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Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for compressive behaviour of continuous fibre-reinforced composites at room temperature

Céramiques techniques — Méthode d'essai de résistance à la compression des composites renforcés de fibres continues à température ambiante

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 20504 was prepared by Technical Committee ISO/TC 206, *Fine ceramics*.

Fine ceramics (advanced ceramics, advanced technical ceramics) — Test method for compressive behaviour of continuous fibre-reinforced composites at room temperature

1 Scope

This International Standard describes procedures for determination of the compressive behaviour of ceramic matrix composite materials with continuous fibre reinforcement at room temperature. This method applies to all ceramic matrix composites with a continuous fibre reinforcement, uni-directional (1D), bi-directional (2D) and tri-directional (xD, with $2 < x \leqslant 3$), tested along one principal axis of reinforcement. This method may also be applied to carbon-fibre-reinforced carbon matrix composites (also known as: carbon/carbon or C/C). Two cases of testing are distinguished: compression between platens and compression using grips.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 3611, *Micrometer callipers for external measurements*

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

ISO 14126, *Fibre-reinforced plastic composites — Determination of compressive properties in the in-plane direction*

ASTM E1012, *Standard Practice for Verification of Test Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application*

3 Terms and definitions

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

3.1
gauge section
part of the test specimen which has uniform and minimum cross-sectional area

3.2
gauge section length
l
length of the gauge section

3.3
initial gauge length
L_o
initial distance between reference points on the test specimen in the gauge section before initiation of the test

3.4
final gauge length
L_f
final distance between reference points on the test specimen in the gauge section at the completion of the test

3.5
initial cross-sectional area
A_o
initial area of the gauge section's cross-section

3.6
longitudinal deformation
ΔL
change (contraction) of the initial gauge due to the application of a uniaxial compressive force

NOTE The longitudinal deformation corresponding to the maximum force should be denoted as $\Delta L_{c,m}$.

3.7
compressive strain
ε
relative change in the gauge length defined as the ratio $\Delta L/L_o$

NOTE The compressive strain corresponding to the maximum force is denoted as $\varepsilon_{c,m}$.

3.8
compressive force
F_c
uniaxial compressive force applied to a test specimen

3.9
maximum compressive force
$F_{c,m}$
greatest uniaxial compressive force applied to a test specimen when tested to failure

3.10
compressive stress
σ
compressive force supported by the test specimen at any time in the test divided by the initial cross-sectional area such that $\sigma = F_c/A_o$

3.11
compressive strength
$S_{c,m}$
greatest compressive stress applied to a test specimen when tested to failure

3.12
proportionality ratio or pseudo-elastic modulus
E_p
slope of the linear region of the stress-strain curve, if any

NOTE Examination of the stress-strain curves for ceramic matrix composites allows definition of the following cases:

— Material with a linear region in the stress-strain curve.

For ceramic matrix composites that have a mechanical behaviour characterised by a linear region, the proportionality ratio E_p is defined as:

$$E_p(\sigma_1, \sigma_2) = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \quad (1)$$

where (ε_1, σ_1) and (ε_2, σ_2) lie near the lower and the upper limits of the linear region of the stress-strain curve (see Figures A.1 and A.2).

— Material with non-linear region in the stress-strain curve. In this case only, stress-strain couples can be determined at specified stresses or specified strains.

3.13
elastic modulus
E
proportionality ratio or pseudo-elastic modulus, in the special case where the linearity starts near the origin

See Figure A.2.

3.14
axial strain
average of the longitudinal strain measured at the surface of the test specimen at specified locations

See Annex B.

3.15
bending strain
difference between the longitudinal strain at a given longitudinal location on the test specimen surface and the axial strain at the same location

See Annex B.

3.16
buckling force
critical axially applied force at which an initially straight column assumes a curved shape

3.17
critical buckling stress
critical axial compressive stress at which an initially straight column assumes a curved shape

4 Principle

A test specimen of specified dimensions is loaded in compression. The compression test is usually performed at a constant cross-head displacement rate or at a constant deformation rate.

NOTE Constant force rate is only allowed in the case of linear stress-strain behaviour up to failure.

For cross-head displacement tests, a constant rate is recommended when the test is conducted to failure.

The force and longitudinal deformation are measured and recorded simultaneously.

5 Apparatus

5.1 Test machine

The machine shall be equipped with a system for measuring the force applied to the test specimen that shall conform to grade 1 or better in accordance with ISO 7500-1.

5.2 Load train

The load train is composed of movable and fixed cross-heads, the loading rods and the grips or platens. Load train couplers may additionally be used to connect the grips or platens to the loading rods.

The load train shall align the test specimen axis with the direction of force application without introducing bending or torsion in the test specimen. The misalignment of the test specimen shall be verified and documented in accordance with the procedure described in Annex B. The maximum percent bending shall not exceed 5 % at an average axial strain of 500×10^{-6}.

There are two alternative means of force application:

a) Compression platens are connected to the force transducer and the moving cross-head. The parallelism of these platens shall be better than 0,01 mm, in the loading area and the faces of the platens shall be perpendicular to the force application direction.

   NOTE 1 The use of platens is not recommended for compression testing of 1D and 2D materials with small thicknesses because of buckling.

   NOTE 2 A compliant interlayer material (composed only of paper or cardboard), between the test specimen and platens, can be used for testing macroscopically inhomogeneous materials to ensure uniform contact pressure.

   When the dimensions of the test specimen are such that buckling may occur, it is recommended to use antibuckling devices similar to those described in ISO 14126. These devices should not introduce parasitic stresses (i.e. stresses other than the uniform, axial stress) during loading of the test specimen.

b) Grips are used to clamp and load the test specimen. The grip design shall prevent the test specimen from slipping and the grips shall align the test specimen axis with that of the applied force.

Alignment shall be verified and documented in accordance with, for example, the procedure described in Annex B.

5.3 Strain measurement

5.3.1 General

For continuous measurement of the longitudinal deformation as a function of the applied force, either strain gauges or a suitable extensometer may be used. Use an extensometer that meets the requirements of at least class 1 in ISO 9513. Measurement of longitudinal deformation over a length as long as possible within the gauge section length of the test specimen is recommended.

5.3.2 Strain gauges

Strain gauges are used for the verification of the alignment on the test specimen. They may also be used to determine longitudinal deformation during testing. In both cases, the length of the strain gauges shall be such that the readings are not affected by local features on the surface of the specimen, such as fibre crossovers. Unless it can be shown that strain gauge readings are not unduly influenced by localized strain events, such as fibre crossovers, strain gauges should be not less than 9 mm to 12 mm in length for the longitudinal direction and not less than 6 mm in length for the transverse direction. The strain gauges, surface preparation and bonding agents/adhesives should be chosen to provide adequate performance on the subject materials.

