Load Rate Effects on the Crush Response of Laminated Corrugated Beams

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Abstract. This experimental study addresses the progressive crushing responses of laminated corrugated beams fabricated using Newport NB321/7781 E-glass prepreg material. Stacking sequences of $[0]_n$and $[45]_n$ where n=4,8 and 12 have been used. The progressive crushing behavior has been studied at quasi-static rates and at selected dynamic loading rates. The test data indicates that the peak load levels increase with load rate, while the sustained crushing load decreases. $[0]_n$ surpass $[45]_n$ in terms of energy absorbing capability at various loading rates by at least 30%. The failure modes in $[0]_n$ beams was observed to be rate sensitive with the number of fronds and frond fragmentation changing with test speed.

1. Introduction

Aircraft structure is designed in such a way that it absorbs crash energy and protects the occupants. Energy absorbing devices in composite materials are frequently used for dissipating kinetic energy in airframes to enhance their crashworthiness. The geometry of the corrugated beams is chosen as energy absorbing device because it promotes stable crushing behavior thereby maximizing the crushed volume of the material. To investigate its energy absorption and failure mechanism, constant stroke rate experiments with test speeds ranging between 0.001in/s to 100in/s have been used in this study.

2. Experimental Set-up

The corrugated laminates were fabricated using Newport NB321/7781 E-glass fabric prepreg. Stacking sequences of $[0]_n$ and $[\pm45]_n$, where n=4,8 and 12 have been used. Corrugated laminated were fabricated using a closed mold process where the prepreg assembly was cured between two matching molds made of aluminum. The prepreg assemblies were cured in the matched molds in an oven at a temperature of 275°F for 90 minutes. The match molds were encapsulated in a vacuum bag and subjected to vacuum pressure during the curing cycle. Corrugated laminates of length of 14" were obtained using the molds, from which specimens with a height of 2" were cut. One edge of the specimen was chamfered at 45° using a grinding wheel. The chamfering was done to initiate failure along this edge and reduce the peak loads under compression. The quasi-static compression tests were conducted using a 22kips capacity MTS electromechanical testing machine. The dynamic compression tests were conducted using a 5kips capacity MTS high rate servo hydraulic testing machine. The specimens were crushed to a nominal length of 1". The data acquisition rate is defined as 2Hz, 100 KHz and 1 MHz for the three loading rates. All the test data is collected and reduced for comparison purposes.

3. Results and Discussion

The behaviors of corrugated specimens have been characterized in terms of their load displacement behavior and the specific energy absorption (SEA). The specific energy absorption is defined as the energy absorbed per unit crushed volume of the specimen. The load displacement behavior of the $[0]_4$ and $[45]_4$ corrugated beams are illustrated in figure 1. The plots compare the behavior at different test speeds. The load-displacement behavior was characterized by an initial peak load followed by a sustained crushing region.

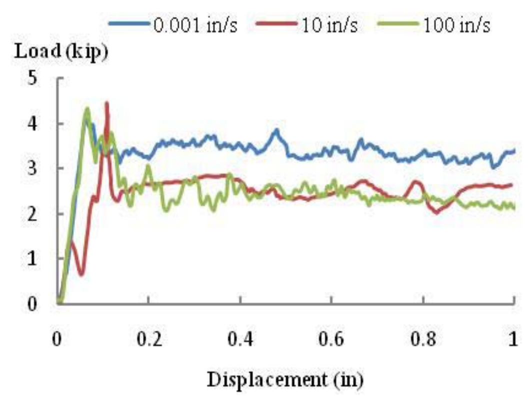

Fig.1: Load-displacement response of $[0]_4$ E-glass prepreg at various loading rate.

Specific energy absorption for $[0]_8$ and $[0]_{12}$ are higher than $[45]_4$, $[45]_8$, and $[45]_{12}$ as seen in figure 2. 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.

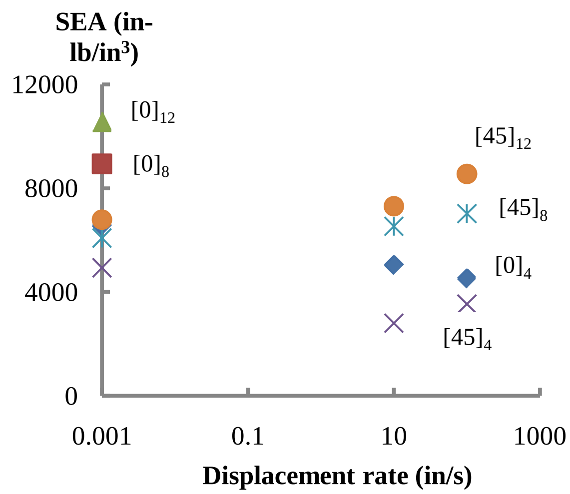

Fig.2: Specific energy absorption for different ply stacking sequence at various loading rates.

The correlation between energy absorption and complex failure mechanism such as fiber and matrix failure, delamination, etc are extremely critical to understand energy absorbing capabilities of composite materials.The failure modes in the corrugated specimens were observed to be dependent on the test speed. The failure modes observed in $[0]_4$ and $[45]_4$ corrugated beams tested at different speeds are compared and shown in figure 3 and figure 4.

In the $[0]_4$ test specimens tested at quasi-static rate, the fronds were not clearly visible, i.e., tearing of the plies was not clear. However, at higher speeds, the fronds were clearly defined and the numbers of fronds were observed to increase with test speed. The fronds formed at quasi-static speed further tended to break-off into fragments while at the higher speeds, long fronds were found intact at the end of the test. The failure modes in $[45]_4$specimens tested at different speeds were however not clearly distinguishable. The specimens tested at higher speeds broke into several smaller fragments from shear cracking, while larger fragments were found in tests conducted at quasi-static rate.

Figure 3: Failure mode of $[0]_4$

Figure 4: Failure mode of $[45]_4$

4. Conclusions

The initial study indicates that the load rate effects on laminated corrugated beam cannot simply be ignored during design of energy absorbing devices. Also, delamination and tearing of plies contribute to energy absorption process. Rate sensitivity of each individual failure mechanism must be further investigated.

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