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Plastics — Determination of flexural properties

Plastiques — Détermination des propriétés en flexion

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties*.

This sixth edition cancels and replaces the fifth edition (ISO 178:2010), which has been technically revised. It also incorporates the Amendment ISO 178:2010/Amd.1:2013. The main changes compared to the previous edition are as follows:

— differentiating calibration requirements according to the type of test;

— the introduction of deflectometers;

— the reinstatement of procedures for compliance correction;

— the addition of a new Annex D showing the relation between tensile and flexural modulus.

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

Plastics — Determination of flexural properties

1 Scope

This document specifies a method for determining the flexural properties of rigid and semi-rigid plastics under defined conditions. A preferred test specimen is defined, but parameters are included for alternative specimen sizes for use where appropriate. A range of test speeds is included.

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).

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 document applies to fibre-reinforced compounds with fibre lengths ≤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 1 For certain types of textile-fibre-reinforced plastic, a four-point bending test is used. This is described in ISO 14125.

The method is performed using specimens which can 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.

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

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

2 Normative references

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

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

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

ISO 294-1:2017, *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 — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system*

ISO 9513, *Metallic materials — Calibration of extensometer systems 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*

3 Terms, definitions and symbols

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

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

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

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

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

Note 1 to entry: 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 1 to entry: It is calculated from the relationship given in Formula (5).

Note 2 to entry: It is expressed in megapascals (MPa).

3.3
flexural stress at break
σ_{fB}
flexural stress at break of the test specimen

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: See Figure 1, curves a and b.

3.4
flexural strength
σ_{fM}
maximum *flexural stress* (3.2) sustained by the test specimen during a bending test

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: See Figure 1, curves a and b.

3.5
flexural stress at conventional deflection
σ_{fc}
flexural stress at the *conventional deflection*, s_C (3.7)

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: See also Figure 1, curve c.

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

3.7
conventional deflection
s_C
deflection (3.6) equal to 1,5 times the thickness, h, of the test specimen

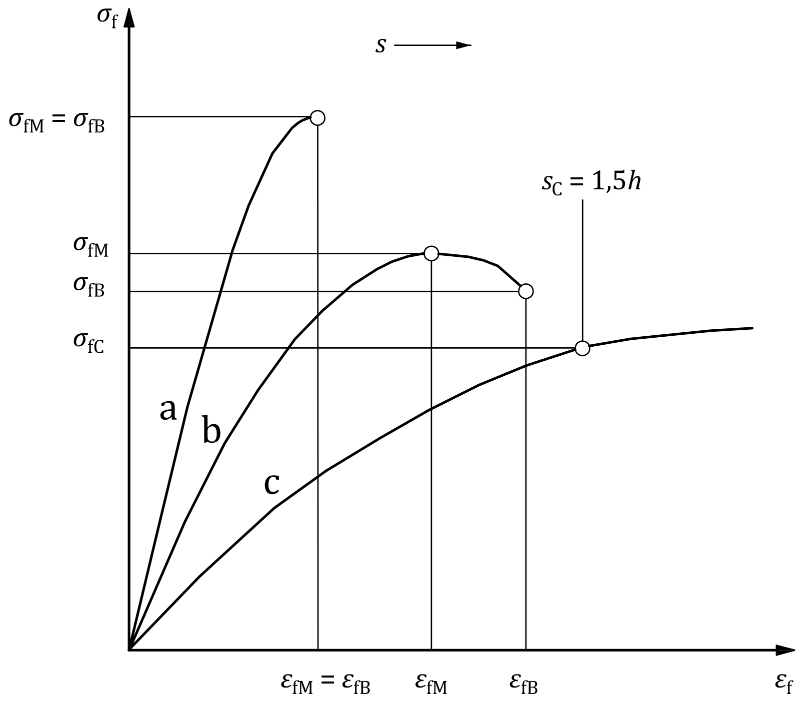
Note 1 to entry: It is expressed in millimetres (mm).

Note 2 to entry: Using a span, L, of $16h$, the conventional deflection corresponds to a *flexural strain* (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 to entry: It is expressed as a dimensionless ratio or a percentage (%).

