

## Module 8: Composite Testing

### Lecture 35: Background to Mechanical Testing

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#### Introduction

The testing of materials has got immense important because it gives the required data, that is, mechanical and other required properties for the designing and analysis of the structures for its safe, reliable and cost effective functioning. When one uses the data derived from tests, the following questions arise:

1. What tests should be carried out to give the required data?
2. How precisely are these tests conducted and who guarantees it?
3. What does the data actually mean?
4. Are these data produced reliable?
5. Are data obtained from small test specimens meaningful when large structures are being designed?
6. What will be the effect operating environment?

These questions arise when one needs to establish the response of these materials various types of loading like tensile, compressive or shear, for short-term or long-term duration, or cyclic. Further, their behaviour in the presence of high or low temperatures or other environments which might significantly modify their behaviour is essential.

#### Societies for Testing Standards

There are few societies which develops the standards related to composites. They essentially provide the information and guidance necessary to design and fabricate end items from composite materials. Their primary purpose is the standardization of engineering data development methodologies related to testing, data reduction, and data reporting of property data for current and emerging composite materials.

In the following, we briefly give the background of these societies.

a) ASTM International, formerly known as the American Society for Testing and Materials was founded in 1898 by chemists and engineers from Pennsylvania Railroad, USA. At the time of its establishment, the organization was known as the American Section of the International Association for Testing and Materials. In 2011, the society became known as ASTM International.

ASTM members deliver the test methods, specifications, guides and practices that support industries and governments worldwide. ASTM International standards are developed in accordance with the guiding principles of the World Trade Organization for the development of international standards: coherence, consensus, development dimension, effectiveness, impartiality, openness, relevance and transparency.

The ASTM standards are also available in the volume form as *The Composite Materials Handbook*.

b) Composites Research Advisory Group (CRAG), which set about in the early 1980s to attempt to define what the best practice should be over a range of test methods. The CRAG recommendations were proposed to the British Standards Institution and subsequently had a considerable effect in the development of new international standards.

c) Society of Automobile Engineers (SAE) was formed in 1905. In early 1900s there were a lot of automobile companies worldwide, which needed to address their common design issues, patent protection and the development of engineering standards. The development of standards for

composite fabrication, testing, etc. is under progress.

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## Background to Mechanical Testing of Composites:

### *Objectives of Mechanical Testing:*

The development of the mechanical testing of the materials depends upon other scientific factors. These factors help in better understanding and facilitate the progress in evaluating the various processes. These processes include:

1. quality control of a process
2. quality assurance for the material developed and structure fabricated from thereof
3. better material selection
4. comparisons between available materials
5. can be used as indicators in materials development programmes
6. design analysis
7. predictions of performance under conditions other than test conditions
8. starting points in the formulation of new theories

It should be noted that these processes are dependent upon each other. However, if they are considered individually then the data required can be different for the evaluation. For example, some tests are carried out as multipurpose tests using various processes. A conventional tensile test carried out under fixed conditions may serve quality control function whereas one carried out varying factors like temperature, strain rate, humidity etc. may provide information on load bearing capacity of the material.

The properties evaluated for materials like composite is very sensitive to various internal structure factors. However, these factors depend mainly upon the fabrication process or other factors. The internal structure factors that affect the properties are, in general, at atomic or molecular level. These factors mostly affect the matrix and fibre-matrix interface structure.

The mechanical properties of the fibrous composite depend on several factors of the composition. These factors are listed below again for the sake of completeness.

1. properties of the fibre
2. surface character of the fibre
3. properties of the matrix material
4. properties of any other phase
5. volume fraction of the second phase (and of any other phase)
6. spatial distribution and alignment of the second phase (including fabric weave)
7. nature of the interfaces

Another important factor is processing of the composites. There are many parameters that control the processing of composites that access the quality of adhesion between fibre and matrix, physical integrity and the overall quality of the final structure.

In case of composite the spatial distribution and alignment of fibres are the most dominating factor which causes the variation of properties. The spatial distribution and alignment of the fibres can change during the same fabrication process. Thus, for a given fabrication process the property evaluated from the composite material may show a large variation.

### Effect of Anisotropy of Composites on Mechanical Testing

The long fibre composite exhibits the characteristics of inhomogeneity, anisotropy and inelasticity. If the composite is viscoelastic then the testing procedure demands much more things. However, we will not consider this fact in this study. We will consider the effect of anisotropy on mechanical testing.

The following are the key points in the mechanical testing of long-fibre composites:

1. generation of a uniform stress field in the critical reference volume
2. avoiding the 'end-effects'
3. attainment of adequate loading levels without damage or failure near the loading points
4. appropriate specimen dimensions related to the scale of structural inhomogeneities
5. tension – shear coupling

The first four considerations are similar to the testing of homogeneous isotropic materials. These considerations give rise to various constraints on specimen dimension, test configurations and machine specifications. However, the fact of heterogeneity imposes more severe constraints and demands more considerations while testing.

In case of composite, the St. Venant's Principle reflects in more stringent requirement. In anisotropic composites, the region of uniform stress is developed more gradually. It is shown that the decay length,  $\lambda$ , is of the order

$$\lambda = b \left( \frac{E_{11}}{G_{12}} \right)^{\frac{1}{2}} \quad (8.1)$$

where  $b$  is the maximum dimension of the cross-section. In case of rectangular strips subjected to end tractions

$$\lambda \approx \frac{b}{2\pi} \left( \frac{E_{11}}{G_{12}} \right)^{\frac{1}{2}} \quad (8.2)$$

where,  $\lambda$  is the distance over which a self equilibrated stress applied at the ends decays to its end value of  $1/e$ . In above expressions, the ratio  $\frac{E_{11}}{G_{12}}$ , that is degree of orthotropy, is an important factor. For unidirectional composites this ratio varies between 40 to 50 whereas for an isotropic material this is about 3. Thus, the ratio of respective decay lengths is about 3.5:1.

