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Compression Testing - Comparison of Various Test Methods

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Abstract

Several test laminates were fabricated for evaluation of mechanical properties under in-plane compression loading. The panels were constructed using a conventional E-glass/vinyl ester knit, a carbon/epoxy prepreg, and an E-glass/epoxy prepreg. The laminates were cured and post-cured according to typical FRP manufacturing practices.

Different types of test specimens were cut from each panel to compare test methods. For example, the carbon fiber laminate was tested for compressive strength using ASTM and SACMA procedures. All of the methods evaluated are commonly used to determine the compressive strength of an FRP laminate. Each of the specimens were cut in the same orientation, with the test axis being the 0° reinforcement axis.

It was shown that the results of compressive strength testing of a given laminate will vary according to the method chosen. Some procedures are not appropriate for medium-to-high modulus composite laminates at all, due to the type of failure mode. Recent methods designed specifically for high modulus composite materials yield higher, more consistent values for compressive strength. Older, historical methods may have value when testing lower modulus or thicker laminates.

Introduction

Like many composite testing procedures, the determination of compressive properties has long been considered a "black art". The various methods can produce wildly different results, when the same material is tested. The choice of test method will influence the results – some procedures yield higher strengths, and others produce lower values.

Studies dating back to the 1980's have looked at the influence of test method on results[1]. Some of the differences between methods include how load is applied (shear vs end loading), whether the gauge length is free or supported, and whether tabs are bonded to the specimen ends.

The "shear" compression failure mode has long been considered ideal for basic laminate properties usage, while a buckling failure is generally considered to be undesirable. But in reality, all compression failures have an element of buckling, although this can be confined to a very localized area. The challenge is to reduce the tendency of the test specimen to buckle on a global scale (column buckling) during the test.

The Test Methods

The different test procedures vary in two main respects – specimen shape and method of loading. In most cases, the test specimen is held or restrained in some sort of "jig" or fixture during loading. It is interesting to note that the methods that work best have been developed relatively recently (specifically for the composites industry), while the older and less desirable methods were adapted for composites from thermoplastic sheet testing procedures.

The common methods in the early days of composites testing were all "end-loaded", in which a coupon was held erect in the test fixture, with an end protruding slightly from the top. The specimen was held fairly loosely in a supporting fixture to prevent buckling. The fixture was loose enough so that it would not bind up in the fixture during loading, but tight enough to prevent all but the smallest out-of-plane movements. In these tests the end that was loaded would tend to "mushroom", or "broom", when relatively high modulus materials were tested. In some cases, the test specimen would be of the dog-bone or dumbbell shape, similar to thermoplastic tensile test specimens. This was done to try to force a failure within the gauge length area. ASTM D695 is an example of this type of test (see Figures 1 & 2).

The Suppliers of Advanced Composite Materials Association (SACMA) developed another end-loaded compression test, SRM 1R-94. This method uses the same holding fixture as ASTM D695, however it utilizes a tabbed, straight-sided specimen (see Figure 3). The tabbed ends reduce the probability of mushroom-type failures, while the holding fixture prevents global buckling as in the D695 method. While the short gauge length of the SACMA procedure encourages the preferred failure mode, its very small area precludes the use of a strain gage for modulus determination. A separate, untabbed specimen must be loaded to measure elastic properties. SACMA is no longer in existence, so this method is not reviewed or updated periodically.

Shear-loaded test methods use a tabbed specimen, with the tabbed ends held in wedges or grips, similar to tensile grips. Shear loading eliminates the possibility of mushroom failures. The gage length of the specimen (distance between tabs) can be opened up to allow the use of a strain gage, if desired. Increasing the gauge length increases the possibility of a buckling failure. Shear-loaded methods include ASTM D3410 and ISO 14126 (see Figures 4 & 5).

A relatively new method uses a "combined loading" scheme, with the untabbed specimen held securely between wedge faces, while a cap prevents a mushroom failure. This method (ASTM D6641) has been found very effective for balanced (0/90) laminates. A short specimen gauge length reduces the buckling tendency.