Suitable strain-conditioning and recording equipment should be used. Care shall be taken to ensure that the strain gauge readings are not influenced by the surface preparation and the adhesive used.

5.3.3 Extensometry

The linearity tolerance of the extensometer shall be less than 0,15 % of the extensometer range used. Extensometers shall meet the requirements of at least class 1 in accordance with ISO 9513.

Types of commonly used extensometers are described in 5.3.3.1 and 5.3.3.2.

5.3.3.1 Mechanical extensometer

For a mechanical extensometer, the gauge length corresponds to the longitudinal distance between the two locations where the extensometer contacts the test specimen. Mounting of the extensometer to the test specimen shall prevent slippage of the extensometer at the contact points and shall not initiate failure under the contact points. Any extensometer contact forces shall not introduce bending greater than that allowed in 5.2.

5.3.3.2 Electro-optical extensometer

Electro-optical measurements of strain require reference marks on the test specimen. For this purpose, fiducial marks such as rods or flags are attached to the test specimen surface perpendicular to the longitudinal axis of the test specimen. The gauge length corresponds to the longitudinal distance between the two fiducial marks.

NOTE The use of integral flags as part of the test specimen geometry is not recommended, because of stress concentrations induced by such features.

5.4 Data recording system

A calibrated recorder may be used to record force-deformation curves. The use of a digital data recording system combined with an analog recorder is recommended.

5.5 Dimension measuring devices

Devices used for measuring linear dimensions of the test specimen shall be accurate to ± 0,1 mm. Micrometers shall be in accordance with ISO 3611.

6 Test specimens

6.1 General

The choice of test specimen geometry depends on several parameters:

- the nature of the material and of the reinforcement structure;
- the type of testing system.

The ratio between the length of the test specimen subject to buckling and the thickness of the test specimen, in addition to the stiffness of the material, will influence the resistance of the test specimen to buckling.

If buckling occurs, it may be necessary to modify the dimensions of the test specimen or alternatively to use an antibuckling device (e.g. fixed lateral guides pressed against the test specimen so as to freely allow longitudinal motion while simultaneously suppressing transverse motion).

The volume in the gauge length shall be representative of the material.

Two types of test specimens can be distinguished.

a) As-fabricated test specimens, where only the length and the width are machined to the specified size. In this case, the two faces of the test specimen may present irregular surfaces while the two edges present regular machined surfaces.

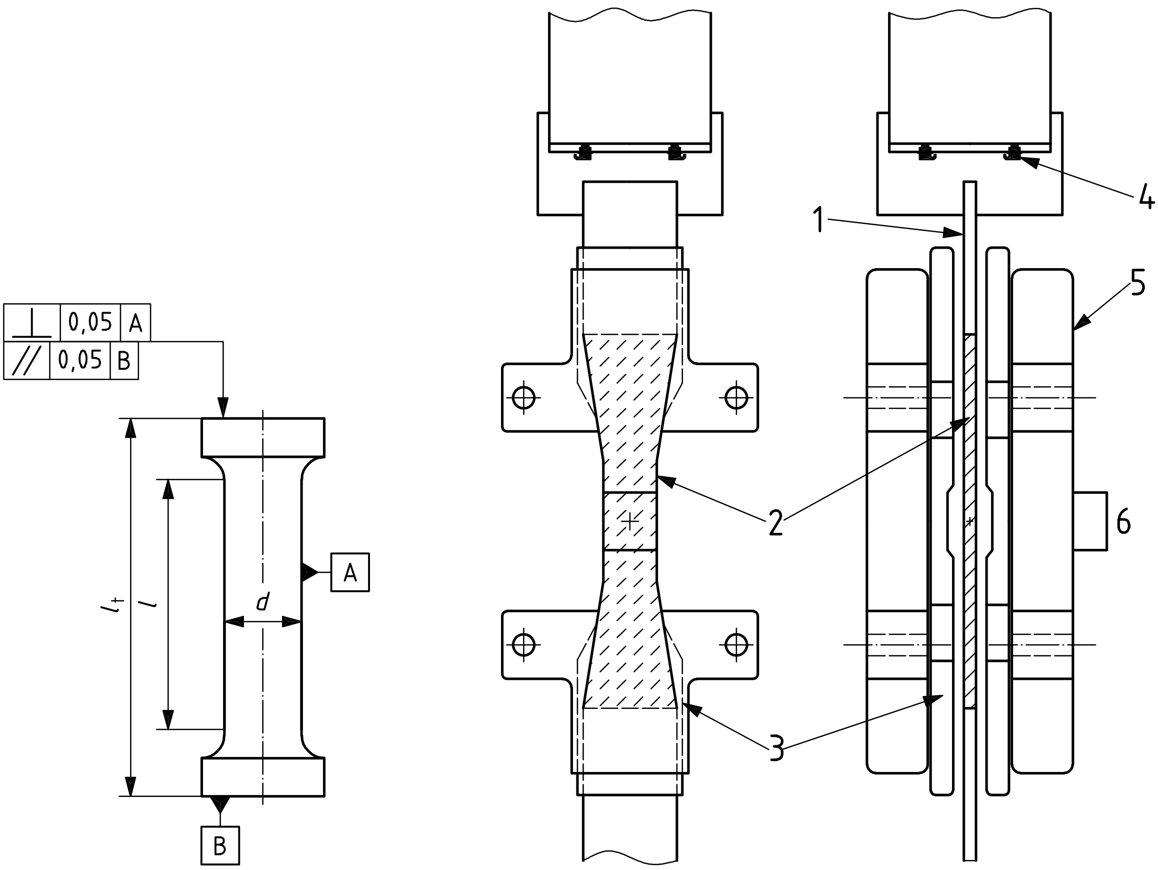
b) Machined test specimens, where the length and the width, as well as the two faces of the test specimen, have been machined and present regular machined surfaces.

Tolerance on the thickness dimension only applies to machined test specimens. For as-fabricated test specimens, the difference in thickness out of three measurements (at the centre and at each end of the gauge section length) should not exceed 5 % of the average of the three measurements.

6.2 Compression between platens

The test specimen geometry and/or compliant interlayers may be adapted in order to avoid buckling and damage at the edges due to contact forces.

