INTERNATIONAL STANDARD

ISO 178

Fifth edition
2010-12-15

Plastics — Determination of flexural properties

Plastiques — Détermination des propriétés en flexion

Reference number
ISO 178:2010(E)

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Published in Switzerland

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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 2.

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 178 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

This fifth edition cancels and replaces the fourth edition (ISO 178:2001), which has been technically revised to harmonize it with ISO 527-2[2] with respect to the test speeds used for the determination of the flexural modulus and for the determination of other flexural properties. This has been done by specifying two methods, method A and method B. Method A is identical to the method specified in previous editions of ISO 178, i.e. it uses the same strain rate throughout the test, whereas method B uses two different strain rates (see 1.8 for details).

It also incorporates the Amendment ISO 178:2001/Amd.1:2004.

Plastics — Determination of flexural properties

1 Scope

1.1 This International Standard specifies a method for determining the flexural properties of rigid (see 3.12) and semi-rigid plastics under defined conditions. A standard test specimen is defined, but parameters are included for alternative specimen sizes for use where appropriate. A range of test speeds is included.

1.2 The method is used to investigate the flexural behaviour of the test specimens and to determine the flexural strength, flexural modulus and other aspects of the flexural stress/strain relationship under the conditions defined. It applies to a freely supported beam, loaded at midspan (three-point loading test).

1.3 The method is suitable for use with the following range of materials:

— thermoplastic moulding, extrusion and casting materials, including filled and reinforced compounds in addition to unfilled types; rigid thermoplastics sheets;

— thermosetting moulding materials, including filled and reinforced compounds; thermosetting sheets.

In agreement with ISO 10350-1[5] and ISO 10350-2[6], this International Standard applies to fibre-reinforced compounds with fibre lengths $\leqslant$ 7,5 mm prior to processing. For long-fibre-reinforced materials (laminates) with fibre lengths $>$ 7,5 mm, see ISO 14125[7].

The method is not normally suitable for use with rigid cellular materials or sandwich structures containing cellular material. In such cases, ISO 1209-1[3] and/or ISO 1209-2[4] can be used.

NOTE For certain types of textile-fibre-reinforced plastic, a four-point bending test is preferred. This is described in ISO 14125.

1.4 The method is performed using specimens which may be either moulded to the specified dimensions, machined from the central section of a standard multipurpose test specimen (see ISO 20753) or machined from finished or semi-finished products, such as mouldings, laminates, or extruded or cast sheet.

1.5 The method specifies the preferred dimensions for the test specimen. Tests which are carried out on specimens of different dimensions, or on specimens which are prepared under different conditions, can produce results which are not comparable. Other factors, such as the test speed and the conditioning of the specimens, can also influence the results.

NOTE Especially for semi-crystalline polymers, the thickness of the oriented skin layer, which is dependent on the moulding conditions, also affects the flexural properties.

1.6 The method is not suitable for the determination of design parameters but can be used in materials testing and as a quality control test.

1.7 For materials exhibiting non-linear stress/strain behaviour, the flexural properties are only nominal. The equations given have been derived assuming linear elastic behaviour and are valid for deflections of the specimen that are small compared to its thickness. With the preferred specimen (which measures 80 mm × 10 mm × 4 mm) at the conventional flexural strain of 3,5 % and a span-to-thickness ratio, L/h, of 16, the deflection is 1,5h. Flexural tests are more appropriate for stiff and brittle materials showing small deflections at break than for very soft and ductile ones.

1.8 Contrary to the previous editions of this International Standard, this edition specifies two methods, method A and method B. Method A is identical to the method in previous editions of this International Standard, i.e. it uses a strain rate of 1 %/min throughout the test. Method B uses two different strain rates: 1 %/min for the determination of the flexural modulus and 5 %/min or 50 %/min, depending on the ductility of the material, for the determination of the remainder of the flexural stress-strain curve.

2 Normative references

The following referenced documents are indispensable for the application 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 293, *Plastics — Compression moulding of test specimens of thermoplastic materials*

ISO 294-1:1996, *Plastics — Injection moulding of test specimens of thermoplastic materials — Part 1: General principles, and moulding of multipurpose and bar test specimens*

ISO 295, *Plastics — Compression moulding of test specimens of thermosetting materials*

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

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

ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system*

ISO 9513, *Metallic materials — Calibration of extensometers used in uniaxial testing*

ISO 10724-1, *Plastics — Injection moulding of test specimens of thermosetting powder moulding compounds (PMCs) — Part 1: General principles, and moulding of multipurpose test specimens*

ISO 16012, *Plastics — Determination of linear dimensions of test specimens*

ISO 20753, *Plastics — Test specimens*

ISO 23529, *Rubber — General procedures for preparing and conditioning test pieces for physical test methods*

3 Terms and definitions

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

3.1
test speed
v
rate of relative movement between the specimen supports and the loading edge

NOTE It is expressed in millimetres per minute (mm/min).

