INTERNATIONAL STANDARD

ISO 15310

First edition
1999-12-15

Fibre-reinforced plastic composites — Determination of the in-plane shear modulus by the plate twist method

Composites plastiques renforcés de fibres — Détermination du module de cisaillement dans le plan par la méthode de torsion de plaque

Reference number
ISO 15310:1999(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 15310 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 13, *Composites and reinforcement fibres*.

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Fibre-reinforced plastic composites — Determination of the in-plane shear modulus by the plate twist method

1 Scope

1.1 This International Standard specifies a method for determining the in-plane shear modulus (G_{12}) of fibre-reinforced plastic composites using a standard plate specimen. When applied to isotropic materials, the shear modulus measured is independent of direction.

1.2 The method is used to determine the shear modulus of the test specimens but not to determine the shear strength. It applies to a plate supported on two points on one diagonal and loaded on the other diagonal by the simultaneous movement of two loading points attached to a cross-beam.

1.3 The method is suitable for use with fibre-reinforced plastic composites with both thermoset and thermoplastic matrices.

Due to the shear deformation being applied under flexural conditions, for laminated materials with different fibre formats and/or different orientations, the layers of material must be well distributed across the section so that it is approximately “homogeneous” in the through-thickness direction.

The principal material axes, if present, must be orientated normal to the plate edges (see 3.8).

NOTE This method can be applied to unreinforced polymers and other materials (e.g. metals, ceramics and metal- or ceramic-matrix composites).

For material fabricated using unidirectional plies, the shear modulus obtained using a multidirectional specimen (i.e. 0°/90°/± 45°) is not the same as that obtained for unidirectional or cross-ply (0°/90°) material.

1.4 The method is performed using specimens which may be moulded to the chosen dimensions, machined from test plates or machined from flat areas of products.

1.5 The method specifies preferred dimensions for the specimen. Tests which are carried out on specimens of other dimensions, or on specimens which are prepared under different conditions, may produce results which are not comparable. Other factors, such as the speed of testing and the conditioning of the specimens, can influence the results. Consequently, when comparative data are required, these factors must be carefully controlled and recorded.

NOTE The stress-strain response in shear is very non-linear at higher strain levels. This test method determines the modulus within a low strain region and is not applicable to higher strains.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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ISO 291:1997, *Plastics — Standard atmospheres for conditioning and testing.*

ISO 1268:1974[1)], *Plastics — Preparation of glass fibre reinforced, resin bonded, low-pressure laminated plates or panels for test purposes.*

ISO 2602:1980, *Statistical interpretation of test results — Estimation of the mean — Confidence interval.*

ISO 2818:1994, *Plastics — Preparation of test specimens by machining.*

ISO 5893:1993, *Rubber and plastics test equipment — Tensile, flexural and compression types (constant rate of traverse) — Description.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1
plate deflection
w
the distance over which the loading points move relative to the support points (see Figure 2), expressed in mm

NOTE The plate deflection is normally taken from the movement of the rigid cross-beam carrying the two loading points.

3.2
modulus of elasticity in shear
in-plane shear modulus
G_{12}
<isotropic materials> the shear modulus, expressed in GPa, in a direction other than that of the reinforcement, measured between plate deflections of 0,1h and 0,3h, where h is the plate thickness (see 3.7)

3.3
speed of testing
the rate of movement of the loading points relative to the support points, expressed in mm/min

3.4
span
S
the mean of the distance S_1 between the two support points and the distance S_2 between the two loading points (see Figure 3), expressed in mm

3.5
diagonal length
D
the distance between diametrically opposite corners of the plate, expressed in mm

It is calculated as follows:

$$D = \left(a'^2 + a''^2\right)^{\frac{1}{2}}$$

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1) ISO 1268:1974 is under revision in nine parts covering a wide range of composite materials and fabrication processes (e.g. RTM, SMC, filament winding).

