भारतीय मानक
Indian Standard

IS 13360 (Part 5/Sec 7) : 2022
ISO 178 : 2019

प्लास्टिक — परीक्षण पध्दतियाँ

भाग 5 यांत्रिक गुणधर्म

अनुभाग 7 आकांचन गुणधर्म ज्ञात करना

(दूसरा पुनरीक्षण)

Plastics — Method of Testing

Part 5 Mechanical Properties

Section 7 Determination of Flexural Properties

(*Second Revision*)

ICS 83.080.01

भारतीय मानक ब्यूरो
BUREAU OF INDIAN STANDARDS
मानक भवन, 9 बहादुर शाह ज़फर मार्ग, नई दिल्ली - 110002
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI - 110002
www.bis.gov.in www.standardsbis.in

October 2022 **Price Group 11**

Methods of Sampling and Test for Plastics Sectional Committee, PCD 27

NATIONAL FOREWORD

This Indian Standard (First Revision) which is identical with ISO 178 : 2019 'Plastics — Determination of flexural properties' issued by the International Organization for Standardization (ISO) was adopted by the Bureau of Indian Standards on the recommendation of the Methods of Sampling and Test for Plastics Sectional Committee and approval of the Petroleum, Coal and Related Products Division Council.

The standard was originally published in 1996 and subsequently revised in 2017. The first revision was based on ISO 178 : 2010. The second revision of this standard has been undertaken to align it with the latest version of ISO 178 : 2019.

The major changes in this draft revision are as follows:

a) differentiating calibration requirements according to the type of test;
b) the introduction of deflectometers;
c) the reinstatement of procedures for compliance correction; and
d) the addition of a new Annex D showing the relation between tensile and flexural modulus.

The text of ISO Standard has been approved as suitable for publication as an Indian Standard without deviations. Certain conventions are, however, not identical to those used in Indian Standards. Attention is particularly drawn to the following:

a) Wherever the words 'International Standard' appear referring to this standard, they should be read as 'Indian Standard'.
b) Comma (,) has been used as a decimal marker while in Indian Standards, the current practice is to use a point (.) as the decimal marker.

In this adopted standard, reference appears to certain International Standards for which Indian Standards also exist. The corresponding Indian Standards, which are to be substituted in their respective places, are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard*	*Degree of Equivalence*
ISO 291 Plastics — Standard atmospheres for conditioning and testing	IS 196 : 1966 Atmospheric conditions for testing (*revised*)	Not Equivalent
ISO 293 Plastics — Compression moulding of test specimens of thermoplastic materials	IS 13360 (Part 2/Sec 1) : 2016/ISO 293 : 2004 Plastics — Methods of testing: Part 2 Sampling and preparation of test specimens, Section 1 Plastics — Compression moulding of test specimens of thermoplastic materials (*first revision*)	Identical
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	IS 13360 (Part 2/Sec 3) : 2019/ISO 294-1 : 2017 Plastics — Methods of testing: Part 2 Sampling and preparation of test specimens, Section 3 Injection moulding of test specimens of thermoplastic materials — General principles and moulding of multipurpose and bar test specimens (*first revision*)	Identical

(*Continued on third cover*)

Contents

Page

1 Scope 1
2 Normative references 1
3 Terms, definitions and symbols 2
4 Principle 5
5 Test machine 5
5.1 General 5
5.2 Test speed 6
5.3 Supports and loading edge 6
5.4 Force- and deflection-measuring systems 6
5.4.1 Introductory remarks 6
5.4.2 Definition of precision and accuracy requirements 6
5.4.3 Deflection measurement 8
5.5 Equipment for measuring the width and thickness of the test specimens 9
6 Test specimens 9
6.1 Shape and dimensions 9
6.1.1 General 9
6.1.2 Preferred specimen type 9
6.1.3 Other test specimens 10
6.2 Anisotropic materials 10
6.3 Preparation of test specimens 11
6.3.1 From moulding, extrusion and casting compounds 11
6.3.2 From sheets 11
6.4 Specimen inspection 11
6.5 Number of test specimens 12
7 Atmosphere for conditioning and testing 12
8 Procedure 12
9 Calculation and expression of results 16
9.1 Flexural stress 16
9.2 Flexural strain 16
9.3 Flexural modulus 16
9.4 Statistical parameters 17
9.5 Significant figures 17
10 Precision 17
11 Test report 17
Annex A (informative) **Precision statement** 19
Annex B (informative) **Influence of changes in test speed on the measured values of flexural properties** 21
Annex C (normative) **Compliance correction for Type III-tests** 22
Annex D (informative) **Relation between tensile and flexural modulus: Theoretical expectations and experimental observations** 24
Bibliography 25

