

A Review of Current In-Plane Composites Compression Testing Methods & Standards

Introduction

Full characterization of the properties of, anisotropic and inhomogeneous, composite materials for use in demanding structural applications requires a wide range of mechanical tests. Determination of bulk properties requires; Tension, Compression, Shear and Flexure tests. Other test types are used to explore more complex properties e.g. Open Hole Tension / Compression, Inter-laminar Fracture toughness, Compression After Impact (CAI) and Fatigue. Furthermore tests will generally need to be conducted over a range of temperatures on materials conditioned in a variety of different environmental conditions.

The compressive modulus and/or strength of a composite material are critical parameters for many structural uses. The factors that determine the compression strength, of a composite material, are complex involving the fiber/matrix interface and the values of compressive strength for a composite can be much lower than values for tensile strength.

Of the basic test types Compression testing is, arguably, the most difficult to perform and most complex in terms of variety of test types and standards. This paper seeks to outline the different test methods and standards and explain the key differences between the different approaches. This review restricts itself to In-plane compression testing; however, test methods also exist for through thickness compression testing.

Compression Test Types

Composite Compression test methods need to provide a means of introducing a compressive load into the material and to prevent buckling of the material under the compressive load. Most composite materials are in the form of laminate panels, the material being tested will be in the form of a, relatively, thin flat rectangular test specimen.

There are three methods of introducing a compressive load into a test specimen:

- End Loading – all of the load is introduced in to the flat end of the test specimen
- Shear Loading – the load is introduced into the wide faces of the test specimen
- Combined Loading – Some mix of shear and end loading is used.

There are two methods of preventing buckling of a test specimen:

- Use of a test specimen with a short unsupported gauge length
- The use of lateral support along the length of the specimen

All compression fixtures are required to have good axial alignment and a high lateral stiffness in order to provide, and maintain, good alignment under the lateral loads that can be generated by a compressive test. Bending will have a significant effect on the test results and most of the compression test methods include a figure for the maximum allowed specimen bending expressed in terms of Percentage Bending Strain (PBS) a typical value being 10% . PBS is defined as the maximum difference in strain across the specimen divided by the sum of the strains.

$$PBS = \left(\frac{|\epsilon_f - \epsilon_b|}{|\epsilon_f + \epsilon_b|} \right) \times 100$$

Where ϵ_f and ϵ_b are the strains on the front and back face of the specimen respectively.

End-Loading Methods

End Loading is probably the simplest in terms of test fixtures, however it is not generally suitable for high strength composites as these materials have relatively low transverse strengths and tend to fail by end crushing (“brooming”). The main current End-Loading standards are:

ASTM D695-10, ISO 14126: 1999, and prEN 2850 1997 (Annex C). End-Loading fixtures are also detailed in Boeing BSS 7660 (where the fixture and L shaped support is referred to as “Modified D695”) and SACMA SRM-1. The End-Loading fixture described in these standards is basically the same (Figure 1); however, there are differences in some of the dimensions.

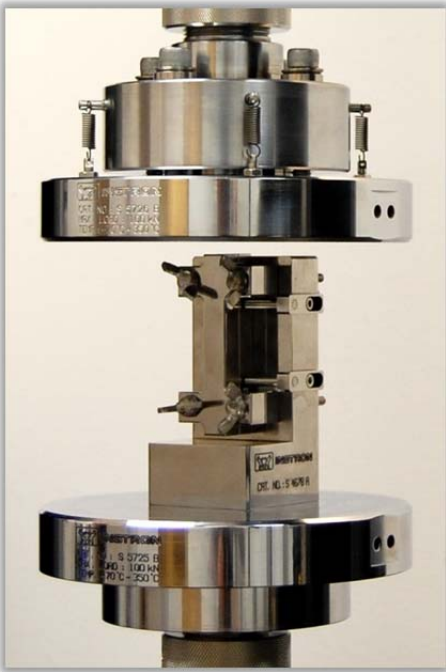


Figure 1: Modified ASTM D695 Fixture and Base Support

The End Loading fixtures defined in these standards incorporate ribbed guides to provide lateral support for the specimen whilst minimizing the contact area with the specimen (the rib detail in SACAM SRM-1 is slightly different to that in ASTM D695-10). The fixtures are bolted together sandwiching the specimen (ISO 14126:1999 specifies a torque setting for the bolts). The specimen and fixtures are located between pairs of Compression Platens. ASTM D695-10 describes placing the specimen and fixtures directly between the platens but the other testing standards mentioned all require the use of an L shaped base support. The base support provides stability and controls the specimen alignment. Because the load is introduced in to the specimen through the end face it is very important that the specimen is accurately machined and that the platens are well aligned (it is recommended that one of the platens incorporates a lockable spherical seat to ensure parallelism).

Compression tests on plastics to ASTM D695-10 use a single wasted flat specimen design for the determination of both modulus and ultimate strength. Compression tests on

High-strength composite materials require different specimen designs for modulus and ultimate strength. Modulus is determined using a rectangular flat specimen but the determination of ultimate strength requires a tabbed specimen with a short unsupported gauge section.

