Delamination Behavior of Composite T-Sections with Z-Fibers

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Summary

Three-point bending tests were performed to examine the delamination behavior of composite T-sections. Two specimens with 2 and 4% of third directional reinforcement (z-fibers) and one specimen with no z-fibers were tested under static loading at room temperature. Preliminary results show that the initial behaviors of the specimens with and without z-fibers are similar up to first failure; on the other hand, the delamination modes and post-failure responses are different. Existence of z-fibers improved the delamination toughness of the composite T-sections. There is also a slight increase in the first failure load of the specimens with z-fibers. Furthermore, a thermoelasticity measurement system with infrared camera was used to acquire the thermal measurements in order to observe the material variability and the stress concentration areas in the T-sections due to the insertion of z-fibers.

Introduction

Composite T-sections are used in different components of airplanes, such as wing, fuselage. Interlaminar delamination, which is not visible from outside is the most common failure mode in these T-shaped composite laminates. A successful solution to this problem is to manufacture new composites with through-the-thickness reinforcements such as z-fibers to improve structural damage tolerance. One of the methods to provide through-the-thickness reinforcement to the laminated composites is z-fiber pinning. This method was developed by Foster-Miller Inc [1] in the USA. Several experimental investigations have shown that these new composites not only offer significant improvements in fracture toughness, impact resistance, and interlaminar strength but also using them is a cost effective method [2].

This study examines the delamination behavior of composite T-sections with z-fibers under three-point bending load at room temperature. The effects of z-fibers on the material variability and the stress concentrations in these sections were also investigated by using thermoelasticity measurement system with infrared camera. To this end, two specimens with 2 and 4% z-fibers and a control specimen with no z-fibers were tested. The main objective of this study is to assess the effect of through-the-thickness reinforcement on the strength and post-failure response of composite T-shaped specimens and to compare these with a similar two-dimensional laminated composite.

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Manufacture Composite T-Sections with Z-fibers

Three types of T-sections with 2 and 4%, and with no z-fiber reinforcements were manufactured by Aztex Inc [3]. Figure 1 shows the dimensions of a representative T-section. Different lay-ups were used for the skin, web and flanges of the T-sections. Forty layers with a quasi-isotropic lay-up of $[0/90/45/-45]_{5s}$ were used for the skin. Twenty layers, $[0/45/90/-45/-45/45/45/90/-45/0]_s$ lay-up, were used for the web part which divides equally to form the flanges. At the skin-web-flange interface, a resin-rich pocket exists for all T-sections. Three-dimensionally reinforced T-sections are processed with z-fibers at the skin-flange interface to show the effect of through-the-thickness reinforcement. A single z-fiber was 0.02 inches in diameter.

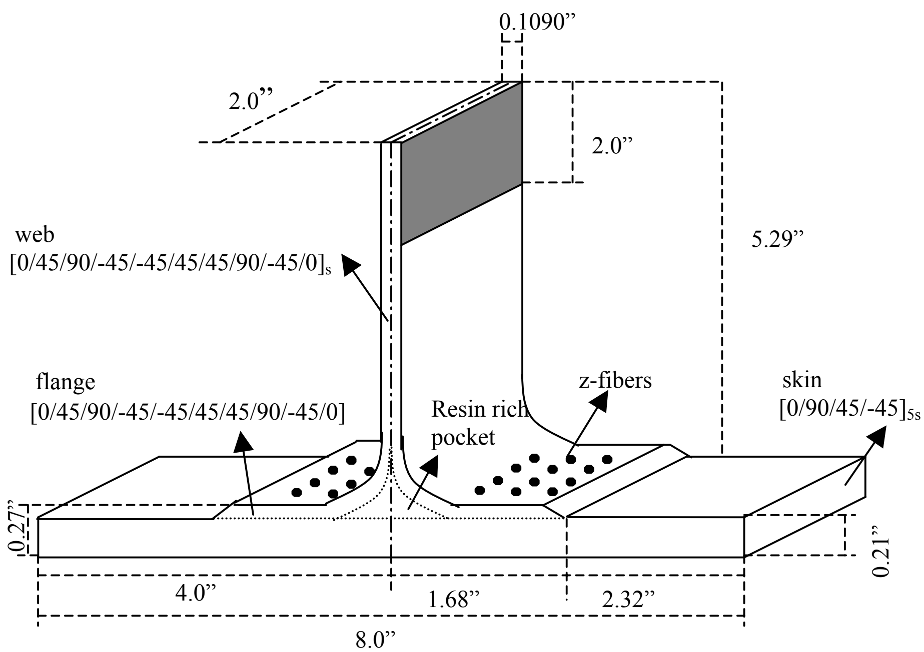


Figure 1. Specimen dimensions and lay-ups.

The process for inserting through-the-thickness fibers was developed by Foster-Miller to meet the need for control of delamination. In this technique, short fibers initially contained in foam are inserted into the composite through a combination of heat and pressure compacting the foam. The through-the-thickness fibers are elastically supported by the foam to prevent buckling during insertion. As a result, the process converts a two-dimensional prepreg lay-up to a three-dimensional composite with little or no change to standard cure cycles. After cure, the foam residue and excess fibers are removed.

