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Fibre-reinforced plastic compositess — Determination of laminate through-thickness properties —

Part 2: Determination of the elastic modulus, the strength and the Weibull size effects by flexural test of unidirectional laminate, for carbon-fibre based systems

Composites plastiques renforcés de fibres — Détermination des propriétés de l'épaisseur traversante d'un composite stratifié —

Partie 2: Détermination du module d'élasticité, de la résistance et des effets de la taille de Weibull par essai en flexion sur un composite stratifié unidirectionnel, pour systèmes à base de fibres de carbone

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Foreword

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This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 13, *Composites and reinforcement fibres*.

A list of all parts in the ISO 20975 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

With the increasing number of applications of composite materials, the necessity of a test method for evaluating through-thickness mechanical properties has been recognized. ASTM D6415[1] and ASTM D7291[2] were proposed for evaluating out-of-plane properties. However, ASTM D6415 has no method for evaluating through-thickness tensile modulus because this test method is based on evaluating the curved beam strength of a fibre-reinforced polymer matrix composite laminate panel. Further, the following problems have been reported regarding ASTM D7291[2]; bonding between the specimen and the loading tab is required, the stress distribution in the specimen is not uniform, and a local stress concentration is generated[3],[4]. This means that the fracture load depends on the maximum stress induced at the point of the stress concentration. Therefore, through-thickness strength evaluated by ASTM D7291 cannot be simply compared with other specimens. In addition, it was reported that the apparent out-of-plane modulus evaluated under ASTM D7291 varies with strain gage position, strain gage length, and specimen thickness[5]. This document provides a test method to evaluate the through-thickness mechanical properties of composite materials.

Fibre-reinforced plastic compositess — Determination of laminate through-thickness properties —

Part 2:
Determination of the elastic modulus, the strength and the Weibull size effects by flexural test of unidirectional laminate, for carbon-fibre based systems

1 Scope

This document specifies a flexural test method for determining the through-thickness (out-of-plane) tensile properties of laminated carbon fibre-reinforced plastic (CFRP) composites, including strength, fracture strain, and modulus. This document is applicable to unidirectional CFRP (UD-CFRP) laminates. In addition, the calculation of effective volume is also described due to size effects of the through-thickness tensile strength.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 1268-1, *Fibre-reinforced plastics — Methods of producing test plates — Part 1: General conditions*

ISO 1268-4, *Fibre-reinforced plastics — Methods of producing test plates — Part 4: Moulding of prepregs*

ISO 2818, *Plastics — Preparation of test specimens by machining*

ISO 5893, *Rubber and plastics test equipment — Tensile, flexural and compression types (constant rate of traverse) — Specification*

ISO 20501, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Weibull statistics for strength data*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
span length of flexural test
L
length of span between supports

3.2
flexural load
P
load on specimen from loading nose at any given time

3.3
through-thickness tensile stress
σ
nominal stress in the outer surface of the flexural test specimen at mid-span

Note 1 to entry: It is calculated according to the relationship given by Formula (2).

3.4
deflection
D
distance through which the top or bottom surface of the test specimen at mid-span has deflected during flexure from its original position

3.5
through-thickness strain
ε
nominal fractional change in length of an element in the outer surface of the test specimen at mid-span

3.6
through-thickness tensile strength
σ_f
maximum through-thickness tensile stress by flexural test or through-thickness stress at failure

3.7
through-thickness modulus
E
slope calculated from linear region of through thickness stress–strain curve

3.8
Weibull modulus of through-thickness strength data
m
empirical parameter that decides the probability density function of the Weibull distribution

3.9
effective volume of flexural specimen
V_{eff}
size of an equivalent uniaxial tensile specimen that has the same probability of rupture as the test specimen

Note 1 to entry: The effective volume is parameter of Weibull size effects of strength. It is calculated from the thickness, the width and the span length of the flexural test, and the Weibull modulus based on beam theory.

