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Fibre-reinforced plastic composites — Determination of flexural properties

Composites plastiques renforcés de fibres — Détermination des propriétés de 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.

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 14125 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 13, *Composites and reinforcement fibres.*

Annexes A and B form an integral part of this International Standard.

Introduction

This standard is based on ISO 178 but deals with fibre-reinforced plastic composites. As such it retains the test conditions relevant for glass-fibre-reinforced systems. The test conditions are extended from ISO 178 to include both three-point (Method A) and four-point (Method B) loading geometries, and to include conditions for composites based on newer fibres such as carbon and aramid fibres.

Other source documents consulted include ASTM D 790 (four-point loading), prEN 2562 (test conditions), CRAG 200 and JIS K 7074 (use of shims for four-point loading, figure 6). The overall specimen length for four-point loading is the same as for three-point loading.

The scope of ISO 178 will be revised and limited to unreinforced and filled plastics.

EN 63:1977, *Glass-reinforced plastics — Determination of flexural properties — Three-point test*, will be withdrawn.

Fibre-reinforced plastic composites — Determination of flexural properties

1 Scope

1.1 This International Standard specifies a method for determining the flexural properties of fibre-reinforced plastic composites under three-point (Method A) and four-point (Method B) loading. Standard test specimens are defined but parameters included for alternative specimen sizes for use where appropriate. A range of test speeds is included.

1.2 The method is not suitable for the determination of design parameters, but may be used for screening materials, or as a quality-control test.

NOTE – For example, the flexural modulus is only an appropriate value of the tensile Young's modulus of elasticity as the test is not for the additional deflection due to the shear stress which leads to a lower value of the flexural modulus but uses test span/specimen thickness ratios that minimise this effect. Differences between tensile and flexural properties are also caused by the material structure/lay-up.

1.3 The method is suitable for fibre-reinforced thermoplastic and thermosetting plastic composites.

Unreinforced and particle-filled plastics and plastics reinforced with short (i.e. less than 1 mm length) fibres are covered by ISO 178.

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

1.5 The method specifies preferred dimensions for the specimen. Tests which are carried out on specimens of other dimensions, or on specimens which are prepared under different conditions, may produce results which are not comparable. Other factors, such as the speed of testing and the conditioning of the specimens can influence the results. For materials which are not homogeneous through the section, or above the linear-elastic response region, the result applies only to the thickness and structure tested. Consequently, when comparative data are required, these factors must be carefully controlled and recorded.

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 possiblitiy of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 178 1993 *Plastics - Determination of flexural properties.*

ISO 291 1997 *Plastics - Standard atmospheres for conditioning and testing.*

ISO 293 1986 *Plastics - Compression moulding test specimens of thermoplastic materials.*

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

ISO 295 1991 *Plastics - Compression moulding of test specimens of thermosetting materials.*

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

ISO 2602 1980 *Statistical interpretation of test results - Estimation of the mean - Confidence interval.*

ISO 2818 1994 *Plastics - Preparation of test specimens by machining.*

ISO 3167 1993 *Plastics - Multipurpose test specimens.*

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

3 Principle

The test specimen, supported as a beam, is deflected at a constant rate until the specimen fractures or until the deformation reaches some pre-determined value. During this procedure, the force applied to the specimen and the deflection are measured.

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 in three- or four-point flexure. The test geometry is chosen to limit shear deformation and to avoid an interlaminar shear failure.

NOTE – The four-point loading geometry provides a constant bending moment between the central loading members. The compressive contact stresses due to the two central loading members are lower in comparison with the stresses induced under the single loading member of the three-point test. The four-point geometry is chosen so that the centre span equals one-third of the outer span. The distance between the outer support points is the same as in the equivalent three-point loading case, therefore the same specimen can be used.

4 Definitions

For the purpose of this International Standard, the following definitions apply:

4.1 speed of testing, *v*

The rate of relative movement between the supports and the loading member(s), expressed in millimetres per minute (mm/min).

4.2 flexural stress, σ_f

The nominal stress in the outer surface of the test specimen at mid-span. It is calculated according to the relationship given in clause 10, equation (3) or (8), and is expressed in megapascals (MPa).

4.3 flexural stress at break (rupture), σ_{fB}

The flexural stress at break (or rupture) of the test specimen (see figure 1, curves A and B). It is expressed in megapascals (MPa).

4.4 flexural strength, σ_{fM}

The flexural stress sustained by the test specimen at the maximum load (see figure 1) for acceptable failure modes (see subclause 9.9 and figure 6). It is expressed in megapascals (MPa).

