



**International  
Standard**

**ISO 14544**

**Fine ceramics (advanced ceramics,  
advanced technical ceramics) —  
Mechanical properties of ceramic  
composites at high temperature  
— Determination of compressive  
properties**

*Céramiques techniques — Propriétés mécaniques des composites  
à matrice céramique à haute température — Détermination des  
caractéristiques en compression*

**Second edition  
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CP 401 • Ch. de Blandonnet 8  
CH-1214 Vernier, Geneva  
Phone: +41 22 749 01 11  
Email: [copyright@iso.org](mailto:copyright@iso.org)  
Website: [www.iso.org](http://www.iso.org)

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## Foreword

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

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This document was prepared by Technical Committee ISO/TC 206, *Fine ceramics*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 184, *Advanced technical ceramics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 14544:2013), which has been technically revised.

The main changes are as follows:

- alignment of the terms and definition with the vocabulary standard ISO 20507;
- addition of illustration of compressive modulus in [Annex A](#);
- addition of a calibration method of the test temperature by using a cartographic specimen equipped with thermocouples in [Annex B](#).

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

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# Fine ceramics (advanced ceramics, advanced technical ceramics) — Mechanical properties of ceramic composites at high temperature — Determination of compressive properties

## 1 Scope

This document specifies procedures for determination of the compressive behaviour of ceramic matrix composite materials with continuous fibre reinforcement at elevated temperature in air, vacuum and inert gas atmospheres. This document applies to all ceramic matrix composites with a continuous fibre reinforcement, uni-directional (1D), bidirectional (2D) and multi-directional (xD, with  $x > 2$ ), tested along one principal axis of reinforcement or off axis conditions for 2D and xD materials. This document also applies 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 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 3611, *Geometrical product specifications (GPS) — Dimensional measuring equipment — Design and metrological characteristics of micrometers for external measurements*

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 19634, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Ceramic composites — Notations and symbols*

ISO 20507, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Vocabulary*

IEC 60584-1, *Thermocouples — Part 1: EMF specifications and tolerances*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 20507 and ISO 19634 and the following apply.

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

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

— IEC Electropedia: available at <https://www.electropedia.org/>

### 3.1 test temperature

$T$

temperature of the test piece at the centre of the gauge length

**3.2  
calibrated length**

$l$   
part of the test specimen that has uniform and minimum cross-section area

[SOURCE: ISO 20504:2022, 3.1]

**3.3  
gauge length**

$L_0$   
initial distance between reference points on the test specimen in the calibrated length

[SOURCE: ISO 20504:2022, 3.2, modified — term and definition, words before initiation of the test deleted.]

**3.4  
controlled-temperature zone**

part of the calibrated length, including the gauge length, where the temperature is within a range of 50 °C of the test temperature

**3.5  
initial cross-section area**

$S_0$   
cross-section area of the test specimen within the calibrated length, at room temperature before testing

**3.5.1  
apparent cross-section area**

$S_{0\text{ app}}$   
area of the cross section

**3.5.2  
effective cross-section area**

$S_{0\text{ eff}}$   
area corrected by a factor, to account for the presence of a coating

**3.6  
longitudinal deformation**

$A$   
decrease in the gauge length under a compressive force in the load direction

Note 1 to entry: The longitudinal deformation corresponding to the maximum compressive force is denoted as  $A_{c,m}$ .

**3.7  
compressive strain**

$\varepsilon$   
ratio of deformation to initial gauge length defined as the ratio  $A/L_0$

Note 1 to entry: The compressive strain corresponding to the maximum compressive force is denoted as  $\varepsilon_{c,m}$ .

**3.8  
compressive force**

$F_c$   
uniaxial force carried by the test specimen at any time during the compression test

[SOURCE: ISO 20504:2022, 3.6, modified — word "compression" added.]

**3.9  
compressive stress**

$\sigma$   
*compressive force* (3.8) supported by the test specimen at any time in the test divided by the *initial cross-sectional area* (3.5) such that  $\sigma = F_c/S_0$

[SOURCE: ISO 20504:2022, 3.8]

### 3.9.1

#### apparent compressive stress

$\sigma_{app}$

ratio of the *compressive force* (3.8) supported by the test piece to the *apparent cross-section area* (3.5.1)

### 3.9.2

#### effective compressive stress

$\sigma_{eff}$

ratio of the *compressive force* (3.8) carried by the test piece to the *effective cross-section area* (3.5.2)

### 3.10

#### maximum compressive force

$F_{c,m}$

highest force recorded or force at failure during a compressive test

### 3.11

#### compressive strength

$\sigma_{c,m}$

greatest *compressive stress* (3.9) applied to a test specimen when tested to failure

[SOURCE: ISO 20504:2022, 3.9]

#### 3.11.1

##### apparent compressive strength

$\sigma_{c,m app}$

ratio of the *maximum compressive force* (3.10) to the *apparent cross-section area* (3.5.1)

#### 3.11.2

##### effective compressive strength

$\sigma_{c,m eff}$

ratio of the *maximum compressive force* (3.10) to the *effective cross-section area* (3.5.2)

### 3.12

#### compressive modulus

$E$

slope of the linear section of the stress-strain curve at or near the origin

Note 1 to entry: It is possible that a linear part does not exist or does not start at the origin. The different situations are then described in the [Annex A](#).