4 Principle

A rectangular test specimen, whose longitudinal direction coincides with the through-thickness direction of the CFRP laminate, is positioned between two supports and deflected by means of a loading edge acting on the specimen midway between the supports. The test specimen is deflected at a constant rate until rupture occurs on the outer surface of the specimen. The through-thickness properties are determined by estimating tensile stress and strain generated in the flexural test specimen. Size effects are estimated quantitatively by estimating tensile strength and effective volume due to dependence of strength on size effects.

5 Conditioning

5.1 Conditioning of test specimen

The test specimens shall be conditioned as specified in the standard for the material being tested. In the absence of this information, select the most appropriate conditions from ISO 291, unless otherwise agreed upon by the interested parties, e.g. for testing at high or low temperatures. The preferred set of conditions in ISO 291 is standard atmosphere 23/50, except when the flexural properties of the material are known to be insensitive to moisture, in which case humidity control is unnecessary.

5.2 Temperature and humidity in testing

The test shall be carried out under the conditions specified in 5.1.

6 Apparatus

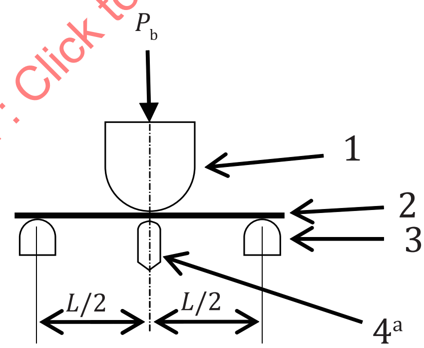
6.1 Testing machine, which shall conform to ISO 5893 according to the requirements specified in 5.1 and 5.2.

The speed of testing shall be kept constant according to ISO 5893.

6.2 Load and deflection indicators, indicator for the load shall be used, and the error in the indicated force shall be kept to less than 0,1 N.

6.3 Test fixture

The two supports and the central loading edge shall be arranged as shown in Figure 1. The radius of supports and loading nose are 2 mm ± 0,2 mm and 5 mm ± 0,2 mm, respectively (refer to ISO 14125).



Key

1 loading nose
2 test specimen
3 supports
4 displacement transducer
a See 6.4 for details.

Figure 1 — Example of test fixture and specimen

6.4 Deflection-measuring system: displacement transducer, shall be valid over the entire range of deflections to be measured. Using displacement transducer shall be agreed upon between the interested parties. The force required to operate the displacement transducer shall not exceed 1 % of the force at failure.

6.5 Data acquisition system, which shall be able to record the flexural force versus deflection data.

6.6 Devices for measuring: Micrometer or **equivalent**, capable of reading to 0,005 mm or better, and suitable for measuring the width, *b*, and thickness, *t*, of the test specimen.

7 Test specimens

7.1 Shape and dimensions

The shape and dimensions of the test specimens shall be according to Table 1.

Table 1 — Dimensions of test specimen

Parameter	mm
Width b	10 ± 0,5
Thickness t	$1{,}0^{+0{,}2}_{-0}$
Length l	>25t + 4

The span length shall be over 25 times the thickness of the test specimen.

In any test specimen, the thickness within the central third of the length shall not deviate by more than 2 % from the mean value. In addition, the width shall not deviate within this section of the specimen by more than 3 % from the mean value. The shape and dimensions shall be selected from Table 1 or agreed upon between the interested parties under the condition of $L/t > 25$.

