A Review of Contacting Strain Measurement Techniques for Composites Laminate Testing

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Introduction

Characterization of the properties of anisotropic and inhomogeneous composite materials for use in demanding structural applications requires a wide range of mechanical tests. The measurement of strain is a key requirement in many tests. Common tests that require the measurement of axial strain include tension and compression, along with transverse strain if Poisson's Ratio is being determined. Other tests, such as In Plane Shear (IPS) and V-Notch Shear, require the measurement of Shear Strain. Furthermore, tests will generally need to be conducted over a range of temperatures on materials conditioned in a variety of different environmental conditions.

The most common approaches to strain measurement in Composites coupon testing involve the use of strain gauges bonded to the surface of the specimen or clip-on extensometers.

General Aspects of Strain Measurement for Coupon Testing

Measurement of axial strain in tension (e.g. ASTM D3039, ISO 527-4/5) can be achieved using a single strain measurement on one side of the specimen; however, more consistent and accurate results can be achieved by using the average of a pair of measurements on opposite sides of the specimen in order to compensate for any specimen bending due to mis-alignment. For compression testing (e.g. ASTM D3410, ASTM D6641, ISO 14126) use of an average strain value derived from measurements on opposite sides of the specimen is required. Independent measurement of strain on both sides of the specimen also allows specimen bending to be monitored during the test (a specific requirement of most compression tests). Specimen bending is usually reported in terms of Percentage bending Strain (PBS). 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.

If Poisson's Ratio is being determined then transverse strain must also be measured.

In principle, since the strains in tension and compression test specimens are generally uniform, strain measurements can be made using either strain gauges or clip-on extensometers; however, the use of clip-on extensometers may be restricted by size of the specimen gauge section and the test fixtures (notably in compression testing – see Figure 1).

Figure 1: ASTM D6641 Combined Loading Compression Fixture showing limited space for extensometer

Tests to determine shear properties e.g. In Plane Shear (e.g. ASTM D3518, ISO 14129), Rail Shear (e.g. ASTM D4255) and V-Notch Shear (e.g. ASTM D5379, ASTM D 7078) tests require the measurement of shear strain. Shear strain can be determined by measuring axial and transverse strain and calculating the difference between these strains.

In an In Plane Shear test the strain distribution is more-or-less uniform across the test specimen and the axial and transverse strain measurement can be performed using either pairs of orthogonal strain gauges or a biaxial extensometer. In the V-Notch Shear test specimens the strain distributions are non-uniform with the strain being concentrated in the region around the notch. Accurate measurements of such local strains require the use of small strain gauges located on the notch. Again, it is recommended to use the average of strain measurements on both sides of the specimen.

Strain Gauges

Strain gauges rely on the change in resistance of an electrical conductor when subject to an applied strain.

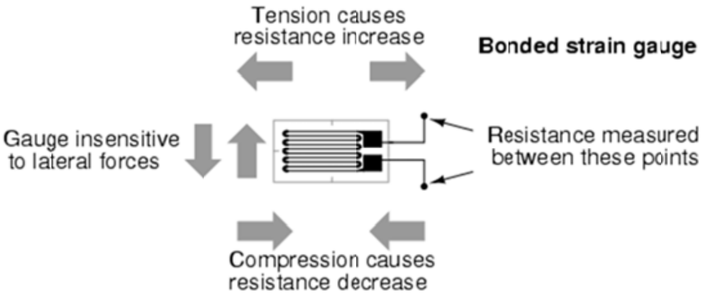

Figure 2: Typical Strain Gauge

When used with suitable instrumentation bonded electrical resistance, strain gauges provide a method of determining the surface strains below the active area (typically a few mm^2) of the gauge. Usually the types of strain gauges used for measurement on composite specimens consist of a thin metal foil grid on an organic backing. The sensitivity of the gauge (known as the Gauge Factor) is required in order for the correct calibration of the measurement system, normally this information is provided by the manufacturer of the gauges. In order to make accurate measurements, strain gauges must be precisely aligned and carefully bonded to the surface of the test specimen and is some cases, e.g. with specimens that have been wet conditioned, this can be difficult. Strain gauges are mainly sensitive to strains in the direction parallel to gauge grid (Figure 2). However, strain gauges are also somewhat sensitive to transverse strains i.e. strains at right angle to the grid and in some cases this can cause significant errors. Strain gauges are available in a variety of forms as either single gauge or as pre-aligned gauge combinations known, generically, as rosettes. Strain gauges can be used over a range of temperatures from cryogenic to several hundred degrees.

