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Fibre-reinforced plastic composites — Determination of open-hole compression strength

Composites plastiques renforcés de fibres — Détermination de la résistance à la compression avec trou nu

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12817 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 13, *Composites and reinforcement fibres*.

Introduction

In preparing this (harmonized) International Standard, reference has been made to other similar open-hole compression methods (JIS K 7093,[1] ASTM D6484/D6484M-09[2]) and related methods, i.e. open-hole tension in ASTM D5766/D5766M6[3] and pin-bearing in ISO 12815.[4]

The scope covers all current and future fibre-reinforced plastic composites meeting the requirements of this International Standard. This International Standard incorporates three methods that have different suitability and do not necessarily yield identical properties. All the methods use the maximum load to define the open-hole compressive strength.

Fibre-reinforced plastic composites — Determination of open-hole compression strength

1 Scope

This International Standard specifies the test method to determine the open-hole compressive strength of laminated fibre-reinforced plastic composites. The laminate is intended to be a balanced and symmetrical lay-up or be otherwise homogeneous through the thickness. This International Standard applies to all textile diameter fibre types (carbon, glass, aramids, etc.) and matrices (e.g. thermoset, thermoplastic) that meet the requirements of this International Standard.

This International Standard includes three methods:

— method 1 (short specimen with support fixture);

— method 2 (short specimen without support fixture);

— method 3 (long specimen with support fixture as in ASTM D6484/D6484M-09, methods A and B).

Method 1 employs an L-shaped base fixture and two end fixtures. These end fixtures are compressed between the platens of the test machine.

Method 2 employs end supports similar to the fixtures given in C.1 of ISO 14126:1999. Method 2 is useful for cyclic loading conditions test, including under fully or partly reversed loading conditions when the specimen is clamped by hydraulic grips without support fixtures

Method 3 has two types of loading methods, i.e. 3A and 3B. In method 3A, the specimen is placed within a stabilization fixture, which is then clamped by hydraulic grips. In method 3B, the specimen is placed within a stabilization fixture and then end-loaded by platens. Full details of test methods 3A and 3B are given in ASTM D6484/D6484M-09, procedure A and procedure B, respectively.

NOTE Specimen configurations and force introduction varies for the three methods covered within this International Standard. Results obtained using methods 1, 2 and 3 might not be equivalent for all laminates in all environments.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable to its application. 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 472, *Plastics — Vocabulary*

ISO 1268 (all parts), *Fibre-reinforced plastics — Methods of producing test plates*

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 14126:1999, *Fibre-reinforced plastic composites — Determination of compressive properties in the in-plane direction*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472 and the following apply.

3.1
open-hole diameter
diameter of the open hole in the centre of the test specimen

Note 1 to entry: Open-hole diameter is expressed in millimetres (mm).

Note 2 to entry: See Figure 1.

3.2
width
w
overall width of the specimen

Note 1 to entry: Width is expressed in millimetres (mm).

3.3
coordinate axes of a test specimen
direction parallel with the plate longitudinal axis, which is the X direction and the direction perpendicular, which is the Y direction

Note 1 to entry: See ISO 1268-4.

3.4
open-hole compressive stress
value obtained by dividing a compressive load applied to a test specimen by the gross cross-section based on the overall width and thickness of the test specimen

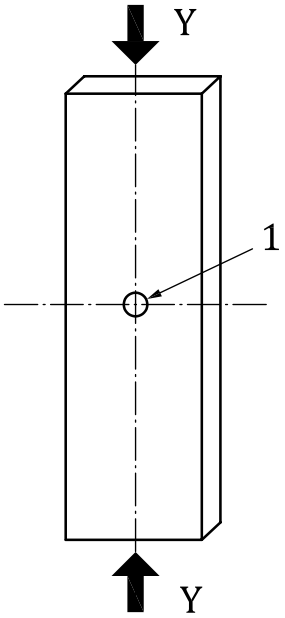
Note 1 to entry: Open-hole compressive stress is expressed in megapascals (MPa).

3.5
open-hole compressive strength
maximum open-hole compressive stress generated in the test specimen

Note 1 to entry: Open-hole compressive strength is expressed in megapascals (MPa).

4 Principle

A test specimen consisting of a strip of rectangular cross-section with a plain open hole centrally positioned, as shown in Figure 1, is loaded in compression. The maximum load sustained by the specimen is used to determine the open-hole (notched) compressive strength based on the gross specimen cross-section.



