Thermal and Thickness Effects in Para-Aramid Core

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ABSTRACT

This paper presents results from a recent test program on para-aramid (Kevlar®) honeycomb core. Test results from several suppliers are combined to obtain knockdown factor curves for thermal and thickness effects. The results were compared to curves published for non-metallic core in the Hexcel® core design guide. Some historical test data from the suppliers was also used in the analyses.

INTRODUCTION

The Hexcel® design guide “HexWeb™ Honeycomb Attributes and Properties” [1] was developed many years ago. The design guide lists properties for “non-metallic honeycomb” or “HRH-10” which is their trademark for meta-aramid (Nomex®) honeycomb core. Many aerospace engineers have looked to this document for design guidance.

When Gulfstream decided to use para-aramid core (Kevlar®) on one of their models, a study was launched to determine the applicability – or lack thereof – of the curves for elevated temperature and for thickness variations. In addition to L and W shear strength, stabilized compression and flatwise tension were tested. Modulus was also evaluated for the shear and compression properties. The results were compared with the curves in the Hexcel® document. Note that there were four kinds of core tested and the data combined to create the charts shown herein. In some cases the data is shown separated by supplier, but not by core type. This was done to show that there were no significant differences between the suppliers, nor between core types.

THERMAL EFFECTS

Strength Knockdown Factors

The elevated temperature of interest to Gulfstream was 180°F. It was decided to test the core at laboratory ambient moisture rather than attempt to saturate the core. Therefore the core was first dried, then exposed to the ambient moisture of the laboratory, which was controlled to a maximum of 60% relative humidity.

One of the charts in “HexWeb™ Honeycomb Attributes and Properties” is “Temperature Effects – 30 Minute Exposure (tested at temperature)”. It includes a curve for Nomex® core, designated HRH-10 in the Hexcel nomenclature. A copy of this curve is shown in Figure 1. There are no comments with the chart, so it is not clear what properties it applies to. Test data
from this program was combined with test data obtained from the suppliers to a) determine which properties the graph applies to; and b) determine preliminary knockdown values for conditions not covered by the graph.

Figure 1. Hexcel® Curve for Temperature Effects

To test whether the curve for Nomex® core (HRH-10) also applies to Kevlar® core, some historical test data at elevated temperature dry and elevated temperature wet was available from Euro-Composites, as well as test data from the current study. The combined data was compared to the predictions from this curve to see if the curve applied to the para-aramid core also. The results, shown in Figures 2 and 3, indicate that:

- Predictions from the Hexcel model appear to be applicable (conservative) to para-aramid core in the dry state for:
  - Flatwise Tension
  - L-Shear
  - W-Shear
- Predictions for the Hexcel model are clearly not applicable for the wet state.
- The Hexcel model is clearly not applicable to stabilized compression strength, dry or wet.

Figure 2 shows an estimated curve for FWT, L and W Shear, and Figure 3 shows an estimated curve for Stabilized Compression in the dry and wet condition. For Stabilized compression, three data points at the wet condition suggest that there may be little or no additional knockdown for the wet condition.
Suggested knockdown factors for modulus are shown in Figures 4 and 5. Note that the suggested models are mean models. This is because variability should already be accounted for in the acceptance values used for the core, and mean modulus is generally used for design purposes. Each data point shown is an average of at least six test data points.
The finding above, that compression strength does not follow the Hexcel® curve, while shear strength and flatwise tension strengths do, is not surprising, since the compression mode of resistance is different from the shear and flatwise tension mode of resistance. It would be unusual for one curve to represent two completely different resistance modes. Shear and flatwise tension are dependent on binding the fibers of the para-aramid paper together to produce a
continuous flow of the load and therefore are limited by the bond strength between the fibers and resin. Compression, however, is dependent on the geometry and quality of the “support column” composed primarily of phenolic resin. From the data represented in Figures 2 to 5, it appears elevated temperatures have a stronger degradation influence on the resin than they do on the bond between the resin and fibers.

