

STIFFNESS AND STRENGTH OF LAMINATES FABRICATED WITH BI-DIRECTIONAL TAPE

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Abstract

In this investigation, the stiffness and strength of laminates manufactured with bi-directional pre-preg tape were evaluated. [45/0/-45/90]_s flat panels were manufactured with [45/0] IM7/8552 bi-directional pre-preg tape by CNC tape laying. The bi-directional tape under discussion consisted of a 6" wide pre-preg layer of 45 degree fiber with a 5" wide pre-preg layer of 0 degree fiber centered on top of it. The bi-directional tape was laid up in side-by-side passes using an automated tape laying machine. An overlap of 0.5" between adjacent plies was formed to bridge the discontinuous seam of the off-axis ply. Stiffness and strength data of tensile specimens cut from the manufactured panel in various angles were measured and the properties were compared to the same properties of specimens cut from panels with continuous plies. Finite element analyses were conducted to predict the properties of the specimens and the results were found to be in good agreement with the measured properties. The most important advantage of the bi-directional concept presented is the savings in layup time using a tape laying machine. This is achieved by eliminating the need to layup the off-axis plies.

1 Introduction

By utilizing bi-directional tape for tape laid panels, there is a potential for great reduction in processing time when compared with that of panels made from unidirectional tapes. This savings is due to the fact that the off-axis plies are imbedded in the bidirectional tape and do not require a separate pass.

In the bi-directional tape configuration under discussion, the off-axis [45] plies are wider than the

[0] plies resulting in an extra 0.5" lip on each side of the tape that can overlap the adjacent tape, as shown in Fig. 1, without any changes in overall ply count. This overlap bridges the discontinuous seam of the off-axis ply.

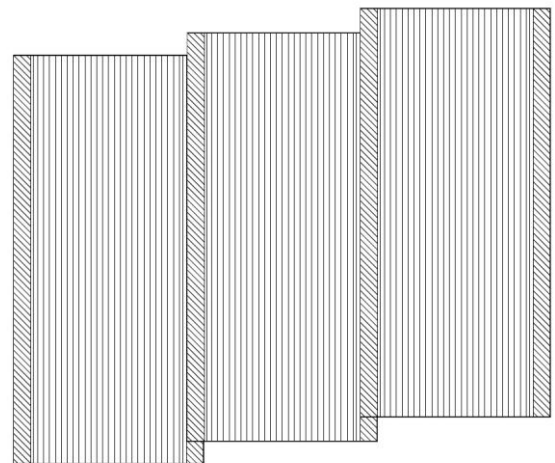


Figure 1: Bi-directional tape with 0.5" overlap repeating every 5.5". Each tape strip is 6.0" wide.

Many unique configurations are possible with this concept. Different ply materials such as carbon and glass can be assembled to form hybrid bi-directional tapes according to user specifications. Customizable bi-directional tape can be utilized in tape laying situations where using unidirectional tape is cost prohibitive.

2 Experimental

A panel was fabricated using [45/0] tape, as shown in Fig. 2. Four passes in total were required to make the [45/0/-45/90]_s bi-directional panel.



Figure 2: Layup operation using bi-directional tape.

A panel was also fabricated using continuous fibers for baseline comparison. Tensile specimens were cut from both the bi-directional tape laid panel and the continuous panel to investigate the stiffness and strength of bi-directional tape layups and assess the effect that discontinuous fibers have on those properties.

1" wide specimens at 5 orientations (0, 90, 45, 22.5 and 67.5 deg) were water jet cut for tensile testing. The specimens were 10" long providing for a 6" gage length. Specimens were pulled to failure and both the initial elastic modulus and the strength were recorded.

3 FEA Simulation

Finite element simulations were performed for both the continuous ply specimens and the bi-directional tape specimens. The analysis includes progressive degradation and failure of individual plies to predict the maximum strength [1][2]. The analysis was performed with MSC.MARC 2010 [3] using a 3D shell model with 8 layers.

4 Results

The 0.5" wide tape overlaps were expected to provide a "soft" strip with reduced strength and modulus. The specimen area comprised of the soft strip varied depending on the position and orientation of the specimen in the panel. For a 0 deg orientation specimen, the soft strip could comprise a maximum of 50% of the specimen width (Fig. 3.a). This represents a worst-case condition, as wide panels will have less than 20% of the area with soft strips in a given direction. For an off-angle specimen, there can be 2 or 3 soft-strip locations

depending on specimen location within the panel (Fig. 3.b).

