INTERNATIONAL STANDARD

# ISO 178

Third edition
1993-05-15

# Plastics — Determination of flexural properties

*Plastiques — Détermination des propriétés en flexion*



Reference number
ISO 178:1993(E)

## 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.

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.



International Standard ISO 178 was prepared by Technical Committee ISO/TC 61, *Plastics*, Sub-Committee SC 2, *Mechanical properties*.

This third edition cancels and replaces the second edition (ISO 178:1975), which has been improved in the following ways:



— normative references have been added especially for specimen preparation and the use of multipurpose test specimens complying with ISO 3167;

— a definition of modulus is given;

— one strain rate only is recommended;

— designation of quantities has been harmonized with those of other International Standards for testing plastics, in accordance with ISO 31.



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# Plastics — Determination of flexural properties

## 1 Scope

**1.1** This International Standard specifies a method for determining the flexural properties of 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 testing speeds is included.

**1.2** The method is used to investigate the flexural behaviour of the test specimens and for determining 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:

- thermoplastics moulding and extrusion materials, including filled and reinforced compounds in addition to unfilled types; rigid thermoplastics sheets;
- thermosetting moulding materials, including filled and reinforced compounds; thermosetting sheets, including laminates;
- fibre-reinforced thermoset and thermoplastics composites, incorporating unidirectional or non-unidirectional reinforcements such as mat, woven fabrics, woven rovings, chopped strands, combination and hybrid reinforcements, rovings and milled fibres; sheets made from pre-impregnated materials (prepregs);
- thermotropic liquid-crystal polymers.

The method is not normally suitable for use with rigid cellular materials and sandwich structures containing cellular material.

NOTE 1 For certain types of textile-fibre-reinforced plastics, a four-point bending test is preferred. This is currently under consideration in ISO.

**1.4** The method is performed using specimens which may be either moulded to the chosen dimensions, machined from the central portion of a standard multi-purpose test specimen (see ISO 3167) or machined from finished and semi-finished products such as mouldings, laminates and extruded or cast sheet.

**1.5** The method specifies 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, may produce results which are not comparable. Other factors, such as the speed of testing and the conditioning of the specimens, can also influence the results. Consequently, when comparative data are required, these factors must be carefully controlled and recorded.

**1.6** Flexural properties can only be used for engineering design purposes for materials with linear stress/strain behaviour. For non-linear material behaviour the flexural properties are only nominal. The bending test should preferentially be used with brittle materials, for which tensile tests are difficult.

## 2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 291:1977, *Plastics — Standard atmospheres for conditioning and testing.*

ISO 293:1986, *Plastics — Compression moulding test specimens of thermoplastic materials.*

ISO 294:—[1], *Plastics — Injection moulding of test specimens of thermoplastic materials.*

ISO 295:1991, *Plastics — Compression moulding of test specimens of thermosetting materials.*

ISO 1209-1:1990, *Cellular plastics, rigid — Flexural tests — Part 1: Bending test.*

ISO 1209-2:1990, *Cellular plastics, rigid — Flexural tests — Part 2: Determination of flexural properties.*

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

ISO 2557-1:1989, *Plastics — Amorphous thermoplastics — Preparation of test specimens with a specified maximum reversion — Part 1: Bars.*

ISO 2557-2:1986, *Plastics — Amorphous thermoplastics — Preparation of test specimens with a specified reversion — Part 2: Plates.*

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

ISO 2818:—[2], *Plastics — Preparation of test specimens by machining.*

ISO 3167:—[3], *Plastics — Multipurpose test specimens.*

ISO 5893:1985, *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 speed of testing,** $v$**:** Rate of relative movement between the supports and the striking edge, expressed in millimetres per minute (mm/min).

**3.2 flexural stress,** $\sigma_f$**:** Nominal stress of the outer surface of the test specimen at midspan.

It is calculated according to the relationship given in 9.1, equation (3), and is expressed in megapascals (MPa).

**3.3 flexural stress at break,** $\sigma_{fB}$**:** Flexural stress at break of the test specimen (see figure 1, curves a and b).

It is expressed in megapascals (MPa).