The compressive strength of FRP skins on a sandwich panel can be determined using a 4-point bending test. In this instance, the composite skin is restrained only by its adhesion to the core material; no other restraining fixturing is used. The test is set up so as to result in a compressive failure of the upper skin, between the loading noses. This method is represented by ASTM D5467 (see Figures 6 &7)

A summary of specimen type and method of loading is provided in Table 1.

Experimental Procedure

Typical materials used for composites parts were chosen for test. Several test panels were fabricated using conventional techniques. Separate panels were made using these raw materials:

- carbon/epoxy prepreg (single-skin)
- E-glass/epoxy prepreg (single-skin)
- E-glass/vinyl ester (single-skin & sandwich)

The plies of fabric were all laid up in the same orientation with respect to each other; i.e., the 0° reinforcement axis laid down in the same direction for each ply. The prepreg layups were then vacuum bagged, and cured according to manufacturer's instructions in an autoclave. The E-glass/vinyl ester panel was fabricated using a wet resin infusion technique. A sandwich panel was also infused using the same skin laminate schedule as the E-glass/vinyl ester panel.

After cure, test specimens were cut from each panel. All tests were performed along the 0° reinforcement axis. Great care was taken to maintain this alignment when cutting the specimens. The specimens were machined according to the instructions, schematic diagrams, and tolerances as given in the test procedure. Where tabs were required, they were cut from sheet stock of a commercially available fiberglass material (G-10).

The compression testing was performed on an Instron universal test machine, using holding fixtures as required by the method. The rate of loading was that specified in the procedure. All tests were conducted under ambient lab conditions, those being 75°F (+/- 3°F) and 50% relative humidity (+/- 10% RH).

A minimum of 5 specimens was tested for each sample/procedure combination. The results as shown in the tables below represent the average value for the set of test specimens.

Test Results

In almost all cases the SACMA method yielded the highest compressive strengths. For the E-glass/vinyl ester infusion sample, the 4-point bending test produced at result that was ~20 MPa higher than the SACMA test. The SACMA test has the shortest specimen gage length, and thus the least tendency to buckle.

Generally, the ASTM D695 test produced results 10%-20% lower than the rectangular, tabbed type of test, even when "mushroom" failures were eliminated from the data set.

The test results are summarized in Table 2.

Conclusions & Recommendations

Determination of compressive properties using the 4-point bending test is more time consuming and expensive than any of the other methods. There would not usually be any advantage to the use of this method for typical composite materials testing.

The legacy test (ASTM D695) will produce lower material strength than the other methods, but may still be of use for thick composites and low modulus materials.

No significant difference was seen between the SACMA test and the relatively new combined loading test (ASTM D6641).

The choice of test method is dependent on cost, time, ease of sample and specimen preparation, and the potential end use of the data. Composites engineers should beware of attempting to get the highest design values possible, as a few spectacular compression failures of composite parts will slow the introduction of composite materials into new markets.

Figure 1 – ASTM D695 Test Specimens

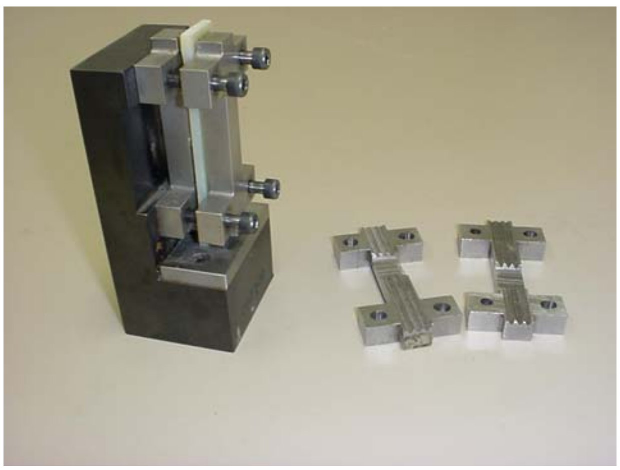

Figure 2 – ASTM D695 Support Jig (also used for SACMA SRM 1R)