3.2
flexural stress
σ_f
nominal stress at the outer surface of the test specimen at midspan

NOTE It is calculated from the relationship given in 9.1, Equation (5), and is expressed in megapascals (MPa).

3.3
flexural stress at break

σ_{fB}

flexural stress at break of the test specimen (see Figure 1, curves a and b)

NOTE It is expressed in megapascals (MPa).

3.4
flexural strength

σ_{fM}

maximum flexural stress sustained by the test specimen during a bending test (see Figure 1, curves a and b)

NOTE It is expressed in megapascals (MPa).

3.5
flexural stress at conventional deflection

σ_{fc}

flexural stress at the conventional deflection, s_C, defined in 3.7 (see also Figure 1, curve c)

NOTE It is expressed in megapascals (MPa).

3.6
deflection

s

distance over which the top or bottom surface of the test specimen at midspan deviates from its original position during flexure

NOTE It is expressed in millimetres (mm).

3.7
conventional deflection

s_C

deflection equal to 1,5 times the thickness, h, of the test specimen

NOTE 1 It is expressed in millimetres (mm).

NOTE 2 Using a span, L, of $16h$, the conventional deflection corresponds to a flexural strain (see 3.8) of 3,5 %.

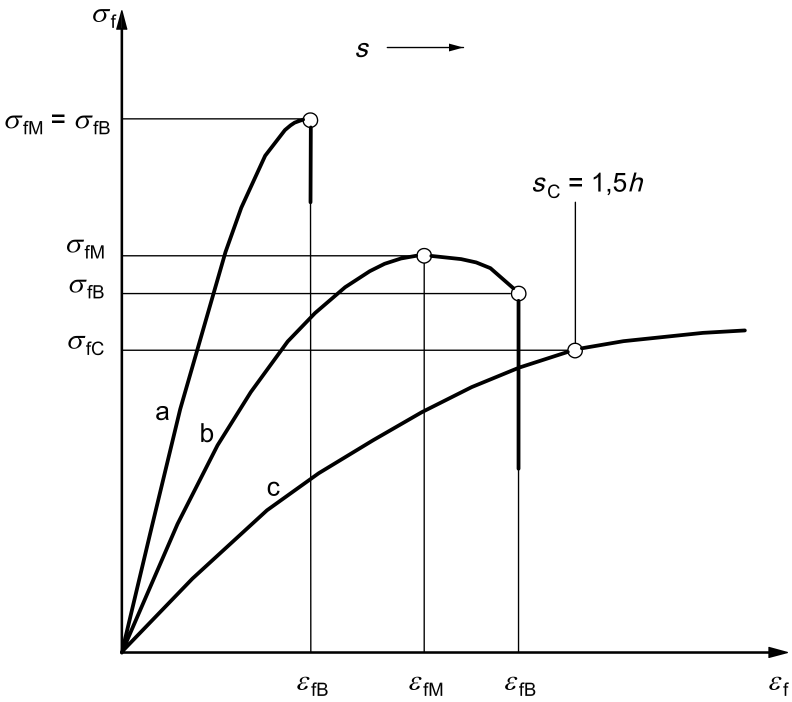
3.8
flexural strain

ε_f

nominal fractional change in length of an element of the outer surface of the test specimen at midspan

NOTE 1 It is expressed as a dimensionless ratio or a percentage (%).

NOTE 2 It is calculated in accordance with the relationships given in 9.2, Equations (6) and (7).



Curve a Specimen that breaks before yielding.

Curve b Specimen that gives a maximum and then breaks before the conventional deflection, s_C.

Curve c Specimen that neither gives a maximum nor breaks before the conventional deflection, s_C.

Figure 1 — Typical curves of flexural stress, σ_f, versus flexural strain, ε_f, and deflection, s

3.9
flexural strain at break

ε_{fB}

flexural strain at which the test specimen breaks (see Figure 1, curves a and b)

NOTE It is expressed as a dimensionless ratio or a percentage (%).

3.10
flexural strain at flexural strength

ε_{fM}

flexural strain at maximum flexural stress (see Figure 1, curves a and b)

NOTE It is expressed as a dimensionless ratio or a percentage (%).

3.11
modulus of elasticity in flexure
flexural modulus

E_f

ratio of the stress difference, $\sigma_{f2} - \sigma_{f1}$, to the corresponding strain difference, ε_{f2} (= 0,002 5) – ε_{f1} (= 0,000 5) [see 9.3, Equation (9)]

NOTE 1 It is expressed in megapascals (MPa).

NOTE 2 The flexural modulus is only an approximate value of Young's modulus of elasticity.

3.12
rigid plastic
plastic that has a modulus of elasticity in flexure or, if that is not applicable, then in tension, greater than 700 MPa

[ISO 472[1]]

3.13
span between specimen supports
L
distance between the points of contact between the test specimen and the test specimen supports (see Figure 2)

NOTE It is expressed in millimetres (mm).