Key

Y load direction

1 open hole

Figure 1 — Open-hole laminated composite test specimen and load direction

5 Apparatus

5.1 Test machine

5.1.1 General, the machine shall conform to ISO 5893, as appropriate to the requirements given in 5.1.2 and 5.1.3.

5.1.2 Speed of testing. The test machine shall be capable of maintaining the required speed of testing (see 8.4).

5.1.3 Indication of load, the error for the indicated load not exceeding 1 %.

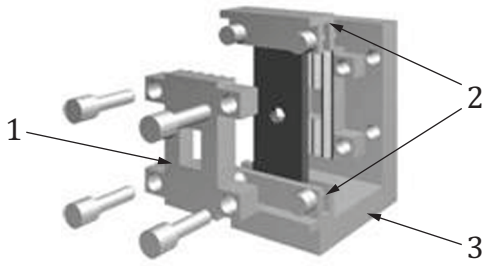
5.1.4 Load measurement system, comprising a mechanism to indicate continuously the compressive load applied to the test piece. The loading mechanism shall not cause delay due to inertia at the specified test speed and shall indicate the load value with a precision equal to or higher than ±1 % of the full scale of load cell measurement capacity.

5.1.5 Loading platens (method 1 and method 3B), each (platen plate) being located on the movable part (platen plate) and fixed part (base plate), respectively, of the test machine and the centre of the upper and lower pressing faces coinciding with the centreline of the loading direction of the test machine. The alignment of the test fixture shall enable a compressive load to be applied to the platen plate and the base plate in the axial direction of a test specimen, and forces other than the compressive load shall be minimized.

5.1.6 Hydraulic grips (method 2 and method 3A), each located on the movable and fixed parts, respectively, of the test machine and the centre of the upper and lower grips coinciding with the centreline of the load gauge. The test set-up arrangement shall be such that a compressive load is applied to the upper and lower grips in the axial direction of a test specimen, and forces other than the compressive load shall be minimized.

5.2 Test fixtures, for method 1 and method 3, which support the test specimen to prevent buckling phenomenon, and which apply compressive load to the test specimen. They shall be made of low-carbon steel or stainless steel. Figure 2 shows an outline of the out-of-plane deformation support fixture assembly for method 1. Figures 3 to 7 show detailed dimensions of the out-of-plane deformation support fixture, L-shaped base plate, end-loading fixtures and support fixture for method 1.

Method 3 requires out-of plane support fixtures. There are two compression-loading conditions for method 3, shear loaded by clamped hydraulic wedge grips (method 3A) and end loaded by platen plates (method 3B). Methods 3A and 3B require the same stabilization fixture. Details of the support fixture for method 3 are given in ASTM D6484/D6484M-09.



Key

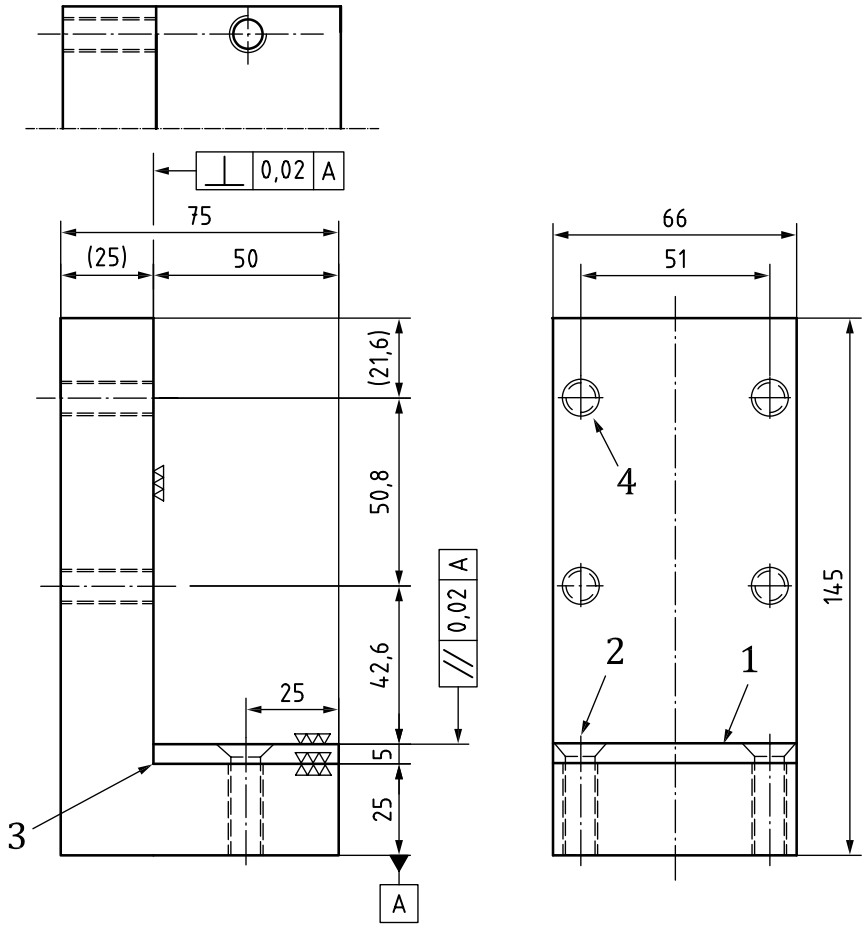
1 out-of-plane deformation support fixture