**3.4 flexural strength,** $\sigma_{fM}$**:** Maximum flexural stress sustained by the test specimen during a bending test (see figure 1, curves a and b).

It is expressed in megapascals (MPa).

**3.5 flexural stress at conventional deflection,** $\sigma_{fc}$**:** Flexural stress at the conventional deflection $s_C$ according to 3.7 (see figure 1, curve c).

It is expressed in megapascals (MPa).

**3.6 deflection,** $s$**:** Distance over which the top or bottom surface of the test specimen at midspan has deviated during flexure from its original position.

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.

It is expressed in millimetres (mm).

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



**3.8 flexural strain,** $\varepsilon_f$**:** Nominal fractional change in length of an element of the outer surface of the test specimen at midspan.

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



It is calculated according to the relationship given in 9.2, equation (4).

**3.9 flexural strain at break,** $\varepsilon_{fB}$**:** Flexural strain at break of the test specimen (see figure 1, curves a and b).

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

**3.10 flexural strain at flexural strength,** $\varepsilon_{fM}$**:** Flexural strain at maximum flexural stress (see figure 1, curves a and b).

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 values $(\varepsilon_{f2} = 0{,}002\,5) - (\varepsilon_{f1} = 0{,}000\,5)$ [see 9.2, equation (5)].

It is expressed in megapascals (MPa).

1) To be published. (Revision of ISO 294:1975)

2) To be published. (Revision of ISO 2818:1980)

3) To be published. (Revision of ISO 3167:1983)

NOTES

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

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

## 4 Principle

The test specimen, supported as a beam, is deflected at constant rate at the midspan until the specimen fractures or until the deformation reaches some predetermined value. During this procedure the force applied to the specimen is measured.

## 5 Apparatus

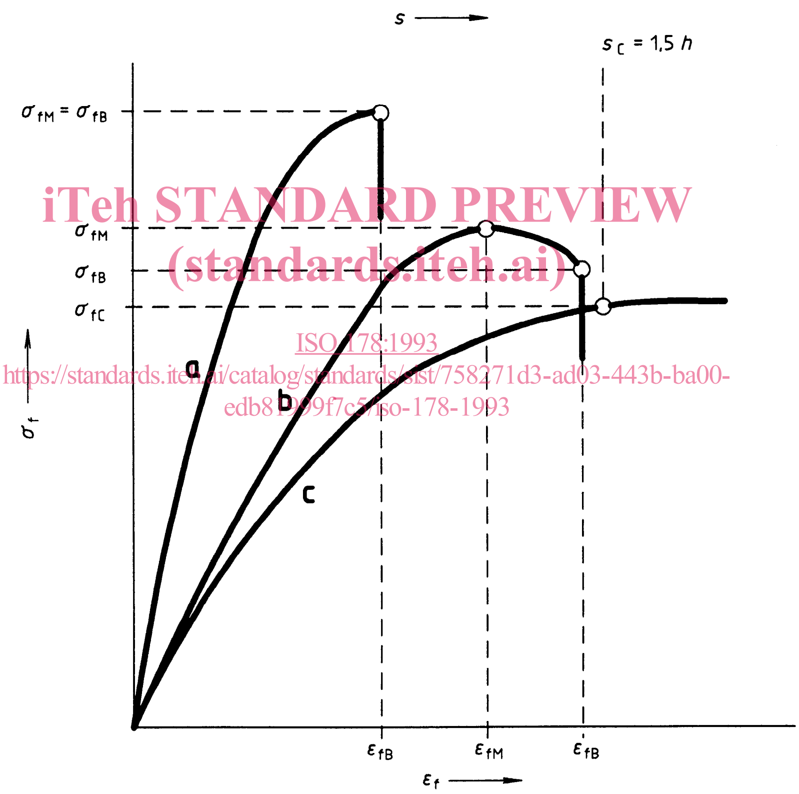
### 5.1 Testing machine

#### 5.1.1 General

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

#### 5.1.2 Speed of testing

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






Curve a Specimen that breaks before yielding

Curve b Specimen that shows a maximum and then breaks before the conventional deflection $s_C$

Curve c Specimen that neither has a yield point nor breaks before the conventional deflection $s_C$