Thermoelasticity Measurements with Infrared Camera

A DeltaTherm DT1500 thermoelastic stress analysis (TSA) measurement system with infrared camera was used to observe the material variability and the stress concentration regions in the T-sections with and without z-fibers. A cyclic load was applied using an MTS 810 servo-hydraulic test system. The DeltaTherm's infrared array detector synchronized with the applied cyclical loading enables the detection of the transient thermoelastic effect. Application of direct mechanical cyclic loads will create a temperature change in the material. The amount of change in temperature in different areas will be different. Figure 2 shows a schematic of the TSA test setup.

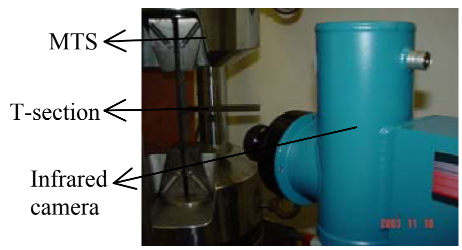


Figure 2. TSA test set-up.

Figure 3 shows the temperature fields of T-sections with and without z-fibers, taken by infrared camera at a load level of 1 kip, amplitude of 0.75 kips, and frequency of 5 Hz. Light colors (yellow) indicate the stress concentration areas in the sections under applied loads. In both T-sections the resin rich area at the skin-web-flange interface and the tapered-end at the end of the skin-flange interface are the high stress concentration areas. Therefore, failure of the sections has to be expected at these regions. Existence of the stress concentration regions in the T-sections with z-fibers can be attributed to the addition of different material (z-fiber) than the original lay-up, separation of in-plane fibers during the z-fiber pinning process, and the existence of residual stresses at the z-fiber locations.

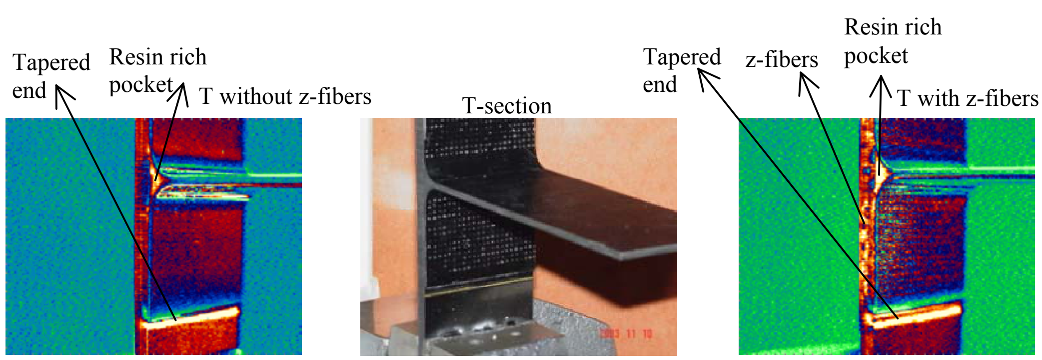
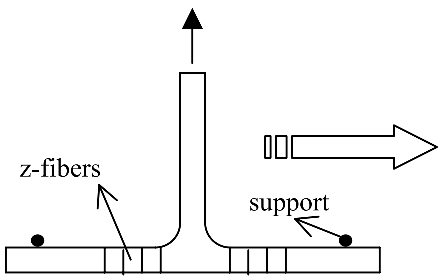


Figure 3. TSA pictures from infrared camera.

Three-Point Bending (TPB) Tests

All the specimens were tested at room temperature using a 20-kips ATS test machine. A TPB test fixture was used as seen in Figure 4. The web of the specimen was clamped using mechanical grips and the load was applied at this end. Tests were run under displacement control with a loading rate of 0.02 in./min. Three specimens with 2 and 4%, and no z-fibers were tested.



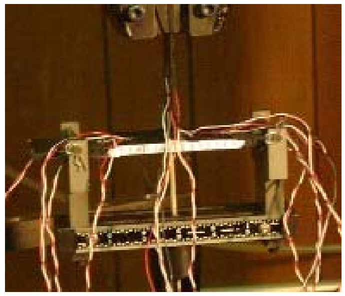


Figure 4. TPB test fixture.

The load-stroke responses of all specimens are plotted in Figure 5. The z-fibers provide a slight increase in the initial failure load, but the primary benefit of the reinforcement is in damage tolerance. Evaluating the area under the load-stroke curve of the T-sections with z-fibers shows a significant increase in the amount of energy required for final failure (Figure 5). The 2% and 4% z-fiber reinforced T-sections can sustain 4.5 and 12.6 times the energy, respectively, of the unreinforced T-section.