This Page has been Intentionally left blank

Indian Standard

PLASTICS —METHOD OF TESTING
PART 5 MECHANICAL PROPERTIES
Section 7 Determination of flexural froperties

(Second Revision)

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

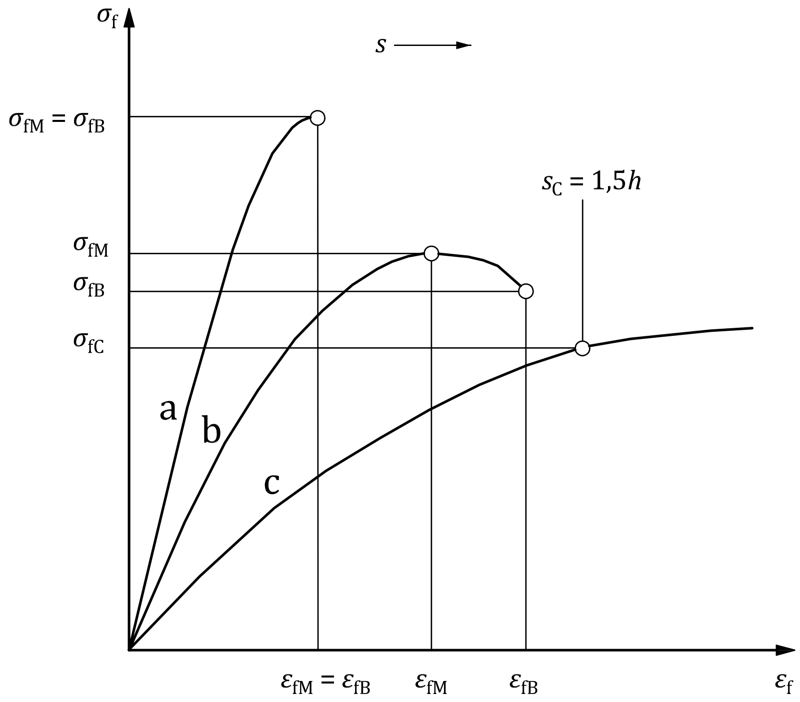
Note 1 to entry: It is expressed in millimetres (mm).

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 ($\% \cdot min^{-1}$).

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.