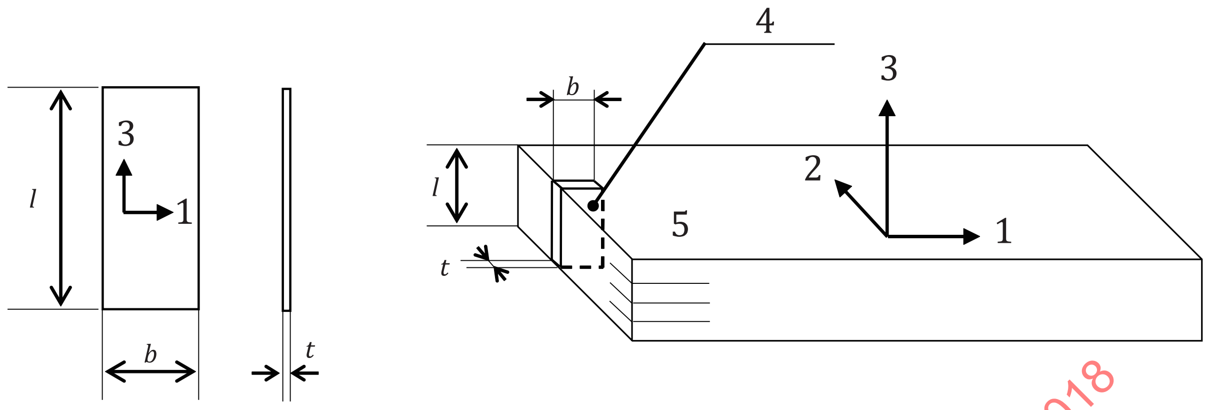
7.2 Preparation of specimens

7.2.1 General

Specimens shall be machined from a test plate prepared in accordance with ISO 1268-1 and ISO 1268-4 or another specified or agreed-upon procedure. Specimens shall be machined from plates in accordance with ISO 2818. These operations shall be properly performed to prevent the generation of damage on specimen.

7.2.2 Test plate

Figure 2 shows the UD-CFRP test plate for a test specimen. The in-plane fibre direction, in-plane transverse direction, and thickness direction are defined as 1, 2, and 3, respectively.



Key

1 in-plane fibre direction (width direction of flexural specimen)
2 in-plane transverse direction (thickness direction of flexural specimen)
3 thickness direction (length direction of flexural specimen)
4 specimen
5 test plate
b width of flexural specimen (machined from test plate)
l length of flexural specimen (machined from test plate)
t thickness of flexural specimen (machined from test plate)

Figure 2 — Test plate and test specimen of UD-CFRP

7.3 Specimen inspection

The specimens shall be free of twist and preferably have mutually perpendicular surfaces. All surfaces and edges shall be free of sink marks, scratches, pits and flash. The specimens shall be checked for conformity with these requirements by visual observation against a straight edge, square, or flat plate and by measurement with micrometre callipers. Specimens showing measurable or observable departure from one or more of these requirements shall be rejected before testing.

7.4 Number of specimens

If the estimated effective volume and Weibull modulus is not required, a minimum of five specimens shall be tested. If the estimated effective volume and Weibull modulus are required then a minimum of 30 specimens shall be tested.

8 Procedure

a) Measure the width, *b*, and thickness, *t*, of the test specimens to the nearest 0,005 mm.

b) Set the test fixture and adjust the span. The span length shall be over 25 times the thickness of the test specimen.

c) The test speed shall be calculated using Formula (1).

$$V = \frac{S_{ra} L^2}{6t} \quad (1)$$

where

V is the test speed (mm/min);

S_{ra} is the strain rate (min^{-1}), S_r = 0,01;

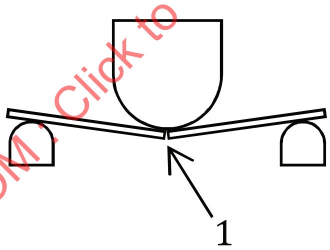
L is the length of span (mm);

t is the thickness of the specimen (mm).

d) Place the test specimen symmetrically on the two supports.

e) Record the force and displacement continuously throughout the test.

f) Measure the position of fracture if required, using a rule or calliper. Acceptable failure might occurs near the area under loading nose (Figure 3).



Key

1 failure

Figure 3 — Example of acceptable failure

9 Calculations

9.1 Through-thickness tensile stress

Calculate the through-thickness tensile stress using Formula (2):

$$\sigma = \frac{3PL}{2bt^2} \quad (2)$$

where

σ is the through-thickness tensile stress (MPa);

P is the flexural force (N);

L is the length of span (mm);

b is the width of specimen (mm);

t is the thickness of specimen (mm).