2 end-loading fixtures

3 L-shaped base plate

Figure 2 — Outline of the fixture

Dimensions in millimetres

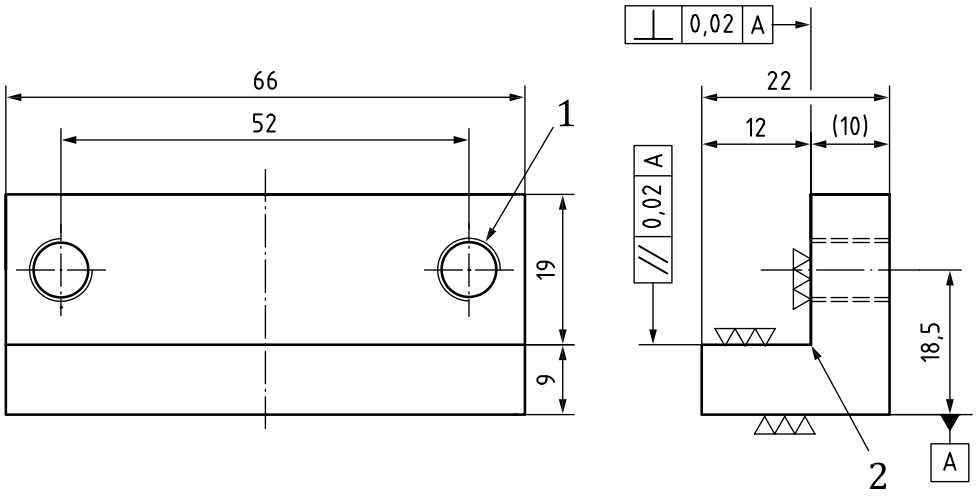


Key

1 S55C, quenched, HRC 50
2 2 × M6 countersunk screw
3 relief radius R0,1 plate R0,5
4 4 × M8 × 1,25 through

Figure 3 — L-shaped base plate for method 1

Dimensions in millimetres



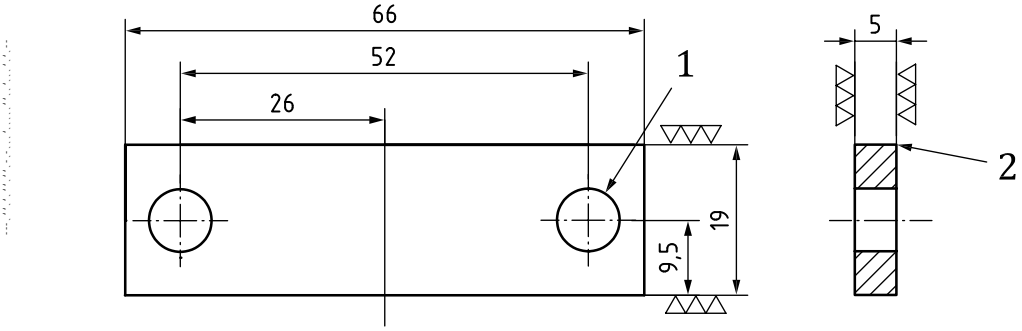
Key

1 2 × M8 × 1,25

2 relief radius R0,1 maximum

Figure 4 — End-loading fixture (upper) for method 1

Dimensions in millimetres



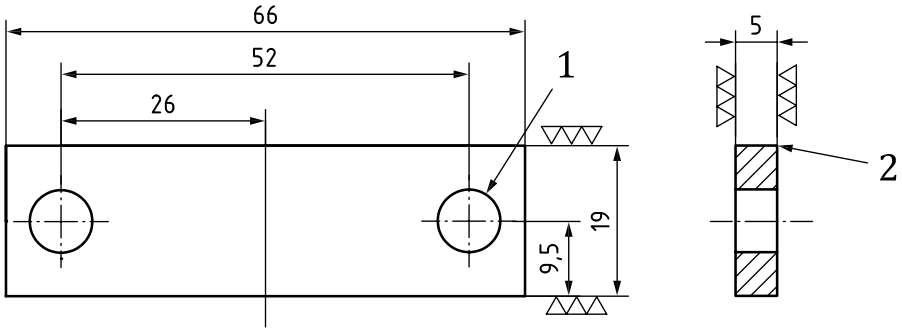
Key

1 2 × M8 × 1,25

2 relief radius R0,1 maximum

Figure 5 — End-loading fixture (lower) for method 1

Dimensions in millimetres



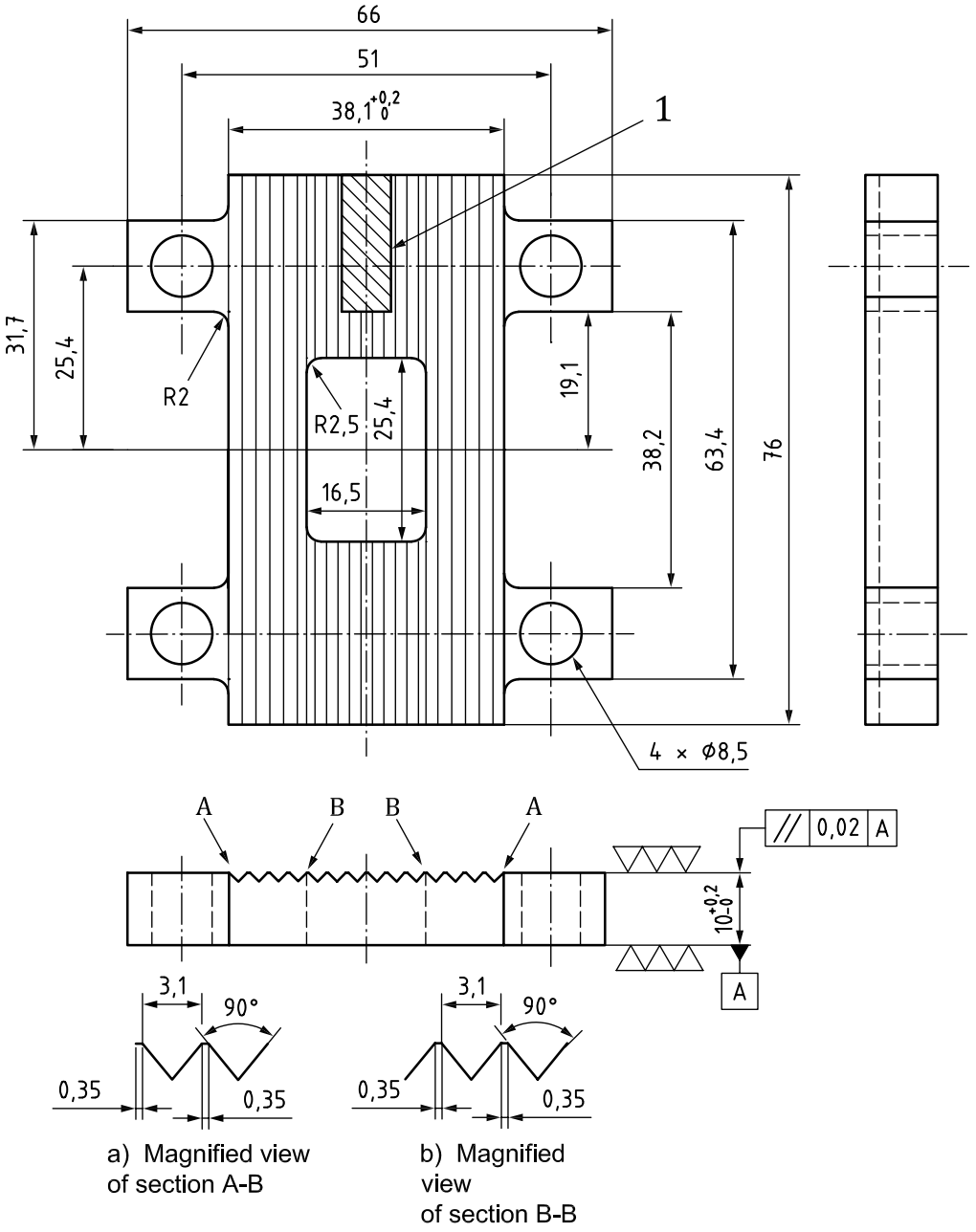
Key

1 2 × M8 × 1,25

2 relief radius R0,1 maximum

Figure 6 — End-loading fixture plate for method 1 (quantity: 2, common for the upper and lower)

Dimensions in millimetres



Key

1 strain gauge bonding area (strain gauge shall be located on the specimen) (6,8 × 18,9 mm, machined to grooved bottom surface)

Figure 7 — Out-of-plane support fixture for method 1 (quantity: two sets)

5.3 Micrometers and calipers

a) **Vernier caliper**, used to measure the length and width of the test specimen, and having a precision of 0,05 mm or better.

b) **Micrometer or equivalent**, used to measure the specimen thickness and open-hole diameter of a test specimen, and having a precision of 0,01 mm or better. The micrometer shall have faces appropriate to the surface being measured (i.e. flat faces for flat, polished surfaces and hemispherical faces for irregular surfaces).