#### 3.12.1

##### apparent compressive modulus

$E_{app}$

slope of the linear part of the stress-strain curve at or near the origin when the *apparent compressive stress* (3.9.1) is used

#### 3.12.2

##### effective compressive modulus

$E_{eff}$

slope of the linear part of the stress-strain curve at or near the origin, when the *effective compressive stress* (3.9.2) is used

## 4 Principle

A test specimen of specified dimensions is heated to the test temperature, and loaded in compression. The test is performed at constant crosshead displacement rate or constant deformation rate (or constant loading rate). Force and longitudinal deformation are measured and recorded simultaneously.

NOTE The test duration is limited to reduce creep effects.

When constant loading rate is used in the nonlinear region of the compressive curve, only the compressive strength can be obtained from the test. In this region, constant crosshead displacement rate or constant deformation rate is recommended to obtain the complete curve.

## 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. This should prevail during actual test conditions of, e.g. gas pressure and temperature.

### 5.2 Load train

The load train configuration shall ensure that the load indicated by the load cell and the load experienced by the test specimen are the same.

The load train performance including the alignment system and the force transmitting system shall not change because of heating.

The load train shall align the specimen axis with the direction of load application without introducing bending or torsion in the specimen. The misalignment of the specimen shall be verified at room temperature and documented. Several standards address this topic but it is recommended to comply with the procedure described in ISO 17161. The percent bending strain shall not exceed 5 % at an average strain of  $500 \times 10^{-6}$ .

There are two alternative means of load application:

- a) Compression platens are connected to the load cell and on the moving crosshead. The platens should have a larger diameter than the specimen base. The parallelism of these platens should be better than 0,01 mm, in the loading area, at room temperature and they shall be perpendicular to the load direction.

The use of platens is not recommended for compression testing of 1D and 2D materials with low thickness due to buckling. For high temperature tests set-up, the platens parallelism value specified in ISO 20504 is sometimes difficult to be determined by dimensional controls but remains a suitable recommendation.

A compliant interlayer material between the test specimen and platens can be used for testing macroscopically inhomogeneous materials to ensure even contact pressure. This material should be chemically compatible with both test specimen and platen materials.

- b) Grips are used to clamp and load the test specimen.

The grip design shall prevent the test specimen from slipping. The grips shall align the test specimen axis with that of the applied force.

Conformity to this requirement should be verified and documented according to, for example, the procedure described in Reference [1].

The grips or the platens may either be in the hot zone of the furnace or outside the furnace.

NOTE When grips or platens are outside the furnace, a temperature gradient exists between the centre of the specimen, which is at the prescribed temperature, and the ends that are at the same temperature as the grips or platens.

### 5.3 Gastight test chamber

The gastight chamber shall allow proper control of the test specimen environment in the vicinity of the test specimen during the test. The installation shall be such that the variation of load due to the variation of pressure is less than 1 % of the scale of the load cell being used.

Where a gas atmosphere is used, the gas atmosphere shall be chosen depending on the material to be tested and on test temperature. The level of pressure shall be chosen depending: on the material to be tested, on temperature, on the type of gas, and on the type of extensometer.

Where a vacuum chamber is used, the level of vacuum shall not induce chemical and/or physical instabilities of the test specimen material, and of extensometer rods, when applicable. Primary vacuum (typically 1 Pa pressure) is recommended.

## 5.4 Set-up for heating

The set-up for heating shall be constructed in such a way that:

- the test coupon maximal temperature will never exceed the desired test temperature by more than 5 °C;
- the gauge length is actually included in the controlled temperature zone.

NOTE 1 When tests are performed in vacuum or inert gas atmospheres, this maximal temperature gradient of 50 °C in the controlled temperature zone is considered to be low enough to avoid large discrepancy of material behaviour in the gauge length and then to bias the material properties determination.

NOTE 2 This value of 50 °C is a maximum value of the temperature gradient of the controlled temperature zone especially for very high temperature test in cold grip configuration. If tests are performed at lower temperature, temperature gradient lower than 50 °C can be easily achieved.

If the tests are performed under oxidative environment, for CMC materials which are sensitive to oxidative degradation, the test duration and the controlled temperature zone thermal gradient parameters are to be set at the lowest values possible in order to limit the impact on the material properties of the oxidative degradation. For instance, for material such as CMC including a carbon interphase which are sensitive to chemical degradation, it is recommended to not exceed  $\pm 5$  °C below 500 °C for the temperature gradient within the controlled temperature zone.

NOTE 3 An example of calibration method of test temperature and temperature gradient determination is described in the [Annex B](#).

## 5.5 Strain measurement

### 5.5.1 General

For continuous measurement of the longitudinal deformation as a function of the applied force at high temperature, either suitable contacting or non-contacting extensometer may be used. Measurement of longitudinal deformation over a length as long as possible within the controlled-temperature zone of the test specimen is recommended.