3.14
flexural strain rate
r
rate at which the flexural strain (see 3.8) increases during a test

NOTE It is expressed in reciprocal seconds (s^{-1}) or percent per second ($\% \cdot s^{-1}$).

4 Principle

A test specimen of rectangular cross-section, resting on two supports, is deflected by means of a loading edge acting on the specimen midway between the supports. The test specimen is deflected in this way at a constant rate at midspan until rupture occurs at the outer surface of the specimen or until a maximum strain of 5 % (see 3.8) is reached, whichever occurs first. During this procedure, the force applied to the specimen and the resulting deflection of the specimen at midspan are measured.

5 Test machine

5.1 General

The machine shall comply with ISO 7500-1 and ISO 9513 and the requirements given in 5.2 to 5.4.

5.2 Test speed

The test machine shall be capable of maintaining the test speed (see 3.1), as specified in Table 1.

Table 1 — Recommended values of the test speed, v

Test speed, v mm/min	**Tolerance** %
1[a]	±20
2	±20
5	±20
10	±20
20	±10
50	±10
100	±10
200	±10
500	±10

[a] The lowest speed is used for specimens with thicknesses between 1 mm and 3,5 mm (see also 8.5).

5.3 Supports and loading edge

Two supports and a central loading edge shall be arranged as shown in Figure 2. The supports and the loading edge shall be parallel to within ±0,2 mm over the width of the test specimen.

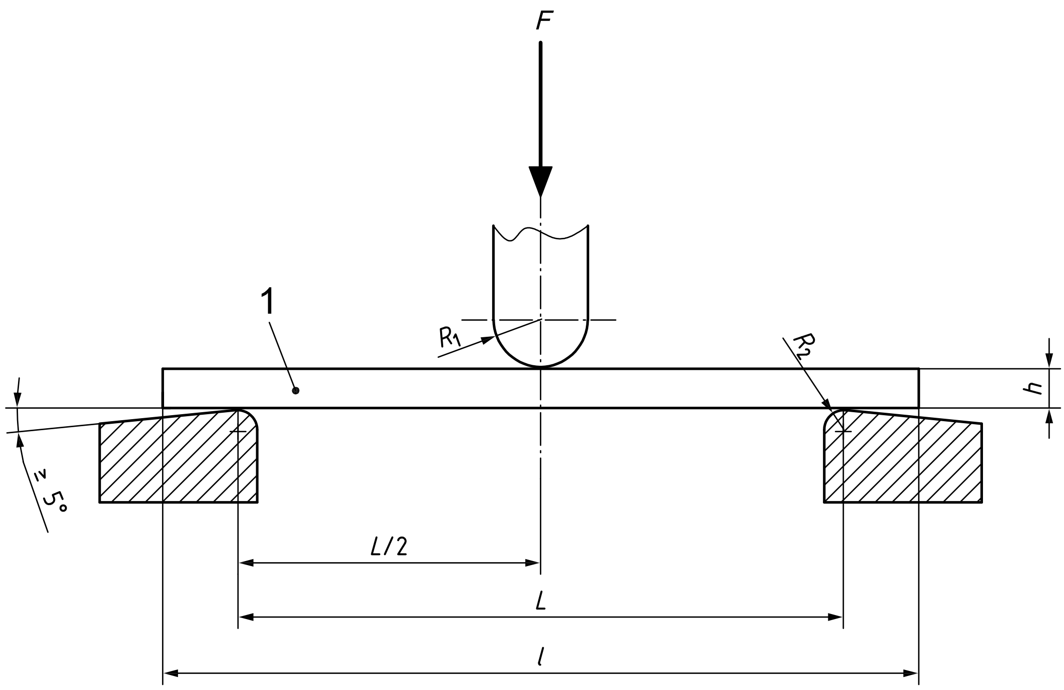
The radius, R_1, of the loading edge and the radius, R_2, of the supports shall be as follows:

R_1 = 5,0 mm ± 0,2 mm;

R_2 = 2,0 mm ± 0,2 mm for test specimen thicknesses $\leqslant$ 3 mm;

R_2 = 5,0 mm ± 0,2 mm for test specimen thicknesses $>$ 3 mm.

The span, L, shall be adjustable.



Key

1 test specimen

F applied force

R_1 radius of loading edge

R_2 radius of supports

h thickness of specimen

l length of specimen

L length of span between supports

Figure 2 — Position of test specimen at start of test

5.4 Force- and deflection-measuring systems

5.4.1 Force-measuring system

The force-measuring system shall comply with the requirements of class 1 as defined in ISO 7500-1.