Note 2 to entry: It is calculated in accordance with the relationships given in Formulae (6) and (7).



Key

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

Note 1 to entry: It is expressed as a dimensionless ratio or a percentage (%).

Note 2 to entry: See Figure 1, curves a and b.

3.10
flexural strain at flexural strength
ε_{fM}
flexural strain at maximum flexural stress

Note 1 to entry: It is expressed as a dimensionless ratio or a percentage (%).

Note 2 to entry: See Figure 1, curves a and b.

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)

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: The flexural modulus is only an approximate value of Young's modulus.

Note 3 to entry: See Formula (9).

3.12
rigid plastic
plastic that has a *modulus of elasticity in flexure* (3.11) or, if that is not applicable, then in tension, greater than 700 MPa under a given set of conditions

[SOURCE: ISO 472:2013, 2.884, modified — Note to entry has been omitted.]

3.13
semi rigid plastic
plastic that has a *modulus of elasticity in flexure* (3.11) or, if that is not applicable, then in tension, between 70 MPa and 700 MPa under a given set of conditions

[SOURCE: ISO 472:2013, 2.909, modified — Note to entry has been omitted.]

3.14
span between specimen supports
L
distance between the points of contact between the test specimen and the test specimen supports

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

Note 2 to entry: See Figure 2.

3.15
flexural strain rate
r
rate at which the *flexural strain* (3.8) increases during a test

Note 1 to entry: It is expressed in percent per minute ($\% \cdot \text{min}^{-1}$).

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.

This document specifies two methods: method A and method B. Method A 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.

NOTE 1 The strain rates mentioned above are to be interpreted as nominal ones. Nominal test speeds are calculated using Formula (4). For the machine settings the best fitting ones are selected from Table 1.

NOTE 2 For materials exhibiting nonlinear stress/strain behaviour, the flexural properties are only nominal. The formulae 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.

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, 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 ≤3 mm;

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

The span, *L*, shall be adjustable.

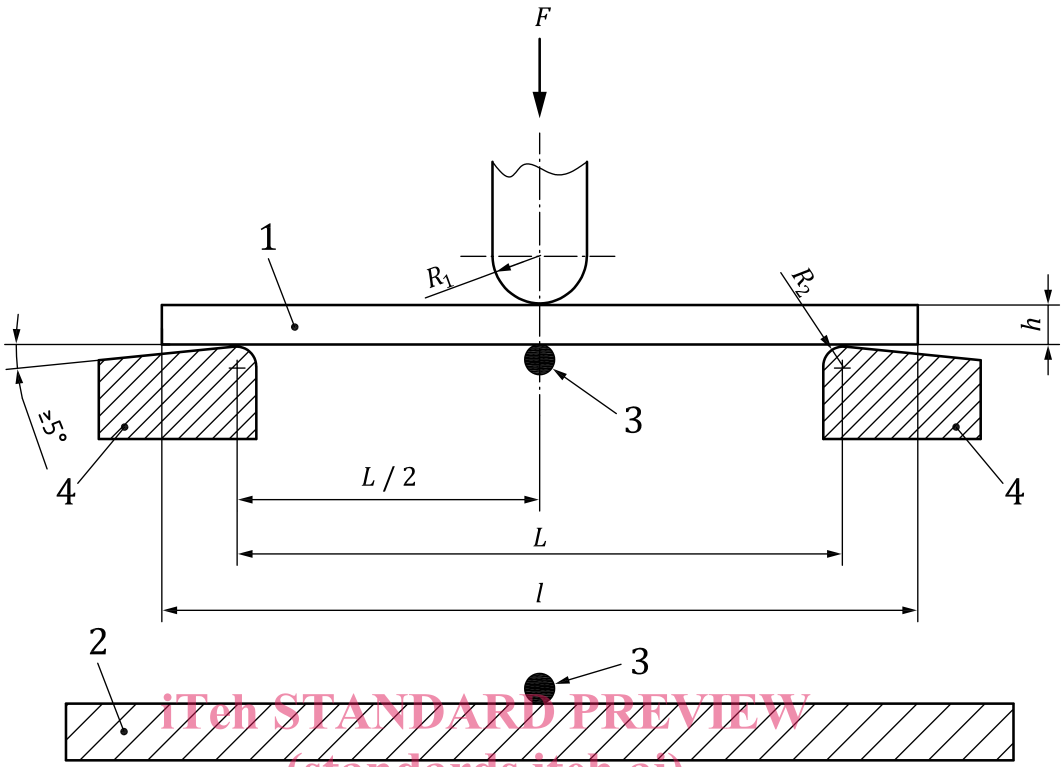
5.4 Force- and deflection-measuring systems