6 Test specimens

6.1 Shape and dimensions

The major dimensions of these test specimens are shown as specified in Table 1, and are shown in Figures 8 and 9. Details of the test specimen for method 3 are given in ASTM D6484/D6484M-09.

Table 1 — Dimensions of test specimens for methods 1 and 2

Dimensions in millimetres

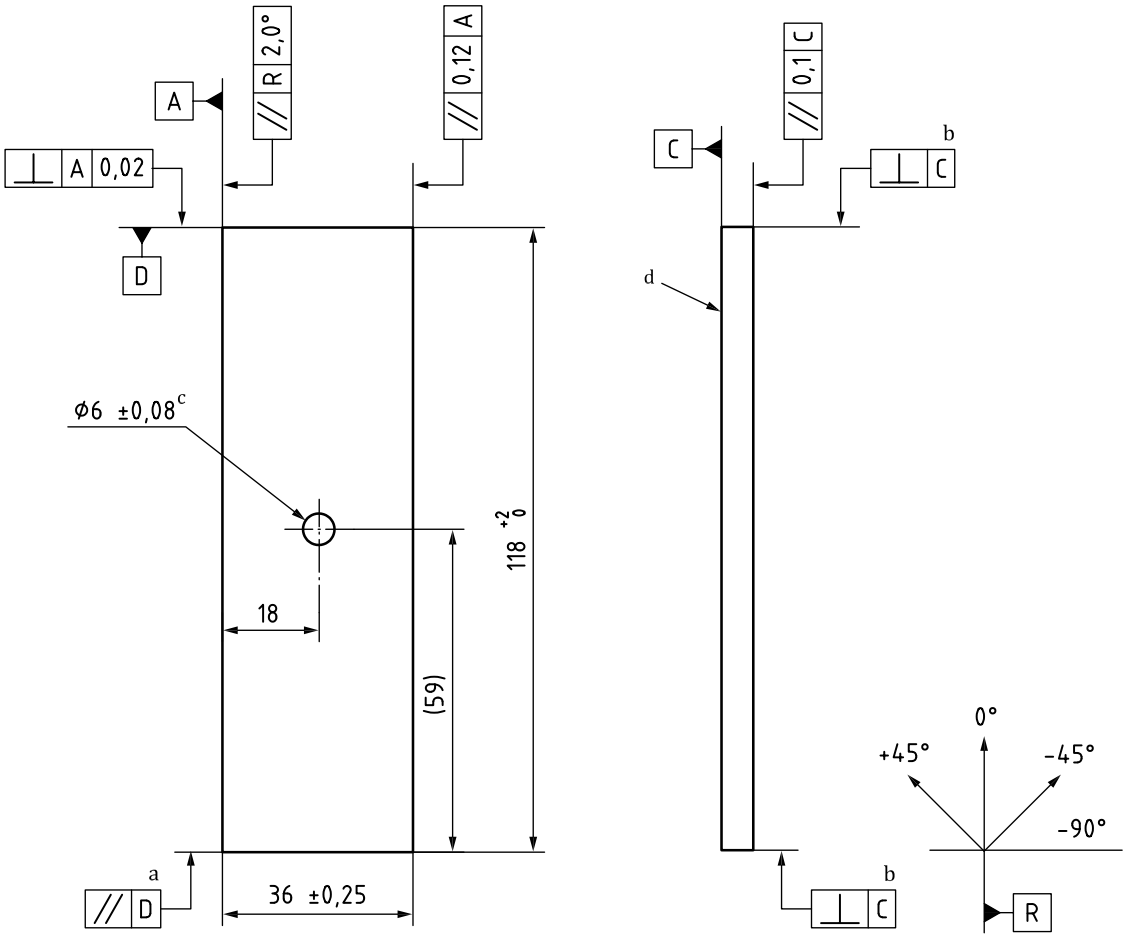
Item	Method 1	Method 2	Method 3[a]
Width *b*	36,0 ± 0,25	36,0 ± 0,5	36
Length *l*	118,0 + 2,0/-0	125.0 ± 1,0	300
Thickness *h*	2,5 (std.)	4,0 (min.)	4
Open-hole diameter *d*	6,0 ± 0,08	6,0 ± 0.02	6
[a] Mean values only; see ASTM D6484/D6484M for tolerances.			

6.2 Alternative specimen

Alternative specimens shall maintain a specimen width-to-hole diameter ratio of 6.

NOTE A 0,25“ (6,35mm) hole in a 1,5” (38,1 mm) wide specimen meets this requirement.

Dimensions in millimetres



a Parallelism of top and bottom surfaces shall be within 0,02 mm for method 1.