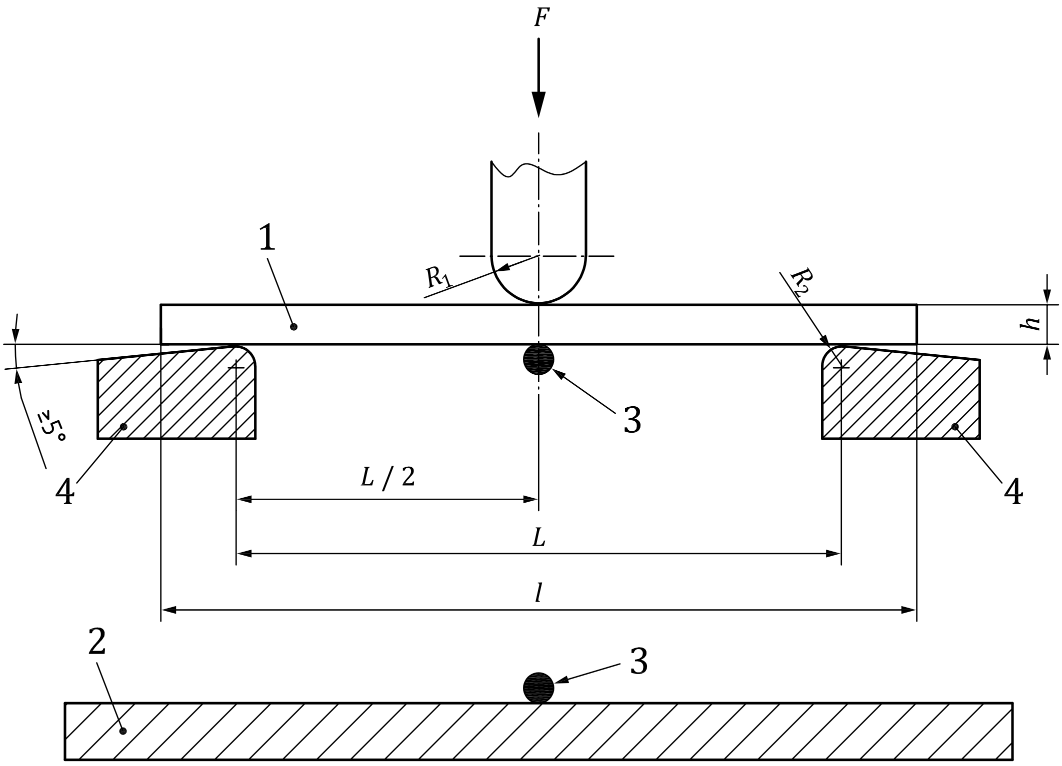
5.4 Force- and deflection-measuring systems

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

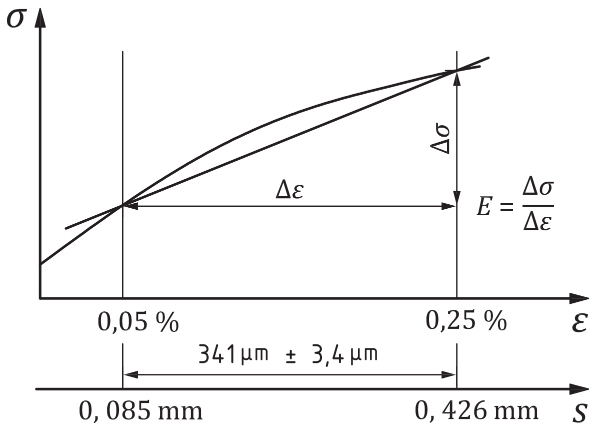
Other support spans and specimen thicknesses will lead to different requirements for the accuracy of the deflection-measuring system.

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.



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

Use micrometres with an accuracy of ±0,01 mm.

Use measuring tips that allow to determine the thickness centrally within the measuring range and the width at half height as indicated in Figure 5.

Different geometry of the contact faces of the measuring tips, i.e. circular, rectangular or sharp edges, are acceptable. Spherical tip faces shall have a radius ≥50 mm. Flat tips are recommended. The face diameter of cylindrical measuring tips shall be between 1,5 mm and 6,4 mm. Rectangular faces of measuring tips shall have a long side of 4 mm to 6,4 mm length.

It is recommended to use such a configuration that allows determining the width and the thickness with the same instrument.

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 one 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 shall preferably be rectangular, with no rounded edges, except as explained in the NOTE in 6.4.

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

6.1.3 Other test specimens

If it is not possible or desirable to use the preferred test specimen, use a specimen with the dimensions given in Table 3.

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 3 — Values of specimen width, *b*, in relation to thickness, *h*