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3.6
specimen widths
a', *a*''
the mean widths of the specimen in each direction (see Figure 2), expressed in mm

3.7
specimen thickness
h
the mean thickness of the specimen, expressed in mm

3.8
specimen coordinate axes
the coordinate axes for the material under test, as defined in Figure 1

The direction parallel to the principal fibre axis is defined as the "1"-direction, and the direction perpendicular to this axis, and in the plane of the fibres, as the "2"-direction. The "1"-direction is also referred to as the 0-degree (0°) or longitudinal direction, and the "2"-direction as the 90-degree (90°) or transverse direction. A similar definition can be used for material with a preferred lay-up of fibres and for cases where a direction (e.g. length) can be related to the production process.

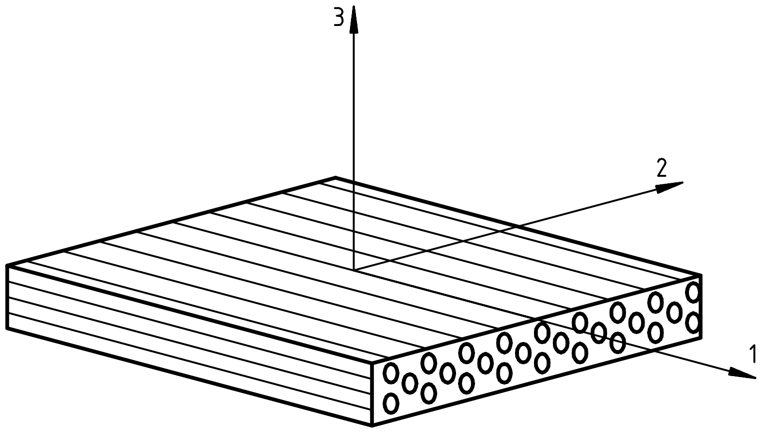

Figure 1 — Symmetry axes for a fibre-reinforced material

4 Principle

The test specimen is supported on two support points positioned near opposite corners on one diagonal of the plate. The plate is deflected at constant rate by two loading points on the opposite diagonal (see Figure 2) until the deformation of the specimen reaches a pre-determined value. During this procedure, the total force on the loading points is measured as a function of the deflection of the loading points.

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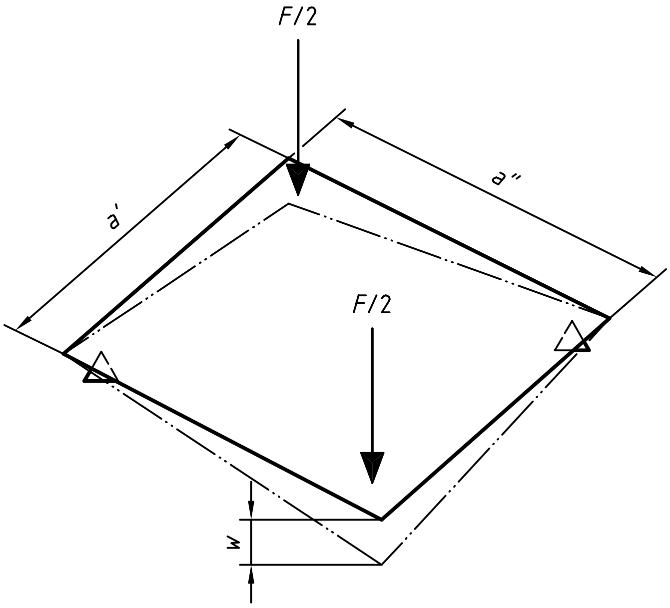
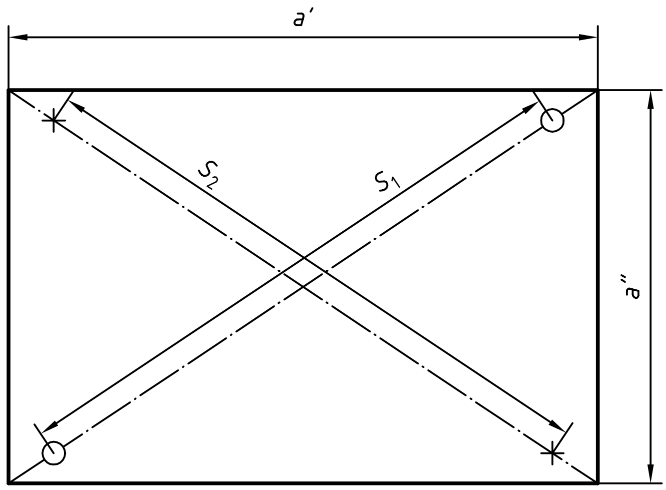