5.4.1 Introductory remarks

Flexural tests, according to the specific requirements on the data to be obtained, can be differentiated in several classes, comprising different complexity and requirements on accuracy. This starts with simple tests for obtaining flexural strength only on the one hand and on the other hand necessitates the use of a deflectometer to obtain the deflection accurately and free of compliance effects of the machine. The compliance of flexural testing machines has several possible sources (play and deformations in fixtures, deformations in the load train, and deformations of the load cell). Precise and true determination of deflection is especially important for the determination of the flexural modulus, for which the use of uncorrected crosshead displacement is not suitable. For a repeatable determination of flexural modulus results a compliance correction shall be applied or, preferably, a deflectometer shall be used.

5.4.2 Definition of precision and accuracy requirements

Table 2 defines objectives of testing in increasing order of test complexity and appertaining need for accuracy. A good precision without absolute accuracy as indicated in type III-tests can be sufficient in many quality control environments when properties are to be supervised over periods of time only. Accurate, meaning true and precise, results as indicated in type IV-tests are needed if the results are to be compared between laboratories. Different types of deflection measurement and different accuracy requirements for the deflection measurement are therefore defined, based on the needs on precision and trueness of the test results.



Key

1 test specimen
2 support base plate
3 deflectometer position
4 supports
R_1 radius of loading edge
h thickness of specimen
F applied force
l length of specimen
L length of span between supports
R_2 radius of supports

Figure 2 — Position of test specimen and deflectometer at start of test

Table 2 — Types of tests and calibration requirements

	Types (I-IV) of tests in increasing order of complexity and requirements for accuracy			
Required objective of testing	Stress/strength only	Stress/strength/ strains > 1 %	Stress/strength/ strains/repeatable and precise modulus	Stress/strength/ strains/true and precise = accurate modulus
Property	**I**	**II**	**III**	**IV**
σ_{fB}	×	×	×	×
σ_{fM}	×	×	×	×
σ_{fC}		×	×	×
s_C		×	×	×
ε_{fB}		×	×	×
ε_{fM}		×	×	×
E_f			×	×
Calibration requirement				
Force	ISO 7500-1, class 1			
Deflection measurement	—	ISO 9513, Class 2	ISO 9513, Class 2 plus condition set in 5.4.3	ISO 9513, Class 1 plus condition set in 5.4.3
Type of deflection measurement	—	Crosshead displacement	Crosshead displacement with compliance correction	Direct measurement using a deflectometer

5.4.3 Deflection measurement

The machine shall be capable of continuously recording the crosshead displacement with an accuracy conforming to the class of ISO 9513 indicated in Table 2. 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 as indicated in type IV, the deflection-measuring system, in accordance with ISO 9513 Class 1, 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).

For type III tests the deflection-measuring system, in accordance with ISO 9513 Class 2, shall be capable of measuring the change in deflection to an accuracy of 2 % of the relevant value or better, corresponding to ±6,8 µm for a support span, L, of 64 mm and a specimen thickness, h, of 4,0 mm.

Other support spans and specimen thicknesses will lead to different requirements for the accuracy of the deflection-measuring system.

For the determination of the flexural modulus using the crosshead displacement as indicated in Type III, the latter shall be corrected for the compliance of the machine. If the machine is equipped with built in routines for compliance correction these shall preferably be applied. If such routines are not available, the procedure given in Annex C shall be used.

NOTE Annex C also gives some explanation of the possible sources of machine compliance.

The use of a deflectometer further reduces errors introduced by the test setup and is therefore preferred.

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

