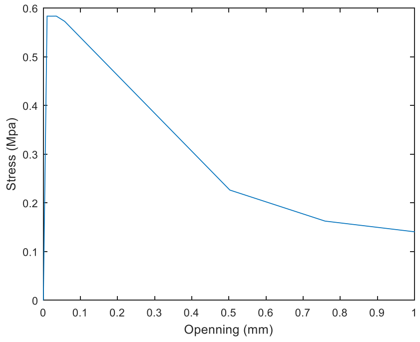
$$Error = \sum\left(J_{CAL} - J_{TEST}\right)^2 \tag{1}$$

4. RESULTS

Figure 3 shows the results for the test case obtained from ABAQUS/CAE. As the stiffness of the top element is large compared to the bridging stress input, the stress distribution in loading direction appears constant. The displacement field in X-direction, which is caused by the Poisson effect, varies linearly. For the simple case of uniform deformation (the same displacement boundary condition on all top nodes), the original bridging law is obtained from the reaction forces, element area and the opening of the element.



(a) contour plots



(b) History Plot

Figure 3. Verification of 2D user element

5. CONCLUSIONS

The efficient implementation of a cohesive user element into the commercial FE code ABAQUS is carried out in this study. This element type proves to be a versatile tool in predicting crack opening, crack length and crack profiles as a function of the crack growth resistance. Cohesive element has the distinct advantage that a higher number of integration points can be used to improve the numerical performance for a given mesh density. This reduces the computational time for the analysis greatly. First-order HDMR with more number of sample points or second-order HDMR approximation results in dramatic reduction of the approximation error.

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