**Figure 1 — Typical curves of flexural stress $\sigma_f$ versus flexural strain $\varepsilon_f$ and deflection $s$**

**Table 1 — Recommended values for the speed of testing**

| Speed<br>mm/min | Tolerance<br>% |
|---|---|
| 1 [1)] | ± 20 [2)] |
| 2 | ± 20 [2)] |
| 5 | ± 20 |
| 10 | ± 20 |
| 20 | ± 10 |
| 50 | ± 10 |
| 100 | ± 10 |
| 200 | ± 10 |
| 500 | ± 10 |

1) The lowest speed is used for specimens with thicknesses between 1 mm and 3,5 mm, see 8.3.

2) The tolerances on the speeds 1 mm/min and 2 mm/min are lower than indicated in ISO 5893.

#### 5.1.3 Supports and striking edge

Two supports and a central striking edge are arranged according to figure 2. The parallel alignment of the supports and the striking edge shall lie within ± 0,02 mm.

The radius $R_1$ of the striking edge and the radius $R_2$ of the supports shall be as follows:

$R_1 = 5{,}0$ mm ± 0,1 mm

$R_2 = 2{,}0$ mm ± 0,2 mm for thicknesses of the test specimen $\leqslant 3$ mm, and

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

The span $L$ shall be adjustable.

#### 5.1.4 Indicators for load and deflection

The error for the indicated force shall not exceed 1 %, and the error for the indicated deflection shall not exceed 1 % of full scale (see ISO 5893).

### 5.2 Micrometers and gauges

**5.2.1 Micrometer**, or equivalent, reading to $\leqslant$ 0,01 mm (for measuring the thickness $h$ and width $b$ of the test specimen, see figure 3).

**5.2.2 Vernier caliper**, or equivalent, accurate to within ± 0,1 % of the span $L$, for determining the span (see 8.2 and figure 2).

## 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.



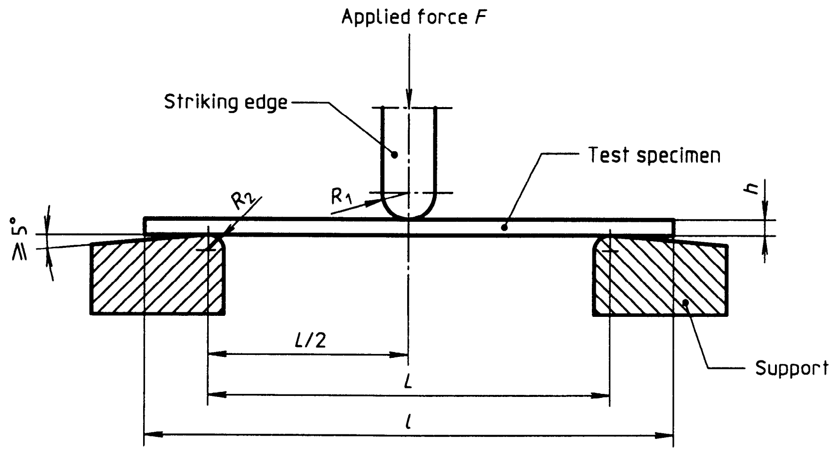



**Figure 2 — Position of test specimen at the start of the test**

### 6.1.2 Preferred specimen type

The preferred dimensions, in millimetres, shall be

| | |
|---|---|
| length: | $l = 80 \pm 2$ |
| width: | $b = 10{,}0 \pm 0{,}2$ |
| thickness: | $h = 4{,}0 \pm 0{,}2$ |

In any one test specimen, the thickness within the central third of the length shall nowhere deviate by more than 2 % from its mean value. The corresponding maximum deviation for width is 3 %. The cross-section shall be rectangular, with no rounded edges.

NOTE 4 The preferred specimen may be machined from the central part of a multi-purpose test specimen complying with ISO 3167.

### 6.1.3 Other test specimens

When it is not possible or desirable to use the preferred test specimen, the following limits shall apply.

The length and thickness of the test specimen shall be in the same ratio as in the preferred test specimen, i.e.:

$$\frac{l}{h} = 20 \pm 1 \qquad \ldots (1)$$

unless affected by the provisions of 8.2 a), 8.2 b) or 8.2 c).