Dimensions in millimetres

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

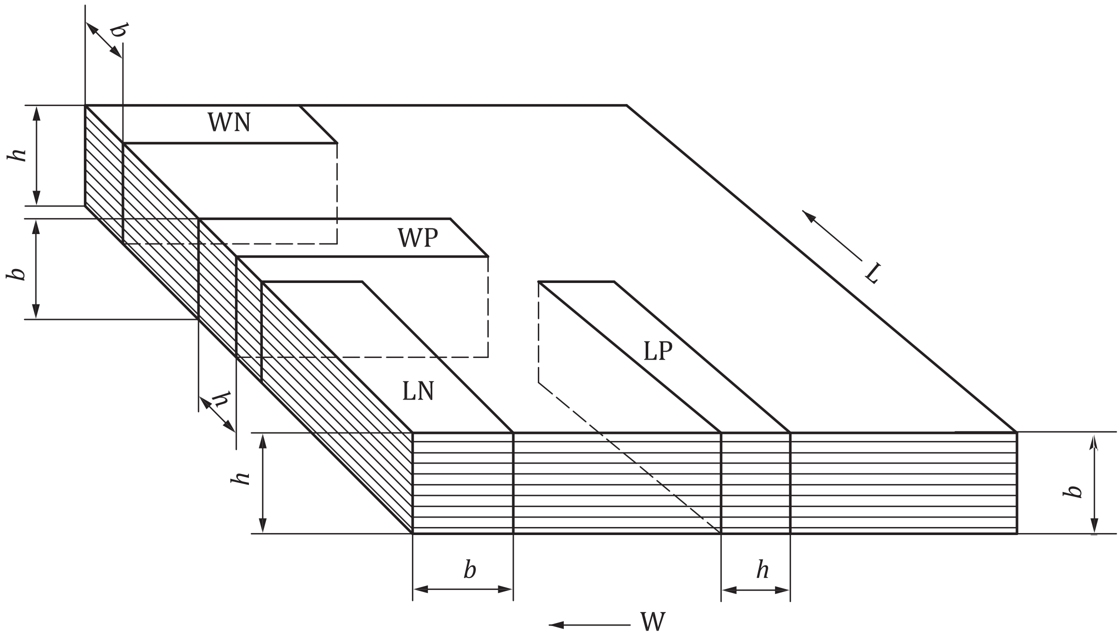
[a] For materials with very coarse fillers, the minimum width shall be 30 mm.

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

b width of test specimen

h thickness of test specimen

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.

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 micrometre 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. See ISO 294-1:2017, Annex D for guidance on how to adjust the hold pressure to minimize sink marks in injection-moulded specimens.

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).

NOTE If six specimens are used the standard deviation is identical to the 95 % confidence interval of the mean.

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, for example, for testing at high or low temperatures. The preferred set of conditions in ISO 291 is standard atmosphere 23/50 class 2, 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 and the thickness at mid length of the test specimen (see NOTE 2), following the general guidance of ISO 16012 within the measurement ranges indicated in Figure 5, to the nearest 0,1 mm for the width and to the nearest 0,01 mm for the thickness.

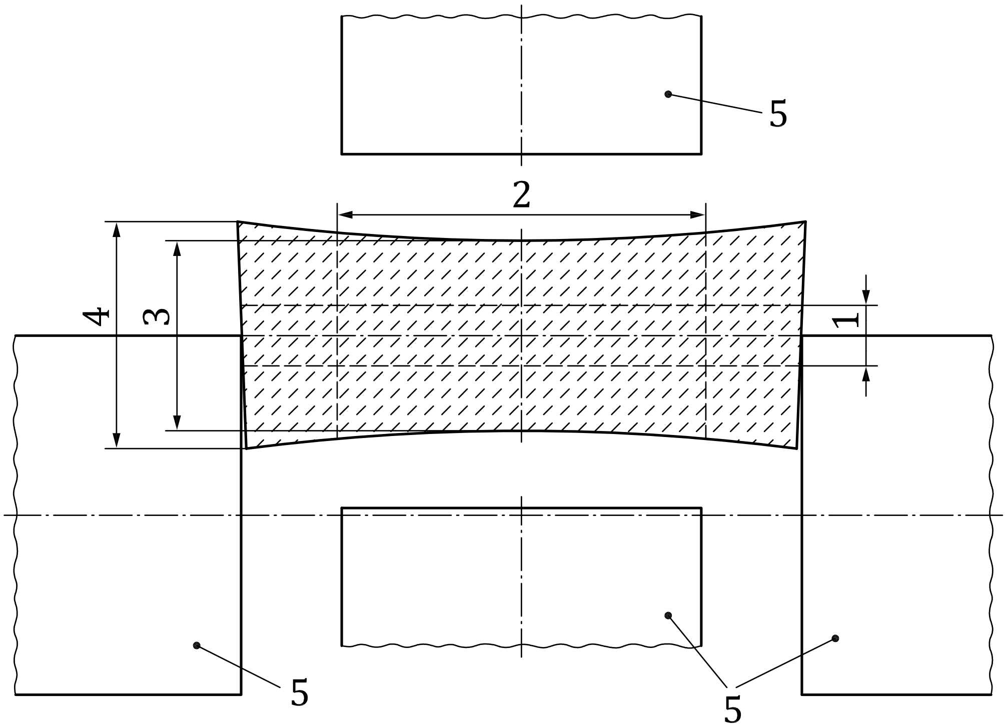
Avoid measuring the thickness at the edge of the specimen and directly in the centre (see NOTE 1). With rectangular or sharp tip faces the long side of the tip shall be parallel to the width direction when measuring thickness, and parallel to the thickness direction when measuring width.

