Test Guide
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Tensile Properties of FRP Composite

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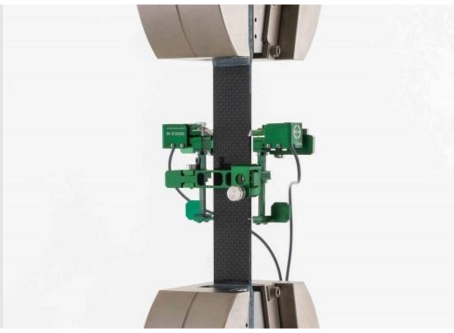

DESCRIPTION

As per Theories, Composite materials are being used from ancient times in direct or indirect ways, either in conventional or non-conventional forms. Research made worldwide has proved that composite materials exhibit extraordinary properties. Hence most of the world is adopting modern composite materials over conventional engineering materials.

Now the question arises: "How come it has been proved that Composites are better than Conventional materials"

Answer: "Testing and analysis of composite materials".

Thorough Testing practices and Standards have helped to evaluate the performance of composite materials. The data derived from composite materials testing and analysis can be used to compare the composite materials against conventional materials.

1. Scope

This guide determines the method of determination of the ultimate tensile strength, tensile modulus and, if required, the Poisson's ratio and strain at failure in tension of polymer matrix composite materials reinforced by high-modulus fibers in the form of unidirectional laminates.

2. Principle

A thin flat strip of composite specimen having a constant rectangular cross section is mounted in the grips of a mechanical testing machine. The specimen is then monotonically loaded in tension while the force is being recorded. The ultimate strength of the material can be determined from the maximum force carried before failure. The ultimate tensile strain, tensile modulus of elasticity, Poisson's ratio, and transition strain can all be obtained from the stress-strain response of the material if the coupon strain is monitored using strain or displacement transducers.

3. Testing Apparatus

3.1 Tensile-testing Machine

3.1.1 Testing Machine Heads: The testing machine shall have both an essentially stationary head and a movable head.

3.1.2 Drive Mechanism: The testing machine drive mechanism shall be capable of imparting to the movable head a controlled velocity with respect to the stationary head.

3.1.3 Force Indicator: The testing machine force-sensing device shall be capable of indicating the total force being carried by the test specimen.

3.1.4 Grips: Each head of the testing machine shall carry one grip for holding the test specimen so that the direction of force applied to the specimen is coincident with the longitudinal axis of the specimen. The grips shall apply sufficient lateral pressure to prevent slippage between the grip face and the coupon.

3.2 Strain-Indicating Device

Force-strain data, if required, shall be determined by means of either a strain transducer or an extensometer. The strain-indicating device's attachment to the coupon shall not cause damage to the specimen surface.

If Poisson's ratio is to be determined, the specimen shall be instrumented to measure strain in both longitudinal and lateral directions. If the modulus of elasticity is to be determined, the longitudinal strain should be simultaneously measured on opposite faces of the specimen to allow for a correction as a result of any bending of the specimen.

4. Test Specimens

4.1 Number of test specimens

Test at least five specimens per test condition. If any of the specimens fails within the grips or at the tabs, or because of damage caused by the extensometer, discard the result and carry out a repeat determination on a fresh test specimen.

4.2 Test Specimen Geometry

The requirements list of specimen shape and dimensions is shown in Table 1.

4.3 Specimen Preparation

4.3.1 Specimen Fabrication: Specimen preparation is extremely important for this specimen. Mold the specimens individually to avoid edge and cutting effects or cut them from plates. Test specimens should be prepared by vacuum process or combining multiple/single layers of fibers with resins and then compressing them under high pressure which produces a uniformly impregnated, smooth specimen. Control of fiber alignment is critical. Improper fiber alignment will reduce the measured properties. This method is only applicable to specimens where the axis is parallel to the direction of the fibres. For each degree of fiber direction deviation, 10-15% should be added to the final results.

4.3.2 Impregnating Resin: The impregnating resin shall be compatible with the yarn and its size. The viscosity of the resin or resin solution shall be such that sufficient resin pick-up is achieved to ensure uniform impregnation.

