Trigger Mechanisms of Progressive Crushing – Energy Absorption in Flat Plate Fiber-Reinforced Composites

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Abstract. A study has been made of flat plate chamfer-based, crush trigger mechanisms subjected to axial compression, for use with energy-absorbing Fiber reinforced composites. This paper will focus on the trigger mechanisms in flat panels made of Newport Nb321/7781 fiber composites. Progressive crushing can often be induced by initiating or triggering fracture at one end of the plate. Crushing initiates in the highly stressed region at the tip of the chamfer and this develops into a stable crush zone. The sequence of crushing events depends on the type of chamfer and chamfer angle. The test panels would be subjected to low and high speed compression testing. We would like to validate the best optimized model for trigger mechanisms using FEA, with the experimental results.

1. Introduction

Composite materials provide significant benefit such as enhanced strength and durability, weight reduction and lower fuel consumption; in addition to being an efficient crashworthy structure. Crashworthiness is typically defined as the ability of a structure to absorb energy in a collision or the ability to ensure the survivability of the airplane/helicopter passenger. Most structural composites are in the form of plate-like elements.

The variable known to affect energy absorption in composite structure is the method of failure initiation, commonly called triggering. The crushing of a structure is generally triggered by providing a zone of stress concentration which initiates crush and away from which the crush propagates. The bevel trigger, produced by beveling the end edges to sharp edges, is the initiator that is most frequently used in energy absorption studies. For a composite structure to absorb a large amount of energy during crushing it is important to establish a crush zone that will propagate through the material. This is usually attained by introducing a chamfer at one edge, shown in Fig 1. The ideal progressive crushing mechanism in composites is a balance between brittle fracturing and lamina bending as this imparts the highest energy absorption. Such complex crushing mechanisms require careful design of the composite crush structures, and a significant amount of testing. Composite materials under crushing may experience a wide variety of interacting failure modes, including fiber and matrix fracture, delamination, local instability [1]. Experiments on the crushing of composite laminates under axial crushing loads have shown that the appearance and growth of delamination can significantly influence the energy absorbency of the laminate [2, 3]. The high stresses generated in the chamfer owing to an external applied load $P$ initiate a crushing zone and prevent the load from building up to values which exceed the critical buckling load of structure [5].

![Fig 1: Schematic of Flat laminate](image1.png)

![Fig 2: Test setup for Flat laminate](image2.png)

![Fig 3: Crushed 12 ply [45] degree specimen](image3.png)

The ability of a material to dissipate energy can then be expressed in terms of Specific energy absorption $SEA$.

$$SEA = \frac{EA}{\delta L t} \quad (1)$$

The EA can be calculated as the total area under the Load-displacement diagram:
\[ EA = \int F \cdot \delta \]  

(2)

It can be summarized that for flat plate specimens, delamination suppression is indeed crucial to maintain high levels of energy absorption [3].

2. Experiment

Test-setup is shown in Fig 2, it’s a Quasi-static uni-axial test and chamfer end is at the bottom as shown in the schematic Fig 1. Flat plate specimens with chamfer of 30 degree were crushed in a cyclic loading-unloading compression cycle and the resulting microstructure were examined microscopically.

Specimen have a length of 4 inch and width 1 inch, having a chamfer about 30 degrees. 12 ply specimens of two different stacking sequence were tested \([0]_{12}\) and \([45]_{12}\). For the \([45]_{12}\) specimen had 13 cycles in steps of 0.025 inch increase at a speed of 0.001 in/sec and the \([0]_{12}\) specimen had 29 cycles in steps of 0.01 inch at a speed of 0.001 in/sec. The specimens were cleaned and the crush zone was observed under the microscope. The \([45]_{12}\) showed a crack formation (Fig 3) which was filled with debris unlike the \([0]_{12}\) specimen. Initial bending always occurred outwards followed by delamination.

3. Result

Fig 4, shows the Load-Displacement, [Energy absorption] of the specimen. The \(L_{ch}\), chamfer length of \([0]_{12}\) and \([45]_{12}\) are 0.2689 inch and 0.2195 inch respectively, with chamfer angles of 25.189 degree and 31.0175 degree. The \(E_{abs}\) in the \([0]_{12}\) is \(770\) lb-in and in \([45]_{12}\) is \(546.75\) lb-in, hence we observe a \(29\%\) better \(E_{abs}\) in the \([0]_{12}\) than \([45]_{12}\).

![Fig 4: Energy Absorption in 12 ply](image)

4. Conclusion

Although a limited amount of testing has been performed, and the analytical substantiation through explicit finite element analysis has not yet begun, preliminary results seem to suggest that trigger mechanisms in the fiber reinforced composites under compression, depend on the chamfer angle. In future flat plate specimens of chamfer angle 30, 45 and 60 degrees will be tested at different speeds in the denomination of 0.001 in/sec, 0.01 in/sec and 10 in/sec. Failure modes are highly dependent on a number of parameters, geometry of the structure, material, stacking sequence and test speed.

Reference