NOTE 5 Certain specifications require that test specimens from sheets of thickness greater than a specified upper limit shall 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 striking edge to the machined surface of the specimen.

The values of applicable width given in table 2 shall be used.

## 6.2 Anisotropic materials

**6.2.1** In the case of materials having physical properties that depend on direction, e.g. elasticity, the test specimens shall be chosen so that the flexural stress in the test procedure will be applied in the same direction as that to which products (moulded articles, sheets, tubes, etc.) will be subjected in service. The relationship of the test specimen to the application will determine the possibility of using standard test specimens (see 6.1 and 8.2).

**Table 2 — Values for the width, $b$, in relation to the thickness $h$**

Dimensions in millimetres

<table>
<tr><th rowspan="2">Nominal thickness, h</th><th colspan="2">Width b ± 0,5 1)</th></tr>
<tr><th>Moulding and extrusion compounds, thermoplastic and thermosetting sheets</th><th>Textile and long-fibre-reinforced plastics materials</th></tr>
<tr><td>1 < h ⩽ 3</td><td>25,0</td><td rowspan="3">15,0</td></tr>
<tr><td>3 < h ⩽ 5</td><td>10,0</td></tr>
<tr><td>5 < h ⩽ 10</td><td>15,0</td></tr>
<tr><td>10 < h ⩽ 20</td><td>20,0</td><td>30,0</td></tr>
<tr><td>20 < h ⩽ 35</td><td>35,0</td><td>50,0</td></tr>
<tr><td>35 < h ⩽ 50</td><td>50,0</td><td>80,0</td></tr>
<tr><td colspan="3">1) For materials with very coarse fillers, the minimum width shall be 20 mm to 50 mm.</td></tr>
</table>

NOTE 6 The position or orientation and the dimensions of the test specimens sometimes have a very significant influence on the test results. This is particularly true for laminates.



**6.2.2** When the material shows a significant difference in flexural properties in two principal directions, it shall be tested in these two directions. The orientation of the test specimens relative to the principal directions shall be recorded (see figure 3).

NOTE 7 If, because of the application, this material is subjected to stress at some specific orientation to the principal direction, it is desirable to test the material in that orientation.

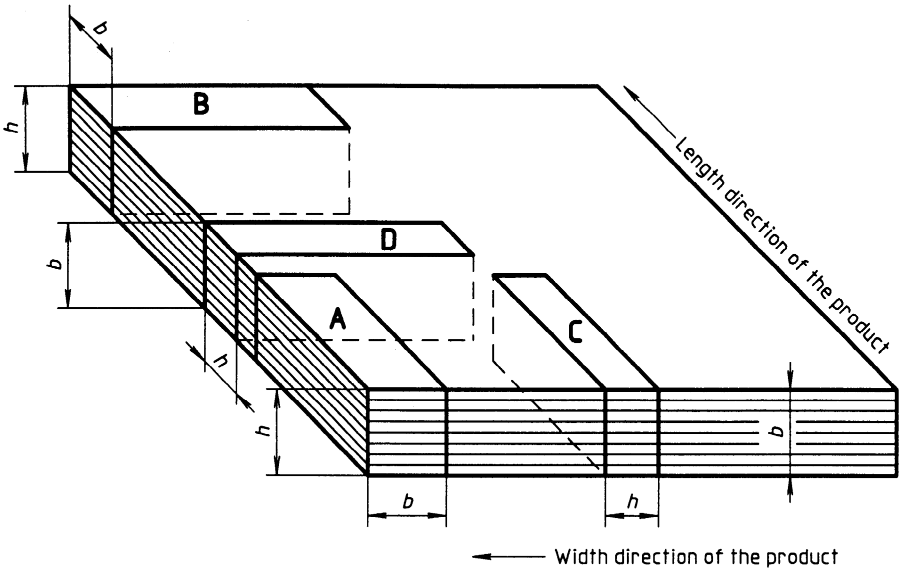
## 6.3 Preparation of test specimens

### 6.3.1 Moulding or extrusion compounds

Specimens shall be prepared in accordance with the relevant material specification. When none exists, or unless otherwise specified, specimens shall be either directly compression moulded or injection moulded from the material in accordance with ISO 293, ISO 294, ISO 295, ISO 2557-1 or ISO 2557-2, as appropriate.