Type 1 is commonly used and is illustrated in Figure 1. Recommended dimensions are given in Table 1.



a) Test specimen **b) Example of anti-buckling guides**

Key

1 loading anvil
2 specimen
3 lateral support
4 O-ring
5 frame
6 unsupported length

Figure 1 — Compression test specimen (type 1) used between platens and anti-buckling guides

Table 1 — Dimensions for compression test specimen (type 1) used between platens

Dimensions in millimetres

Parameter	1D, 2D, xD	Tolerance
l, gauge section length	⩾ 15	± 0,5
l_t, total length	⩾ 1,5 × l mm	± 0,5
d, cylindrical or square-section side length or diameter	⩾ 8	± 0,2
Parallelism of machined parts	0,05	N/A
Perpendicularity of machined parts	0,05	N/A
Concentricity of machined parts	0,05	N/A

Type 2 is cylindrical in shape and is not used as frequently as type 1. It is illustrated in Figure 2 and recommended dimensions are given in Table 2.

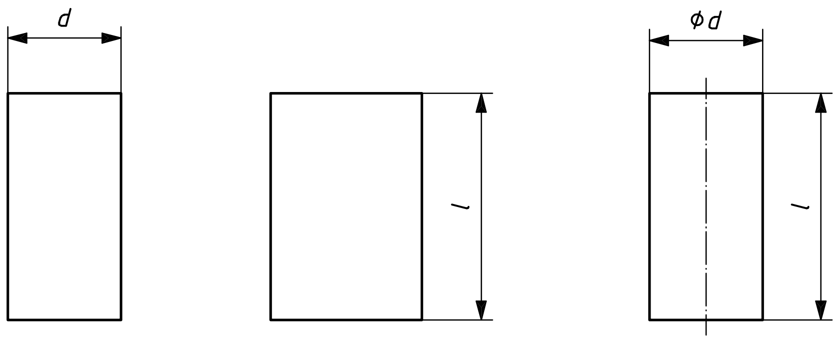


Figure 2 — Compression test specimen (type 2) used between platens

Table 2 — Dimensions for compression test specimen (type 2) used between platens

Dimensions in millimetres

Parameter	1D, 2D, xD	Tolerance
l, gauge section length	⩾ 10	± 0,5
d, cylindrical or square-section	⩾ 10	± 0,2
Parallelism of machined parts	0,05	N/A
Perpendicularity of machined parts	0,05	N/A
NOTE This test specimen is mainly used when the thickness of the part is not sufficient to machine a test specimen of type 1.		

6.3 Test specimen used with grips

For these types of test specimens, the total length l_t depends on the gripping system. These types of test specimens allow testing of thin test specimens without using an anti-buckling device. It is, however, necessary to verify that the chosen l/h ratio does not lead to buckling.

Type 3 is represented in Figure 3 and recommended dimensions are given in Table 3.

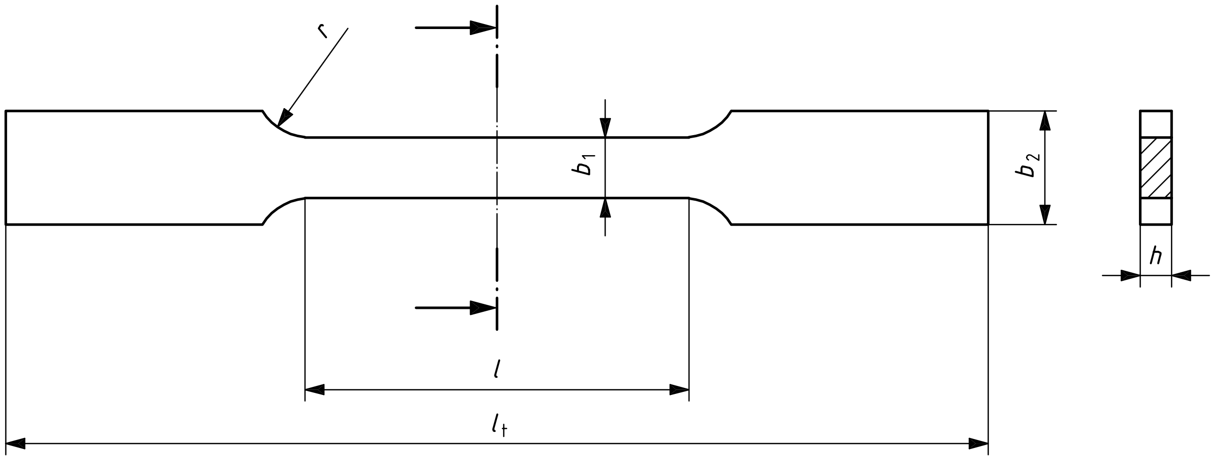


Figure 3 — Compression test specimen (type 3) for use with grips

Table 3 — Dimensions of compression test specimen (type 3) for use with grips

Dimensions in millimetres

Parameter	1D, 2D, xD	**Tolerance**
Long length		
l_t, total test specimen length	$\geqslant 1,5 \times l$ mm	± 0,5
l, gauge section length	$\geqslant$ 15	± 0,5
h, thickness	$\geqslant$ 3	± 0,2
b_1, width in the gauge section length	$\geqslant$ 8	± 0,2
b_2, width	$b_2 = \alpha b_1$ with α: 1,2 to 2	± 0,2
r, radius	$\geqslant$ 30	± 2
Plane parallelism of machined parts	0,05	N/A
Short length		
l_t, total test specimen length	$\geqslant 1,5 \times l$ mm	± 0,5
l, gauge section length	$\leqslant$ 15	± 0,5
h, thickness	$\geqslant$ 3	± 0,2
b_1, width in the gauge section length	$\geqslant$ 8	± 0,2
b_2, width	$b_2 = \alpha b_1$ with α: 1,2 to 2	± 0,2
r, radius	$\geqslant$ 30	± 2
Plane parallelism of machined parts	0,05	N/A
NOTE This type of test specimen is recommended, if buckling occurs, using type 3 test specimen dimensions given in this table (for long lengths). With this type of test specimen, it is very difficult to obtain strain measurements.		

Type 4 is a straight-sided test specimen. It is represented in Figure 4 and the dimensions are given in Table 4.