4.5 deflection, *s*

The distance through which the top or bottom surface of the test specimen at mid-span has deflected during flexure from its original position. It is expressed in millimetres (mm).

4.6 deflection at break, s_B

The deflection at break of the test specimen (see figure 1, curves A and B). It is expressed in millimetres (mm).

4.7 deflection at flexural strength, s_M

The deflection at the load equal to the flexural strength (4.4) (see figure 1, curves A and B). It is expressed in millimetres (mm).

4.8 flexural strain, ε_f

The nominal fractional change in length of an element in the outer surface of the test specimen at mid-span. It is used for calculating the flexural modulus (4.9) and is expressed as a dimensionless ratio.

4.9 modulus of elasticity in flexure; flexural modulus; chord modulus, E_r

The ratio of the stress difference ($\sigma_f'' - \sigma_f'$) divided by the corresponding strain difference ($\varepsilon_f'' = 0{,}0025 - \varepsilon_f' = 0{,}0005$) (see 10.1.2 and 10.2.2). It is expressed in megaspascals (MPa).

NOTE – With computer-assisted equipment, the determination of the modulus using two distinct stress/strain points can be replaced by a linear regression procedure applied to the part of the curve between the two points.

4.10 interlaminar shear modulus, G_{13}

The shear modulus in the through-thickness direction for laminated materials. It is expressed in megapascals (MPa).

NOTE – For materials with mainly in-plane reinforcement, the shear modulus G_{13} is of the order of 3 000 MPa to 6 000 MPa.

4.11 specimen coordinate axes (aligned materials)

The coordinate axes for an aligned material are defined in figure 2. The direction parallel to the fibre axes is defined as the "1" direction and the direction perpendicular to it the "2" direction.

For other materials, the 1, 2 and 3 directions are generally described by the *x*, *y*, *z* system of coordinates.

NOTES

1 The "1" direction is also referred to as the 0 degree (0°) or longitudinal direction, and the "2" direction as the 90 degree (90°) or transverse direction.

2 A similar definition can be used for material with a preferred fibre lay-up or in cases where a direction (e.g. the lengthwise direction) can be related to the production process.

For materials with anisotropy as defined above, the designations include an additional subscript "1" or "2" to indicate the direction tested.

5 Apparatus

5.1 Test machine

5.1.1 General

The test machine shall comply with ISO 5893 as appropriate to the requirements given in 5.1.2 to 5.1.4, as follows:

5.1.2 Speed of testing

The test machine shall be capable of maintaining the speed of testing (4.1), as specified in table 1.

Table 1 – Recommended values for the speed of testing

Speed (mm/min)	Tolerance (%)
0,5	± 20
1	± 20
2	± 20
5	± 20
10	± 20
20	± 10
50	± 10
100	± 10
200	± 10
500	± 10

The speed 0,5 mm/min is not indicated in ISO 5893. The tolerances on the speeds 1 mm/min and 2 mm/min are lower than those indicated in ISO 5893.

5.1.3 Loading member(s) and supports

Supports and central loading member(s) are arranged according to figure 3 (3-point) or figure 4 (4-point). The radius R_1 and the radius R_2 shall be as given in table 2. The axes of the supports and the loading member(s) shall be parallel.

The span L (distance between the supports) shall be adjustable.

Table 2 – Loading and support member dimensions

Dimension	Value (mm)
R_1	5 ± 0,2
R_2 for $h \leq 3$ mm	2 ± 0,2
R_2 for $h > 3$ mm	5 ± 0,2

5.1.4 Load and deflection indicators

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

Deflection obtained from movement of the test machine crosshead shall be corrected for loading train deflection and indentation at the loading points.

5.2 Micrometers and gauges

5.2.1 Micrometer, or equivalent, capable of reading to 0,01 mm or less, and suitable for measuring the width b and thickness h of the test specimen.

The micrometer shall have contact faces appropriate to the surface being measured (i.e. flat faces for flat, polished surfaces and hemispherical faces for irregular surfaces).

5.2.2 Vernier callipers, or equivalent, accurate to within 0,1 % of the span L, for determining the span (see 9.2).

6 Test specimens

6.1 Shape and dimensions

6.1.1 General

Unless otherwise agreed, the dimensions of the specimen shall comply with those given in the standard for the material under test or those given in 6.1.3.

6.1.2 Test direction

The test specimen axis shall be in one of the principal directions (see 4.11 and figure 5).