5.4.2 Deflection-measuring system

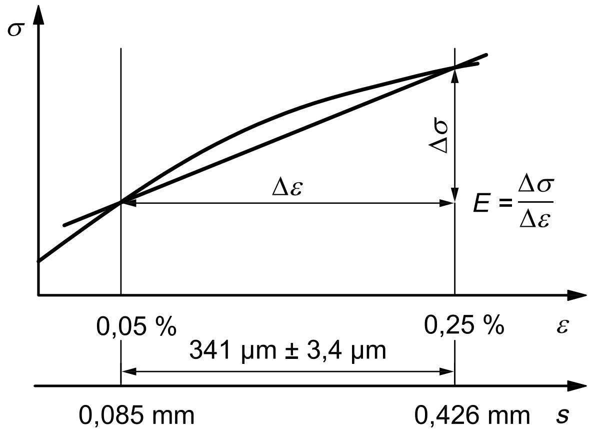
The deflection-measuring system shall comply with the requirements of class 1 as defined in ISO 9513. This shall be valid over the whole range of deflections to be measured. Non-contact systems may be used provided they meet the accuracy requirements stated above. The measurement system shall not be influenced by machine compliance.

When determining the flexural modulus, the deflection-measuring system shall be capable of measuring the change in deflection to an accuracy of 1 % of the relevant value or better, corresponding to ±3,4 μm for a support span, L, of 64 mm and a specimen thickness, h, of 4,0 mm (see Figure 3). Other support spans and specimen thicknesses will lead to different requirements for the accuracy of the deflection-measuring system.

Any deflection indicator capable of measuring deflection to the accuracy specified above is suitable.

NOTE The crosshead displacement includes not only the specimen deflection but also the indentation of the loading edge and the supports into the specimen and deformation of the machine. The last of these is machine-dependent as well as load-dependent. Results determined on different types of machine are therefore not comparable.

In general, measurement of crosshead displacement is not suitable for modulus determination unless a compliance correction is applied.



Key

σ flexural stress

ε flexural strain

s corresponding deflection for a specimen thickness of 4 mm and a span between supports of 64 mm

Figure 3 — Accuracy requirements for determination of flexural modulus

5.5 Equipment for measuring the width and thickness of the test specimens

5.5.1 Rigid materials

5.5.1.1 Specimen thickness

Measure the thickness using a micrometer, at points lying within ±2 mm of the centre of the specimen, in accordance with ISO 16012, but using a micrometer that has an accuracy of ±0,01 mm as opposed to the accuracy of ±0,02 mm specified in ISO 16012. The presser foot shall have a flat, circular contact face with a diameter of $\geqslant$ 4 mm and the anvil shall have a spherical contact face of radius 50 mm to avoid errors caused by misalignment with the test piece.

5.5.1.2 Specimen width

Measure the width in accordance with ISO 16012, using a micrometer that has an accuracy of ±0,02 mm as specified in ISO 16012. The presser foot shall have either a flat contact face which is circular with a diameter of 1 mm or a rectangular contact face with the side which will be parallel to the specimen thickness direction 1 mm long.

5.5.2 Flexible materials

Measure the dimensions of the test specimens in accordance with ISO 23529.

6 Test specimens

6.1 Shape and dimensions

6.1.1 General

The dimensions of the test specimens shall comply with the relevant material standard and, as applicable, with 6.1.2 or 6.1.3. Otherwise, the type of specimen shall be agreed between the interested parties.

6.1.2 Preferred specimen type

The dimensions, in millimetres, of the preferred test specimen are:

length, l: 80 ± 2

width, b: 10,0 ± 0,2

thickness, h: 4,0 ± 0,2

In any one test specimen, the thickness within the central third of the length shall not deviate by more than 2 % from its mean value. The width shall not deviate from its mean value within this part of the specimen by more than 3 %. The specimen cross section should preferably be rectangular, with no rounded edges, except as noted in 6.4.

The preferred specimen may be machined from the central part of a multipurpose test specimen complying with ISO 20753.

6.1.3 Other test specimens

When it is not possible or desirable to use the preferred test specimen, use a specimen with the dimensions given in Table 2.

NOTE Certain specifications require that test specimens from sheets of thickness greater than a specified upper limit be reduced to a standard thickness by machining one face only. In such cases, it is conventional practice to place the test specimen such that the original surface of the specimen is in contact with the two supports and the force is applied by the central loading edge to the machined surface of the specimen.

Table 2 — Values of specimen width, b, in relation to thickness, h

Dimensions in millimetres

Nominal thickness, h	**Width, b**[a] (±0,5)
$1 < h \leqslant 3$	25,0
$3 < h \leqslant 5$	10,0
$5 < h \leqslant 10$	15,0
$10 < h \leqslant 20$	20,0
$20 < h \leqslant 35$	35,0
$35 < h \leqslant 50$	50,0