### 5.5.2 Strain gauges

Strain gauges are used for the verification of the alignment on the test specimen at room temperature. They are not recommended to determine longitudinal deformation during testing at high temperature.

### 5.5.3 Extensometer

#### 5.5.3.1 General

The extensometer shall be capable of continuously recording the longitudinal deformation at test temperature. The use of an extensometer with the greatest possible gauge length is preferable.

Extensometers shall meet the requirements of class 1 or less (class 0,5) in accordance with ISO 9513. Types of commonly used extensometers are described in [5.5.3.2](#) and [5.5.3.3](#).

### 5.5.3.2 Mechanical extensometer

For a mechanical extensometer, the gauge length shall be the initial longitudinal distance between the two locations where the extensometer rods contact the test specimen.

The rods may be exposed to temperatures higher than the test specimen temperature. Temperature and/or environment induced structural changes in the rod material shall not affect the accuracy of deformation measurement. The material used for the rods shall be compatible with the test specimen material.

Any extensometer contact forces shall not introduce bending greater than that allowed in [5.2](#).

Care should be taken to correct for changes in calibration of the extensometer that may occur as a result of operating under conditions different from calibration. Verification may be done by measuring the compressive modulus on a well-known material specimen.

Rod pressure onto the test specimen should be the minimum necessary to prevent slipping of the extensometer rods.

### 5.5.3.3 Electro-optical extensometer

Electro-optical measurements in transmission require reference marks on the test specimen. For this purpose, rods or flags shall be attached to the surface perpendicular to its axis. The gauge length shall be the distance between the two reference marks. The material used for marks (and adhesive if used) shall be compatible with the test specimen material and the test temperature and shall not modify the stress field in the specimen.

NOTE 1 The use of integral flags as parts of the test specimen geometry is not preferred because of stress concentration induced by such features.

NOTE 2 An electro-optical extensometer is not appropriate in the case where it's impossible to distinguish the colours of the reference marks and the test specimen.

### 5.5.3.4 Digital image correlation

Digital image correlation (DIC) method can be used for non-contacting strain field measurement. In order to improve the measurement accuracy, the size of furnace window may be minimized and an optical filter might be used to get high contrast random patterns at elevated temperatures<sup>[2]</sup>.

NOTE Creating a flyspeck that can be used at high temperature is a major technical challenge with little or no documentation to date.

Stress-strain response of ceramic composites can be determined for on-axis or off-axis compressive tests by using DIC technique, as well as for tensile tests on SiC/SiC CMCs up to 1 316 °C<sup>[2]</sup>.

Full-field deformation output procedure and calibration data shall be annexed to the test report.

## 5.6 Temperature measurement devices

For temperature measurement, either thermocouples conforming to IEC 60584-1 shall be used or, when thermocouples not conforming to IEC 60584-1 or pyrometers are used, calibration data shall be annexed to the test report.

## 5.7 Data recording system

A calibrated recorder may be used to record the force-deformation curve. The use of a digital data recording system is recommended.

NOTE More detailed information is available in ISO 6892-1:2019, Annex A<sup>[3]</sup>.

## 5.8 Dimension measuring devices

Devices used for measuring linear dimensions of the test specimen shall be accurate to  $\pm 0,01$  mm. Micrometres shall conform to ISO 3611.

## 6 Test specimens

### 6.1 General

The choice of specimen geometry depends on several factors, such as:

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

The volume in the gauge length shall be representative of the material and calibrated length shall be chosen such as to avoid buckling failure. If buckling occurs, it can be necessary to modify the dimensions of the test specimen.

A test piece volume of a minimum of five representative volume elements is recommended. In the case of off-axis loading conditions, results can depend on the cross-sectional area of specimens due to scale effect.

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, two faces of the test specimen can present irregular 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 length) should not exceed 5 % of the average of the three measurements.

### 6.2 Compression between platens

The cross-sections of the recommended test specimens may be cylindrical, square or rectangular.

A Type 1 specimen is commonly used and is represented on [Figure 1](#), where  $d$  and  $d_t$  represent the diameter, side and short side respectively of the three specimen geometries.

Recommended dimensions are given in [Table 1](#).