Clip-on Extensometers

Clip-on extensometers measure engineering strain by determining displacement over a fixed gauge length. They are widely used in the testing of composites laminates, over a range of temperatures from cryogenic to several hundred degrees. They attach directly to and are supported by the test specimen (Figure 3). Clip-on extensometers are available with gauge lengths from below 10 mm to over 200 mm. Full-scale strains are in the range of 5% to 100%. For composites testing the most commonly used gauge lengths are 25 mm / 1 inch and travels are generally less than 5%.

Figure 3: Clip-on Axial Extensometer

Clip-on extensometers incorporate a means of setting the reference Gauge Length and a transducer to measure the extension of the test specimen. The extensometer illustrated in Figure 3 has a manually-operated spring loaded gauge length setting mechanism. Another common means of setting the gauge length is a close fitting pin, which locks the extensometer to the required gauge length and is removed after the extensometer has been mounted on the specimen.

With any type of clip-on extensometer the effect of energetic specimen breaks on the long-term reliability of the extensometer should be considered. If possible, the extensometer should be removed from the specimen prior to failure, e.g. after the modulus determined.

The most common transducer mechanism employed in a clip-on extensometer is a strain-gauged flexure; however LVDTs, Capacitive, and incremental digital transducers are also used.

Strain gauged flexures are compact and lightweight making them easy to integrate into a, compact, clip-on extensometer design. They have a very high inherent resolution; the limiting factor is the noise level or digital resolution of the conditioning electronics. The accuracy of clip-on extensometers using strain-gauged flexures will usually be sufficient to meet ASTM E83 grade B1/B2 or ISO 9513 grade 0.5 (i.e. accuracy is better than 0.5% of reading). It should be noted that parameters such as modulus are usually measured at small strains (e.g. 0.1% to 0.3% for an ASTM D3039 Tensile test) and that the extensometer used should be calibrated in this region.

Operation at temperatures above about 200°C requires either a strain gauged extensometer with some form of cooling (e.g. water or air) or the use of a transducer capable of operating at the test temperature e.g., a high-temperature encapsulated strain gauge or capacitive type.

Clip-on extensometers can be used when testing in environments other than air e.g. in high humidity air, in fluids or gases. In tmchese situations care should be taken to ensure that all the materials used in the construction of the extensometer are compatible with the particular environment in use.

In addition to single axial clip-on extensometers there are a number of other clip-on extensometers types used for composites testing.

The averaging axial clip-on extensometer uses a pair of axial extensometers positioned across the width or thickness of the test specimen. As noted earlier the measurement of average axial strain eliminates strain measurement errors arising from the presence of bending in the test specimen caused by alignment errors in the load string.

Measurement of shear strains and Poisson's Ratio requires the simultaneous measurement of axial and transverse strain. Transverse clip-on extensometers are similar in design to axial types, but they measure the change in width of the test specimen. A gauge length setting mechanism is usually not required; the gauge length (in this case a Gauge Width) is determined by the dimensions of the specimen. Biaxial extensometers, which integrate both axial and transverse extensometers in to a single unit, are available and these units are more convenient to attach than two separate extensometers.

Extensometers v Strain Gauges

Some of the important characteristics of strain gauges and clip-on extensometers are summarized in the table below:

	Extensometer	**Strain Gauge**
Ease of application	**Simple**	**Complex**
Recurring Cost	**Low**	**High**
Strain Measurement	**Average(over gauge length)**	**Local (over grid)**
Compatibility with compression fixtures	**Limited**	**Good (small size)**
Transverse sensitivity	**Low**	**May be significant**

Conclusion

Both strain gauges and extensometers have a role is composites testing. Generally extensometers are preferred because of their ease of use and consequently lower costs; however there are many test situations where strain gauges are still required. Examples of tests where strain gauges are required include; compression tests where the short specimen gauge sections and/or the available space inside the fixture prevent the use of an extensometer and V-Notch shear tests where the strain is concentrated in a small region.

References

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ISO 9513:2012 Metallic materials – Calibration of extensometer systems used in uniaxial testing

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