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Proceeding Paper

Investigation of Progressive Delamination Growth Characterization in Composite Materials †

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Abstract: Composite-materials-based structures are extensively used in aerospace structures owing to their high strength-to-weight ratio and high specific modulus. There are different types of failures in a composite material subjected to multiple types of loading, but delamination is the most important one and occurs where the material fractures into layers. In this current research, a cohesive zone method approach is applied to investigate the fracture mechanics due to delamination. Finite element analysis was used for the delamination characterization in composite materials in which 2D and 3D models of double cantilever beams (DCBs) were used. ABAQUS Software was used for analysis completion. It is observed that the cohesive element's size must be 0.5 mm or less in order to forecast delamination precisely for double cantilever beams. It was also determined that the initial stiffness could not be less, or else the damage initiation cannot be forecast correctly. The value for initial stiffness used in this research was 10^6 kJ/m^2.

Keywords: delamination growth characterization; composite materials; double cantilever beam

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1. Introduction

A composite is a type of material that comprises collective elements which are united at the macroscopic level and are insoluble in each-other. Delamination is a significant failure within the composite materials laminates due to weak strengthening through the thickness. The delamination among the laminae of composite materials is critical because it may lead to the debonding of the laminae and cause progressive damage to the entire structure.

In the literature, the cohesive zone method (CZM) is broadly used for investigating the crack progression. The cohesive zone method is founded on the idea of Barenblatt [1], who presented it for brittle materials. In CZM, the interlaminate separation around the cohesive zone is incurred. The fundamental idea of the CZM is based on the idea that the inelastic effects that occur at the crack vicinity can be lumped into a surface cohesive damage zone. In this regard, Elliott [2] considered nonlinear fabric failure and added an interatomic attracting pressure in line with unit area to research the fracture of a crystalline substance alongside a cleavage plane. Dugdale [3] employed an equal cohesive zone version to analyze yielding at a crack tip and size of the plastic region.

The objective of this research is to investigate the debonding of laminae and the progressive damage behavior of double cantilever beams manufactured by composite materials by using experimental and finite element techniques. For this purpose, a double cantilever beam was modelled in Abaqus to investigate the delamination behavior. The results of the 2D model of the double cantilever beam are prepared for two composite materials, i.e., glass epoxy and HTA-6376 carbon epoxy, and finally compared with experimental published data. Finally, the results of 2D and 3D models are compared for both materials and their delamination process is evaluated in detail.

2. Methodology

Modeling

Double cantilever beam (DCB) specimen was made up of 2 four-sided beams with a pre-cracked surface in the center plan of Figure 1. The dimensions of the double cantilever beam were 150 mm length, 25 mm width and 4.2 mm is thickness/depth. The initial crack length was 35 mm. A cohesive zone was also sandwiched between two rectangular beams. Cohesive zone thickness was 0.02 mm.

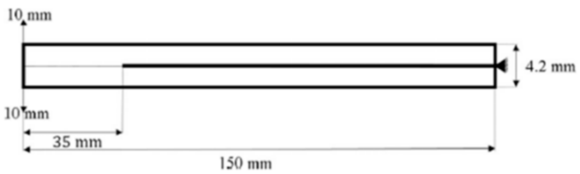

Figure 1. Double cantilever beam specimen.

The analysis was completed using displacement control boundary conditions, and the linear method was used. The magnitude of displacement was 10 mm, which was applied on the upper-left edge and the lower-left edge, while the other side was kept fixed. Throughout the analysis, the geometric properties of the double cantilever beam and applied displacement boundary conditions were kept constant. A detailed mesh-independent study was performed during the analysis. Several sets of simulations were performed with different mesh sizes from 0.1 to 0.35 million for glass epoxy, as shown in Figure 2. For glass epoxy, it was concluded that the results at 0.2 million mesh size were optimum, and were thus used for the rest of simulation process. Similarly, for carbon epoxy sample, 0.15 million mesh size was chosen.