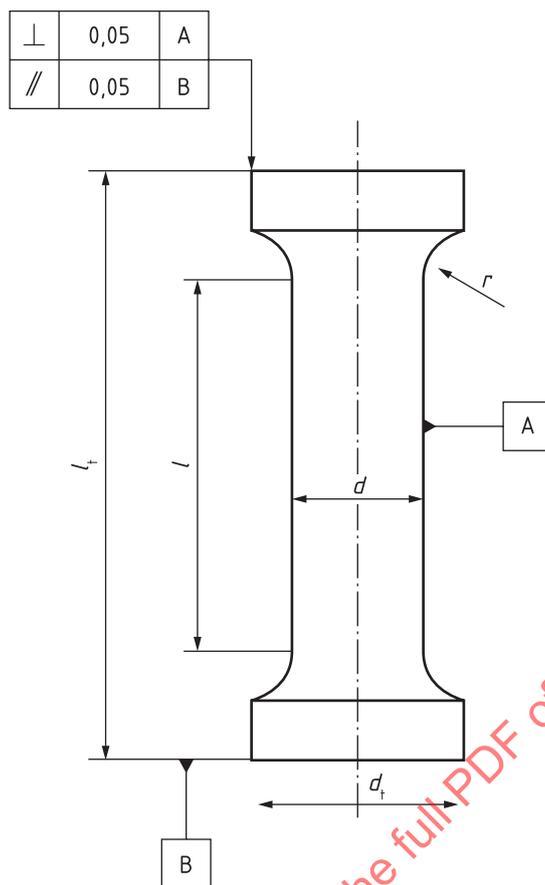


Figure 1 — Type 1 specimen geometry

Table 1 — Recommended dimensions for a Type 1 specimen

Dimensions in millimetres

	2D and xD	Tolerance
$l$ , calibrated length	$\geq 15$	$\pm 0,5$
$l_t$ , total length	$\geq 1,5 l$	$\pm 0,5$
$d$ , circular or square section diameter or side length	$\geq 8$	$\pm 0,2$
$d_t$ , circular or square section diameter or side length at the specimen base	$\geq d + 0,8r$	$\pm 0,5$
$r$ , radius of shoulder	$\geq 10$	$\geq 2$
Parallelism of machined parts	0,05	
Perpendicularity of machined parts	0,05	
Concentricity of machined parts	0,05	

A Type 2 specimen is sometimes used and is represented in [Figure 2](#). This specimen is mainly used when the thickness of the part is not sufficient to machine a specimen of type 1.

Recommended dimensions are given in [Table 2](#).



Figure 2 — Type 2 specimen geometry

Table 2 — Recommended dimensions for a Type 2 specimen

Dimensions in millimetres

	1D, 2D and xD	Tolerance
$l$ , calibrated length	$\geq 10$	$\pm 0,5$
$d$ , circular or square section diameter or side length	$\geq 10$	$\pm 0,2$
Parallelism of machined parts		0,05
Perpendicularity of machined parts		0,05

### 6.3 Test specimen used with grips

For these types of specimens, the total length  $l_t$  depends on furnace and gripping system.

A Type 3 specimen is represented in Figure 3. This type of specimen is recommended in the case of buckling with the specimen of Table 3. With this type of specimen it is very difficult to obtain strain measurements.

Recommended dimensions are given in Tables 3 and 4.

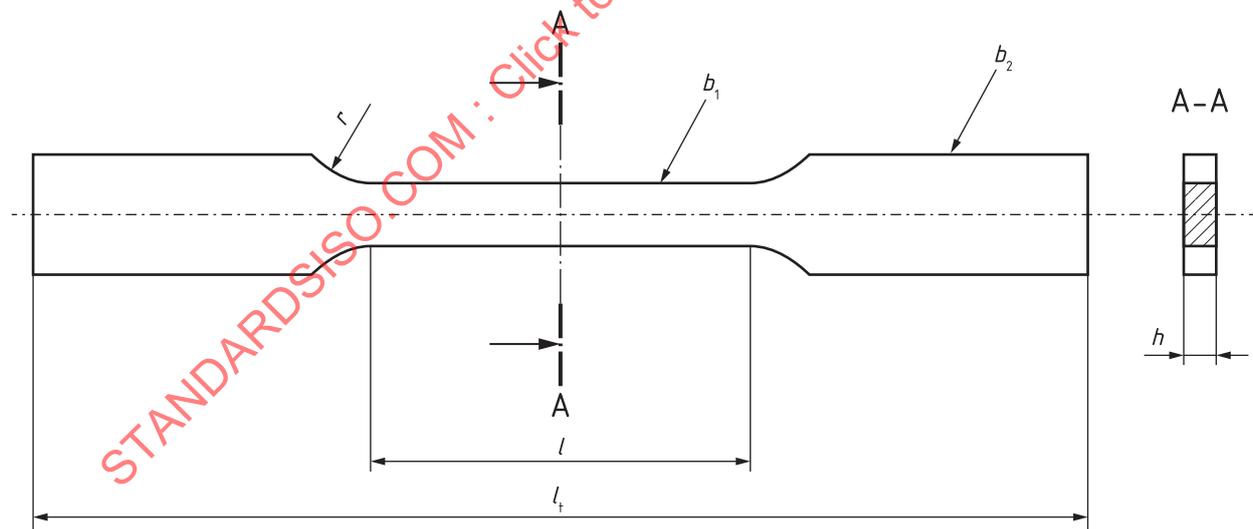


Figure 3 — Type 3 specimen geometry

Table 3 — Recommended dimensions for a Type 3 specimen

Dimensions in millimetres

	2D and xD	Tolerance
$l$ , calibrated length	$\geq 15$	$\pm 0,5$
$h$ , thickness	$\geq 2$	$\pm 0,2$
$b_1$ , width in the calibrated length	$\geq 8$	$\pm 0,2$
$b_2$ , width	$b_2 = \alpha b_1$ with $\alpha = 1,2$ to $2$	$\pm 0,2$
$r$ , radius of shoulder	$\geq 30$	$\pm 2$
Parallelism of machined parts	0,05	

Table 4 — Alternative recommended dimensions for a Type 3 specimen

Dimensions in millimetres

	2D and xD	Tolerance
$l$ , calibrated length	$\leq 15$	$\pm 0,5$
$h$ , thickness	$\geq 1$	$\pm 0,2$
$b_1$ , width in the calibrated length	$\geq 8$	$\pm 0,2$
$b_2$ , width	$b_2 = \alpha b_1$ with $\alpha = 1,2$ to $2$	$\pm 0,2$
$r$ , radius of shoulder	$\geq 30$	$\pm 2$
Parallelism of machined parts	0,05	

A Type 4 is sometimes used and is represented in [Figure 4](#). When used with cold grips, this multi-section specimen allows rupture within the controlled-temperature zone.