NOTE – When the material under test shows a significant difference in properties between the two principal directions (i.e. "1" and "2"), it is recommended that testing be carried out in both directions.

If, because of the application, the material is subjected to stress at some specific orientation to the principal directions, the material shall be tested in that orientation. The orientation of the test specimens relative to the principal directions shall be recorded.

6.1.3 Preferred specimen type

Table 3 – Preferred test specimens for method A (three-point flexure)

Dimensions in millimetres

Material	Specimen length (l)	Outer span (L)	Width (b)	Thickness (h)
Class I Discontinuous-fibre-reinforced thermoplastics	80	64	10	4
Class II Plastics reinforced with mats, continuous matting and fabrics, as well as mixed formats (e.g. DMC, BMC, SMC and GMT)	80	64	15	4
Class III Transverse (90°) unidirectional composites; undirectional (0°) and multidirectional composites with $5 < E_{f1}/G_{13} \leq 15$ (e.g. glass-fibre systems)	60	40	15	2
Class IV Unidirectional (0°) and multidirectional composites with $15 < E_{f1}/G_{13} \leq 50$ (e.g. carbon-fibre systems)	100	80	15	2
Tolerances	– 0 + 10	± 1	± 0,5	± 0,2
NOTE – To reduce variability in data for specimens using coarse reinforcements, a specimen width of 25 mm may be used.				

In any one test, the specimen thickness within the central one-third of the length shall nowhere deviate by more than 2 % from the mean value in the central region. The corresponding maximum deviation for width is 3 %. The cross-section shall be rectangular and without rounded edges.

NOTE – The preferred Class I specimen may be machined from the central part of the multipurpose test specimens given in ISO 3167.

Table 4 – Preferred test specimens for method B (four-point flexure)

Dimensions in millimetres

Material	Specimen length (*l*)	Outer span (*L*)	Inner span (*L'*)	Width (*b*)	Thickness (*h*)
Class I Discontinuous-fibre-reinforced thermoplastics	80	66	22	10	4
Class II Plastics reinforced with mats, continuous matting and fabrics, as well as mixed formats (e.g. DMC, BMC, SMC and GMT)	80	66	22	15	4
Class III Transverse (90°) unidirectional composites; undirectional (0°) and multidirectional composites with $5 < E_{f1}/G_{13} \leq 15$ (e.g. glass-fibre systems)	60	45	15	15	2
Class IV Unidirectional (0°) and multidirectional composites with $15 < E_{f1}/G_{13} \leq 50$ (e.g. carbon-fibre systems)	100	81	27	15	2
Tolerances	+ 10 – 0	± 1	± 1	± 0,5	± 0,2
NOTE – To reduce variability in the data obtained for specimens using coarse reinforcements, a specimen width of 25 mm may be used.					

In any one test, the specimen thickness over the complete length shall nowhere deviate by more than 2 % from the mean value. The corresponding maximum deviation for width is 3 %. The cross-section shall be rectangular and without rounded edges.

6.1.4 Other test specimens

When it is not possible or desirable to use the preferred test specimen, the dimensions of *L*, *l*, *h* and *b* in tables A.1 and A.2 in annex A shall apply.

6.2 Specimen preparation

6.2.1 Moulding and extrusion compounds

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

6.2.2 Plates

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

6.2.3 Long-fibre-reinforced plastic materials

Specimens shall be machined from a panel prepared in accordance with ISO 1268 or another specified or agreed-upon procedure. Guidance on machining of plastics is given in ISO 2818.

6.3 Checking the test specimens

The specimens shall be free of twist and shall have mutually perpendicular pairs of parallel surfaces. The surfaces and edges shall be free from scratches, pits, sink marks and flashes. The specimens shall be checked for conformity with these requirements by visual observation against straight-edges, squares and flat plates, and by measuring with micrometer callipers. Specimens showing measurable or observable departure from one or more of these requirements shall be rejected or machined to the required size and shape before testing.

7 Number of test specimens

7.1 At least five test specimens giving valid failures shall be tested. 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).

7.2 The results from test specimens that rupture outside the central one-third in three-point tests and outside the central portion in four-point tests shall be discarded and new specimens tested in their place.

8 Conditioning

Where applicable, condition the test specimens as specified in the standard for the material under test. In the absence of this information, select the most appropriate conditions from ISO 291, unless agreed otherwise by the interested parties (e.g. for testing at elevated or low temperatures).

9 Procedure

9.1 Where applicable conduct the test in the atmosphere specified in the standard for the material under test. In the absence of this information, select the most appropriate conditions from ISO 291, unless agreed otherwise by the interested parties (e.g. for testing at elevated or low temperatures).