THICKNESS EFFECTS

Strength Knockdown Factors

Thickness effects were evaluated from 0.50 to 2.0 inches. The standard for comparison was the 0.50 test data, to be consistent with the curve given in the Hexcel® document for thickness effects in shear properties, shown in Figure 6, labeled “Nonmetallic”, which approximately passes through $K_t = 1.0$ at 0.5-inch. To address this anomaly, the curve was analytically shifted slightly to the right to force it through 1.0 at $t=0.5$, in the figures that follow.

![Figure 6. Hexcel® Tensile Shear Thickness Effects Curve](image)

The initial test data using tensile plate shear is shown in Figure 7. The first problem that had to be overcome was the difficulty in shear testing thicker specimens. Special plates were built to be consistent with the dimensional requirements in ASTM C273. In preliminary testing of specimens at 2-inches thick, the failure mode was flatwise tension at the ends, followed by shear collapse. Since the only valid failure mode was shear collapse, this was not acceptable. The maximum thickness was therefore cut down to 1.2-inches. Even at 1.2-inches, however, there was some question about the failure mode. In the end, it was decided to take an alternate approach.

The alternate approach taken was to use flex shear testing per ASTM C393. This allowed testing of thicknesses up to 2-inches with the correct failure mode, though there was also localized crushing at the load application points on some 2-inch specimens that is believed to
have occurred simultaneously with the shear collapse. No high speed photography was taken to validate this. A photo of a typical shear failure is shown in Figure 8.

Figure 9 shows the knockdown factors determined from the flex test data. They differ in the L and W directions, but if the two directions were combined, they would approximately match the Hexcel curve. This chart shows all individual data points, not batch averages.

In addition to shear strength knockdowns with thickness, stabilized compression thickness effects were evaluated. As shown in Figure 10, stabilized compression strength drops slightly with increasing thickness. Again, scatter should be accounted for in the design values at the nominal thickness, 0.5-inch.

Figure 7. Thickness Shear Knockdown Factors Using Tensile Plate Shear
Figure 8. Closeup of Flex Shear Failure Mode

Figure 9. Thickness Shear Knockdown Factors Using Beam Flex Test
Modulus Knockdown Factors

Modulus was evaluated also for thickness knockdowns, as shown in Figures 11 and 12. Figure 11 shows that modulus for L and W shear does not change significantly with thickness, so a value of $K = 1$ is recommended for all thicknesses. Figure 12 shows that the stabilized compression stiffness increases significantly with thickness, although for conservatism, a knockdown value of $K = 1$ is recommended for all thicknesses.

![Figure 10. Thickness Effects in Stabilized Compression Strength](image)
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

- Thermal effects in Kevlar® core were shown to be well predicted by the Hexcel® design curve for L and W shear and flatwise tension in the dry condition.
- The Hexcel® design curve for thermal effects was shown not to apply to shear in the wet condition, nor to stabilized compression in any condition.
- Indications from very limited test data are that stabilized compression is not significantly affected by the wet condition at elevated temperature.
- L and W shear modulus drop off slightly with increased temperature.
- Stabilized compression modulus drops off significantly with increased temperature.
- Tensile shear tests were not viable for testing up to 2.0-inch thick specimens due to improper failure modes. Even the failure modes in the 1.2-inch thick specimens were often suspect.
- Flex shear tests (four-point bending) were shown to be viable tests for determining knockdown curves for shear as a function of thickness for Kevlar® core, for core up to 2-inches thick.
- Flex shear test results indicate that the Hexcel core shear thickness curve is:
  - Unconservative for Kevlar® core in the L-Shear direction;
  - Conservative for Kevlar® core in the W-Shear direction.
- A thickness knockdown curve was developed for stabilized compression strength.
• Shear modulus does not appear to be affected by increasing thickness.
• Stabilized compression modulus increases with increasing thickness.

Recommendations

• Additional testing with para-aramid (Kevlar®) core is recommended for thermal effects:
  o Wet condition at room temperature and elevated temperature for all properties;
  o Additional temperatures, including -65°F.
• It is recommended that the thickness variation tests be repeated with additional types of
  core to establish a comprehensive knockdown curve or set of curves for para-aramid core.

REFERENCES

1. Hexcel® design guide “HexWeb™ Honeycomb Attributes and Properties”