Progressive Crushing Energy Absorption Capabilities of Glass Fiber-Reinforced Corrugated Panel

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Abstract. This experimental study addresses the progressive crushing of Newport NB321/7781 E-glass fiber-reinforced corrugated panel. The progressive crushing behavior is being studied at quasi-static rates and at selected dynamic loading rates. The number of ply and the laminate gross thickness affects the energy absorbing capability by 58% at various loading rates. The stacking sequence, $[0]_8$ and $[0]_{12}$ are 40% and 30% greater than $[\pm45]_8$ and $[\pm45]_{12}$, respectively.

1. Introduction

Fiber-reinforced composites are widely used in aircraft structure, automobiles as well as structurally demanding fields. The study of composite structures on aircraft crashworthiness is not only crucial on improving the overall aircraft construction but also enhance the occupant safety. However, application of fiber-reinforced composite on aircraft crashworthiness is less well understood due to the complexity in prediction of energy absorption. Theoretically, in order to avoid occupant injury during certain crash scenarios, kinetic energy has to be dissipated in order to alleviate deceleration loads on the occupants.

2. Experimental Set-up

Prepreg material used is Newport NB321/7781 E-glass. The corrugated panel is fabricated by first laying up sheet of Fiberglass prepreg on a set of aluminum matching molds. After the desired number of ply is reached, the matching mold is closed for applying uniform pressure to the panel. Parting film and breather are laid up subsequently and wrapped up cautiously with vacuum bag. The assembly is then vacuumed and cured in an oven with temperature of 270^{o}F for three hours. After curing, a 14-in x 8-in corrugated panel is machined down to the specimen with length of 4.7-in, height of 2-in and thickness of 0.045-in, 0.075-in, 0.115-in for 4, 8, and 12 plies laminate, respectively. One end of the edges along the cross-section is chamfered for initiating the failure and reducing the peak loads.

Two circular platens were positioned parallel to each other on a 55-kip capacity hydraulic loading machine. The specimen is firmly supported by a corrugated fixture to avoid buckling in the transverse direction. The crushing tests were conducted at three distinct loading speeds which is 10^{-3}-in/s, 10^{-1}-in/s and 1-in/s for $[0]_n$ and $[\pm45]_n$ specimens, respectively and stopped when the displacement of 1-in is reached. The data acquisition rate is defined as 2-Hz, 204.8-Hz and 2048-Hz for the three loading rates. All the test data is collected and reduced for comparison purposes.

3. Results and Discussion

Typically, delamination was first noted on the edges after the test was started. Splaying and lamina buckling occurred consecutively. Energy was absorbed when the crack was propagated and followed by fragmentation. Moreover, transverse shear acted on the edges causing the splaying and the growth of interlaminar cracks more rapidly and eventually fracture.

Fig.1 A $[\pm45]_{12}$ corrugated specimen fractured after crushing.

In general, the initial peak increases when the loading rate is increased as seen in Fig. 2.

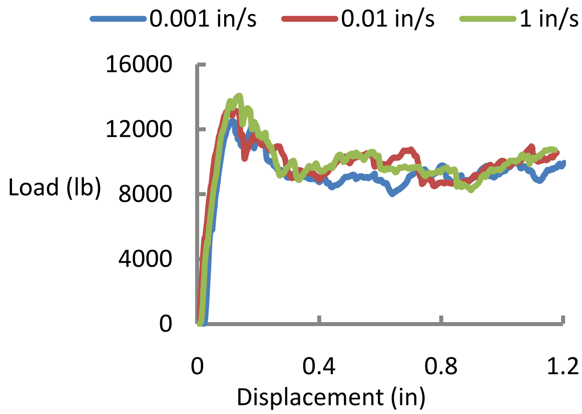

Fig.2 Load-displacement response of $[\pm45]_{12}$ E-glass prepreg at various loading rate.

The test result shows that $[0]_8$ and $[0]_{12}$ has higher initial peak load compared to $[\pm45]_8$ and $[\pm45]_{12}$.The similar pattern is observed on $[0]_8$ and $[\pm45]_{12}$ at various loading rate. Also, the sustained crushing load for $[0]_8$ and $[0]_{12}$ is 8488-lb and 14,732-lb which is 29% and 27% greater than $[\pm45]_8$ and $[\pm45]_{12}$, respectively. The

Crush load efficiency is defined as the ratio of sustained crushing load over initial peak load.

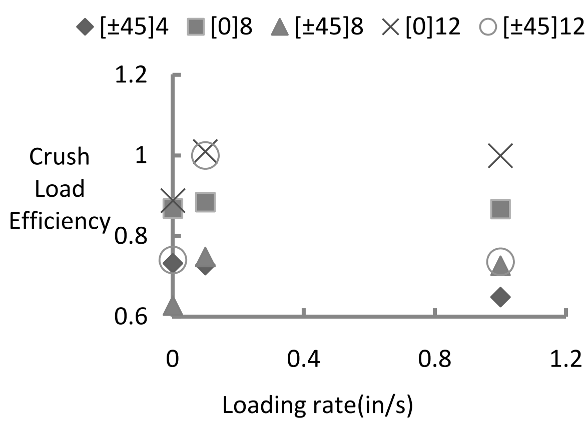

Fig. 3 Crush load efficiency of different ply stacking sequence at various loading rates.

The chamfered end along the cross-section facilitates failure initiation and lowers the initial peak load. Ideally, the crush load efficiency of unity is expected. As seen in fig. 3, efficiency of 0.6 and 0.65 for $[\pm45]_8$ and $[\pm45]_4$ are unlikely and should be avoided whenever possible. In general, as the number of ply and laminate gross thickness increases, the initial peak increases resulting in higher tendency to fail in unstable manner. Energy absorption during crushing is defined as the area under the load-displacement curve and the specific energy absorbed is defined as energy absorption per unit volume.

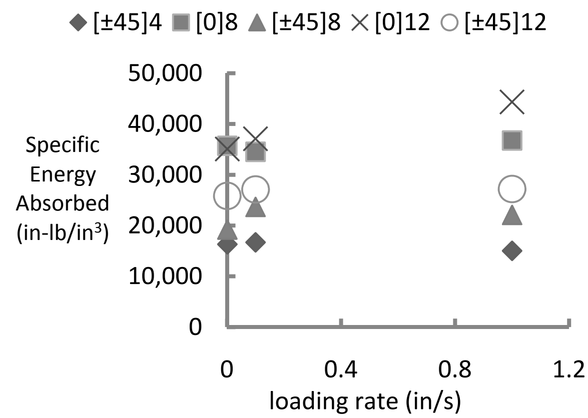

Fig. 4 Specific energy absorption for different ply stacking sequence at various loading rates.

Specific energy absorption for $[0]_8$ and $[0]_{12}$ are higher than $[45]_4$, $[45]_8$, and $[45]_{12}$ as seen in fig. 4. Data shows that $[0]_8$ and $[0]_{12}$ are at least 30% greater than $[45]_4$, $[45]_8$, and $[45]_{12}$ in energy absorbing capability.

4. Conclusions

Overall, $[0]_n$ has approximately 15% greater initial peak load than the $[\pm45]_n$ for ply 4,8,12, respectively. Stacking sequence and number of ply plays a significant role in energy absorbing capability with the difference up to 30% and 40% for $[0]_{12}$, $[\pm45]_{12}$ and $[0]_8$, $[\pm45]_8$ accordingly.

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