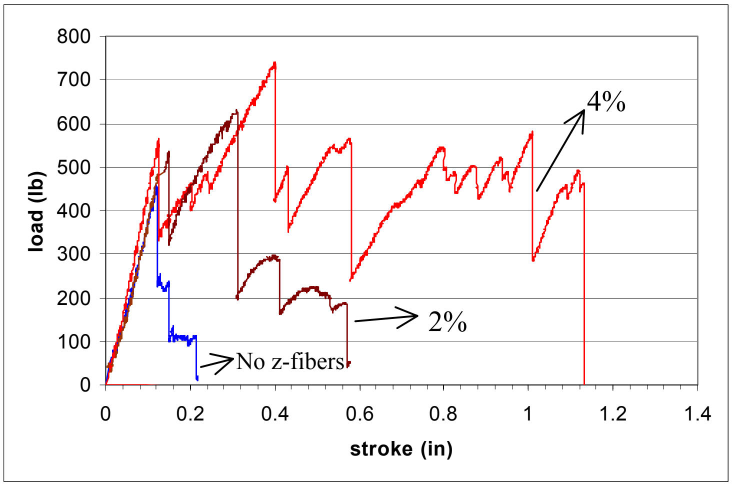
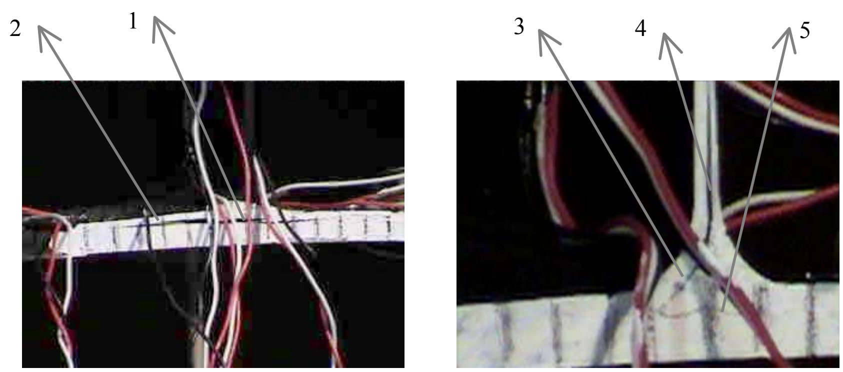


Figure 5. Load stroke readings of T-sections under TPB load.

Delamination Mechanisms in T-sections

As seen in Figure 6, different delamination mechanisms were observed for T-sections with and without z-fibers. The first mechanism, which corresponds to the first failure load, in the T-section without z-fibers is the delamination of the skin-web-flange interface at the bottom of the resin rich area (1). Then, the delamination continues to grow towards the tapered ends of the skin-flange interface (2). On the other hand, delamination of the resin rich area from the web (3) of the T-sections with z-fibers is the first delamination mechanism at the initial failure load. Then, the delamination continues along the web (4). Meanwhile, another delamination mechanism starts in the skin-web-flange interface at the bottom of the resin rich area (5). This delamination mechanisms are consistent on both of the T-sections with 2 and 4% z-fibers.



Without z-fibers With z-fibers

Figure 6. Delamination mechanisms in T-sections with and without z-fibers.

Figure 7 shows the delamination growth during the post failure response of a representative T-section with z-fibers. After the first failure load, delamination continues to grow along the web (1), because the z-fibers hold the growth along the skin-flange interface. When the z-fibers in front of the delamination crack along this interface reach their delamination energy, the delamination starts along the skin-flange interface towards the tapered-end (2). Then, the delamination continues to grow along the web (3) until the next rows of z-fibers at the skin-flange interface reach their delamination energy. Then, the delamination occurs along the skin-flange interface again (4). This mechanism repeats itself until the final failure of the T-section with z-fibers.

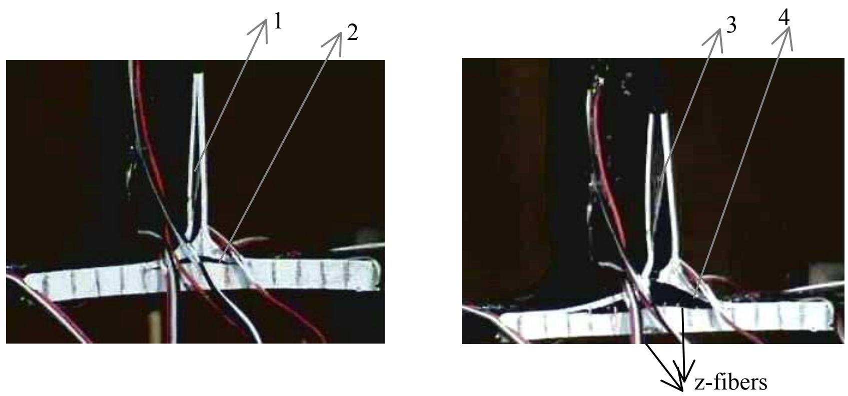


Figure 7. Delamination growth in T-section with z-fibers.

Conclusions

Three-point bending tests were performed to examine the delamination behavior of composite T-sections with 2 and 4%, with no z-fibers. Furthermore, TSA measurements with infrared camera were used to investigate the material variability and stress concentration areas in the T-sections due to the insertion of z-fibers. Preliminary results show that the initial load-stroke responses of the T-specimens with and without the z-fibers are similar up to first failure; on the other hand, the delamination mechanisms and post-failure responses are different. Existence of z-fibers slightly increased the first failure load and improved the delamination toughness of the composite T-sections with z-fibers.

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