9.2 Measure the width b and the thickness h to the nearest 1 % in the centre of each test specimen. Discard any specimen with a thickness exceeding the tolerance of ± 2 % of the mean value and replace it by another one, selected at random. Calculate the mean thickness h of the set of specimens.

Report if specimens are used that do not meet this thickness tolerance requirement.

Adjust the span L to within 1 % of the calculated value, to comply with the test span/mean specimen thickness ratio L/h given in tables 3 and 4 for preferred specimen sizes, and measure the resulting span to better than 0,2 % of the calculated value.

Tables 3 and 4 shall be used unless unacceptable failures modes (e.g interlaminar shear) are obtained (see figure 6). In this case, a higher value of L/h shall be used. Acceptable ratios are, in order, 16/1, 20/1, 40/1 and 60/1.

9.3 Where applicable, set the speed of testing as given in the standard for the material being tested. In the absence of this information, select the value in table 1 that gives a strain rate as near as possible to 0,01. The speed can be calculated from the following equations:

$$v = \frac{\varepsilon' L^2}{6h} \quad \text{(3-point)} \tag{1}$$

$$v = \frac{\varepsilon' L^2}{4,7h} \quad \text{(4-point)} \tag{2}$$

where

ε' is a strain rate of 0,01 (i.e. 1 % per minute).

This results in the test speed that produces a deflection closest to 0,4 times the specimen thickness in 1 min, e.g. 2 mm/min for the preferred Class I materials given in 6.1.3.

9.4 Place the test specimen symmetrically on the two supports and identify the tensile face (i.e. the lower face in figures 3 and 4).

9.5 (Optional.) A thin shim or cushion may be placed between the loading member and the specimen to discourage failure of the compressive face of the specimen, in particular for Class III and IV materials.

NOTE – A 0,2 mm thick shim of polypropylene has been found to be successful in reducing failures of the compressive face associated with the loading member.

9.6 Apply the force at mid-span for three-point and equally on both loading members for four-point (see figures 3 and 4).

9.7 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 load/displacement or flexural stress/flexural strain curve for this operation (see figure 1).

9.8 Determine all relevant stresses, deflections and strains compiled in clause 4 (definitions) from a force/deflection or stress/strain curve or equivalent data.

9.9 Record the type of failure on the basis of figure 6 (indicating tensile or compressive face).

10 Calculation and expression of results

NOTE – Alternative equations are given in annex B to correct for large-deflection effects (i.e. at deflections greater than 0,1 x *L* mm).

10.1 Method A (three-point flexure)

10.1.1 The flexural stress σ_f is given by the following equation:

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

where

σ_f	is the flexural stress, in megapascals (MPa);
F	is the load in newtons (N);
L	is the span, in millimetres (mm);
h	is the thickness of the specimen, in millimetres (mm);
b	is the width of the specimen, in millimetres (mm).

10.1.2 For the measurement of the flexural modulus, calculate the deflections s' and s'', which correspond to the given values of flexural strain $\varepsilon_f' = 0{,}0005$ and $\varepsilon_f'' = 0{,}0025$, by the following equation:

$$s' = \frac{\varepsilon_f' \, L^2}{6\,h} \text{ and } s'' = \frac{\varepsilon_f'' \, L^2}{6\,h} \tag{4}$$

where

s' and s''	are the beam mid-point deflections, in millimetres (mm);
ε_f' and ε_f''	are the flexural strains, whose values are given above.

The flexural modulus is calculated from equation 5 or 6:

(i) Using equation 5

$$E_f = \frac{L^3}{4bh^3}\left(\frac{\Delta F}{\Delta s}\right) \tag{5}$$

where

E_f	is the flexural modulus of elasticity, expressed in megapascals (MPa);
Δs	is the difference in deflection between s'' and s';
ΔF	is the difference in load F' and load F at s'' and s' respectively.

(ii) Using equation 6

$$E_f = 500\left(\sigma_f'' - \sigma_f'\right) \tag{6}$$

where

σ_f' is the stress measured at the deflection s', expressed in megapascals (MPa);

σ_f'' is the stress measured at the deflection s'', expressed in megapascals (MPa).

For computer-assisted equipment, see the note to 4.9.