Figure 3 – SACMA SRM 1R Test Specimens

Figure 4 – ASTM D3410 Test Apparatus

Figure 5 – ASTM D3410 Test Apparatus

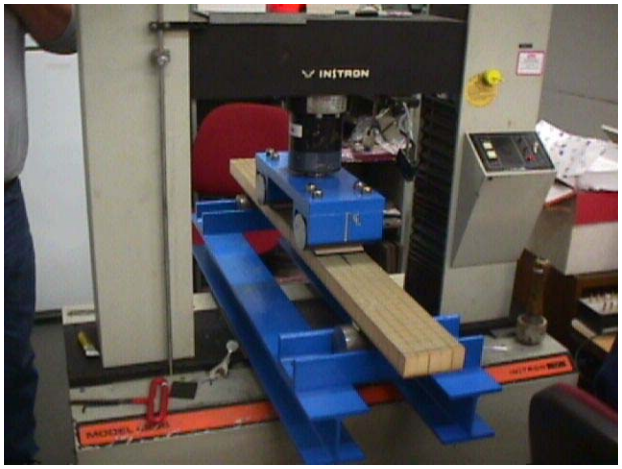

Figure 6 – 4-Point Bend Test Apparatus

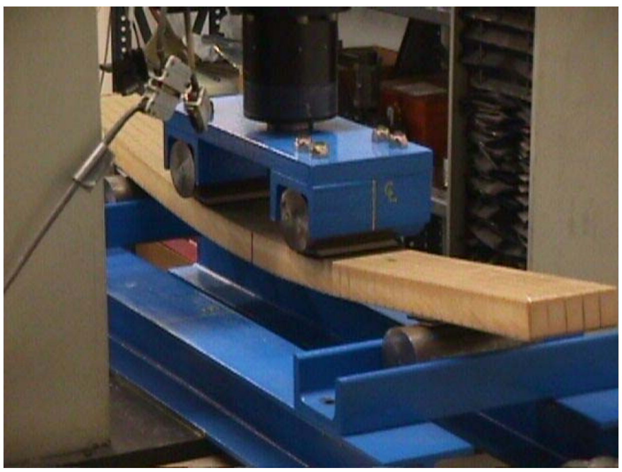

Figure 7 – 4-Point Bend Test Apparatus

Test Method	Specimen Type	Loading Condition
ASTM D695	Dog-bone	End, side support
ASTM D3410	Rectangular, tabbed	Shear, no side support
ASTM D5467	Sandwich panel	4-point bending
ASTM D6641	Rectangular, may be tabbed	Combined end & shear
SACMA SRM 1R	Rectangular, tabbed	End, side support
ISO 604	Rectangular prism	End, no side support
ISO 14126	Rectangular, may be tabbed	Shear or end

Table 1. Test Methods for Composite Materials

	Carbon/Epoxy Prepreg	EGlass/Epoxy Prepreg	EGlass/Vinyl Ester Infusion
ASTM D695	644.5	345.6	331.9
ASTM D3410	703.8	337.1	-
ASTM D5467	-	-	443.1
ASTM D6641	-	377.1	-
SACMA SRM 1R	811.8	378.2	423.4

Table 2. Compression Strength Test Results (MPa)

Note: Values represent the average of 5-8 test specimens

References

1. "Compression Test Results- A Tough Nut to Crack", *Advanced Composites*, July/August 1989, pp. 57-63.

2. "The Influence of Test Method on The Compressive Strength of Several Fiber-Reinforced Plastics", *Journal of Advanced Materials*, Volume 25, No.1, October 1993, pp. 35-45.

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Authors

Art unwittingly joined the composites industry after graduating from college in 1983. Unable to escape, he has since worked in a variety of testing laboratories, and currently coordinates the composites lab at the Engineered Polymer Products division of Goodrich Corporation, Jacksonville, FL. Mike is a Senior Engineer at Goodrich-EPP, and has been involved in the design, fabrication, and testing of many large-scale composite structures.