NOTE 1 This excludes the maximum and minimum thickness, which for injection moulded test specimens usually is found at the edge and in the centre, respectively. Injection moulded test specimens prepared according ISO 294-1 will generally have thickness differences due to sink marks of $\Delta h = h_{max} - h_{min} \leq 0{,}1$ mm (see Figure 5).

NOTE 2 In a three-point flexural test the cross section at the loading nose position carries the maximum load and determines the test results. Width and thickness are therefore only needed for this position.

Calculate the mean values of the thickness h and the width b for the set of test specimens. Discard any specimen(s) with a thickness exceeding the tolerance of ± 2 % of the mean value and replace it by another specimen chosen at random.

NOTE 3 For the purposes of this document, the test specimen dimensions used for calculating 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

1 measuring range for width determination ± 0,5 mm

2 measuring range for thickness determination ± 3,25 mm

3 minimum thickness h_{min}

4 maximum thickness h_{max}

5 micrometre tip

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

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

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

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

Formula (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/h if necessary to avoid delamination in shear.

NOTE 1 Values of L/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 semi-rigid plastics), use a span length based on a lower value of the ratio L/h if necessary to enable measurements to be made within the working range of the test machine.

NOTE 2 A value of L/h of 8 is suitable in such cases.

c) For flexible materials with an expected modulus below 700 MPa (the limit between rigid and semi-rigid plastics), use a span length based on a higher value of the ratio L/h if necessary to prevent indentation of the supports into the test specimen.

NOTE 3 A value of L/h of 32 is suitable 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 shown in Formula (2):

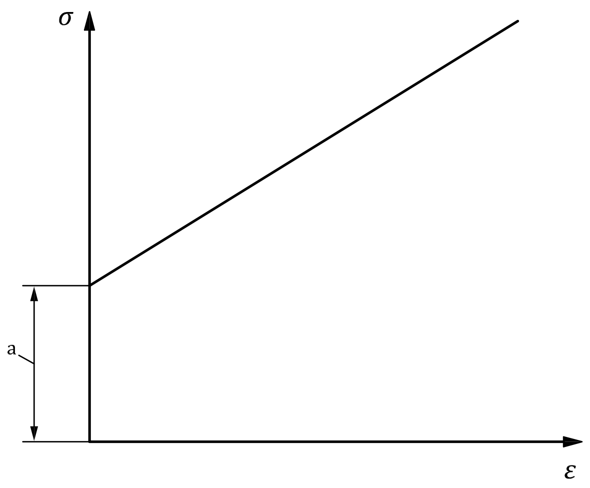
$$0 < \sigma_{f0} \leq 5 \times 10^{-4} E_f \quad (2)$$

which corresponds to a prestrain of $\varepsilon_{f0} \leq 0{,}05$ %, and, when measuring characteristics such as σ_{fM}, σ_{fC} or σ_{fB}, it shall lie within the range shown in Formula (3):

$$0 < \sigma_{f0} \leq 10^{-2} \sigma_{fX} \quad (3)$$

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 $\leq 5 \times 10^{-4} E_f$ or $\leq 10^{-2} \sigma_f$

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 Formula (4).

$$v = \frac{rL^2}{600h} \quad (4)$$

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 % ≤ ε ≤ 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.