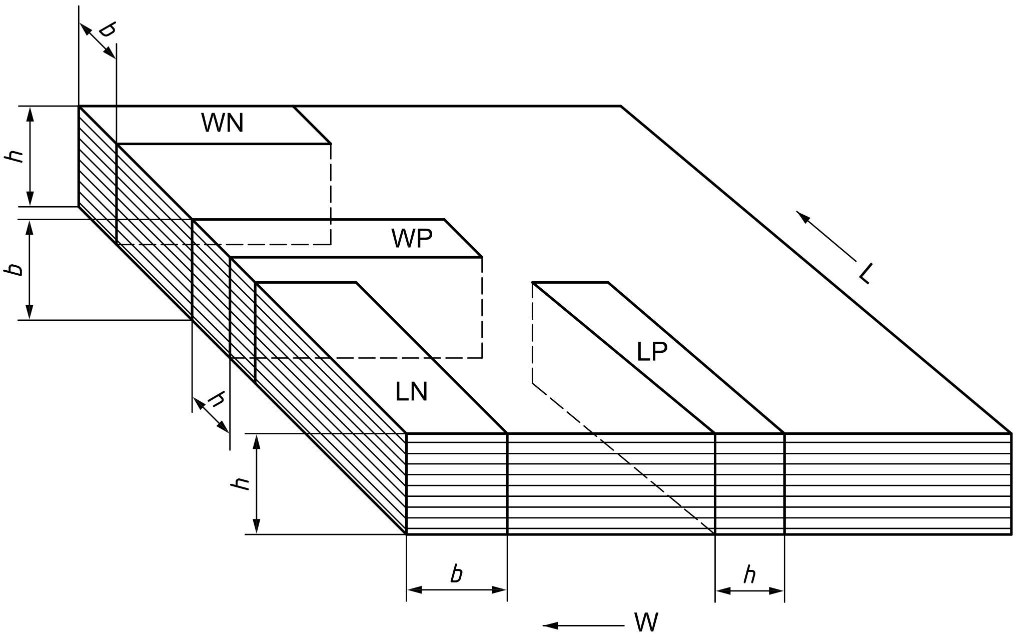
[a] For materials with very coarse fillers, the minimum width shall be 30 mm.

6.2 Anisotropic materials

6.2.1 In the case of materials having flexural properties that depend on direction, the test specimens shall be chosen so that the flexural stress will be applied in the same manner and direction as would be experienced in the end-use application, if known. The relationship between the test specimen and the end-product envisaged will determine the feasibility of using standard test specimens.

NOTE The position or orientation and the dimensions of the test specimens sometimes have a very significant influence on the test results.

6.2.2 When the material shows a significant difference (> 20 %) in flexural properties in two principal directions, it shall be tested in these two directions. The orientation of the test specimen relative to the principal directions shall be recorded (see Figure 4).



Key

L product length direction

W product width direction

Position of specimen	Direction of product	Direction of force
LN	Length	Normal
WN	Width	
LP	Length	Parallel
WP	Width	

Figure 4 — Position of test specimen in relation to product direction and direction of force

6.3 Preparation of test specimens

6.3.1 From moulding, extrusion and casting compounds

Specimens shall be prepared in accordance with the relevant material specification. When none exists, and unless otherwise specified, specimens shall be either directly compression-moulded in accordance with ISO 293 or ISO 295 or injection-moulded in accordance with ISO 294-1 or ISO 10724-1, as appropriate.

6.3.2 From sheets

Specimens shall be machined from sheets or from finished or semi-finished products in accordance with ISO 2818.

6.4 Specimen inspection

The specimens shall be free of twist and preferably have mutually perpendicular surfaces (see, however, the Note). All surfaces and edges shall be free from sink marks, scratches, pits and flash (see ISO 294-1:1996, Amendment 2:2005, Annex D).

The specimens shall be checked for conformity with these requirements by visual observation against a straight edge, carpenter's square or flat plate, and by measuring with micrometer calipers.

Specimens showing measurable or observable departure from one or more of these requirements shall be rejected or machined to proper size and shape before testing.

NOTE Injection-moulded test specimens usually have draft angles of between 1° and 2° to facilitate demoulding. Therefore the side faces in injection-moulded specimens will generally not be parallel. In addition, injection-moulded specimens are never absolutely free of sink marks. Furthermore, due to differences in the cooling history, the thickness at the centre of the specimen is generally smaller than at the edge.

6.5 Number of test specimens

6.5.1 At least five test specimens shall be tested in each direction of test (see Figure 4). The number of specimens may be more than five if greater precision of the mean value is required. It is possible to evaluate this by means of the confidence interval (95 % probability, see ISO 2602).

6.5.2 In the case of directly injection-moulded test specimens, at least five shall be tested.

It is recommended that specimens always be tested oriented in the same way, i.e. with the surface which was in contact with the cavity plate or that which was in contact with the fixed plate (see ISO 294-1 or ISO 10724-1, as appropriate) always in contact with the supports, in order to exclude the effects of any asymmetry generated by the moulding process.

6.5.3 The results from test specimens that rupture outside the central third of their span length shall be discarded and new test specimens tested in their place.

7 Atmosphere for conditioning and testing

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.