Recommended dimensions are given in [Table 5](#).

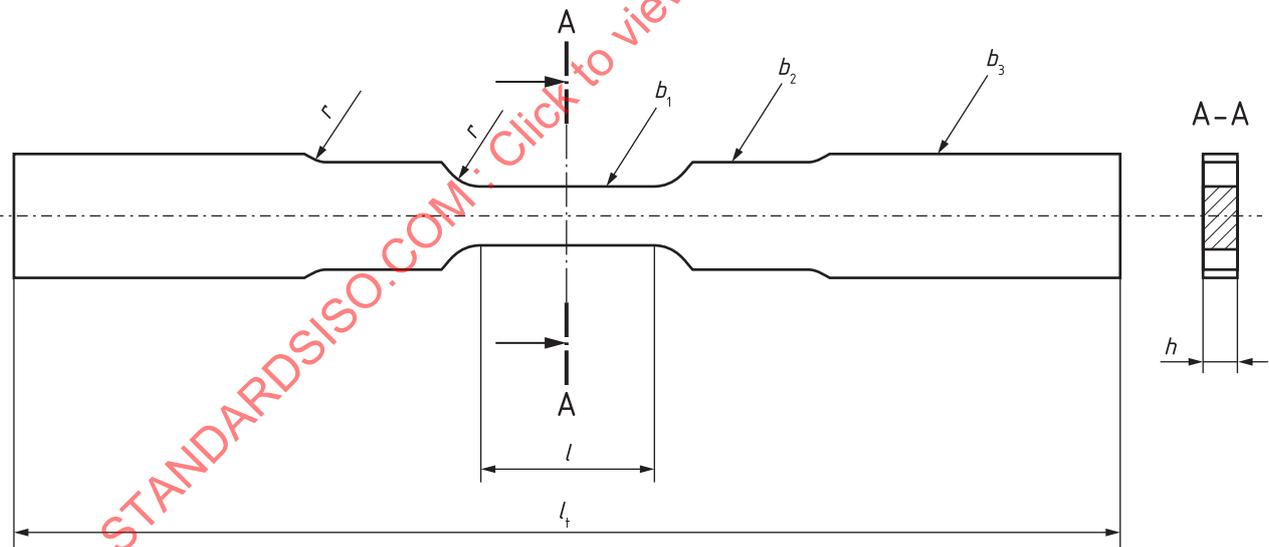


Figure 4 — Type 4 specimen geometry

Table 5 — Recommended dimensions for a Type 4 specimen

Dimensions in millimetres

	2D and xD	Tolerance
$l$ , calibrated length	$\geq 15$	$\pm 0,2$
$h$ , thickness	3	$\pm 0,2$
$b_1$ , width in the calibrated length	8 to 20	$\pm 0,2$
$b_2$ , width	$b_2 = \alpha b_1$ with $\alpha = 1,2$ to 2	$\pm 0,2$
$b_3$ , width	$b_3 = \beta b_2$ with $\beta = 1,2$ to 2	$\pm 0,2$
$r$ , radius of shoulder	$\geq 30$	$\pm 2$
Parallelism of machined parts	0,05	

A Type 5 is sometimes used and is represented in Figure 5. This test specimen is easy to machine and its use allows mainly the determination of modulus, as rupture may not happen in the controlled-temperature zone; it should not be used for strength measurement

Recommended dimensions are given in Table 6.

