

MECHANICAL TESTING OF COMPOSITE MATERIALS

TEST METHODS AND CHALLENGES



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Abstract

Composite materials have revolutionized the automotive, aerospace, and allied industries offering superior strength-to-weight ratios, corrosion resistance, and flexibility in design. However, to ensure safety and performance, these materials must undergo rigorous mechanical characterization testing. This white paper explores the importance, methods, and challenges of mechanical testing of composite materials. Mechanical test methods for characterizing static and dynamic properties have been discussed.

Introduction

Composite materials, particularly carbon fibre-reinforced polymers (CFRP) and glass fibre-reinforced polymers (GFRP), have become integral to modern automotive, aerospace, and allied industry design. Their high strength-to-weight ratio, corrosion resistance, and design flexibility make them ideal for various components, from aircraft fuselages to spacecraft heat shields.

Mechanical testing is crucial to verify the material's ability to withstand the extreme conditions encountered in automotive and aerospace applications. It ensures that the material can tolerate the stresses of impact with crash barriers, take-off, flight, and landing without failures.

MECHANICAL TESTING METHODS

Several mechanical tests are used to assess the properties of composite materials:

1. Tensile Testing: Tensile testing is a fundamental and widely used method to determine the in-plane strength and stiffness properties of composite laminates. ASTM D638, ASTM D3039 and ISO 527 are the standard test methods for tensile testing of polymer matrix composites.

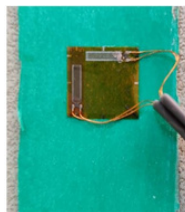


Tensile properties, such as ultimate tensile strength, tensile modulus, and maximum elongation, are crucial for design and analysis of composite structures.

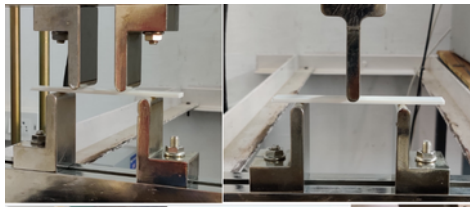
2. Compression Testing: Compression testing is essential for evaluating the compressive strength and modulus of composite materials. ASTM D695 Modified, ASTM D3410 and ISO 14126 provide guidelines for compression testing of composite laminates. The test method involves subjecting a specimen to compressive loads while ensuring proper end-loading and minimizing potential buckling or premature failure.



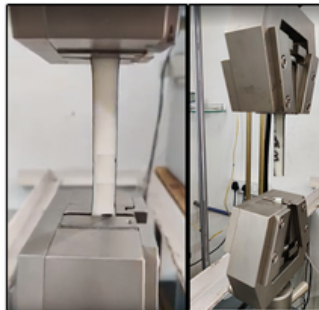
3. Poisson's Ratio Testing: Longitudinal and transverse strain properties are critical for understanding the behaviour of composite materials under multi-axial loading conditions. ASTM D3039 and ISO 14129 outline test methods for Poisson's ratio testing of composite laminates. Poisson's ratio testing results are a much needed input to characterize the material properties for Finite Element Analysis (FEA)



4. **Flexural Testing:** Flexural testing is used to evaluate the bending behaviour of composite materials, which is particularly relevant for aerospace applications such as wing skins and fuselage panels. ASTM D790, ASTM D7264 and ISO 14125 describe the procedures for conducting three-point and four-point bending tests on composite specimens. The short beam shear test as per ASTM D2344 is also a type of 3-point bend test carried out on shorter beam samples.



5. **Fatigue Testing:** Composite structures in automotive, aerospace applications are subjected to cyclic loading during their service life. Fatigue testing is crucial for assessing the long-term durability and damage tolerance of composite materials. ASTM D7791, ASTM D3479 and ISO 13003 provide guidelines for conducting tension-tension, compression-compression, and fully-reversing fatigue tests on composite laminates.



6. Impact Testing: Impact resistance is a critical property for composite materials in various applications, as they may encounter foreign object impacts during service. ASTM D256 Izod Impact test and low velocity impact as per ISO 6603, ASTM D7136 and ISO 18352 outline test methods for evaluating the impact resistance of composite laminates using drop-weight impact towers or instrumented pendulum impact testers.



7. Heat Deflection Temperature: The heat deflection temperature of a reinforced or unreinforced polymer material is a measure of polymer's resistance to distortion under an applied load at elevated temperatures. The test specification for the HDT is ASTM D 648 and ISO 75. HDT tests typically test for the short term performance of the materials under loads at elevated temperatures.