Since different commercial resins are used in different conditions, the resin used to make the composite specimens should not be of the same commercial resins. The viscosity of the impregnating resin used in preparing the specimen should be in accordance with the proposal of valid codes and standards so that the fiber strength in the composite can be derived according to them.

Therefore it is recommended the strain at failure of the cured resin shall be at least twice that of the fibre, preferably three times. In this respect, heatcurable epoxy-resin systems with a viscosity during impregnation of preferably less than 1 000 mPa·s are suitable. The resin formulation, however, shall be specified in detail.

4.3.3 Reinforcement Content, Volume Percent: Calculate reinforcement content, in volume percent, in accordance with Eq 1.

$$V_r = (M_f / M_i) * 100 (\rho_c/\rho_r) \quad (1)$$

where:

ρ_r = density of the reinforcement, g/cm^3

ρ_c = density of the specimen, g/cm^3

M_i = initial mass of the specimen, g

M_f = final mass of the specimen after digestion or combustion, g.

The Reinforcement content shall be at least 70 % by volume. If the reinforcement content of the each specimen is outside the acceptable range, the result shall be verified for 70% reinforcement content.

4.3.4 Matrix Content, Volume Percent: Calculate matrix content, in volume percent, in accordance with Eq 2.

$$V_m = (M_i - M_f)/M_i * \rho_c / \rho_m * 100 \quad (2)$$

where:

ρ_m = density of the matrix, g/cm^3

ρ_c = density of the specimen, g/cm^3

4.3.5 Fiber Effective Cross-sectional Area: Before the tension testing, determine the fiber effective cross-sectional area as $A_{effective}=(W*h)*V_m$, at three places in the gage section, and report the area as the average of these three determinations. Record the average effective area in units of mm^2.

where:

h = specimen thickness, mm

w = specimen width, mm

4.3.5 Labeling: Label the specimens so that they will be distinct from each other and traceable back to the raw material and in a manner that will both be unaffected by the test and not influence the test.

5. Procedure for Tensile Testing

Table 1 Tensile Specimen Geometry Requirements

Parameter	Requirement
specimen width*	15 mm
specimen overall length	250 mm
Tab Length	56 mm

* Considering the observed changes in the value of tensile strength (by 30-40%) , it is recommended to consider the width of the specimen as 5 mm.

5.1 Specimen Insertion: Place the specimen in the grips of the testing machine, taking care to align the long axis of the gripped specimen with the test direction. Tighten the grips, recording the pressure used on pressure controllable (hydraulic or pneumatic) grips.

5.2 Loading: Apply the force to the specimen at the specified rate until failure, while recording data.

5.2 Speed of Testing: Set the speed of testing to a nearly constant strain rate in the gage section. The strain rate should be selected so as to produce failure within 1 to 10 min. The suggested standard speeds are:

- Strain-Controlled Tests: A standard strain rate of 0.01 min^{-1}.
- Constant Head-Speed Tests: A standard head displacement rate of 2 mm/min

5.3 Data Recording: Record force versus crosshead displacement (and force versus strain, if extensometers are utilized) continuously or at frequent regular intervals. For this test method, a sampling rate of 2 to 3 data recordings per second, and a target minimum of 100 data points per test are recommended.

6. Expression of results

6.1 Tensile Strength/ Tensile Stress: For each test specimen, calculate the ultimate tensile strength using Eq 3 and report the results. If the tensile modulus is to be calculated, determine the tensile stress at each required data point using Eq 4.

$$F^{tu}=P_{max}/A_{effective} \quad (3)$$

$$\sigma_i = P_i/A_{effective} \quad (4)$$

F^{tu} = ultimate tensile strength, MPa

P_{max} = maximum force before failure, N

σ_i = tensile stress at ith data point, MPa

P_i = force at ith data point, N

A = average cross-sectional area, mm^2

$A_{effective}$ = average fiber effective cross-sectional area, mm^2

6.2 Tensile Strain/Ultimate Tensile Strain: If tensile modulus or ultimate tensile strain is to be calculated, and material response is being determined by an extensometer, determine the tensile strain from the indicated displacement at each required data point using Eq 5 and report the results.