8 Procedure

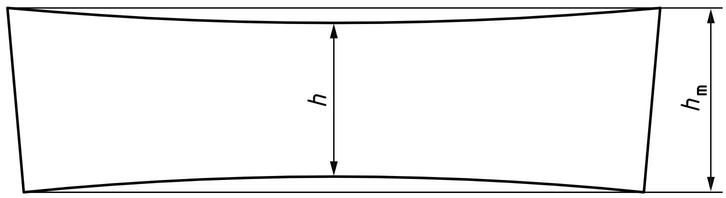
8.1 Measure the width, b, of the test specimens to the nearest 0,1 mm and the thickness, h, to the nearest 0,01 mm at the centre of the test specimens (see Note 1 and Figure 5). Calculate the mean thickness, $\bar{h}$, for the set of specimens.

NOTE 1 Injection-moulded test specimens are never exactly flat or rectangular in cross section. Measuring the thickness at the centre of the specimen gives the smallest value of the thickness.

Discard any specimens with a thickness exceeding the tolerance of ±2 % of the mean value and replace them by other specimens chosen at random.

A thickness difference, Δh, of up to 0,1 mm due to sink marks (see Figure 5) is acceptable. ISO 294-1:1996, Amendment 2:2005, D.1.2, gives guidance on how to adjust the hold pressure to minimize sink marks in injection-moulded specimens.

NOTE 2 For the purposes of this International Standard, the test specimen dimensions used to calculate flexural properties are measured at room temperature only. For the measurement of properties at other temperatures, therefore, the effects of thermal expansion are not taken into account.



Key

h_m largest thickness of test specimen in this cross section

h smallest thickness of test specimen in this cross section

Requirement: Δh (= $h_m - h$) $\leqslant$ 0,1 mm

Figure 5 — Cross section of injection-moulded test specimen showing sink marks and draft angle (exaggerated)

8.2 Adjust the span, L, to comply with the following equation:

$$L = (16 \pm 1)\,\bar{h} \tag{1}$$

and measure the resulting span to the nearest 0,5 %. For the preferred test specimen (see 6.1.2), the span is 64 mm.

Equation (1) shall be used except in the following cases:

a) For very thick and unidirectional fibre-reinforced specimens, use a span length based on a higher value of the ratio $L/\bar{h}$ if necessary to avoid delamination in shear.

   NOTE Values of $L/\bar{h}$ of up to 60 might be necessary in such cases.

b) For very thin specimens with an expected modulus below 700 MPa (the limit between rigid and non-rigid plastics — see 3.12), use a span length based on a lower value of the ratio $L/\bar{h}$ if necessary to enable measurements to be made within the working range of the test machine.

   A value of $L/\bar{h}$ of 8 is recommended in such cases.

c) For soft thermoplastics with an expected modulus below 700 MPa (the limit between rigid and non-rigid plastics — see 3.12), use a span length based on a higher value of the ratio $L/\bar{h}$ if necessary to prevent indentation of the supports into the test specimen.

   A value of $L/\bar{h}$ of 32 is recommended in such cases.

8.3 Do not load the specimen substantially prior to testing. A small load shall be applied, however, to avoid a curved region at the start of the stress/strain diagram. For modulus measurement, the flexural stress in the specimen at the start of a test, σ_{f0} (see Figure 6), shall be positive and shall lie within the range

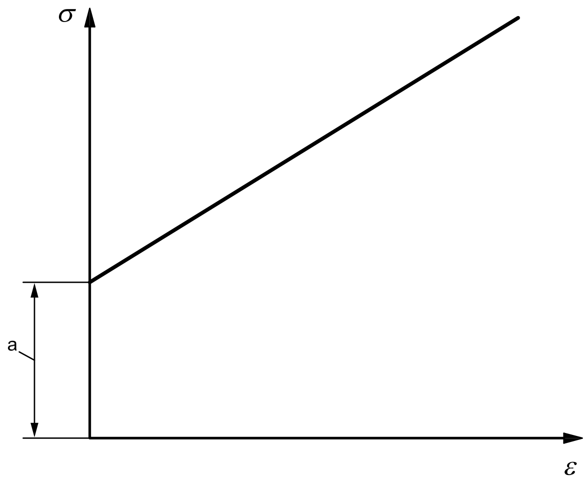
$$0 < \sigma_{f0} \leqslant 5 \times 10^{-4} E_f \tag{2}$$

which corresponds to a prestrain of $\varepsilon_{f0} \leqslant 0,05$ %, and, when measuring characteristics such as σ_{fM}, σ_{fC} or σ_{fB}, it shall lie within the range

$$0 < \sigma_{f0} \leqslant 10^{-2}\sigma_{fX} \tag{3}$$

where X stands for M, B or C.

NOTE The measured flexural modulus of strongly viscoelastic, ductile materials like polyethylene, polypropylene and polyamides containing a certain level of moisture depends markedly on the preload.



a $\leqslant 5 \times 10^{-4} E_f$ or $\leqslant 10^{-2}\sigma_f$.

Figure 6 — Example of a stress/strain curve obtained after application of a preload

8.4 Place the test specimen symmetrically on the two supports, at right angles to the loading edge and the supports, and apply the preload (see 8.3) at midspan as shown in Figure 2. For preloading, a crosshead speed of 1 mm/min is recommended. When the preload has been reached, set the deflection measurement system to zero.