9. Shear Testing: This test method is designed to produce shear property data for material specifications, research and development, quality assurance, and structural design and analysis. Either in-plane or interlaminar shear properties may be evaluated, depending upon the orientation of the material coordinate system relative to the loading axis. Biaxial strain gauges are pasted at the location of interest under the notch area and tests are carried out by compression displacement that results in a shear strain at the location of interest. ASTM D5379 provide guidelines for the tests.




9. Environmental Conditioning: Composite materials can be susceptible to environmental factors such as temperature, moisture, and ultraviolet radiation. Environmental conditioning of test specimens is essential to assess the long-term performance and durability of composite materials under various service conditions. ASTM D5229 and ISO 14615 provide guidelines for environmental conditioning of composite test specimens.

CHALLENGES IN MECHANICAL TESTING

While mechanical testing provides invaluable data for the design and analysis of composite structures, there are several challenges associated with testing these heterogeneous and anisotropic materials:

1. **Material Variability:** Composite materials exhibit inherent variability due to factors such as fibre misalignment, voids, and resin-rich or resin-starved regions. This variability can lead to significant scatter in the mechanical properties, making it challenging to establish reliable design allowables.
2. **Specimen Preparation:** Preparing high-quality composite test specimens is crucial for obtaining accurate and repeatable results. Factors like specimen geometry, machining-induced defects, and fibre waviness can influence the test results, necessitating strict adherence to specimen preparation procedures.
3. **Gripping and End-Effects:** In tensile and compressive testing, the gripping of composite specimens can introduce stress concentrations, premature failures, and spurious results if not addressed properly. Special gripping techniques, such as adhesive bonding or tabbing, are often required to minimize gripping-related issues.




4. Failure Modes: Composite materials can exhibit complex failure modes, including fibre breakage, matrix cracking, delamination, and their interactions. Interpreting and correlating these failure modes with the measured properties can be challenging, especially under multi-axial loading conditions.

5. Size Effects: The mechanical properties of composite materials can be influenced by the specimen size and geometry, making it difficult to extrapolate coupon-level test results to full-scale structural components or assemblies.

6. Environmental Factors: The influence of environmental factors, such as temperature, moisture, and chemical exposure, on the mechanical properties of composites can be significant. Accurately simulating and accounting for these effects during testing is crucial for predicting real-world performance.

7. Specialized Equipment: Mechanical testing of composite materials often requires specialized equipment, such as environmental chambers, high-temperature furnaces, and advanced instrumentation for strain measurement and damage monitoring, which can be costly and complex to operate.



8. Data Interpretation and Analysis: The analysis and interpretation of mechanical test data for composite materials can be intricate, involving advanced analytical techniques, failure criteria, and micromechanical models, necessitating expertise in composite material behaviour and failure mechanisms.

9. Anisotropy: Unlike metals, composites often have different properties in different directions, making testing more complex. Addressing these challenges requires a combination of rigorous testing procedures, advanced instrumentation, statistical analysis techniques, and a deep understanding of composite material behavior. Collaboration between material suppliers, testing laboratories, and design engineers is essential to overcome these challenges and ensure the reliable and safe implementation of composite materials in automotive, aerospace, and allied industry applications.

CONCLUSION

Mechanical testing plays a vital role in the use of composite materials in the automotive, aerospace, and allied industries. Despite the challenges, advancements in testing methods continue to provide reliable data on these materials' performance under various loading and service conditions. As the use of composite materials continues to grow, so too will the importance of mechanical testing and the requirements to obtain accurate, reliable and repeatable test data.

References:

- 1) Coutney, T.H., Mechanical Behavior of materials, Waveland, 1996.
- 2) Dowling, N.E., Mechanical Behavior of materials, engineering methods for deformation, fracture and fatigue, Pearson, 2016.
- 3) Ian McEnteggart, Composites Testing: Challenges & Solutions.
- 4) V. Shanmugam et al., The mechanical testing and performance analysis of polymer-fibre composites prepared through the additive manufacturing. PT, 21
- 5) Filip Stojcevski, Tim Hilditch, Luke C. Henderson, A modern account of Iosipescu testing, Composites Part A: Applied Science and Manufacturing, Volume 107, 2018,

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