Figure 2 — Principle of test



+ Support point

o Loading point

Figure 3 — Positions of support and loading points

5 Apparatus

5.1 Test machine

5.1.1 General

The machine shall comply with ISO 5893 as appropriate to the requirements given in 5.1.2 to 5.1.4.

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5.1.2 Speed of testing

The test machine shall be capable of maintaining a constant speed of 1 mm/min ± 20 %.

5.1.3 Support and loading points

Two support and two loading points are arranged as shown in Figure 3. The support and loading points shall be adjustable to within 0,5 mm of the required position.

The support and loading points are normally mounted on rigid cross-beams in the same manner as the support rollers in a flexure loading test, with the cross-beams set perpendicular to each other. As the test machine is operated, the loading points are moved, by virtue of their attachment to the rigid cross-beam, simultaneously and equally relative to the fixed support points.

NOTE A suitable design for the support and loading points is shown in Figure 4.

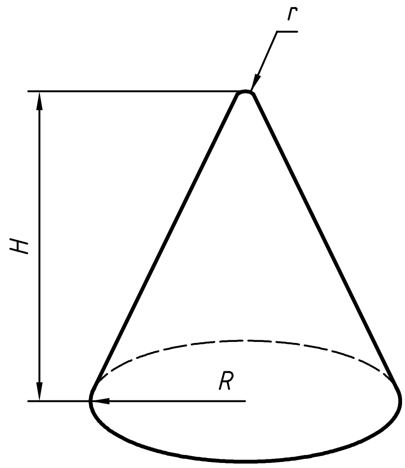

Figure 4 — Suggested support and loading point design

The radius r of the support and loading points shall be 2,0 mm ± 0,2 mm (see Figure 4). The recommended value for the cone height H is 20 mm and for the base radius R is 10 mm.

5.1.4 Indicators for load and deflection

The error in the indicated force and deflection shall not exceed ± 2 % of the full scale (see ISO 5893).

NOTE When crosshead movement is used to measure the plate deflection, a correction should preferably be made for the loading train deflection (i.e. errors due to all additional deflections, such as displacements in the test machine, flexure of the support beam, displacement in the load cell and local indentation).

5.2 Micrometers and gauges

5.2.1 Micrometer or equivalent, reading to less than or equal to 0,01 mm, for measuring the thickness h of the test specimen.

5.2.2 Vernier callipers or equivalent, accurate to within 0,1 mm, for determining the test spans and specimen widths.

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6 Test specimens

6.1 Shape and dimensions

The test specimens shall be square, flat plates of the material under test.

6.1.1 Standard plate specimen

See Table 1.

Table 1

Material	Specimen widths a', a'' mm	Thickness h mm
Discontinuous, mat, fabric, multidirectionally reinforced	150 ± 1,5	4 ± 0,5
Unidirectionally reinforced	150 ± 1,5	2 ± 0,5

In any one test, the specimen thickness shall not deviate by more than 5 % from its mean value. The corresponding maximum deviation for width is 1 %.