8.5 For modulus determination, set the test speed in accordance with the standard for the material being tested. In the absence of this information, select a value from Table 1 that gives a flexural-strain rate as near as possible to 1 %/min. This gives a test speed of 2 mm/min for the preferred test specimen specified in 6.1.2. The test speed required to give a specified flexural strain rate can be calculated using Equation (4).

$$v = \frac{rL^2}{600h} \tag{4}$$

where

v is the test speed, in millimetres per minute;

r is the flexural strain rate, in percent per minute;

L is the span, in millimetres;

h is the thickness, in millimetres, of the test specimen.

8.6 Start the test within 1 min of reaching the preload, using the test speed specified/selected for modulus determination (see 8.5). After reaching the end of the modulus determination region ($0,05\ \% \leqslant \varepsilon \leqslant 0,25\ \%$), continue the test as specified in method A (see 8.7) or method B (see 8.8).

8.7 Method A (determination of the flexural-stress/flexural-strain curve using only one test speed): Continue to record the force and the specimen deflection without interruption, using the same test speed as that used over the modulus determination region (see 8.5).

8.8 Method B (determination of the flexural-stress/flexural-strain curve using two test speeds): After recording the data in the modulus determination region (see 8.6), either unload the specimen and restart using a higher speed appropriate to the material or change to the higher speed directly (without unloading the specimen). Use as the higher speed the speed specified in the standard for the material being tested. In the absence of this information, select a value from Table 1 that gives a flexural-strain rate as near as possible to 5 %/min or 50 %/min. This gives a test speed of 10 mm/min or 100 mm/min for the preferred test specimen specified in 6.1.2. Use 10 mm/min for materials that break without giving a pronounced stress maximum and 100 mm/min for all other materials.

NOTE 1 This is equivalent to the procedure used in tensile testing, where the test speeds utilized are 1 mm/min for modulus determination and 5 mm/min or 50 mm/min for other tensile properties at strains larger than 0,25 % (see ISO 10350-1[5]).

NOTE 2 In tensile tests, a tenfold increase in crosshead speed (from 5 mm/min to 50 mm/min) has been shown to lead to an increase of 8 % in the yield stress measured. The effect of changes in test speed on the results of flexural tests are given in Annex B.

8.9 Record the force and the corresponding deflection of the specimen during the test, using, if practicable, an automatic recording system that yields a complete flexural-stress/deflection curve for this operation [see 9.1, Equation (5)]. Determine all relevant stresses, deflections and strains defined in Clause 3 from a force/deflection or stress/deflection curve or equivalent data.

9 Calculation and expression of results

9.1 Flexural stress

Calculate the flexural-stress parameters defined in Clause 3 using the following equation:

$$\sigma_f = \frac{3FL}{2bh^2} \tag{5}$$

where

σ_f is the flexural-stress parameter in question;

F is the applied force, in newtons;

L is the span, in millimetres;

b is the width, in millimetres, of the specimen;

h is the thickness, in millimetres, of the specimen.

9.2 Flexural strain

Calculate the flexural-strain parameters defined in Clause 3 using one of the following equations:

$$\varepsilon_f = \frac{6sh}{L^2} \tag{6}$$

$$\varepsilon_f = \frac{600sh}{L^2} \% \tag{7}$$

where

ε_f is the flexural strain parameter in question, expressed as a dimensionless ratio or as a percentage;

s is the deflection, in millimetres;

h is the thickness, in millimetres, of the test specimen;

L is the span, in millimetres.

9.3 Flexural modulus

To determine the flexural modulus, calculate the deflections s_1 and s_2 corresponding to the given values of the flexural strain ε_{f1} = 0,000 5 and ε_{f2} = 0,002 5 using the following equation:

$$s_i = \frac{\varepsilon_{fi} L^2}{6h} \qquad (i = 1 \text{ or } 2) \tag{8}$$

where

s_i is one of the deflections, in millimetres;

ε_{fi} is the corresponding flexural strain, whose values ε_{f1} and ε_{f2} are given above;

L is the span, in millimetres;

h is the thickness, in millimetres, of the specimen.

Calculate the flexural modulus, E_f, expressed in megapascals, using the following equation:

$$E_f = \frac{\sigma_{f2} - \sigma_{f1}}{\varepsilon_{f2} - \varepsilon_{f1}} \tag{9}$$

where

σ_{f1} is the flexural stress, in megapascals, measured at deflection s_1;

σ_{f2} is the flexural stress, in megapascals, measured at deflection s_2.

All equations referring to flexural properties hold exactly for linear stress/strain behaviour only (see 1.7); thus, for most plastics, they are accurate at small deflections only. The equations given may, however, be used for comparison purposes.

With computer-aided equipment, the determination of the modulus, E_f, using two distinct stress/strain points may be replaced by a linear-regression procedure applied to the part of the curve between these two points.

9.4 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.