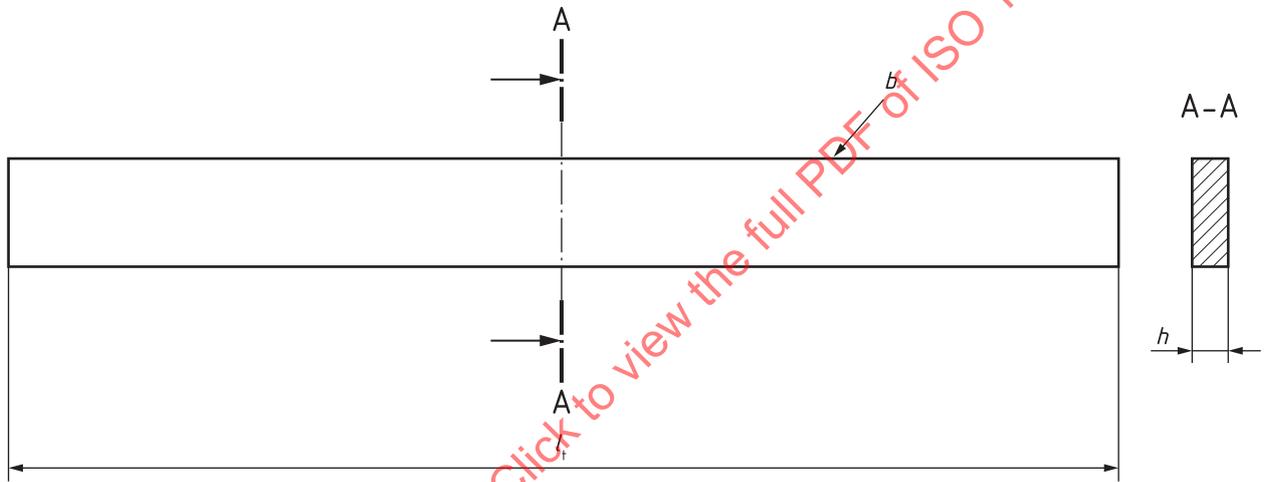


Figure 5 — Type 5 specimen geometry

Table 6 — Recommended dimensions for a Type 5 specimen

Dimensions in millimetres

	1D, 2D and xD	Tolerance
$h$ , thickness	$\geq 2$	$\pm 0,2$
$b$ , width	8 to 20	$\pm 0,2$
Parallelism of machined parts	0,05	

## 7 Test specimen preparation

### 7.1 Machining and preparation

During cutting out, care shall be taken to align the test specimen axis with the desired fibre related loading axis. For off-axis tests, care shall be taken to determine the angle between main reinforcement and loading axis.

Machining methods that do not cause damage to material are recommended. Machining parameters should be traceable.

When specimens are machined from a plate which has been protected against oxidation, the cut surfaces of the specimen are unprotected. These surfaces should be protected to prevent a possible oxidation under air test.

When a cold gripping system is used, the surface of the part of specimen which is at a temperature between the test temperature and the grips temperature can need appropriate antioxidant protection.

## 7.2 Number of test specimens

At least three valid test results, as specified in [8.4](#) are recommended for any condition.

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

## 8 Test procedures

### 8.1 Test set-up: temperature considerations

#### 8.1.1 General

The following determinations shall be carried out under conditions representative of the tests, and shall be repeated every time there is a change, e.g. in material, in specimen geometry, in gripping configuration. In establishing them, time shall be allowed for temperature stabilization.

#### 8.1.2 Controlled-temperature zone

Prior to testing, the temperature gradient within the calibrated length inside the furnace shall be established over the temperature range of interest in order to define the controlled temperature zone. This shall be done if possible at test temperature (especially for very high temperature), by measuring the specimen temperature at a minimum of three locations of the gauge length, which shall be the extensometer reference points and midway between the two, and at least to other points outside the gauge length.

NOTE 1 An example of thermal cartography test specimen is described in the [Figure B.1](#).

NOTE 2 Controlled temperature zone is defined as per [3.4](#).

Temperatures shall be measured in accordance with [5.6](#). If thermocouples are used to measure the temperature at different locations of the specimen, they shall be embedded (and sealed if necessary) into a dummy specimen to a depth approximately equal to half the specimen dimension in the direction of insertion.

#### 8.1.3 Temperature calibration

During a series of tests, the test temperature may be determined either directly by measurement on the specimen itself, or indirectly from the temperature indicated by the temperature control device.

In the latter case, calibration will be necessary. The relationship between the control temperature and test specimen temperature at the centre of the gauge length shall be established beforehand on a dummy test specimen over the range of temperature of interest.

NOTE The relationship between the temperature indicated by the temperature control system and the test temperature is usually established simultaneously with the controlled-temperature zone.

## 8.2 Test set-up: other considerations

### 8.2.1 Displacement rate

Displacement rate that allows specimen rupture within 1 min shall be used. The displacement rate and the loading mode shall be reported. If the material to be tested is sensitive to creep at the temperature of test, the displacement rate shall be significantly increased but impact loading shall be avoided.

### 8.2.2 Measurement of test-specimen dimensions

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

The necessary dimensions to calculate cross-section area are measured with an accuracy of  $\pm 0,01$  mm.

The cross-section area varies with temperature and the variation is very difficult to measure, for this reason, cross-section area is measured at room temperature.

If the test specimen is equipped with marks, the gauge length measured at room temperature, shall be known with an accuracy of  $\pm 1$  %. If thermal expansion between room temperature and the test temperature is less than the tolerance on the gauge length measurement, then the gauge length may be measured at room temperature. If this is not the case, the gauge length shall be corrected to take the thermal expansion into account.

### 8.2.3 Buckling

During a compression test, the test specimen may be subjected to buckling. This phenomenon can be increased at high temperature due to the use of a longer size sample and compression using grips. At ambient temperature, this can be handled using anti-buckling system according to ISO 20504. At high temperature, the use of these systems is limited by the size of the furnace and the temperature resistance of the material used for the system. Otherwise, to be sure of the validity of the test, it is necessary to verify that no buckling occurs in the conditions of the test.