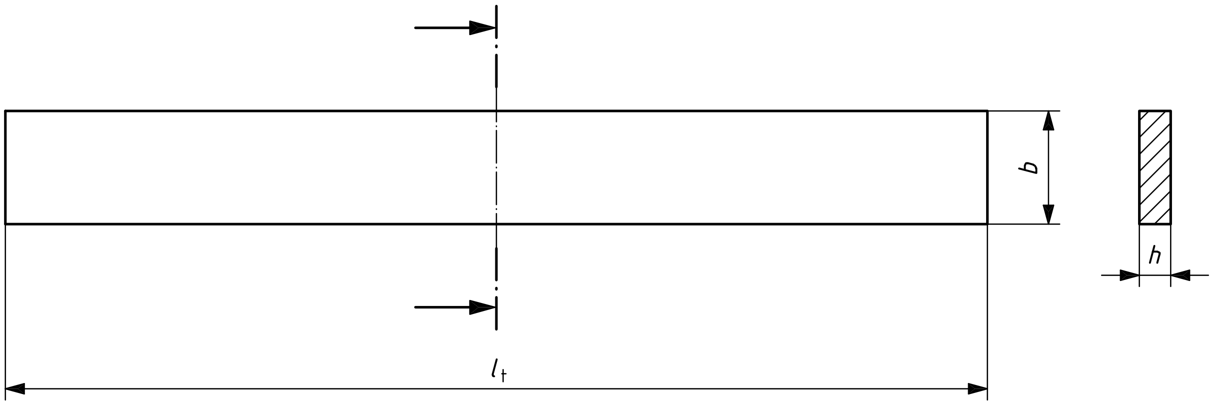


Figure 4 — Compression test specimen for use with grips (straight-sided, without tabs)

Table 4 — Dimensions of compression test specimen (type 4) for use with grips (straight-sided, without tabs)

Dimensions in millimetres

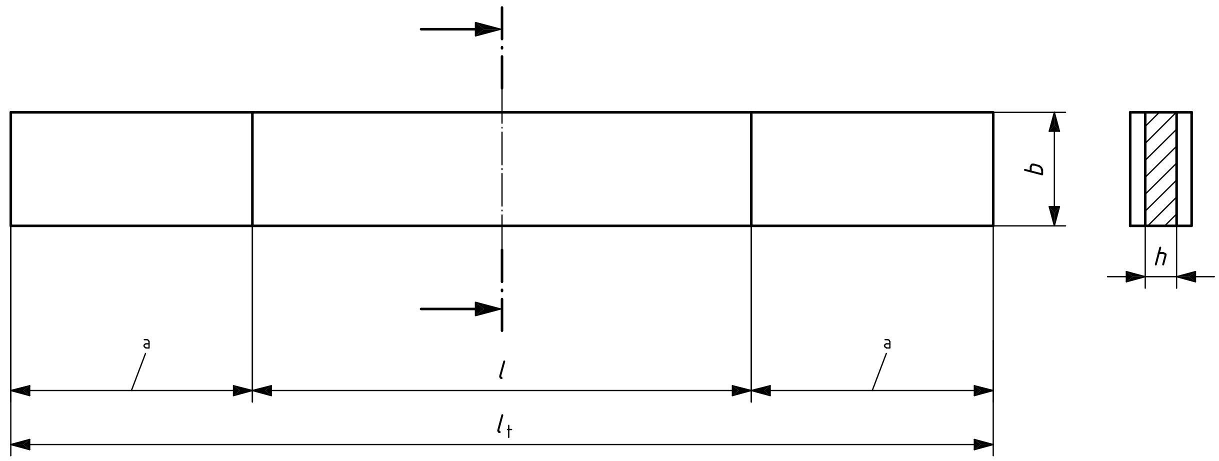
Parameter	1D, 2D, xD	Tolerance
l_t, total length	⩾ 100	± 0,5
l, gauge section length (ungripped)	⩾ 40	± 0,2
h, thickness	⩾ 3	± 0,2
b, width	⩾ 10	± 0,2
Plane parallelism of machined part	0,05	N/A
NOTE This test specimen is easy to machine and, although its use allows the determination of elastic modulus; it should not be used for strength measurement.		

Type 5 is a straight-sided test specimen equipped with end tabs that are either metallic or polymeric composite, and bonded or cured onto the test specimen. The dimensions are given in Table 5 and the test specimen is illustrated in Figure 5. This type of test specimen is mainly used for 1D, 2D and xD (with $2 < x < 3$) materials.

Table 5 — Dimensions of compression test specimen (type 5) for use with grips (straight-sided with end tabs)

Dimensions in millimetres

Parameter	1D, 2D, xD	Tolerance
l_t, total length	⩾ 100	± 0,5
l, gauge section length	⩾ 40	± 0,2
End tab length	⩾ 30	± 0,2
h, thickness	⩾ 3	± 0,2
b, width	⩾ 10	± 0,2
Plane parallelism of machined parts and of tab faces	0,05	N/A
NOTE The thickness of the end tabs is generally between 1 mm and 3 mm.		



a End-tab length.

Figure 5 — Straight-sided test specimen with end tabs

Type 6 test specimens are used for elevated temperature tests. All test specimens designed for elevated temperature testing can be used for room temperature testing.

NOTE It is customary to obtain results at room temperature when testing a material at elevated temperature and, to do so, the same type of test specimen is used. However, the costs of test specimens for elevated temperature tests are generally much greater than test specimens used for room temperature tests. Therefore, elevated-temperature test specimen types are not used when only room-temperature properties are required.

7 Test specimen preparation

7.1 Machining and preparation

When extracting test specimens from as-fabricated plates of material, care shall be taken to align the test specimen axis with the desired fibre-related loading axis.

Machining parameters that avoid damage to the material shall be established and documented. These parameters shall be adhered to during test specimen preparation.

7.2 Number of test specimens

At least five valid test results (see 8.5) are required.

If statistical evaluation of the test results is required, the number of test specimens should be chosen using accepted statistical procedures and guidelines.

8 Test procedure

8.1 Test mode and rate

Test modes may involve force, displacement, or strain control. Test rates should be sufficiently rapid so as to complete the test in the range 10 s to 30 s, thereby obtaining the maximum possible compressive strength at fracture of the material. However, test rates may also be used to evaluate rate effects. In all cases, report the test mode and rate.

Strain rates on the order of 50×10^{-6} to 500×10^{-6} s^{-1}, stress rates on the order of 35-50 MPa/s, and cross-head displacement rates on the order of 0,001 to 0,05 mm/s are recommended to minimize environmental effects when testing in ambient air.

8.2 Measurement of test specimen dimensions

The cross-sectional area shall be determined at the longitudinal centre of the test specimen and at each end of the gauge section length. The arithmetic means of the measurements shall be used for calculations.