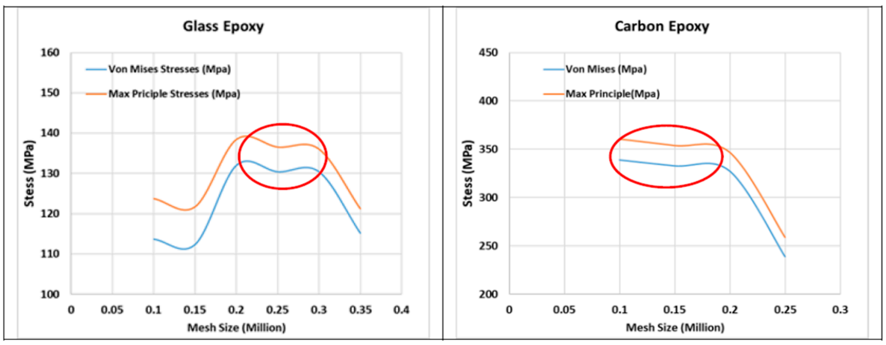

Figure 2. Mesh independence study.

3. Results and Discussion

3.1. Results for 2D Unidirectional Glass Epoxy and Carbon Epoxy

The DCB model's SDEG status in Abaqus is presented in Figure 3. The SDEG variable shows whether the criteria of damage initiation are fulfilled or not. If the value of "SDEG" is equivalent to one then the criteria of initiation is fulfilled. In other words, it shows the state of damage in the model. Similarly, the load vs. displacement curve for glass epoxy 2D, DCB and HTA-6376 carbon epoxy is shown in Figure 4. In this curve, the maximum load or peak load experienced by glass epoxy 2D DCB is 60 N. The load-displacement curve shows the elastic behavior or damage initiation phase at the start, and after reaching the peak load it starts to decline and show the damage progression phase. The minimum load experienced by glass epoxy 2D DCB is 38 N. The same behavior for load–displacement curve for the experimental result is experienced. The peak load for experimental result is 63 N. Similarly, the peak load experienced by HTA-6376 2D DCB is 142 N at 2 mm. The load–displacement curve shows a damage initiation phase at the start, and after reaching the peak load it starts to decline to show damage progression. The minimum load experienced by HTA-6376 carbon epoxy 2D DCB is 60 at the given displacement; the same load–displacement behavior is experienced for glass epoxy.

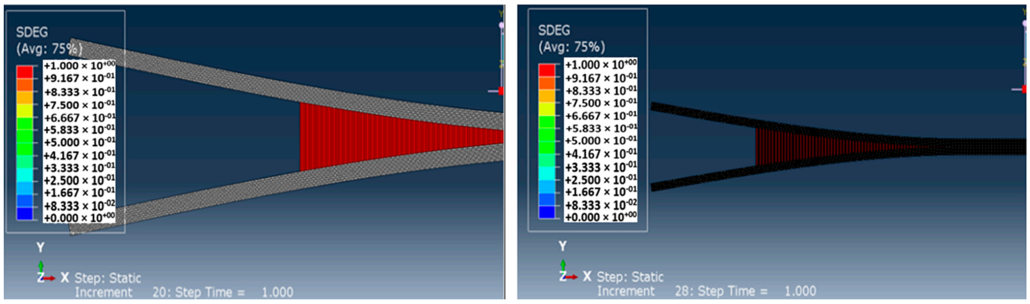

Figure 3. SDEG of carbon and glass epoxy.

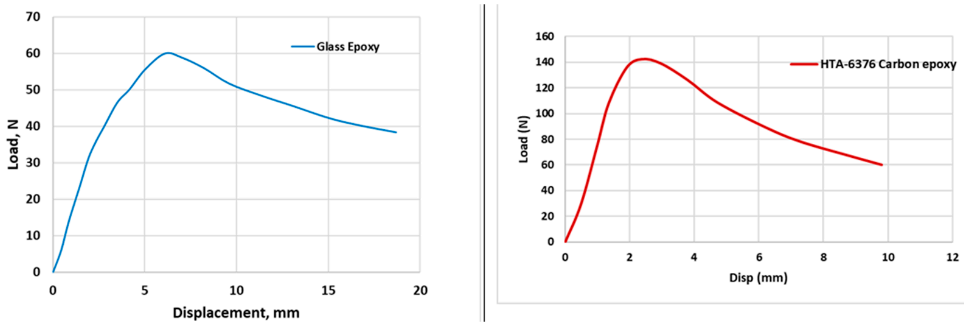

Figure 4. Comparison of peak load vs. displacement for both materials.