### 6.3.2 Sheets

Specimens shall be machined from sheets in accordance with ISO 2818.




| Position of specimen | Direction of product | Direction of force |
|---|---|---|
| A<br>B | length<br>width | normal |
| C<br>D | length<br>width | parallel |



**Figure 3 — Position of test specimen in relation to direction of product and direction of force**

### 6.3.3 Long-fibre-reinforced plastics materials

A panel of the material shall be prepared in accordance with ISO 1268 or another specified or agreed-upon preparation procedure. Specimens shall be machined in accordance with ISO 2818.

## 6.4 Checking

The specimens shall be free of twist and shall have mutually perpendicular parallel surfaces. The surfaces and edges shall be free from scratches, pits, sink marks and flash.

The specimens shall be checked for conformity with these requirements by visual observation against straightedges, squares and flat plates, 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.

## 6.5 Number of test specimens

**6.5.1** At least five test specimens shall be tested in each direction of test, see figure 3. 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 confidence interval (95 % probability, see ISO 2602).

**6.5.2** 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 Conditioning

The test specimens shall be conditioned as specified in the standard for the material 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.

## 8 Procedure

**8.1** Conduct the test in the atmosphere specified in the standard for the material 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.

**8.2** Measure the width $b$ of the test specimens to the nearest 0,1 mm and the thickness $h$ to the nearest 0,01 mm in the centre of the test specimens. Calculate the mean thickness $\bar{h}$ for the set of specimens.

Discard any specimen(s) with a thickness exceeding the tolerance of ± 0,5 % of the mean value and replace it by another specimen chosen at random.

Adjust the span $L$ to comply with the following equation:

$$L = (16 \pm 1)\bar{h} \qquad \ldots (2)$$

and measure the resulting span to the nearest 0,5 %.



Equation (2) shall be used except in the following cases.

a) For very thick and unidirectional fibre-reinforced test specimens, if necessary to avoid delamination in shear, use a distance between supports calculated on a higher ratio of $L/\bar{h}$.

b) For very thin test specimens, if necessary to enable measurements to be made within the load capacity of the testing machine, use a span length calculated on a lower ratio of $L/\bar{h}$.

c) For soft thermoplastics, if necessary to prevent indentation of the supports into the test specimen, use a larger ratio for $L/\bar{h}$.

**8.3** Set the speed of testing according to the standard for the material being tested. In the absence of this information, select a value from table 1 that gives a strain rate as near as possible to 1 % per minute. This gives a testing speed that produces the deflection closest to 0,4 times the specimen thickness in 1 min, e.g. 2 mm/min for the preferred specimen complying with 6.1.2.

**8.4** Place the test specimen symmetrically on the two supports and apply the force at midspan (see figure 2).

**8.5** 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 (3)].

Determine all relevant stresses, deflections and strains defined in clause 4 from a force/deflection or a stress/deflection curve or equivalent data.

## 9 Calculation and expression of results

### 9.1 Flexural stress

Calculate the flexural stress $\sigma_f$, expressed in megapascals, using the following equation:

$$\sigma_f = \frac{3FL}{2bh^2} \qquad \ldots (3)$$

where

$F$ 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 modulus

For the measurement of the flexural modulus, calculate the deflections $s_1$ and $s_2$, which correspond to the given values of flexural strain $\varepsilon_{f1} = 0{,}000\,5$ and $\varepsilon_{f2} = 0{,}002\,5$, by the following equation:

$$s_i = \frac{\varepsilon_{fi} L^2}{6h} \quad (i = 1;2) \qquad \ldots (4)$$

where

$s_i$ is an individual deflection, in millimetres;

$\varepsilon_{fi}$ is the corresponding flexural strain, whose values $\varepsilon_{f1}$ and $\varepsilon_{f2}$ 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:

$$E_f = \frac{\sigma_{f2} - \sigma_{f1}}{\varepsilon_{f2} - \varepsilon_{f1}} \qquad \ldots (5)$$