Necessary dimensions to calculate cross-sectional area shall be measured with an accuracy of ± 0,01 mm.

8.3 Buckling

During a compression test, the test specimen may be susceptible to buckling. To be sure of the validity of the test, it is necessary to verify that no buckling occurs for the conditions of the test.

This verification shall be carried out every time there is a change in material, in test specimen geometry, in gripping configuration, etc.

The degree of buckling is acceptable if the difference between the strains measured in the middle of the gauge section on the opposite width faces on the verification test specimen, for values of stress in the linear region of the stress-strain response (typically, this can be chosen as 0,1 $S_{\text{c,m}}$ to 0,9 $S_{\text{c,m}}$) are such that:

$$\left| \frac{\varepsilon' - \varepsilon''}{\varepsilon' + \varepsilon''} \right| \leqslant 0{,}05 \qquad (2)$$

where

ε' is the compressive strain measured on the width face;

ε'' is the compressive strain measured on the opposite face for the same strain for the same cross-section.

In the case of circular-cross-section test specimens, the strain measurements shall be taken at opposite circumferential positions of the same cross-section.

If the acceptable degree of buckling is not met, another test specimen type or other dimensions shall be defined with a different ratio l/h, using the information contained in Annex B to guide in the choice of l/h.

NOTE If it is not possible to use this pre-test procedure to determine acceptable degree of buckling, then another possibility is to place strain gauges or a dual extensometer on opposite sides of the actual test specimen and conduct a compression test according to 8.4. Differences in strain readings will indicate buckling. Equation 2 can be used to determine the degree of buckling for the actual compression test.

8.4 Testing technique

8.4.1 Test specimen mounting

Install the test specimen in the gripping system or loading system with its longitudinal axis coincident with that of the test machine. If an anti-buckling device is used, then it should be clamped to the test specimen before it is installed in the test machine.

Care shall be taken not to induce flexural or torsional loads.

8.4.2 Extensometers

If used, install the extensometer longitudinally centered within the gauge section length.

8.4.3 Measurements

Zero the force transducer.

Zero the extensometer (or strain gauges, if used).

Initiate recording the force versus longitudinal deformation (or strain).

Initiate loading the test specimen and terminate loading of the test specimen at the end of the test.

Terminate recording the force versus longitudinal deformation (or strain).

Record the temperature as ambient temperature.

Determine the position of fracture location relative to the longitudinal mid-point and record this location to the nearest 1 mm.

8.5 Test validity

The following circumstances invalidate a test:

— failure to specify and record test conditions;

— failure to meet specified test conditions;

— failure to meet buckling criteria according to 8.3;

— test specimen slippage in the grips or crushing (brooming) at the ends;

— extensometer slippage or strain gauge failure;

— fracture in an area outside the gauge section length.

9 Calculation of results

9.1 Test specimen origin

A diagram illustrating the reinforcement directions of the material with respect to the longitudinal axis of the test specimen shall always accompany the test results.

9.2 Compressive strength

Calculate the compressive strength as:

$$S_{c,m} = \frac{F_m}{A_o} \qquad (3)$$

where

$S_{c,m}$ is the compressive strength, in megapascals (MPa);

F_m is the maximum compressive force, in newtons (N);

A_o is the initial cross-sectional area of the test specimen, in square millimetres (mm^2).

9.3 Strain at maximum compressive force

If strain is measured directly, the strain at maximum compressive force, $\varepsilon_{c,m}$, is the measured strain corresponding to the maximum applied compressive force, F_m. Otherwise, calculate the strain using the following equation:

$$\varepsilon_{c,m} = \frac{\Delta L_{c,m}}{L_o} \tag{4}$$

where

$\varepsilon_{c,m}$ is the strain at the maximum compressive force;

$\Delta L_{c,m}$ is the longitudinal deformation at the maximum compressive force, in millimetres, measured by the extensometer;

L_o is the initial gauge length, in millimetres (mm).

9.4 Proportionality ratio or pseudo-elastic modulus, elastic modulus

9.4.1 Calculate the proportionality ratio or pseudo-elastic modulus E_p defined between two points (ΔL_1, F_1) and (ΔL_2, F_2) measured near the lower and upper limits of the linear part of the force-deformation record, according to the equation:

$$E_p(\sigma_1,\sigma_2) = \frac{L_o(F_2 - F_1)}{A_o(\Delta L_2 - \Delta L_1)} \times 10^{-3} \tag{5}$$

where

E_p is the pseudo-elastic modulus, in gigapascals (GPa);

F is the compressive force at the defined point on the force-longitudinal deformation curve, in newtons (N);

A_o is the initial cross-sectional area of the test specimen, in square millimetres (mm^2);

L_o is the initial gauge length, in millimetres (mm);

ΔL is the longitudinal deformation corresponding to F, in millimetres (mm).

9.4.2 If the material has linear behaviour at the origin, calculate the elastic modulus according to the equation:

$$E = \frac{FL_o}{A_o\Delta L} \times 10^{-3} \tag{6}$$

where

E is the elastic modulus, in gigapascals (GPa);

F is the compressive force at a point in the linear part of the force-longitudinal deformation curve, in newtons (N);

A_o is the initial cross-sectional area of the test specimen, in square millimetres (mm^2);

L_o is the initial gauge length, in millimetres (mm);

ΔL is the longitudinal deformation corresponding to F, in millimetres (mm).

Any point (ΔL, F) on the linear section of the force-deformation record may be used for its determination.

9.4.3 For materials with no linear section in the stress-strain (or force-deformation) curve, it is recommended to use stress strain-values corresponding to stresses of 0,1 $S_{c,m}$ and 0,5 $S_{c,m}$, unless other stress-strain values are fixed by agreement between the parties concerned.

In the case where a type 5 test specimen intended for use at elevated temperature is tested at room temperature and where the test specimen is protected by a coating intended for specific environmental conditions, another calculation procedure should be used. Two cross-sections are defined: effective cross-section and apparent cross-section.

9.5 Buckling stress

Calculate the buckling stress as follows for the fixed end condition:

$$\sigma_{cr} = P_{cr} / wb = \pi^2 EI / \left(l^2 wb \right) \tag{7}$$

where

- σ_{cr} is the critical buckling stress;
- P_{cr} is the critical compressive force;
- w is the test specimen width;
- b is the test specimen thickness;
- π is pi (3,142);
- E is the longitudinal elastic modulus of the test material;
- I is the moment of inertia in the b direction, where $I = wb^3/12$;
- l is the actual, free (unsupported) length of the test specimen gauge section.