3.2. Results for 3D Unidirectional Glass and Carbon Epoxy

The contours of U Magnitude for 3D glass epoxy and HTA-6376 carbon epoxy are shown in Figure 5. The maximum value of strain energy is 306 J at time 1 s. As the crack increases in the DCB model, the strain energy increases, while the strain energy curve gradually rises with respect to time, and it reaches to the maximum value of 620 J for the HTA-6376 specimen. Figure 6 shows the strain energy comparison curve for both materials. Figure 7 encloses the near-matching results of 2D and 3D geometries for both specimens.

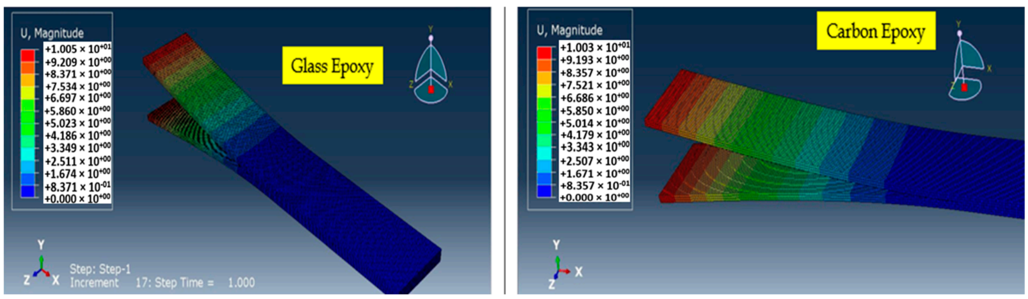

Figure 5. Comparison of U magnitudes for 3D specimens.

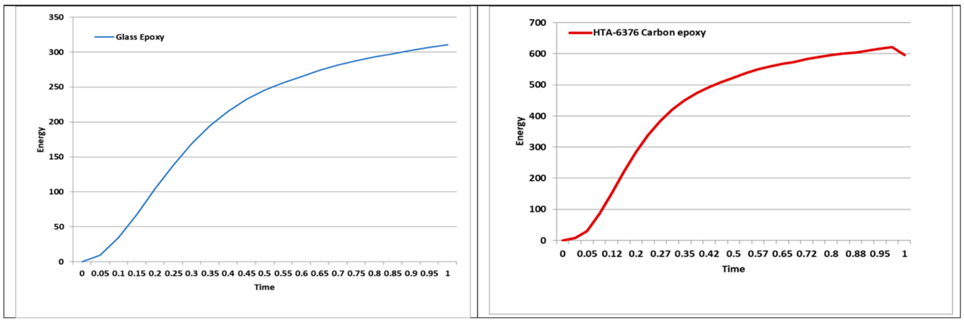

Figure 6. Strain energy comparisons for glass Epoxy and HTA-6376 carbon epoxy material.

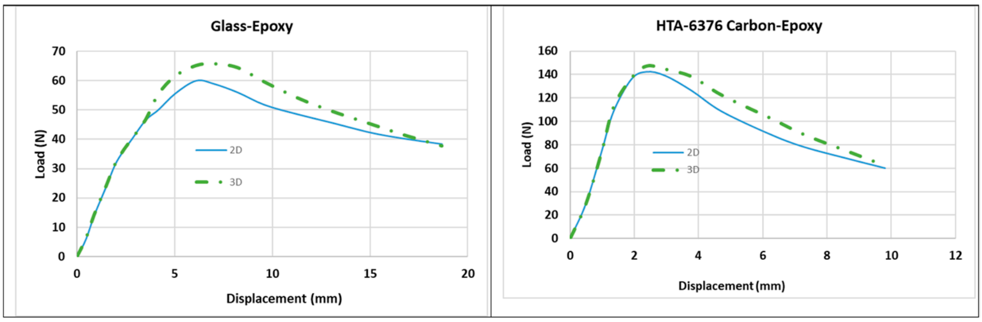

Figure 7. Both 2D and 3D load vs. displacement comparisons for both specimens.

4. Conclusions

In the present study, an investigation of progressive delamination growth characterization in composite materials was performed. It was noticed that the usage of higher fracture energy or lower fracture energy than the nominal value caused the over-assessment or under-assessment of delamination or damage initiation, respectively. Both the 2D and 3D finite element analysis results were compatible with the experimental results. The SDEG value was equivalent to 1, which means the initiation criterion is fulfilled.

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