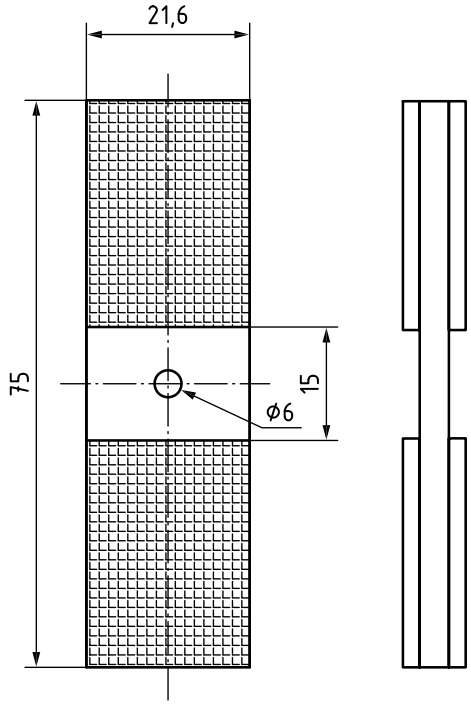
b Perpendicularity of top and bottom surfaces against plane C shall be within 0,02 mm for method 1.

c Hole shall be free of ply peeling or other damage.

d Seal side.

Figure 8 — Shape and dimensions of the test specimen for method 1

Dimensions in millimetres



a End tabs are not normally required. Guidance on tabbing materials and method, if required, is given in ISO 527-4.

Figure 9 — Shape and dimensions of the test specimen for method 2

6.3 Preparation of test plates and specimens

In accordance with ISO 1268 (all parts) or by mutual agreement of the parties concerned, the test specimens shall be machined to the specified dimensions from a laminated fibre-reinforced plastics manufactured by compression moulding, autoclave moulding or other similar methods. The typical configuration of the test specimens lamination of unidirectional material, shall be quasi-isotropic laminates in 16 layers of $(45/0/-45/90)_{2S}$. When using two-dimensionally woven material, such as plain woven or satin woven fabric, $[(45/-45), (0/90)]_{ns}$ shall be employed and the integer "n" that is closest to the thickness given in Table 1 shall be determined. The edges of test specimens shall be prepared by machining in accordance with ISO 2818. The hole shall be made using a drill suitable for use with fibre-reinforced plastics, followed by reamer finishing, if required. These operations shall be properly performed to prevent the generation of burrs or interlaminar resin cracking.

6.4 Inspection of test specimens

Each test specimen shall be flat, free from any twist, and have no defect on its surface and edges. No delamination around the open-hole edges shall be allowed. The thickness and width of each test specimen shall be in accordance within the tolerance and parallelism given in Table 1.

6.5 Number of test specimens

At least five test specimens shall be tested. The number of measurements may be more than five if greater precision of the mean value is required.

7 Conditioning

Conditioning of the test specimen shall be selected in accordance with those specified in ISO 291.

8 Procedure

8.1 Test atmosphere

The specimen shall be tested as specified in ISO 291.

8.2 Measurement of dimensions of the test specimens

Prior to testing, the dimensions of test specimens shall be measured in the test conditions prescribed in Clause 5. The length of a test specimen is measured to a precision of 0,05 mm using a sliding caliper. The width and thickness in the middle area to a precision of 0,01 mm using a micrometer. The hole diameter is also measured to a precision of 0,01 mm using a micrometer.

8.3 Mounting of the test specimens

8.3.1 Method 1

As shown in Figure 2, the end-loading fixtures (see Figures 4, 5, and 6) are attached at the upper and lower ends of the test specimen by four bolts. The test specimen with the out-of-plane support fixtures (see Figure 7) is clamped and installed on the L-shaped base plate that is tighten by torque approximately 0,10 Nm to 0,15 Nm. The assembly of test specimen and fixtures are clamped between the platen plate and base plate of the test machine.

8.3.2 Method 2

The test specimen is clamped by hydraulic or equivalent grip at the upper and lower ends of the test specimen.

8.3.3 Method 3

Test specimen installation of method 3A and method 3B is given in ASTM D6484/D6484M-09, procedures A and B.

8.4 Test speed

The test speed shall be 0,5 mm/min to 1,5 mm/min for method 1 and method 2.

NOTE The test speed of method 3 is given in ASTM D6484/D6484M-09.

8.5 Preliminary loading

To stabilize the loading fixture set-up, apply a preliminary loading of 5 kN, and then, remove the load before conducting the compression strength test for method 1 and method 3. This preliminary loading process is not required for method 2.