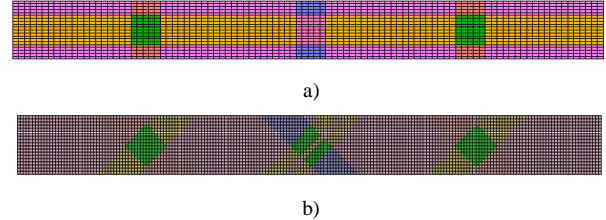


Figure 3: FEA material groups. a) 50% width soft strip model for a 0 deg orientation specimen. b) 45 deg orientation specimen with 3 soft-strips along the gage length of the specimen.

The strength data of continuous ply specimens cut at various orientations are presented in Fig. 4, overlaid with the FEA calculated data. Although 0 deg, 45 deg and 90 deg specimens are expected to display the same strength, some variation was observed in the experimental data.

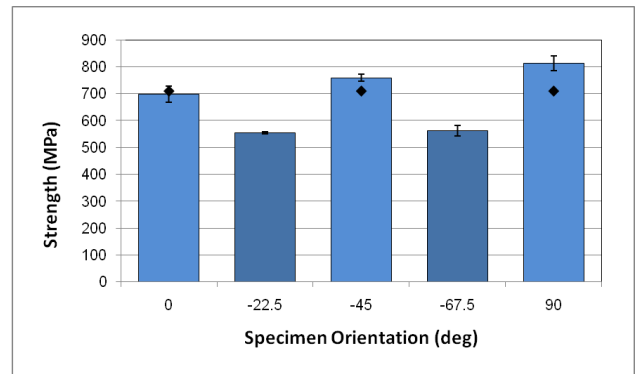


Figure 4: Strength of continuous ply specimens cut at various orientations. (♦) is FEA calculated data.

In Fig. 5, a drop in strength of the off-angle specimens is observed for specimens cut from the bi-directional tape panel. This strength reduction is primarily associated with the fiber discontinuity at the soft strips and is potentially significant for any off-angle orientations (orientations other than 0 deg or 90 deg). Fiber discontinuity was modeled as a narrow strip of elements where the discontinuous layer was given a reduced material modulus equivalent to the modulus of the matrix only (the

fiber contribution to the modulus was fully discounted in the discontinuous region).

FEA calculated strength of the 45 deg off-angle specimens was lower than experimentally measured data. This drop may be explained by the number of “soft” strips along the gage length of the specimen. The FEA data presented assumed the worst-case situation, corresponding to 3 soft-strips along the gage length of the specimen. However, the specimens tested may have had less than the maximum possible soft-strip. A precise assessment of the soft-strip percentage was not available for the off-angle cases.

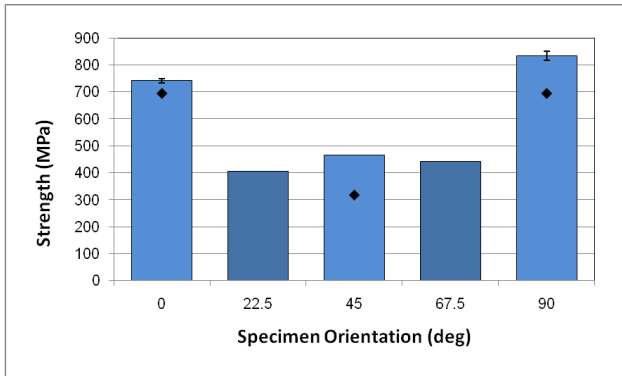


Figure 5: Strength of bi-directional tape specimens cut at various orientations. (♦) is FEA calculated data.

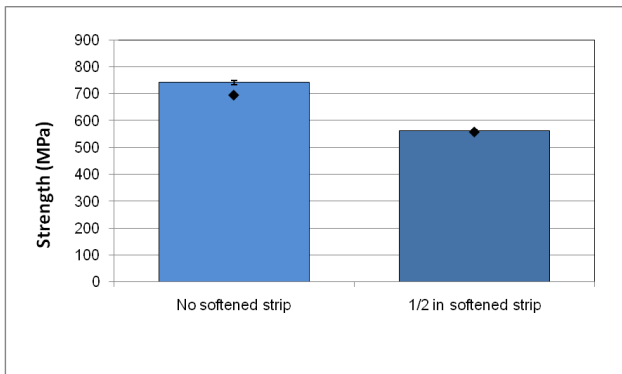


Figure 6: Effect of “soft” strip along the length on strength of bi-directional tape specimens. (♦) is FEA calculated data.

The effect of a soft strip along the length of the specimen is presented in Fig. 6. The

experimental tests showed a 24% strength reduction for the 0 deg orientation specimen with 50% of the specimen width (0.5” out of the 1.0” specimen width) taken up by the soft strip (Fig. 6). This is an extreme case, since the laminate will have a 0.5” wide soft strip for a 5.5” wide overall repeat unit.