9.2 Through-thickness tensile strength

Calculate the through-thickness tensile strength, using Formula (3):

$$\sigma_f = \frac{3P_f L}{2bt^2} \tag{3}$$

where

σ_f is the through-thickness tensile strength (MPa);

P_f is the maximum force or failure force (N);

L is the length of span (mm);

b is the width of specimen (mm);

t is the thickness of specimen (mm).

9.3 Weibull modulus by flexural test

Calculate the Weibull modulus by flexural test by the procedure specified in ISO 20501.

9.4 Effective volume of flexural specimen

Calculate the effective volume of the flexural specimen using Formula (4).

$$V_{\text{eff}} = \frac{Lbt}{2(m+1)^2} \tag{4}$$

where

V_{eff} is the effective volume (mm^3);

L is the length of span (mm);

b is the width of specimen (mm);

t is the thickness of specimen (mm);

m is the Weibull modulus.

9.5 Through-thickness tensile strain

Calculate the through-thickness tensile strain using Formula (5):

$$\varepsilon = \frac{6tD}{L^2} \quad (5)$$

where

ε is the through-thickness tensile strain (–);

L is the length of span (mm);

t is the thickness of specimen (mm);

D is the deflection (mm).

9.6 Through-thickness tensile strain at failure

Calculate the through-thickness tensile strain at failure using Formula (6):

$$\varepsilon_f = \frac{6tD_f}{L^2} \quad (6)$$

where

ε_f is the through-thickness tensile strain at failure (–);

L is the length of span (mm);

T is the thickness of specimen (mm);

D_f is the deflection at failure(mm).

9.7 Through-thickness tensile modulus

The modulus is the ratio of the stress difference, $\sigma'' - \sigma'$, to the corresponding strain difference, ε'' (= 0,003) – ε' (= 0,001). Calculate the tensile modulus using Formula (7):

$$E = \frac{(\sigma'' - \sigma')}{(\varepsilon'' - \varepsilon')} \quad (7)$$

where

E is the flexural modulus (MPa);

σ'' is the flexural stress at ε'' flexural strain (MPa);

σ' is the flexural stress at ε' flexural strain (MPa);

ε' is the flexural strain at 0,003 (–);

ε'' is the flexural strain at 0,001 (–).

9.8 Significant figures of stress and elastic modulus

Calculate the stresses to three significant figures. Calculate the modulus to two or more significant figures.

9.9 Expression of results

When the standard deviation and coefficient of variation are required, these values are calculated using Formulae (8) and (9):

$$s=\sqrt{\frac{\Sigma\left(x-\bar{x}\right)^{2}}{n-1}} \tag{8}$$

$$CV=\frac{s}{x}\times 100 \tag{9}$$

where

s is the standard deviation;

CV is the coefficient of variation (%);

x is the individual measured value;

$\bar{x}$ is the mean measured value;

n is the number of measured values.

10 Precision

The details of an interlaboratory test carried out to validate the test method and the precision data obtained from this test are given in Annex A.

11 Test report

The test report shall include the following information:

a) a reference to this document, i.e. ISO 20975-2:2018;

b) the loading method (flexural method);

c) complete identification of the material tested including type, source, manufacturer's code number, form, and previous history, if these are known;

d) the method of preparing the test specimens and any details of the manufacturing method used;

e) the machining method;

f) the number of specimens tested;

g) the dimensions of the test specimens;

h) the temperature, humidity, and duration of test specimen conditioning;

i) the test temperature and humidity;

j) details of the test machine and displacement transducer;

k) the span length;

l) the L/t ratio of the flexure test;

m) the test speed;

n) the test results given as the mean values of the strength, modulus, and flexural strain at failure and the standard deviations and 95 % confidence intervals of these mean values, if required;

o) the test results given as the mean values of the modulus and the standard deviations and 95 % confidence intervals of these mean values, if required;

p) the test results given as the mean values of flexural strain at failure and the standard deviations and 95 % confidence intervals of these mean values, if required;

q) force-displacement diagram and stress–strain diagram;

r) the position of fracture, if required;

s) the Weibull modulus, if required;

t) effective volume, if required;

u) the date of the test;

v) any operation not specified in this document as well as any incident likely to have affected the results.