9.6 Rounding of results

Results should be reported to the number of significant figures equal to the least number of significant figures of the variables used in the calculations.

9.7 Mean and standard deviation

For each series of tests, the mean, standard deviation, and coefficient of variation for each measured value can be calculated as follows:

$$\text{Mean} = \bar{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{8}$$

$$\text{Standard deviation} = s = \sqrt{\frac{\sum_{i=1}^{n} \left(X_i - \bar{X} \right)^2}{n-1}} \tag{9}$$

$$\text{Coefficient of variation} = \text{CV} = \frac{100\, s}{\bar{X}} \tag{10}$$

where

- X_i is the measured value;
- n is the number of valid tests.

10 Test report

The test report shall contain at least the following information:

a) name and address of the testing establishment;

b) date of the test, unique identification of the report and of each page, customer name and address and signatory;

c) a reference to this International Standard, e.g. "determined in accordance with ISO 20504";

d) test specimen drawing or reference;

e) description of test material (material type, manufacturing code, batch number);

f) description of test specimen fabrication process (if a material removal process is used, report surface roughness/finish on cut or ground surfaces);

g) description of test set-up (gripping system or loading system, extensometer or gauge type, force transducer);

h) displacement rate or deformation rate or force rate;

i) number of tests carried out and the number of valid results obtained;

j) force-longitudinal deformation (or strain or time) record;

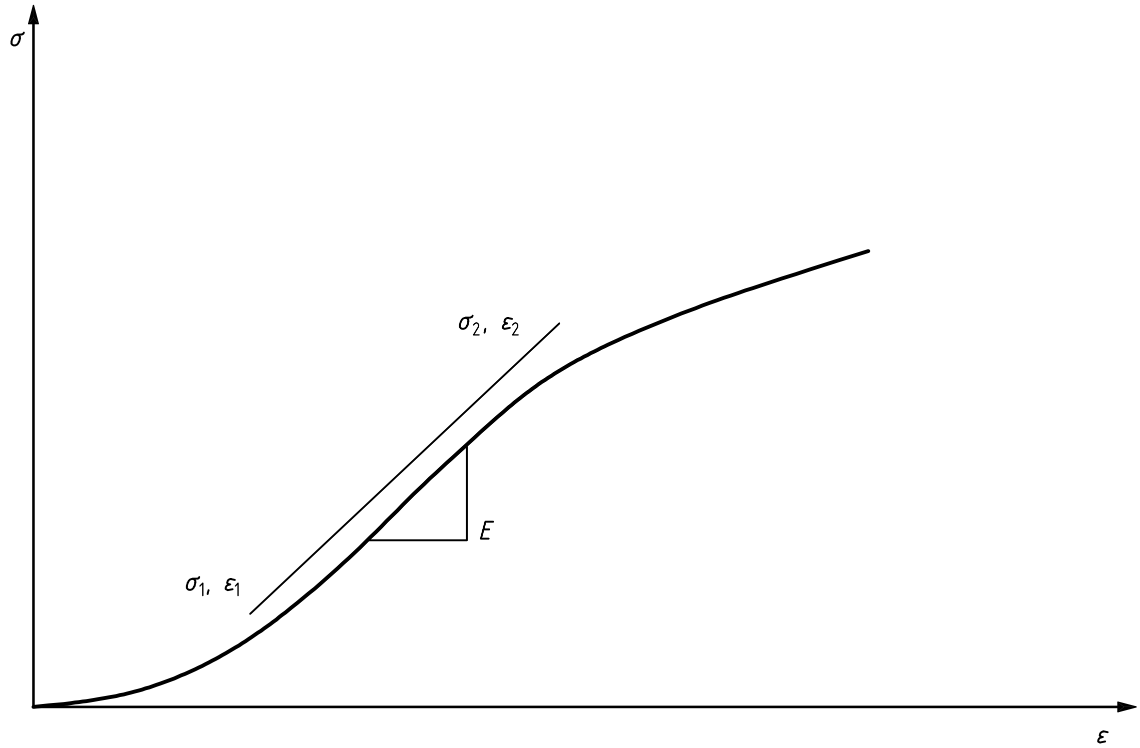
k) valid results, mean value and standard deviations of the compressive strength, the compressive strain at maximum compressive force, the (pseudo-)elastic modulus and proportionality ratio (if applicable);

l) failure location of all the test specimens used to obtain the above results;

m) temperature during test recorded as ambient temperature.

Annex A
(informative)