10.1.3 Calculate the strain in the outer surface of the specimen as follows:

$$\varepsilon = \frac{6sh}{L^2} \qquad (7)$$

10.2 Method B - Four point flexure

10.2.1 The flexural stress σ_f is given by the following equation:

$$\sigma_f = \frac{FL}{bh^2} \qquad (8)$$

where

σ_f is the flexural stress, in megapascals (MPa);

F is the load, in newtons (N);

L is the span, in millimetres (mm);

h is the thickness of the specimen, in millimetres (mm);

b is the width of the specimen, in millimetres (mm).

10.2.2 For the measurement of the flexural modulus, calculate the deflections s' and s", which correspond to the given values of flexural strain $\varepsilon_f' = 0{,}0005$ and $\varepsilon_f'' = 0{,}0025$, by the following equation:

$$s' = \frac{\varepsilon_f' \, L^2}{4{,}7\,h} \text{ and } s'' = \frac{\varepsilon_f'' \, L^2}{4{,}7\,h} \qquad (9)$$

where

s' and s'' are the beam mid-point deflections, in millimetres (mm);

ε_f' and ε_f'' are the flexural strains, whose values are given above.

The flexural modulus is calculated from equation 10 or 11:

(i) Using equation 10

$$E_f = \frac{0{,}21L^3}{bh^3}\left(\frac{\Delta F}{\Delta s}\right) \tag{10}$$

where

E_f is the flexural modulus of elasticity, expressed in megapascals (MPa);

Δs is the difference in deflection between s'' and s';

ΔF is the difference in load F'' and load F' at s'' and s' respectively.

(ii) Using equation 11

$$E_f = 500\ (\sigma_f'' - \sigma_f') \tag{11}$$

where

E_f is the flexural modulus of elasticity, expressed in megapascals (MPa);

σ_f' is the stress measured at the deflection s', expressed in megapascals (MPa);

σ_f'' is the stress measured at the deflection s'', expressed in megapascals (MPa).

10.2.3 Calculate the strain in the outer surface of the specimen as follows:

$$\varepsilon = \frac{4{,}7sh}{L^2} \tag{12}$$

For computer-assisted equipment, see the note to 4.9.

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

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

11 Precision

The precision of this test method is not known. When inter-laboratory data are obtained, a precision statement will be added at the following revision.

12 Test report

The test report shall include the following information:

a) a reference to this International Standard, indicating the test method, material class and test speed;

b) complete 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 on the sheet;

d) the date of measurement;

e) the shape and dimensions of the test specimens (note if the specimens do not meet the thickness tolerance in 9.2);

f) the method of preparing the specimens;

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

h) the number of specimens tested;

i) the nominal length of the span used;

j) the speed of testing;

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

l) the face of the specimen in contact with the loading member(s);

m) the type, material and thickness of the cushion material, if used;

n) the equation used;

o) the test results;

p) the individual measurements, including stress (force) - strain (displacement) diagrams, if required;

q) the type of failure obtained;

r) the standard deviation and the 95 % confidence intervals of the mean values, if required.

Annex A
(normative)

Other test specimens

A.1 The length and thickness of the test specimen shall be in the same ratio as in the preferred test specimen, i.e. as given in table A.1:

Table A.1 – Values for test span *L* and specimen length *l* as a function of thickness *h*

Material class	Three-point		Four-point	
	L/*h*	*l*/*h*	*L*/*h*	*l*/*h*
I	16	20	16,5	20
II	16	20	16,5	20
III	20	30	22,5	30
IV	40	50	40,5	50

unless affected by the provisions of 9.2 (last paragraph).

NOTE – A number of 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 in such a way that the original surface of the specimen is in contact with the two supports and the force is applied by the central loading member(s) to the machined surface of the specimen.

A.2 The applicable value of the width given in table A.2 shall be used.

Table A.2 – Values for width *b* as a function of thickness *h*

Dimensions in millimetres

Nominal thickness *h*	Width (*b*) Class I	Width (*b*) Classes II to IV
$1 < h \leq 3$	25	15
$3 < h \leq 5$	10	15
$5 < h \leq 10$	15	15
$10 < h \leq 20$	20	30
$20 < h \leq 35$	35	50
$35 < h \leq 50$	50	80

For materials with coarse reinforcements, the specimen width shall enable a representative sample to be taken. The tolerances in tables 3 and 4 shall be applied.

Annex B
(normative)

Large-deflection corrections – Calculation and expression of results

B.1 Method A – Three-point flexure

In the case of large deflections, greater than 0,1*L*, the following equation shall be used for the flexural stress σ_f:

$$\sigma_f = \frac{3FL}{2bh^2}\left\{1+6\left(\frac{s}{L}\right)^2 - 3\left(\frac{sh}{L^2}\right)\right\} \quad (3a)$$

where

s is the beam mid-point deflection, in millimetres (mm);

σ_f is the flexural stress, in megapascals (MPa);

F is the load, in newtons (N);

L is the span, in millimetres (mm);

h is the thickness of the specimen, in millimetres (mm);

b is the width of the specimen, in millimetres (mm).