If, e.g. for purposes of quality control, the determination of the flexural modulus is not necessary, start the test directly with the higher speed.

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 effects 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 Formula (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 formula:

$$\sigma_f = \frac{3FL}{2bh^2} \quad (5)$$

where

σ_f is the flexural-stress parameter in question, in megapascals;

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 Formula (6) or Formula (7):

$$\varepsilon_f = \frac{6sh}{L^2} \quad (6)$$

$$\varepsilon_f = \frac{600sh}{L^2}\% \quad (7)$$

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 Formula (8):

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

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 Formula (9):

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

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 formulae referring to flexural properties hold exactly for linear stress/strain behaviour only (see NOTE 2 in Clause 4); thus, for most plastics, they are accurate at small deflections only. The formulae given can, 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 document, i.e. ISO 178:2019;

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 and, if applicable, the dimension of the measuring tips used;

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 force and deflection measurement system (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 E 691[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 11 laboratories and four materials.

The following explanations of *r* and *R* (see 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 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 the conventional deflection, s_C

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

Due to the viscoelastic nature of plastics their mechanical properties are sensitive to the test speed applied. Table B.1 gives two examples, for an amorphous and a glass filled semi crystalline plastic, that show the magnitude of the influence when the test speeds defined in this document are used.

Table B.1 — 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 %

Annex C
(normative)

Compliance correction for Type III-tests

C.1 Sources of compliance

In the simple example of a perfectly elastic spring compliance is the inverse of the stiffness of the spring. For a perfectly elastic body the relation between applied force and resulting deformation, or vice versa, is linear, and stiffness S and compliance C are defined by the relations, in differential form, shown as Formula (C.1):

$$S = \frac{dF}{dx} \text{ and } C = \frac{dx}{dF} \tag{C.1}$$

where

F is the applied force measured by the load cell, in newtons;

x is the resulting deflection of the test specimen, in millimetres.

In the most simple model of a perfectly elastic body the compliance is the slope of the straight line $x(F)$ and as such a constant.

In the case of a flexural testing machine, the situation is more complicated and the simple model of a linear relationship might no longer be applicable. Compliance, interpreted as the instantaneous slope of the deflection vs. force curve, becomes itself a function of deformation.

There are numerous sources of compliance in a real testing machine. Compliance results from the deformation in the load train and from the play in drive elements. Load-cells can show deformations of up to 0,25 mm at their nominal load. The lead screws, under load, show longitudinal deformation and also small amounts of torsion. Also, fixtures that are attached to the machine like the loading nose attached to the load cell and the supports attached to the machine frame, add to the overall compliance.

Another contribution to measuring deformations that are not present in the deflection of the test specimen is the indentation of the loading nose and supports into the specimen surface under load. This is more pronounced in softer material. A rough estimation of this effect can be done by performing preliminary tests at reduced support spans.

All these effects result in an indication of crosshead movement that is in fact not present at the tip of the loading nose.

The compliance correction is as accurate as the deformation of the machine, load-cell and fixture is repeatable. With a well-tightened flexure fixture, it is possible to get a crosshead travel signal accurate to better than ±3 micrometres over the whole range from zero load up to the nominal load of the load-cell being used.

C.2 Procedure for Type III tests

For Type III tests the displacement s_C recorded by the travel indication of the test machine shall be corrected for the compliance C_M of the machine. C_M is determined using a reference bar of highly rigid reference material of known tensile modulus, such as a steel bar, instead of a test specimen. The corrected deflection s is calculated using Formulae (C.2) and (C.3):

$$s = s_C - C_M F \tag{C.2}$$

and

$$C_M = \frac{s_{Ref}}{F} - \frac{L_R^3}{4E_{Ref} b_{Ref} h_{Ref}^3} \tag{C.3}$$

where

- s is the corrected deflection, in millimetres;
- s_C is the travel information obtained from the machines travel indicator, in millimetres;
- C_M is the compliance, in millimetres per newton, of the test machine;
- s_{Ref} is the travel information obtained from the machines travel indicator when the force F is applied to the reference specimen, in millimetres;
- F is the force applied to the reference bar, in newtons;
- E_{Ref} is the tensile modulus, in megapascals, of the reference material;
- L_{Ref} is the span, in millimetres, during compliance determination;
- b_{Ref} is the width, in millimetres, of the reference bar;
- h_{Ref} is the thickness, in millimetres, of the reference bar.