9.5 Significant figures

Calculate the stresses and the modulus to three significant figures. Calculate the deflections to two significant figures.

10 Precision

See Annex A.

11 Test report

The test report shall include the following information:

a) a reference to this International Standard;

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

c) for sheets, the thickness of the sheet and, if applicable, the direction of the major axes of the specimens in relation to some feature of the sheet (for anisotropic material, the direction of testing shall be noted);

d) the shape and dimensions of the test specimens;

e) the method of preparing the specimens;

f) the test conditions and conditioning procedures, if applicable;

g) the number of specimens tested;

h) the nominal span used;

i) the method (A or B) and the test speed(s) used;

j) the accuracy grading of the test machine (see 5.4);

k) the surface on which the force was applied;

l) the individual test results, if required;

m) the mean values of the individual results;

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

o) the date of the test.

Annex A
(informative)

Precision statement

A.1 Tables A.1 and A.2 are based on a round-robin test performed in accordance with ASTM E691[8]. All materials were sampled and distributed by one source. Each "test result" was the average of five individual determinations. Each laboratory obtained and reported two test results for each material.

A.2 Table A.1 is based on a round robin involving nine laboratories and four materials and Table A.2 is based on a round robin involving eleven laboratories and four materials.

The following explanations of r and R (see Clause A.3) are only intended to present a meaningful way of considering the *approximate* precision of this test method. The data in Tables A.1 and A.2 should not be rigorously applied to acceptance or rejection of material, as those data are specific to the round robin and might not be representative of other lots, conditions, materials or laboratories. Users of this test method should apply the principles of ASTM E691 to generate data specific to their laboratory and materials, or between specific laboratories. The principles of Clause A.3 would then be valid for such data.

A.3 Concept of r and R in Tables A.1 and A.2: If s_r and s_R have been calculated from a large enough body of data, and for test results that were averages from testing five specimens for each test result, then:

a) **Repeatability:** Two test results obtained within one laboratory should be judged not equivalent if they differ by more than the r-value for that material, r being the interval representing the critical difference between two test results for the same material, obtained by the same operator using the same equipment in the same laboratory.

b) **Reproducibility:** Two test results obtained by different laboratories should be judged not equivalent if they differ by more than the R-value for that material, R being the interval representing the critical difference between two test results for the same material, obtained by different operators using different equipment in different laboratories.

c) The judgments in a) and b) will have an approximately 95 % (0,95) probability of being correct.

Table A.1 — Precision data for flexural stress at a conventional deflection of 3,5 %

Values in megapascals

Material	Average	s_r	s_R	r	R
Polycarbonate	70,5	0,752	1,99	2,11	5,58
ABS	72,1	0,382	2,67	1,07	7,49
PE-HD	20,4	0,129	0,505	0,36	1,42
PSU-GF	156[a]	1,65	3,13	4,62	8,75

NOTE For the meanings of the algebraic symbols used, see Table A.2.

[a] For PSU-GF, the flexural strength was measured.

Table A.2 — Precision data for flexural modulus

Values in megapascals

Material	Average	s_r	s_R	r	R
Polycarbonate	2 310	45,6	146	128	410
ABS	2 470	33,6	157	94,0	439
PE-HD	1 110	15,0	94,4	41,9	264
PSU-GF	8 510	83,5	578	234	1 618

s_r = within-laboratory standard deviation

s_R = between-laboratory standard deviation

r = 95 % repeatability limit (= $2,8s_r$)

R = 95 % reproducibility limit (= $2,8s_R$)

Annex B
(informative)

Influence of changes in test speed on the measured values of flexural properties

Acrylonitrile-styrene-acrylate plastic, ASA				
Crosshead speed mm/min	E MPa	σ (3,5%) MPa	σ (max.) MPa	ε (max.) %
2	2 700	83	87	5,1
10	2 730	85	92	5,2
100	2 710	91	102	5,6
	Increase (relative to 2 mm/min crosshead speed)			
2		100 %	100 %	100 %
10		103 %	105 %	102 %
100		110 %	117 %	110 %
Poly(butylene terephthalate) with 30 % glass fibre, PBT-GF30				
Crosshead speed mm/min	E MPa		σ (max.) MPa	ε (max.) %
2	10 061		212	2,57
10	10 104		226	2,69
100	10 086		238	2,75
	Increase (relative to 2 mm/min crosshead speed)			
2			100 %	100 %
10			107 %	105 %
100			112 %	107 %

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[1] ISO 472, *Plastics — Vocabulary*

[2] ISO 527-2, *Plastics — Determination of tensile properties — Part 2: Test conditions for moulding and extrusion plastics*

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[5] ISO 10350-1, *Plastics — Acquisition and presentation of comparable single-point data — Part 1: Moulding materials*

[6] ISO 10350-2, *Plastics — Acquisition and presentation of comparable single-point data — Part 2: Long-fibre-reinforced plastics*

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[8] ASTM E691, *Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method*

ICS 83.080.01
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