6.1.2 Other test specimens

If the thickness of the specimen is not within the standard ranges given in 6.1.1, the widths of the specimen shall be as given below:

$$a' = a'' \geqslant 35h$$

NOTE The above ratio has been chosen so that the through-thickness shear modulus does not significantly affect the measured in-plane value. The specimen thickness may only be reduced by machining from thicker materials when the structure of the material is homogeneous throughout the thickness of the material. However, machining of specimens is not recommended.

6.2 Preparation

Prepare specimens in accordance with ISO 1268 or another specified or agreed-upon preparation procedure (guidance on machining is given in ISO 2818). Specimens can also be machined from flat areas of components and sub-components.

6.3 Checking

The specimens shall be flat and free of twist. The surfaces and edges shall be free from scratches, pits, sink marks and flashes. Check the specimens for conformity with these requirements by visual observation against straight edges, squares and flat plates, and by measuring with e.g. Vernier callipers. Reject any specimens showing measurable or observable departure from one or more of these requirements, or machine them to proper size and shape before testing.

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7 Number of test specimens

Test at least five test specimens.

NOTE The number of measurements may be more than five if greater precision of the mean value is required. It is possible to evaluate this by means of the 95 % confidence interval (see ISO 2602).

8 Conditioning

Condition the test specimens as specified in the International Standard for the material being tested. In the absence of this information, select the most appropriate set of conditions from ISO 291, unless otherwise agreed upon by the interested parties, e.g. for testing at elevated or low temperatures.

9 Procedure

9.1 Conduct the test in the atmosphere specified in the International Standard for the material being tested. In the absence of this information, select the most appropriate set of conditions from ISO 291, unless otherwise agreed upon by the interested parties, e.g. for testing at elevated or low temperatures.

9.2 Measure the widths of each test specimen to the nearest 0,5 mm at three evenly spaced positions along the specimen edge and calculate, for each specimen, the mean value for each direction (a' and a'').

9.3 Calculate the test span S from $S = 0{,}95D$, where D is as defined in 3.5.

9.4 Adjust the support and loading point spans to S, to within the nearest 0,5 mm.

9.5 Measure the thickness h of each specimen to the nearest 0,02 mm at the mid-point of each side, 25 mm in from the edge, and calculate the mean value. Discard any specimens for which any of the thickness measurements are not within ± 5 % of the mean value. Replace such specimens by another, chosen at random.

9.6 Set the speed of testing to 1 mm/min ± 20 %.

9.7 Place a test specimen symmetrically on the two support points and bring the two loading points into initial contact.

9.8 Deflect the loading points to a maximum of $0{,}5h$.

9.9 During the test, record the deflection and the corresponding load using, if practicable, an automatic recording system that yields a complete load/deflection curve for this operation.

9.10 Test the remaining specimens in the same way.

10 Calculation and expression of results

10.1 In-plane shear modulus

For the calculation of the in-plane shear modulus, use the loads F_1 and F_2 at the deflections w_1 and w_2, respectively (see Figure 5).

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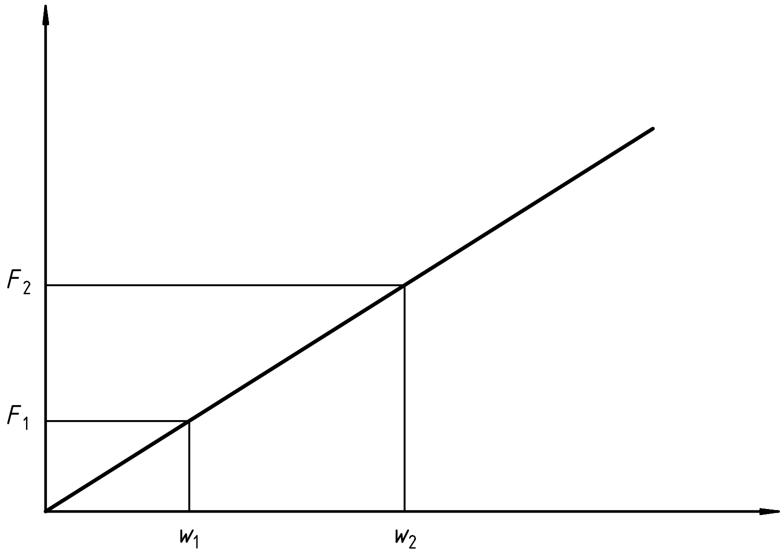