One possibility is to place two extensometers on opposite sides of the specimen during the test. The degree of buckling is acceptable if the difference between the strains measured in the middle of the calibrated length on the opposite width faces of the verification test specimen, for values of stress in the linear region of the stress-strain response (typically, this can be chosen as  $0,1 \sigma_{c,m}$  to  $0,9 \sigma_{c,m}$ ), is such that [Formula \(1\)](#):

$$\left| \frac{\varepsilon' - \varepsilon''}{\varepsilon' + \varepsilon''} \right| \leq 0,05 \quad (1)$$

where

$\varepsilon'$  is the compressive strain measured on the width face;

$\varepsilon''$  is the compressive strain measured on the opposite face for the same stress for the same cross-section.

If it is not possible to place two extensometers on the specimen under test conditions, one of the following procedures shall be used.

#### a) Preliminary room-temperature test

If it is assumed that mechanical behaviour at high-temperature and at room temperature are similar, then resistance to buckling of the high-temperature test specimen may be verified by a test at room temperature with two extensometers.<sup>[1]</sup> If buckling occurs, it is necessary to modify the test specimen geometry.

b) Test with two different specimens

If two specimens of different thickness can be prepared, then a test with two different specimens (of thickness  $h$  and  $2h$ ) shall be carried out. It shall be considered that there are no buckling problems, if results are identical up to rupture. If not, the thicknesses shall be changed to  $2h$  and  $4h$ , respectively.

If preparation of different test specimens is not possible, then two types of tests may be carried out independently. The first test shall be performed for the measurement of the modulus (test specimen with extensometer) and the second test with a short test specimen shall be performed to give only the compressive strength.

Absence of buckling shall be verified every time there is a change in material or specimen geometry.

### 8.3 Testing technique

#### 8.3.1 Specimen mounting

Install the test specimen in the gripping system or loading system with its longitudinal axis coinciding with that of the test machine.

Care shall be taken not to induce flexural or torsional loads. For this purpose, several standards address this topic but it is recommended to comply with the procedure described in ISO 17161.

In some cases, it is necessary to apply a preload during the whole heating period to prevent the alignment from being lost. The preload shall not increase beyond 5 % of the expected failure load at any moment.

#### 8.3.2 Setting of extensometer

Install the extensometer longitudinally centred with axis of the test specimen and adjust to zero.

Where a contacting extensometer is positioned at ambient temperature, the extensometer output shall be adjusted to read zero after the stabilization period at the test temperature.

Where the material has a high thermal expansion coefficient, it is recommended to mechanically preset the extensometer taking expansion into account in order to be close to zero when at test temperature.

#### 8.3.3 Setting of inert atmosphere

When testing in an inert gas, any air or water vapour shall be removed before setting the inert atmosphere. This can be achieved by establishing vacuum ( $<10$  Pa) in the enclosure, or by circulating the gas.

When testing under vacuum, the vacuum pressure is recommended as per [5.3](#).

#### 8.3.4 Heating of test specimen

Raise the test specimen temperature to the required test temperature, and maintain this temperature for a period to allow for temperature stabilization and when applicable, for stabilization of the extensometer readout.

Two ways are possible:

- a) if the test specimen temperature is measured during the test on the specimen itself, this temperature shall be used to control the furnace;
- b) if it is not possible to measure the test specimen temperature directly during the test, then it is necessary to use the relationship between the test specimen temperature and furnace temperature which has been established in [8.1](#).

Ensure that the test specimen stays at the initial state of stress during heating.

Ensure that the test specimen stays at the required temperature during the test (see [Annex B](#)).

### 8.3.5 Measurements

- Zero the load cell;
- zero the extensometer;
- record the force versus longitudinal deformation;
- register temperature, environment conditions (gas and pressure);
- load the test specimen;
- if any, before opening the test chamber, cool down under inert atmosphere to a temperature at which there is no further risk of material degradation;
- note the position of fracture location relative to the mid-point of the specimen to the nearest of 1 mm.

### 8.4 Test validity

The following circumstances invalidate a test:

- failure to specify and record test conditions;
- failure to meet specified test conditions;
- specimen slippage;
- extensometer slippage;
- rupture in an area outside of the controlled-temperature zone;
- buckling of the specimen;
- change in atmosphere.

The following circumstances partially validate some compressive properties measurements:

- in the case of extensometer slippage, the strength is valid and the deformation remains valid in the part of the curve before the slip appears;
- in case of rupture outside of the gauge length, the compressive modulus remains valid.

NOTE For some specific materials, the rupture outside gauge length can invalidate the compressive strain at maximum force.

## 9 Calculation of results

### 9.1 Test specimen origin

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

### 9.2 Compressive strength

Calculate the compressive strength using one of the following formulae:

$$\sigma_{c,m,app} = \frac{F_m}{S_{o,app}} \quad (2)$$

$$\sigma_{c,m,eff} = \frac{F_m}{S_{o,eff}} \quad (3)$$

where

- $\sigma_{c,m,app}$  is the compressive strength at temperature  $T$ , using the apparent area  $S_{o,app}$ , in megapascals (MPa);
- $\sigma_{c,m,eff}$  is the compressive strength at temperature  $T$ , using the effective area  $S_{o,eff}$ , in megapascals (MPa);
- $F_m$  is the maximum compressive force, in newtons (N);
- $S_{o,app}$  is the apparent cross-section area of the specimen, in square millimetres (mm<sup>2</sup>);
- $S_{o,eff}$  is the effective cross-section area of the specimen corrected to take account of the environmental barrier coating, in square millimetres (mm<sup>2</sup>).