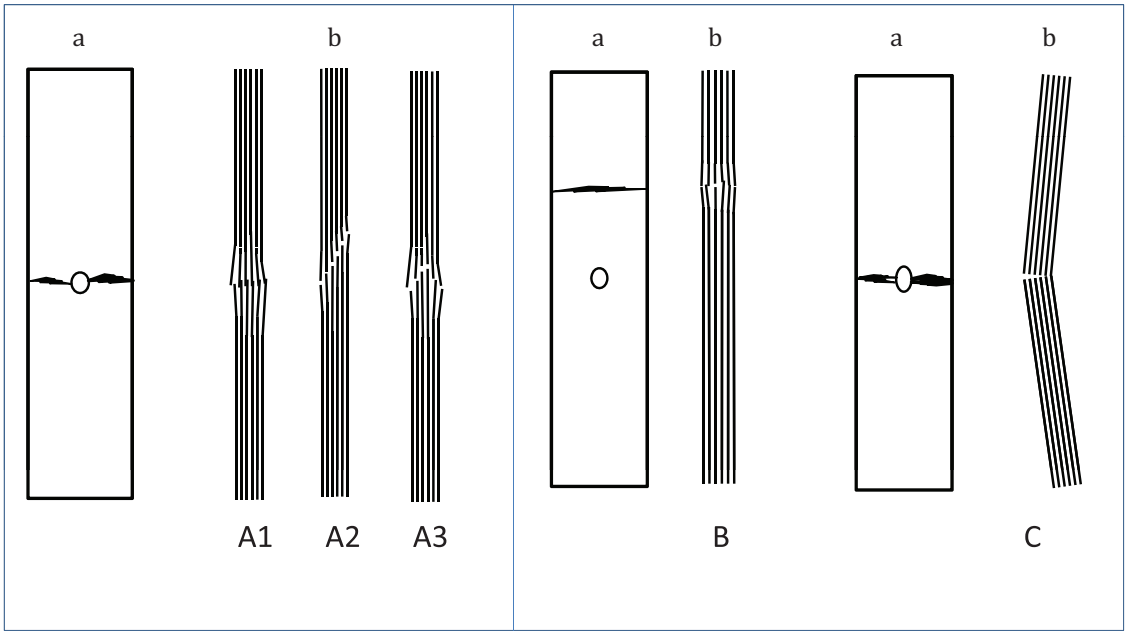
Details of preliminary loading for method 3 are given in ASTM D6484/D6484M-09.

8.6 Recording

Record the load applied to the test specimen and the crosshead travel (displacement) until test specimen failure.

8.7 Failure mode

The failure mode of the test specimen shall be identified corresponding to the open-hole compressive failure indicated in Figure 10. Where the fracture modes are inappropriate, the fracture modes shall be reported in the test results.



a) Appropriate failure modes A1, A2 and A3 **b) Inappropriate failure modes B and C**

a Plane view.

b Side views.

Figure 10 — Typical failure modes of open-hole compressive specimen

9 Calculation

9.1 Open-hole compressive strength

Calculate the open-hole compressive strength using Formula (1).

$$\sigma_{\mathrm{OHC}} = \frac{F}{wh} \tag{1}$$

where

σ_{OHC} is the open-hole compressive strength (MPa);

F is the maximum load (N);

w is the width of test specimen (mm);

h is the thickness of test specimen (mm).

9.2 Expression of results

Calculate the open-hole compressive strength for each test specimen and calculate the mean value to three significant figures. When the standard deviation and coefficient of variation are required, these values are calculated by Formulae (2) and (3).

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

$$C_V = \frac{s}{\bar{x}} \times 100 \tag{3}$$

where

s is the standard deviation;

C_V 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 precision of method 1 obtained in an interlaboratory study is summarized below (see Table 2 and Table 3). Four materials manufactured from prepregs using an autoclave were tested. Full details are reported.[4]

Four materials fabricated from mid-modulus/high-strength carbon fibre/epoxy prepregs using different reinforcement styles, thicknesses and lay-ups were tested as follows:

— material 1 UD 16ply Quasi isotropic, Autoclave, by seven laboratories;

— material 2 UD 32ply Quasi isotropic, Autoclave, by four laboratories;

— material 3 UD 16ply Quasi isotropic, Autoclave, by six laboratories;

— material 4 5HS Satin 8ply Quasi isotropic, Autoclave, by nine laboratories.