And for the strain the following equation shall be used:

$$\varepsilon = \frac{h}{L}\left\{6{,}00\,\frac{s}{L} - 24{,}37\left(\frac{s}{L}\right)^3 + 62{,}17\left(\frac{s}{L}\right)^5\right\} \quad (7a)$$

The stress is also significantly affected by friction at the loading and support members. This can be solved by placing the members on bearings, by restricting the test method to small deflections (not preferred), or by adding correction terms to equation 3a:

$$\sigma_f = \frac{3FL}{2bh^2}\left\{1+6\left(\frac{s}{L}\right)^2 - 3\left(\frac{sh}{L^2}\right) - \mu\left(2\,\frac{s}{L} - \frac{h}{L}\right)\right\} \quad (3b)$$

where μ is an effective coefficient of friction that is relatively easy to determine.

B.2 Method B – Four-point flexure

In the case of large deflections, greater than 0,1*L*, the following equation shall be used for the flexural stress σ_f:

$$\sigma_f = \frac{FL}{bh^2}\left\{1+8{,}78\left(\frac{s}{L}\right)^2 - 7{,}04\left(\frac{sh}{L^2}\right)\right\} \quad (8a)$$

where

σ_f is the flexural stress, in megaspascals (MPa);

F is the load, in newtons (N);

L is the span, in millimetres (mm);

h is the thickness of the specimen, in millimetres (mm);

b is the width of the specimen, in millimetres (mm);

And for the strain the following equation shall be used:

$$\varepsilon = \frac{h}{L}\left\{4{,}70\,\frac{s}{L} - 14{,}39\left(\frac{s}{L}\right)^3 + 27{,}70\left(\frac{s}{L}\right)^5\right\} \quad (11a)$$

Correcting for friction effects as above gives:

$$\sigma_f = \frac{FL}{bh^2}\left\{1+8{,}78\left(\frac{s}{L}\right)^2 - 7{,}04\left(\frac{sh}{L^2}\right) - 3{,}39\,\mu\left(\frac{s}{L}\right)\right\} \quad (11b)$$

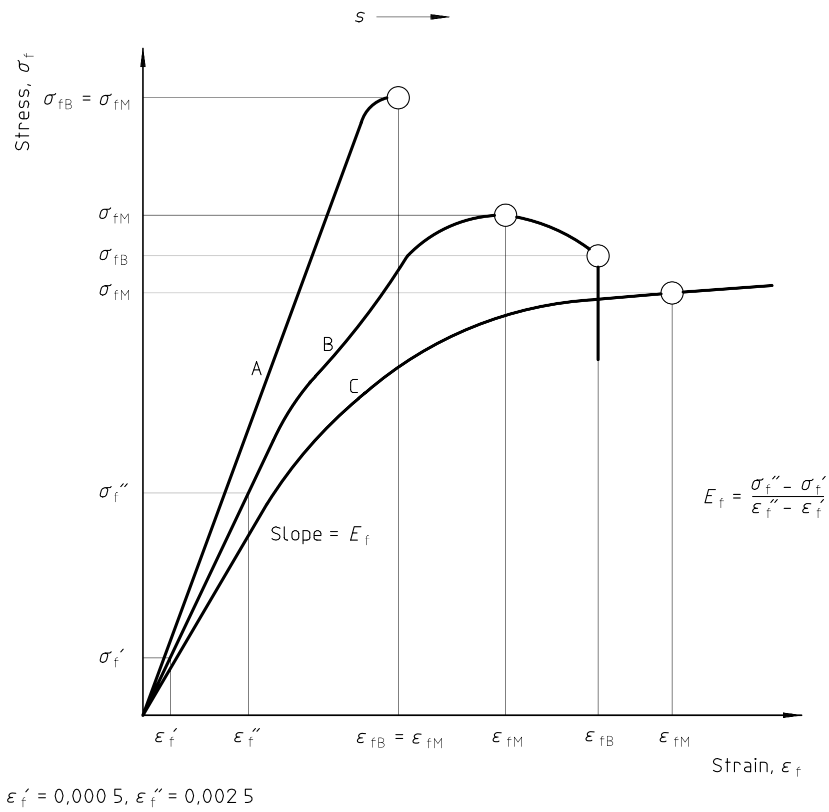

Figure 1 – Typical stress-strain curve
(N.B. Strains ε' and ε'' are equivalent to displacements s' and s'', respectively)