$$\varepsilon_i=\delta_i/L_g \quad (5)$$

where:

ε = tensile strain at ith data point, με

δ= extensometer displacement at ith data point, mm;

L_g=extensometer gage length, mm

6.3 Tensile Chord Modulus of Elasticity: Select the appropriate chord modulus strain range from Table 2. Calculate the tensile chord modulus of elasticity from the stress-strain data using Eq 6.

$$E^{chord} = \Delta\sigma/\Delta\varepsilon \quad (6)$$

where:

E^{chord}:tensile chord modulus of elasticity, GPa

Δσ: difference in applied tensile stress between the two strain points of Table 3, MPa

Δε: difference between the two strain points of Table 2 (nominally 0.002).

6.4 Poisson's Ratio: Select the appropriate chord modulus longitudinal strain range from Table 2. Determine (by plotting or otherwise) the transverse strain (measured perpendicular to the applied force), εt, at each of the two longitudinal strains (measured parallel to the applied force), εl, strain range end points. Calculate Poisson's ratio by Eq 7 and report the results. Also report the strain range used.

$$v= -\Delta\varepsilon_t / -\Delta\varepsilon_l \quad (7)$$

where:

v = Poisson's ratio

$\Delta\varepsilon_t$=difference in lateral strain between the two longitudinal strain points of Table 2, με;

$\Delta\varepsilon_l$=difference between the two longitudinal strain points of Table 2 (nominally either 0.001, 0.002, or 0.005).

7. Validation

7.1 Values for ultimate properties shall not be calculated for any specimen that breaks at some obvious flaw and retests shall be performed for this type of specimen

7.2 Reexamine the means of force introduction into the material if a significant fraction of failures in a sample population occur within one specimen width of the tab or grip. Factors considered should include the tab alignment, tab material, tab angle, tab adhesive, grip type, grip pressure, and grip alignment.

8. Test Report

8.1 The test report shall include the following:

8.1.1 A reference to International Standard

8.1.2 Any variations to test method, anomalies noticed during testing, or equipment problems occurring during testing.

8.1.3 Identification of the material tested including: material specification, material type, , filament diameter, tow or yarn filament count and twist, sizing, form or weave, fiber areal weight, matrix type.

8.1.4 Description of the fabrication steps used to prepare the laminate including: fabrication start date, fabrication end date, process specification, cure cycle, consolidation method, and a description of the equipment used.

8.1.5 Ply orientation stacking sequence of the laminate.

8.1.6 Report density, volume percent reinforcement, specimen sampling method and geometries, test parameters, and test results.

8.1.7 Average ply thickness of the material

8.1.8 Results of any nondestructive evaluation tests

8.1.9 Method of preparing the test specimen, including specimen labeling scheme and method, specimen geometry, sampling method, coupon cutting method, identification of tab geometry, tab material, and tab adhesive used.

8.1.10 Calibration dates and methods for all measurement and test equipment.

8.1.11 Type of test machine, grips, jaws, grip pressure, alignment results, and data acquisition sampling rate and equipment type.

8.1.12 Dimensions of each test specimen.

8.1.13 Temperature and humidity of the testing laboratory.

TABLE 2 Specimen Alignment and Chord Modulus Calculation Strain Ranges

Tensile Chord Modulus Calculation Longitudinal Strain Range	
Start Point	End Point
μ_ε	μ_ε
1000	3000

8.1.14 Number of specimens tested

8.1.15 Speed of testing.

8.1.16 Transducer type and transducer placement on the specimen for each transducer used.

8.1.17 If strain gages were used, the type, resistance, size, gage factor, temperature compensation method, transverse sensitivity, lead-wire resistance, and any correction factors used.

8.1.18 Tabulated data of stress versus strain and Stress-strain curves for each specimen.

8.1.19 Individual strengths and average value

8.1.20 Individual strains at failure and the average value strain range used for chord modulus and Poisson's ratio determination.

8.1.21 Individual values of modulus of elasticity

8.1.22 Failure mode and location of failure for each specimen.