Alternatively, if it is possible to measure precisely the deflection Δs_{Ref} of the reference specimen relative to the supports, the machine compliance can be determined from Formula (C.4):

$$C_M = \frac{1}{F}\left(s^* - \Delta s_{Ref}\right) \tag{C.4}$$

where

- s^* is the displacement indicated by the equipment during the test, e.g. crosshead displacement;
- Δs_{Ref} is the deflection of the reference specimen as determined by a calibrated reference instrument.

In this case, the modulus of the reference material does not have to be known.

With the reference bar in place instead of a test specimen record the displacement s_{Ref}(F) as a function of the applied force F, within the range of forces that are normally encountered when testing.

Ideally, this is a straight line. If so, the term s_{Ref}/F in Formula (C.3) can be replaced by the slope of a regression line fitted to the function s_{Ref}(F). Otherwise, the compliance determined by Formula (C.3) is itself a function of the applied load C_M(F).

Annex D
(informative)

Relation between tensile and flexural modulus: Theoretical expectations and experimental observations

Disregarding influences by the measurement process, from a physical point of view moduli obtained in tension and in flexure should be identical. In practice, differences can arise from indentation and especially for fibre reinforced materials, from orientation effects. Short fibre reinforced plastics show a layered structure after injection moulding with basically two top layers and a layer in the middle of the specimen with perpendicular main orientations of the glass fibres. In the standard test specimen, glass fibres are aligned in longitudinal direction close to the specimen surface and perpendicular in the interior of the specimens. As flexural testing stresses mainly the outer layer of the specimens one would expect higher flexural modulus compared to tensile modulus in short fibre reinforced plastics. Indentation effects compensate this orientation effect, so that it has been found that generally correctly measured flexural moduli are close to tensile moduli obtained at the same specimens.

Table D.1 shows a comparison of tensile and flexural moduli measured periodically over about 18 months with the number of data points between 55 and 78. Flexural moduli were obtained using a deflectometer measuring the distance between lower specimen surface and support frame.

Table D.1 — Comparison of tensile and flexural moduli obtained using deflectometer

Material	Tensile modulus MPa		Flexural modulus MPa
	Machine 1	**Machine 2**	**Machine 3**
PBT GF30 lot 1	9 749 ± 85	9 726 ± 134	9 750 ± 66
PBT GF30 lot 2	9 888 ± 129	9 745 ± 122	9 892 ± 68
ASA	2 523 ± 24	2 521 ± 31	2 705 ± 33
PBT	2 582 ± 35	2 522 ± 31	2 542 ± 27

Bibliography

[1] ISO 472, *Plastics — Vocabulary*

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

[3] ISO 1209-1, *Rigid cellular plastics — Determination of flexural properties — Part 1: Basic bending test*

[4] ISO 1209-2, *Rigid cellular plastics — Determination of flexural properties — Part 2: Determination of flexural strength and apparent flexural modulus of elasticity*

[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*

[7] ISO 14125, *Fibre-reinforced plastic composites — Determination of flexural properties*

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

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

This Page has been Intentionally left blank

(*Continued from second cover*)