When determining modulus strain measurement is required, strain can be measured using a pair of strain gauges one on each side of the specimen (versions of the guide plates incorporating cut-outs to provide clearance for the gauges and connecting wires are available). It is also possible to use clip-on or automatic extensometers.

Shear-Loading Materials

Shear loading generally requires test specimens with bonded tabs to provide a high friction interface between the jaws and the surface and to prevent the serrated faces of the jaws damaging the material under test. Methods of producing the clamping loads include; self-tightening wedges (e.g. ASTM D3410-03 (2008) IITRI Fixture) and hydraulically generated pre-loading (e.g. Hydraulic Grips).

The Shear Loading method using the IITRI compression fixture with self-tightening wedge jaws is described in ASTM 3410 it is also referenced in ISO 14126:1999 The IITRI compression fixture (figure 2) works well, however, it is very massive (over 20 kg), difficult to handle, and slow to heat-up and cool-down when testing at temperature.



Figure 2: ASTM 3410 IITRI Fixture

Other Shear Loading compression test fixtures include; “Celanese” type fixtures referenced in earlier versions of ASTM 3410 and ISO 14126:1999, this incorporates self-tightening jaws sitting in a conical wedge pocket along with an external guide tube. The original Celanese fixture, with conical wedges, requires a very accurately produced specimen in order for the jaws to make full contact with the conical wedge pocket and to prevent the wedges jamming as a result it is no longer in widespread use. The “Wyoming Modified Celanese” improved on the original design by adopting cylindrical wedges which maintain full contact with the mating cavity regardless of the specimen thickness.

A modified so-called “German” version of the Celanese fixture with jaw faces sitting in a flat wedge pocket which also ensures full surface contact between the jaws and the mating cavity is referenced in prEN 2850:1997. The Celanese type fixtures are much lighter than the IITRI fixture and easier to handle.



Figure 3: Wyoming Modified Celanese Fixture

ISO 14126:1999 also states that “Aligned hydraulic grips in aligned test machines are also acceptable” for the shear loading method. Well aligned and laterally stiff hydraulic wedge grips perform very well in this application and provide excellent productivity due to their automatic operation.

Combined Loading Materials

Combined Loading Compression (CLC) uses a mixture of end and shear loading, in this method the shear stresses are reduced and it is possible to generate the clamping forces using bolted clamps (Figure 4 - ASTM D6641-09 CLC fixture). ASTM D6641-09 defines a method of performing CLC tests on a tabbed specimen with a short unsupported gauge section. Compared to the IITRI fixture, the CLC fixture is much lighter and easy to handle.



Figure 4: ASTM D CLC Fixture



Figure 5: ASTM D6484 OHC Fixture

Open-Hole Compression

Originally developed by Boeing, and now defined in ASTM D6484-09, is a guided Compression Fixture (Figure 5) designed for compression tests on Open-Hole specimens. The test uses a long rectangular specimen with a central hole and the fixture provides lateral support (apart from a window to allow the use of strain gauges) for the whole length of the specimen. It is noteworthy because the fixture it can be used in either an End-Loading or a Shear Loading mode. In the End Loading configuration the fixture and specimen are positioned between compression platens. In the Shear Loading configuration the ends of the fixture are clamped between the jaws of hydraulic grips.

Strain Measurement

Determination of compressive modulus requires the measurement of strain and the physical constraints imposed by the various fixtures impose limitations on the devices that can be used. For this reason the most common method of strain measurement for Compression testing is to use strain gauges, although extensometers can be used in some situations. Strain gauges are usually used in pairs, with a gauge located on each side of the specimen, and then the signals from the gauges are averaged to produce strain data. With this arrangement it is also possible to use the difference between the strain gauge signals to monitor any specimen bending during the test. Additional strain gauges are needed to provide a measurement of transverse strain if a compressive Poisson's ratio is being determined.

Conclusion

There are a number of standardized methods for composite compression testing in use today and some of the standards include a number of possible options. In deciding on the appropriate standard it is important to consider not only the nominal material properties, but also the specimen preparation, the test environment, fixture handling and the volume of testing to be performed.

References

- ASTM D695-10: Standard Test Method for Compressive Properties of Rigid Plastics
- ASTM D3410-03 (2008): Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials with Unsupported Gage Section by Shear Loading
- ASTM D6641-09: Standard Test Method for Compressive Properties of Polymer Matrix Composite Materials Using a Combined Loading Compression (CLC) Test Fixture
- ASTM D6484-09: Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates
- ISO14126:1999 Fibre-Reinforced Plastic Composites, Determination of Compressive Properties in the In-Plane Direction
- prEN 2850 1997: Aerospace Series Carbon Fibre Thermosetting Resin Unidirectional Laminates Compression Test Parallel to Fibre Direction
- SACMA SRM-1R: SACMA Recommended Test Method for Compressive Properties of Oriented Fibre-Resin Composites (no longer in print)