Illustration of elastic modulus



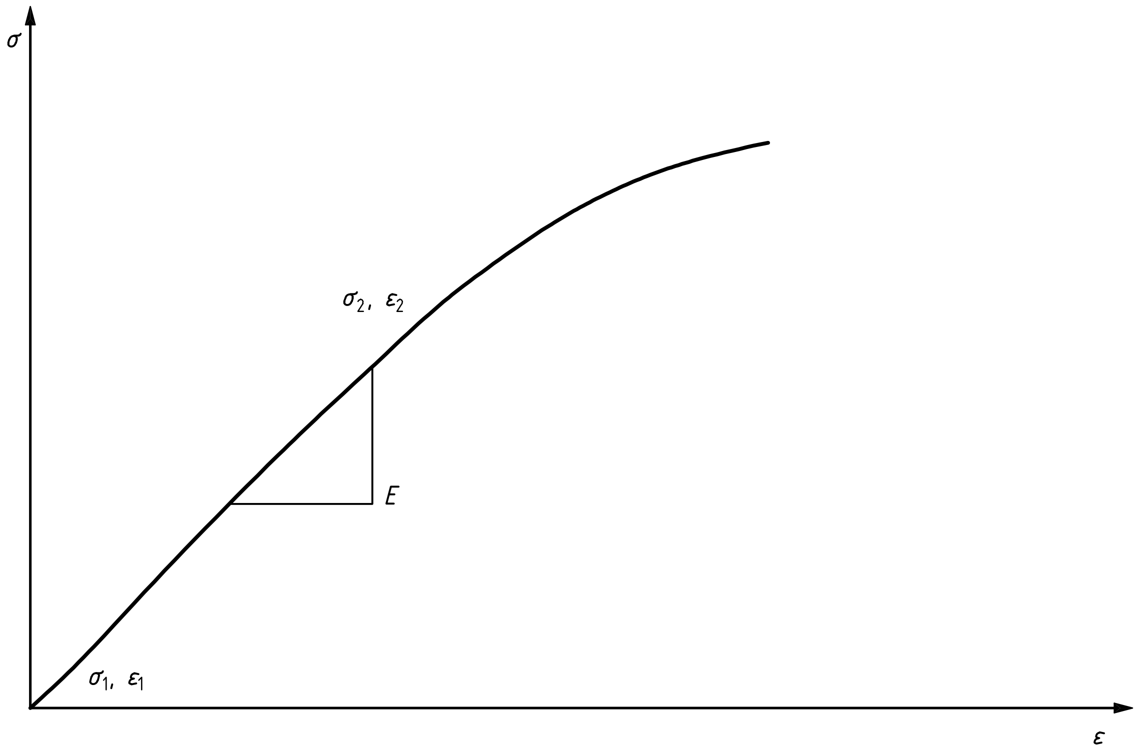
Key

ε compressive strain

σ compressive stress

E elastic modulus

Figure A.1 — Mechanical behaviour with linear region bounded by σ_1, ε_1 and σ_2, ε_2



Key

ε compressive strain

σ compressive stress

E elastic modulus

Figure A.2 — Mechanical behaviour with predominantly linear region bounded by σ_1, ε_1 near the origin and σ_2, ε_2

Annex B
(normative)

Alignment verification

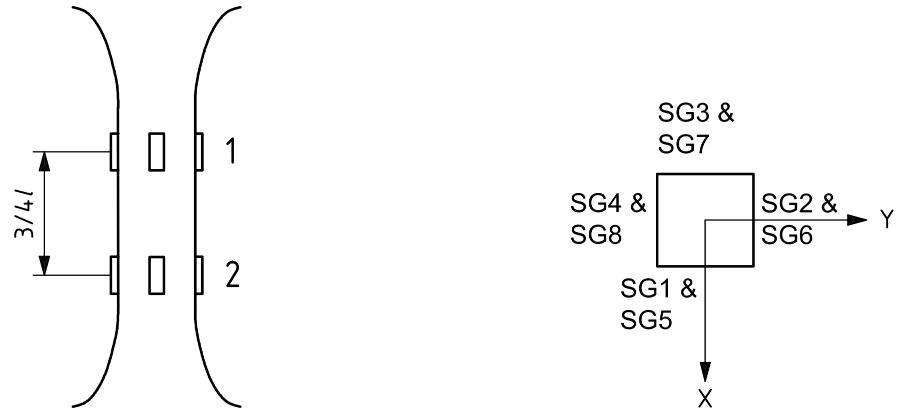
Alignment of the load train shall be measured at a minimum at the beginning and end of a test series using either a dummy or actual test specimen and procedures listed in ASTM E1012 or similar procedures, as discussed in 5.2. Applicable details of the alignment procedure for square or circular cross-sections are given in this annex .

For simplicity, mount a minimum of eight foil resistance-strain gauges on the verification test specimen, as shown in Figure B.1. Separate the strain gauge planes by ~3/4 l, where l is the gauge section length. Mount four strain gauges, equally spaced (90° apart) around the circumference of the gauge section (i.e. one strain gauge on each face), at each of two planes at either end of the gauge section. These planes shall be symmetrically located about the longitudinal midpoint of the gauge section. Employ suitable strain-recording equipment. Mount the top of the test specimen in the grip interface. Connect the lead wires of the strain gauges to the conditioning equipment. Zero the strain gauges before mounting the bottom of the test specimen in the grip interface. Mount the bottom of the test specimen in the grip interface. Apply a sufficient force to the test specimen to achieve a mean strain equal to either one-half the anticipated strain at the onset of the cumulative fracture process (e.g. matrix cracking stress) in the test material or a strain of 0,000 5 (i.e. 500 micro-strain) whichever is greater. Calculate the percent bending as follows for square or circular cross-sections referring to Figure B.1 for the strain gauge numbers. Calculate percent bending (PB) at the upper and lower planes of the gauge section using Equations B.1 and B.2, respectively:

$$PB_{upper} = \frac{\left[\left(\frac{\varepsilon_1 - \varepsilon_3}{2}\right)^2 + \left(\frac{\varepsilon_2 - \varepsilon_4}{2}\right)^2\right]^{1/2}}{\left(\frac{\varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4}{4}\right)} \times 100 \quad \text{(B.1)}$$

$$PB_{lower} = \frac{\left[\left(\frac{\varepsilon_5 - \varepsilon_7}{2}\right)^2 + \left(\frac{\varepsilon_6 - \varepsilon_8}{2}\right)^2\right]^{1/2}}{\left(\frac{\varepsilon_5 + \varepsilon_6 + \varepsilon_7 + \varepsilon_8}{4}\right)} \times 100 \quad \text{(B.2)}$$

where ε_1, ε_2, ε_3, ε_4, ε_5, ε_6, ε_7 and ε_8 are strain readings for strain gauges located at the upper and lower planes of the gauge sections, respectively. Strain gauge readings are in units of strain (i.e. m/m) and compressive strains are negative.



a) Strain gauges (SG) on gauge section planes

b) Strain gauge (SG) numbering

Key

1 upper plane, SG1, 2, 3 and 4

2 lower plane, SG5, 6, 7 and 8

Figure B.1 — Illustration of strain gauge placement on gauge section planes and strain gauge numbering

Annex C
(normative)

Compressive force limits to ensure 'true' compressive failure

The limitations of the compression test as described in this test method are as follows. For exceedingly high-strength materials, irrespective of elastic modulus, the compression test is governed by either the adhesive strength of the end tabs and/or the interlaminar shear strength of the parent end-tab material for type 5 test specimens, and the crushing strength and/or interlaminar strengths of ceramic composite material for types 1, 2, 3 and 4 test specimens. For low-elastic-modulus materials, elastic column buckling may be critical.

The most conservative assumption regarding behaviour of a test specimen under axial compression is to assume that the test specimen behaves as a double-pinned-end column, with one end free to move axially and with length equal to the unsupported length in the test fixture. The most appropriate assumption for the case of frictional face-loaded grips and fixed load-train couplers (types 3, 4 and 5 test specimens) is a double-fixed-end column with one end free to move axially only and whose length is equal to one-fourth the unsupported length of the test fixture. For example, the test specimen illustrated in Figure 5 has an untabbed gauge length of 25 mm, while the unsupported length (ungripped length) of the test specimen, which includes both the untabbed gauge section length and the tapered part of the end tabs, is 38 mm.