ISO 295 Plastics — Compression moulding of test specimens of thermosetting materials	IS 13360 (Part 2/Sec 2) : 2013/ISO 295 : 2004 Plastics — Methods of testing: Part 2 Sampling and preparation of test specimens, Section 2 Compression moulding of test specimens of thermosetting materials (*first revision*)	Identical
ISO 2602 Statistical interpretation of test results — Estimation of the mean — Confidence interval	IS 14277 : 1996 Statistical interpretation of test results — Estimation of mean, standard deviation and regression coefficient — Confidence interval	Not Equivalent
ISO 2818 Plastics — Preparation of test specimens by machining	IS 13360 (Part 2/Sec 4) : 2021/ISO 2818 : 2018 Plastics - Methods of testing: Part 2 sampling and preparation of test specimens, Section 4 Preparation of test specimens by machining (*second revision*)	Identical
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	IS 1828 (Part 1) : 2022/ISO 7500-1 : 2018 Metallic Materials — Verification of static uniaxial testing machines: Part 1 Tension/compression testing machines — Verification and calibration of the force-measuring system (*fifth revision*)	Identical
ISO 9513 Metallic materials — Calibration of extensometer systems used in uniaxial testing	IS 12872 : 2021/ISO 9513 : 2012 Metallic materials — Calibration of extensometer systems used in uniaxial testing (*second revision*)	Identical
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	IS 13360 (Part 2/Sec 10) : 2006/ISO 10724-1 : 1998 Plastics — Methods of testing: Part 2 Sampling and preparation of test specimens, Section 10 Injection moulding of test specimens of thermosetting Powder Moulding Compounds (PMCs) — General principles and moulding of multipurpose test specimens	Identical

The technical committee has reviewed the provisions of the following International Standard referred in this adopted standard and has decided that they are acceptable for use in conjunction with this standard:

International /Other standard no.	*Title*
ISO 16012	Plastics — Determination of linear dimensions of test specimens
ISO 20753	Plastics — Test specimens

In reporting the result of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’.

Bureau of Indian Standards

BIS is a statutory institution established under the *Bureau of Indian Standards Act*, 2016 to promote harmonious development of the activities of standardization, marking and quality certification of goods and attending to connected matters in the country.

Review of Indian Standards

Amendments are issued to standards as the need arises on the basis of comments. Standards are also reviewed periodically; a standard along with amendments is reaffirmed when such review indicates that no changes are needed; if the review indicates that changes are needed, it is taken up for revision. Users of Indian Standards should ascertain that they are in possession of the latest amendments or edition by referring to the website-www.bis.gov.in or www.standardsbis.in.

This Indian Standard has been developed from Doc No.: PCD 27 (18734).

Amendments Issued Since Publication

Amend No.	Date of Issue	Text Affected

BUREAU OF INDIAN STANDARDS

Headquarters:

Manak Bhavan, 9 Bahadur Shah Zafar Marg, New Delhi 110002
Telephones: 2323 0131, 2323 3375, 2323 9402 *Website*: www.bis.gov.in

Regional Offices:		*Telephones*
Central	: 601/A, Konnectus Tower -1, 6th Floor, DMRC Building, Bhavbhuti Marg, New Delhi 110002	2323 7617
Eastern	: 8th Floor, Plot No 7/7 & 7/8, CP Block, Sector V, Salt Lake, Kolkata, West Bengal 700091	2367 0012 2320 9474
Northern	: Plot No. 4-A, Sector 27-B, Madhya Marg, Chandigarh 160019	265 9930
Southern	: C.I.T. Campus, IV Cross Road, Taramani, Chennai 600113	2254 1442 2254 1216
Western	: Plot No. E-9, Road No.-8, MIDC, Andheri (East), Mumbai 400093	2821 8093

Branches : AHMEDABAD. BENGALURU. BHOPAL. BHUBANESHWAR. CHANDIGARH. CHENNAI. COIMBATORE. DEHRADUN. DELHI. FARIDABAD. GHAZIABAD. GUWAHATI. HIMACHAL PRADESH. HUBLI. HYDERABAD. JAIPUR. JAMMU & KASHMIR. JAMSHEDPUR. KOCHI. KOLKATA. LUCKNOW. MADURAI. MUMBAI. NAGPUR. NOIDA. PANIPAT. PATNA. PUNE. RAIPUR. RAJKOT. SURAT. VISAKHAPATNAM.

Published by BIS, New Delhi