In Figs. 7 and 8, the elastic modulus of specimens at various angles taken from the continuous and bi-directional laminates, respectively, are presented. Contrary to its effect on strength, the elastic modulus is much less sensitive to the presence of soft strips, assuming the strip is not oriented along the specimen’s length (Figs. 7 and 8). There was a reduction in elastic modulus for 45 deg specimens of about 10% in predicted data, which was not observed in experimentally measured data (Fig. 8). Again, the off-angle specimens tested may have had less than the maximum possible soft-strip. If the test specimens do actually have less than the maximum amount of soft-strip, the measured modulus should be higher than the FEA modulus prediction.

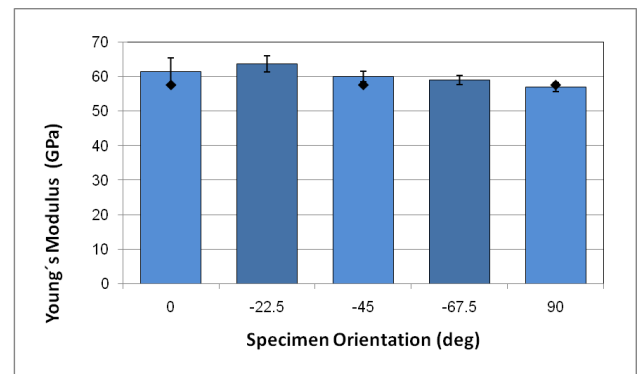


Figure 7: Elastic modulus of continuous ply specimens cut at various orientations. (♦) is FEA calculated data.

A 17% reduction in elastic modulus was observed for the 0 deg orientation specimen configuration with 50% of the specimen width taken up by the soft strip (Fig. 9). Once again, the reduction in modulus is less significant than the reduction in strength.

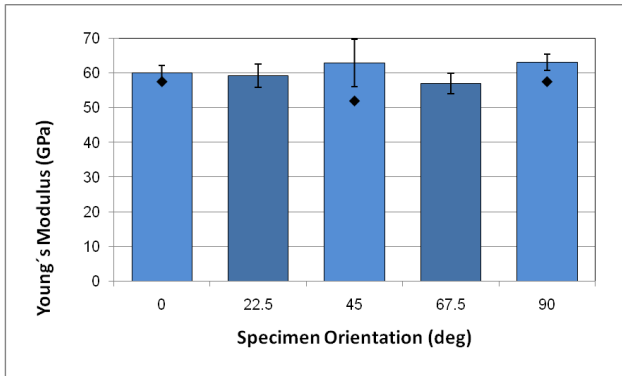


Figure 8: Elastic modulus of bi-directional tape specimens cut at various orientations. (♦) is FEA calculated data.

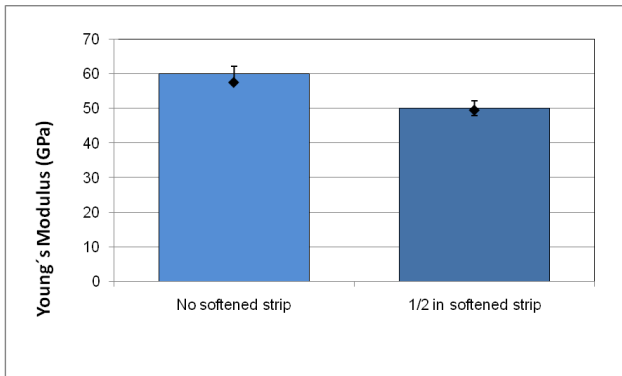


Figure 9: Effect of “soft” strip along the length on elastic modulus of bi-directional tape specimens. (♦) is FEA calculated data.

5 Conclusions

In this study, $[45/0/-45/90]_s$ flat panels were manufactured with $[45/0]$ IM7/8552 bi-directional pre-preg tape by CNC tape laying. A panel was also fabricated using continuous fibers for baseline comparison. Tensile strength and stiffness of both laminates were measured using specimens cut at 5 orientations (0, 90, 45, 22.5 and 67.5 deg) to assess the effect of specimen orientation on those properties.

According to the data presented, the 0 deg orientation simulation confirmed that the soft-strip had a more significant effect when it was aligned with the loading direction and comprised up to 50% of the specimen width. Transverse soft-strips,

however, did not significantly reduce either the specimen strength or modulus. The most significant strength-reduction factor occurred for off-angle specimens and was attributed to layers where the fiber has a narrow, discontinuous region.

For the off-angle specimens, the effect of soft strips is more pronounced in strength and not as significant for the elastic modulus. The data presented indicates good agreement between experimental data and FEA calculated properties.

Three-dimensional (3D) effects such as delamination have not been included in the FEA utilized in this study. These factors may important in specific loading or specimen configurations and should be studied further in the future.

References

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