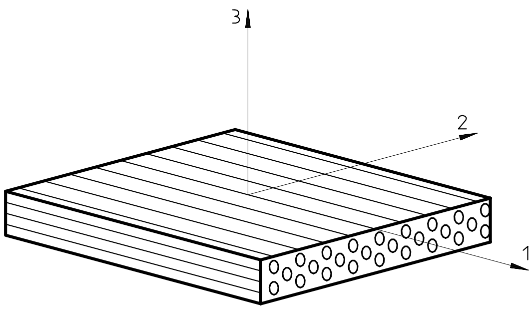

Figure 2 – Unidirectional reinforced composite plate element showing symmetry axes

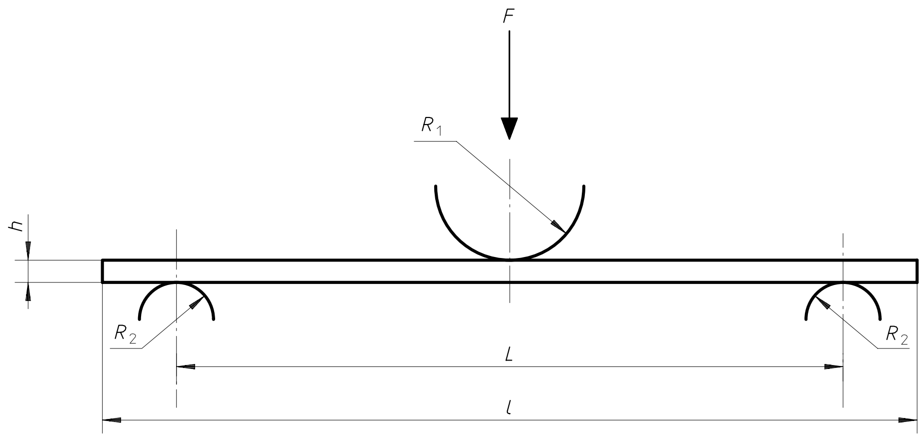

Figure 3 – Three-point loading arrangement

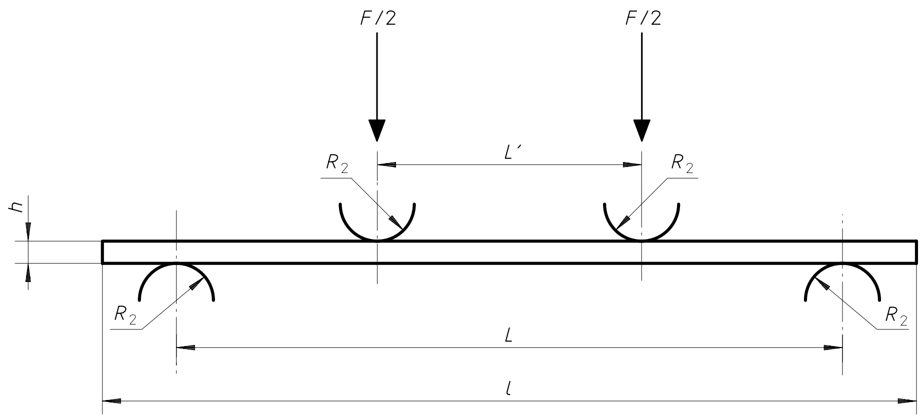

Figure 4 – Four-point loading arrangement
(N.B. $L = 3L'$)