Figure 5 — Load/deflection curve

For the standard specimen, calculate the in-plane shear modulus as follows:

$$G_{12} = \frac{3}{4} \times \frac{\Delta \times a' \times a'' \times K}{1000\, h^3}$$

where

$$\Delta = \frac{F_2 - F_1}{w_2 - w_1}$$

and

$K = 0{,}822$

where

w_1, w_2	are the deflections, in millimetres ($w_1 = 0{,}1h$, $w_2 = 0{,}3h$);
F_1, F_2	are the corresponding loads, in newtons;
a', a''	are the average specimen width in each direction, in millimetres;
h	is the average specimen thickness, in millimetres;
K	is a geometric correction factor;
G_{12}	is the in-plane shear modulus, expressed in gigapascals and equal to G for isotropic materials.

NOTE For span-to-diagonal ratios other than 0,95, the value of K can be calculated from:

$$K = 3s^2 - 2s - 2(1 - s)^2 \ln(1 - s)$$

where

$$s = \frac{S}{D}$$

S being the measured mean span;

D being the length of the diagonal.

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10.2 Statistical parameters

Calculate the arithmetic mean of the test results and, if required, the standard deviation and the 95 % confidence interval of the mean value using the procedure given in ISO 2602.

10.3 Significant figures

Calculate the modulus to three significant figures.

11 Precision

The materials tested and precision data obtained in the validation of this test method are listed in annex A.

12 Test report

The test report shall include the following information:

a) a reference to this International Standard;

b) all details necessary for complete identification of the material tested, including type, source, manufacturer's code number, form and previous history, where these are known;

c) the shape and dimensions of the test specimens;

d) the method of preparing the specimens; the test conditions and the conditioning procedures, if applicable;

e) the number of specimens tested;

f) the length of span S used;

g) the speed of testing;

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

i) the individual test results, if required;

j) the mean value of the individual results;

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

l) the date of testing.

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Annex A
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Precision data

The following materials were tested:

Material 1	UD glass-fibre/epoxy
Material 2	SMC (glass-fibre/filler/polyester)
Material 3	Woven glass-fibre/epoxy
Material 4	Random glass-fibre/polypropylene
Material 5	Injection-moulded glass-fibre/nylon
Material 6	UD carbon-fibre/epoxy

Table A.1 — Repeatability, reproducibility and mean shear moduli

Material	Repeatability conditions		Reproducibility conditions		Mean result
	s_r	r	s_R	R	GPa
1	0,164	0,459	0,302	0,846	5,85
2	0,137	0,385	0,184	0,516	4,30
3	0,106	0,296	0,307	0,859	4,39
4	0,096	0,269	0,098	0,274	1,78
5	0,061	0,171	0,165	0,461	1,16
6	0,200	0,559	0,309	0,865	5,17

Table A.2 — Repeatability and reproducibility values as percentages of mean value

Material	Value as percentage of mean			
	Repeatability conditions		Reproducibility conditions	
	s_r	r	s_R	R
1	2,80	7,84	5,41	14,4
2	3,19	8,96	4,29	12,0
3	2,42	6,75	7,00	19,6
4	5,38	15,1	5,50	15,4
5	5,28	14,8	14,27	39,8
6	3,87	10,8	5,98	16,7

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[1] NIMMO, W., and SIMS, G.D., “Plate Twist Round Robin Validation Exercise”, NPL Report DMM (A) 156, 1995.

[2] Definitions of precision terms are given in ISO 5725-1:1994, *Accuracy (trueness and precision) of measurement methods and results — Part 1: General principles and definitions.*

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