Table 2 — Repeatability, reproducibility and mean notched stress for open-hole compressive specimens

Material code	Repeatability conditions		Reproducibility conditions		Open-hole compressive strength MPa
	Sr	r	S_R	R	
1	5,48	15,20	5,48	15,20	278,9
2	5,52	15,30	6,08	16,80	317,3
3	9,00	24,90	9,00	24,90	307,7
4	9,47	26,20	10,20	28,40	286,6

Table 3 — Repeatability and reproducibility values as a percentage of mean values for open-hole compressive specimens

Material code	Value as percentage of mean			
	Repeatability conditions		Reproducibility conditions	
	S_r	r	S_R	R
1	1,96	5,45	1,96	5,45
2	1,98	5,49	2,18	6,02
3	3,23	8,93	3,23	8,93
4	3,40	9,39	3,66	10,18

The precision of method 2 obtained in an interlaboratory study is summarized below(see Table 4 and Table 5). Four materials representing the range of fibre-reinforced plastic composites were tested in an interlaboratory trial by six laboratories. Full details are reported.[4] The materials tested were:

— material 1 chopped strand-mat glass-fibre/ polyester (CSM) hand laid-up;

— material 2 woven glass-fibre/epoxy press moulded;

— material 3 glass-fibre/polyester mixed format pultrusion (PUL);

— material 4 unidirectional carbon-fibre/ epoxy, autoclave moulded (CFRP).

Table 4 — Repeatability, reproducibility and mean notched stress for open-hole compressive specimens

Material code	Repeatability conditions		Reproducibility conditions		Open-hole compressive strength MPa
	S_r	r	S_R	R	
1	7,82	21,89	7,92	22,17	141,31
2	10,72	30,01	13,24	37,07	272,76
3	9,90	27,71	10,64	29,79	266,93
4	4,77	13,35	11,39	31,88	341,47

Table 5 — Repeatability and reproducibility values as a percentage of mean values for open-hole compressive specimens

Material code	Value as percentage of mean			
	Repeatability conditions		Reproducibility conditions	
	S_r	r	S_R	R
1	5,53	15,49	5,60	15,69
2	3,93	11,00	4,85	13,59
3	3,71	10,38	3,99	11,16
4	1,40	3,91	3,34	9,34

NOTE The definitions are taken directly from ISO 5725 (all parts).

Repeatability value, r: the value below which the absolute difference between two single test results obtained under repeatability conditions may be expected to lie with a probability of 95 %.

Reproducibility value, R: the value below which the absolute difference between two single test results obtained under reproducibility conditions may be expected to lie with a probability of 95 %.

Repeatability standard deviation, S_r: the standard deviation of test results obtained under repeatability conditions.

Reproducibility standard deviation, S_R: the standard deviation of test results obtained under reproducibility conditions.

11 Test report

The test report shall include the following information for methods 1 and 2. (Report requirements for method 3 are given in ASTM D6484/D6484M-09.)

a) a reference to this International Standard, i.e. ISO 12817, and the method used;

b) all details necessary to identify the test material (sample moulding methods, laminate configuration, volumetric or mass content, etc.);

c) the dimensions, preparation conditions and sampling methods of test specimens;

d) the tab material (if applicable to method 2);

e) the number of test specimens tested;

f) the temperature, humidity and time of test specimen conditioning;

g) the test temperature and humidity;

h) the accuracy grading of the test machine (ISO 5893);

i) the test methods employed (method 1, 2, 3);

j) the test speed;

k) the test results for open-hole compressive strength, individual and mean values, standard deviation and coefficient of variation, as required, typical load-displacement diagram;

l) the mode of failure for each test;

m) the date of the test;

n) a statement as to whether any test specimens were rejected and, if so, why;

o) the standard deviations and the 95 % confidence intervals of the mean values, if required;

p) any operation not specified in this International Standard, as well as any incident likely to have affected the results.

Bibliography

[1] JIS K 7093, *Test method for open-hole compressive strength of carbon fibre reinforced plastic*

[2] ASTM D6484/D6484M-09, *Standard Test Method for Open-Hole Compressive Strength of Polymer Matrix Composite Laminates*

[3] ASTM D5766/D5766M-11, *Standard Test Method for Open-Hole Tensile Strength of Polymer Matrix Composite Laminates*

[4] ISO 12815, *Fibre-reinforced plastic composites — Determination of plain-pin bearing strength*

[5] Ishikawa T., Hamaguchi Y., Shikata N., Ben G., Kageyama K. *Journal of the Japan Society for Composite Materials*. 2005, **31** (5)

[6] NPL Measurement Note No. 043, *Round-robin validation exercise for three structural test methods: open-hole compression, open-hole tension and pin-bearing*, 1999

[7] ISO 13003, *Fibre-reinforced plastics — Determination of fatigue properties under cyclic loading conditions*

[8] ASTM D7615/D7615M-11, *Standard Practice for Open Hole Fatigue Response of Polymer Matrix Composite Laminates*

[9] ISO 527-5, *Plastics — Determination of tensile properties — Part 5: Test conditions for unidirectional fibre-reinforced plastic composites*

[10] ISO 5725-1, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions*

[11] ISO 5725-2, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

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