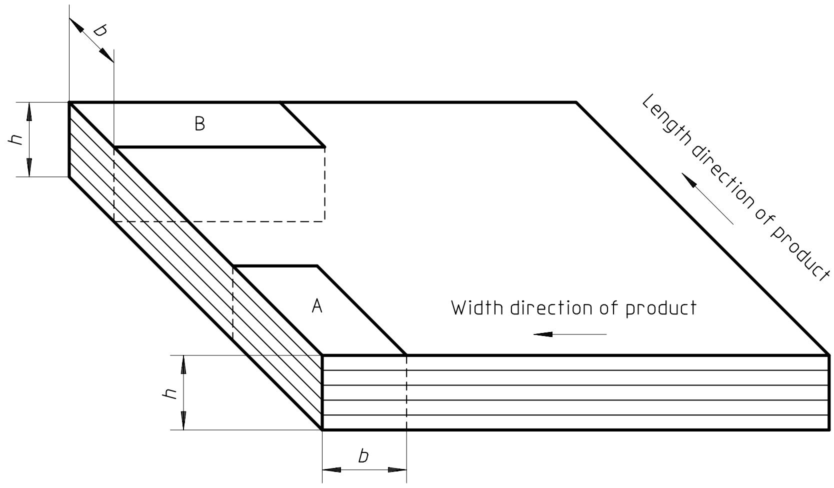

Figure 5 – Location of specimens

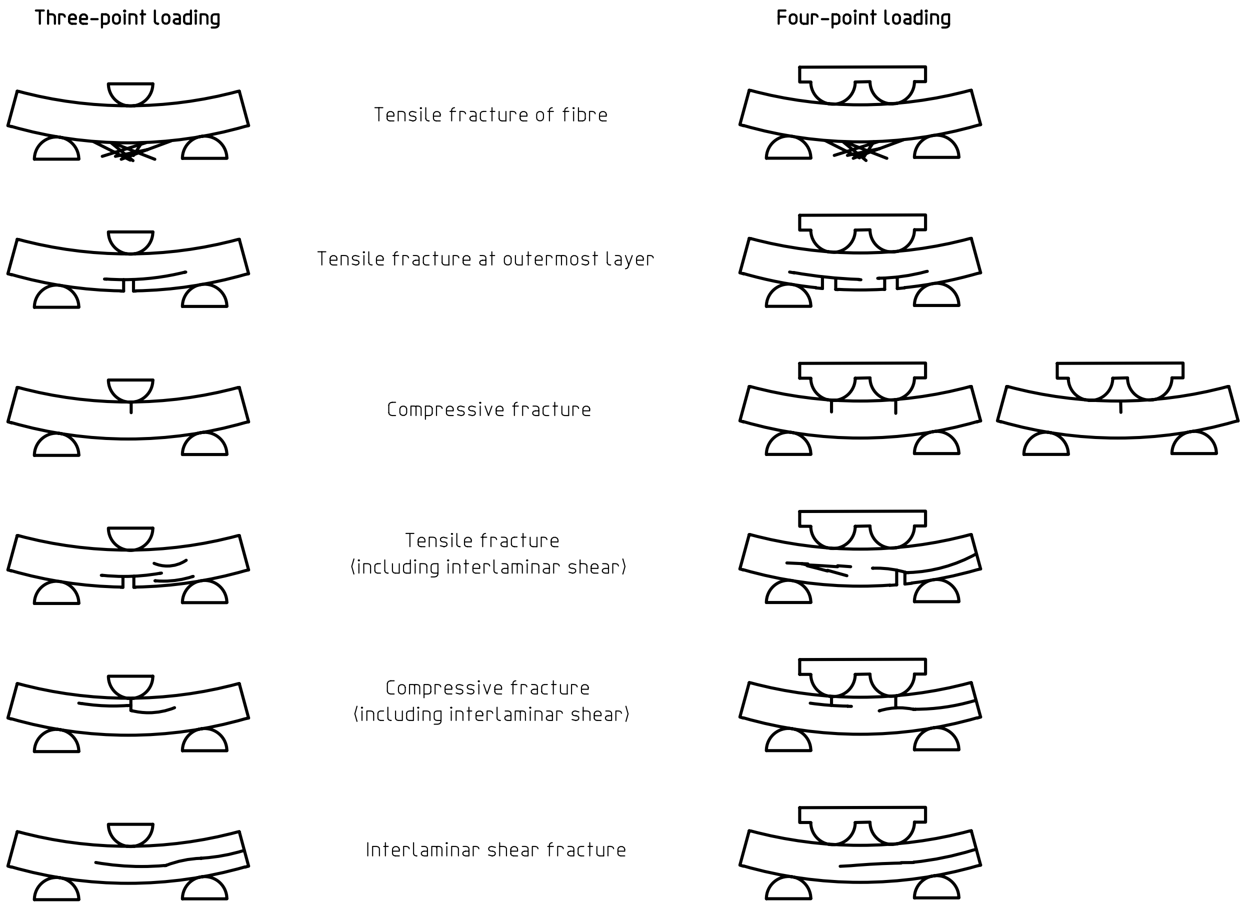

Figure 6 – Examples of possible failure modes
(Tensile-initiated and compression-initiated, remote from the loading points, are acceptable failure modes. Failures initiated by interlaminar shear are not acceptable.)

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Descriptors: plastics, reinforced plastics, tests, bend tests, determination, flexural strength, test specimens.

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