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Another problem with the composite testing arises when the loading directions do not coincide with the symmetry axes of the specimen. This situation gives rise to coupling between the normal-shear modes. This results in extraneous forces and deformations in the coupons. For example, a coupon in tension will exhibit the in-plane shear and a coupon in bending will exhibit the additional twisting. Further, if the laminate has layers oriented with respect to each other then there will be mismatch of interface deformation due to different degree of tension-shear coupling of adjacent layers. This may lead to delamination. The severity of the mismatch of interface deformation depends upon various factors like stacking sequence, test modes, degree of asymmetry, end constraints, etc.

Thus, to summarize, the main practical consequences of anisotropy are as follows:

1. There will be severe end-effects, which extend in the direction of higher stiffness. Further, this is a function of both the specimen geometry and the anisotropy.
2. A premature failure in grips or at other loading points may occur.
3. A premature delamination at free edges or other unintended failure modes may take place. These failures emanate from the interactions between the macrostructure of the composite and system of external forces.
4. There can be property imbalances of the lamina. For example, a tensile modulus (or strength) which is dominated by the properties of the fibre and a shear modulus (or strength) which is dominated by the properties of the matrix.



### Nature and Quality of the Test Data

The quality of the mechanical properties derived from the mechanical testing depends upon various factors. These factors include:

1. Precision
2. Accuracy
3. Authenticity and repeatability
4. Relevance to the test objective
5. Physical significance

The factors precision and accuracy can be attributed to statistical analysis. However, they cannot be separated if the data set is small. The remaining three factors can not readily be quantified.

Usually, there will be scatter in the measured data. The scatter is attributed to the combined effect of the factors:

1. Precision with which the measurements are made
2. Accuracy with which the measurements are made
3. Variations in the structure of the test coupon in the set itself

The mean value and a measure of width of the distribution, like standard deviation or range are the two main statistical factors that are used to characterize the distribution of the values. Apart from their direct role as a measure of the variability in a set of data, the variance and the standard deviation, which is square root of variance, can be used to infer following points:

1. confidence limits for a set of data
2. reliability of apparent differences between sets of data
3. combined uncertainty of measurements when there are several sources of variability
4. separate variabilities when several factors have affected a set of data
5. goodness of fit when correlation between a dependent and an independent variable is derived

## Samples and Specimens for Mechanical Testing

The samples from which the specimens are made for mechanical testing can be in the form of:

1. pultrusions,
2. filament wound tubes and
3. flat sheets

The former two types are used because they represent the most important fabrication processes and their ease of fabrication process. As we know from our earlier studies, in pultrusion the fibres are aligned along the pultrusion axis. In case of filament wound tubes, the fibres are aligned either spirally or circumferentially. However, the alignment can be optimally chosen in case of other filament shapes. In these two fabrication processes, the degree of void content is less and there is better consolidation of structure.

The advantage of using the tubular specimens is the ease with which specimen can be subjected to axial tension or compression, internal pressure, torsion and multi-axial loading. However, the limitations with these specimens include the high cost of fabrication and testing, fabrication may result in different micro-structure and hence different equivalent properties.

The flat sheets available for commercial use come in following four categories:

1. layers of unidirectional fibres aligned with reference to an axis
2. sheets of randomly oriented fibres in a plane
3. layers of woven fibres aligned with reference to an axis
4. sandwich structure

The flat sheets, depending upon the nature of alignment of the fibres can result into various behaviours like orthotropic, transversely isotropic or even isotropic. When one uses the mechanical properties of the composite, it is essential to quote the volume fractions and spatial arrangement of fibres. The flat specimen is an obvious choice because of economic reason.

The limitations with flat specimens can be:

- a. Specific states of stress can not be developed. For example, the state of pure shear is difficult to develop in such specimens.
- b. The axial compression is also a difficult issue due to buckling
- c. Further, developing a combined state of stress in such specimens is also a difficult task.



### Other Issues with Mechanical Testing of Specimens

The other issues associated with the mechanical testing include:

1. Stress concentrations due to material discontinuities at free edges, ply-drop off regions, which results into early failures.
2. In case of compression testing, there is a susceptibility to buckling for thin specimens. This type of testing demands for additional fixtures.
3. Flat specimen requires special geometry for purpose of gripping. For this reason, the flat specimens with end-tabs are favourably used.
4. The composite is heterogeneous and the volume fractions are the essential data required with the mechanical properties. Hence, additional tests are required to determine the volume fractions and void content, if any.
5. The mechanical properties determined are affected by moisture content. Hence, in some applications the amount of moisture present in the composite is required. Therefore, additional tests are required to determine the moisture content in composite.
6. Further, nondestructive evaluation (NDE) methods are required to assess the quality of the fabricated material and damage development during the loading.

The end-tabs are a special requirement in case of flat specimens. Therefore, it needs additional information. The end-tabs are used almost universally to reduce the probability of failure initiating at the grips during a tensile test. End-tabs can also facilitate accurate alignment of the specimen in the test machine, provided that they are symmetrical and properly positioned on the specimen, but if they are deficient in these respects they can cause misalignment and introduce stress concentrations.

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#### Home Work:

1. Write a short note on societies of mechanical testing.
2. What are the objectives of the mechanical testing?
3. What are the effects of the anisotropy of composites in their mechanical testing?
4. What are the issues with the mechanical testing of the specimen?

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