Assuming elastic behaviour, the critical buckling stress for the most conservative, pinned-end column is given as:

$$\sigma_e = P_e / wb = \pi^2 EI / \left(l^2 wb \right) \qquad \text{(C.1)}$$

where

σ_e is the Euler critical buckling stress;

P_e is the critical compressive force;

w is the test specimen width;

b is the test specimen thickness;

π is pi (3,142);

E is the longitudinal elastic modulus of the test material;

I is the moment of inertia in the b direction, where $I = wb^3/12$;

l is the actual, free (unsupported) length of the test specimen gauge section.

The critical buckling stress for the case of a fixed-end column and $b \leqslant w$ is given as:

$$\sigma_{cr} = P_{cr} / wb = 4\,\pi^2 EI / l^2 wb \qquad \text{(C.2)}$$

where

σ_{cr} is the critical buckling stress;

P_{cr} is the critical compressive force.

The critical stress of Equation C.2 is shown in Figure C.1 for a recommended width, w, of 10 mm, but for a variety of thicknesseses, b, and elastic moduli, E. Figure C.1 shows whether the results of a test already performed are in the non-buckling load range, or for a given test specimen, whose moduli is known approximately from fibre or flexure properties, what upper compressive force could be safely attained, and whether a thicker test specimen should be used.

The axial shear stiffness of unidirectional composites is much less than the axial stiffness. This can be accounted for by making a shear modulus correction resulting in a reduced critical buckling stress, $\sigma^{[\mathrm{tgr}]}{}_{\mathrm{cr}}$, expressed as:

$$\sigma^{[\mathrm{tgr}]}{}_{\mathrm{cr}} = P^{[\mathrm{tgr}]}{}_{\mathrm{cr}} / wb = P_{\mathrm{cr}} / wb \left(1 + nP_{\mathrm{cr}} / wbG\right) \qquad \text{(C.3)}$$

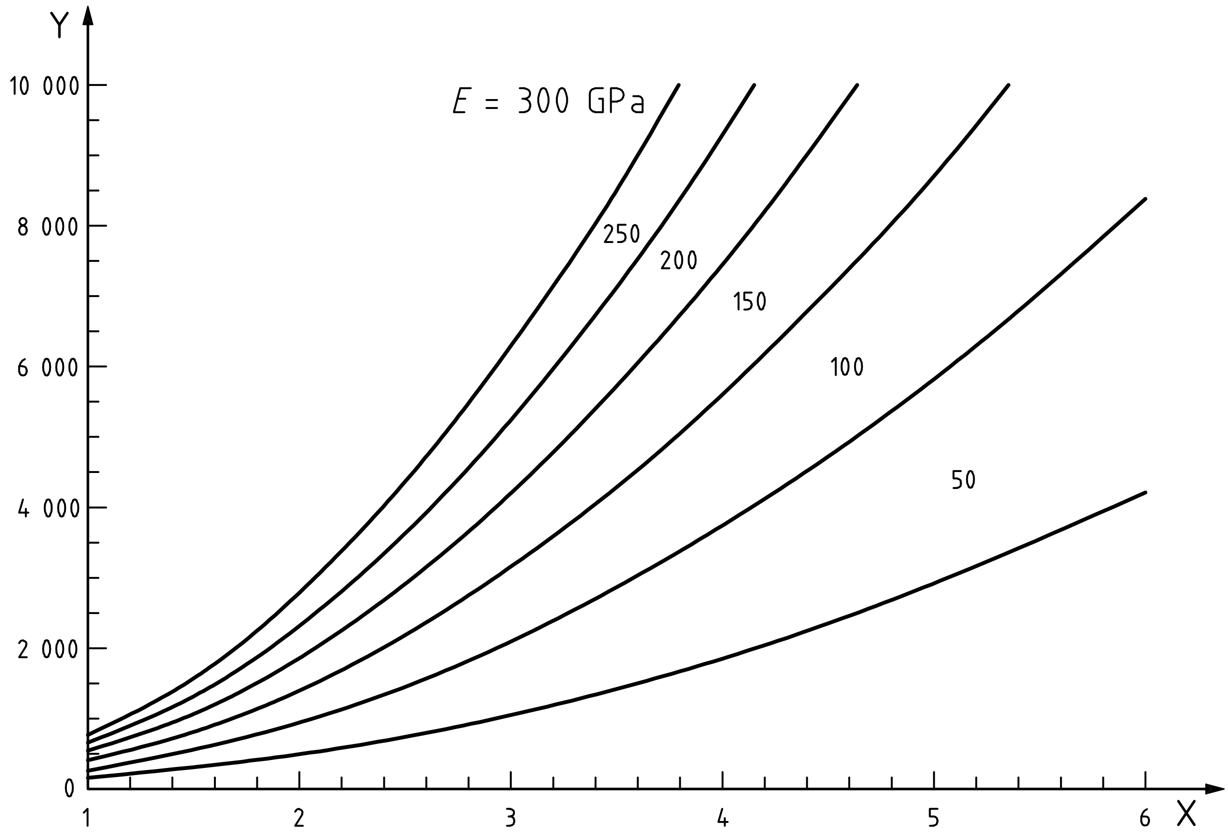
where

n is the shape factor (n = 1,2 for rectangular cross-sections);

G is the axial shear modulus.

Using this relationship, the expected critical buckling stress, $\sigma^{[\mathrm{tgr}]}{}_{\mathrm{cr}}$, of Equation C.3 is corrected upwards to the σ_{cr} of Figure C.1. This ‘new’ σ_{cr} is then coupled with the expected compressive modulus for the test material, to select from Figure C.1 the minimum test specimen thickness required to inhibit buckling.

In most cases (Equations C.2 and C.3 and Figure C.1), fixed-end columns are assumed (types 3, 4 and 5 test specimens). Since the end conditions in the recommended grips are closer to fixed end conditions than pinned end conditions, actual buckling forces will approach higher forces than predicted using Equations C.2 and C.3 and Figure C.1. However, the more conservative criterion of pinned ends of Equation C.1 nearly guarantees that compressive failure rather than column buckling will occur. When this criterion is exceeded, the only way to be certain that buckling does not occur is to use strain readings on opposite sides of the test specimen as recommended in 8.3.



Key

X test specimen thickness, b (mm)

Y critical Euler buckling stress, σ_{cr} (MPa)

E elastic modulus of test specimen material

Figure C.1 — Critical Euler buckling stress for fixed-end column with rectangular cross-section of width

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