### 9.3 Strain at maximum compressive force

Calculate the strain using [Formula \(4\)](#):

$$\varepsilon_{c,m} = \frac{A_{c,m}}{L_0} \quad (4)$$

where

- $\varepsilon_{c,m}$  is the strain at the maximum compressive force;
- $A_{c,m}$  is the longitudinal deformation at the maximum compressive force in millimetres (mm), measured by the extensometer;
- $L_0$  is the gauge length, in millimetres (mm).

### 9.4 Compressive modulus

#### 9.4.1 Calculation of compressive modulus

Calculate the compressive modulus  $E$  defined between two points  $(A_1, F_1)$  and  $(A_2, F_2)$  measured near the lower and upper limits of the linear part of the force-deformation record (see [Figure A.1](#)), according to [Formulae \(5\)](#) and [\(6\)](#):

$$E_{app}(\sigma_1, \sigma_2) = \frac{L_0(F_2 - F_1)}{S_{o,app}(A_2 - A_1)} \times 10^{-3} \quad (5)$$

$$E_{eff}(\sigma_1, \sigma_2) = \frac{L_0(F_2 - F_1)}{S_{o,eff}(A_2 - A_1)} \times 10^{-3} \quad (6)$$

where

- $E_{app}$  is the apparent compressive modulus, in gigapascals (GPa);
- $E_{eff}$  is the effective compressive modulus, in gigapascals (GPa);
- $F$  is the compressive force acting on the specimen, in newtons (N);
- $S_{o,app}$  is the apparent cross-section area of the specimen in square millimetres (mm<sup>2</sup>);
- $S_{o,eff}$  is the effective cross-section area of the specimen corrected to take account of the environmental barrier coating, in square millimetres (mm<sup>2</sup>);
- $L_0$  is the gauge length at temperature  $T$ , in millimetres (mm);
- $A$  is the longitudinal deformation, in millimetres (mm) measured on the curve corresponding to  $F$ .

#### 9.4.2 Calculation of compressive modulus with linear behaviour at the origin

When the material has a linear behaviour at the origin (see [Figure A.2](#)), calculate the compressive modulus according to [Formulae \(7\)](#) and [\(8\)](#):

$$E_{\text{app}} = \frac{FL_0}{S_{\text{o,app}}A} \times 10^{-3} \quad (7)$$

$$E_{\text{eff}} = \frac{FL_0}{S_{\text{o,eff}}A} \times 10^{-3} \quad (8)$$

where

- $E_{\text{app}}$  is the apparent compressive elastic modulus, in gigapascals (GPa);
- $E_{\text{eff}}$  is the effective compressive elastic modulus, in gigapascals (GPa);
- $F$  is the compressive force acting on the specimen, in newtons (N);
- $S_{\text{o,app}}$  is the apparent cross-section area of the specimen, in square millimetres (mm<sup>2</sup>);
- $S_{\text{o,eff}}$  is the effective cross-section area of the specimen corrected to take account of the oxidation protection, in square millimetres (mm<sup>2</sup>);
- $L_0$  is the gauge length at temperature  $T$ , in millimetres (mm);
- $A$  is the longitudinal deformation, in millimetres (mm), measured on the curve corresponding to  $F$ .

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

#### 9.4.3 Calculation of compressive modulus with non-linear behaviour

For materials with no linear section of the stress-strain curve (see [Figure A.3](#)), the couples of stress-strain values corresponding to stresses of  $0,1\sigma_{\text{c,m}}$  and  $0,5\sigma_{\text{c,m}}$  shall be used unless other couples are fixed by agreement between parties.

## 10 Test report

The test report shall contain the following information:

- a) name and address of the testing establishment;
- b) date of the test, unique identification of report and of each page, customer name and address and signatory;
- c) a reference to this document, i.e. determined in accordance with ISO 14544:2025;
- d) test piece drawing or reference and orientation of load versus main fibre direction;
- e) description of the test material (material type, manufacturing code, batch number);
- f) description of the test set up: heating system, temperature measurement device, extensometer, gripping system, load cell, nature and purity of gas and level of pressure or level of vacuum;
- g) temperature gradient over gauge length and controlled-temperature zone;
- h) heating rate, test temperature, and load rate, displacement rate, or strain rate as applied;
- i) number of tests carried out and the number of valid results obtained;
- j) force-longitudinal deformation records;

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- k) valid results, mean values of the compressive strength, the compressive strain at maximum compressive force, the compressive modulus;
- l) value of correction factor applied when effective cross-section area is used and method to obtain it (for example metallographic preparation);
- m) failure location, of all the specimens used for obtaining the above results;
- n) any unusual features observed.

### 11 Uncertainties

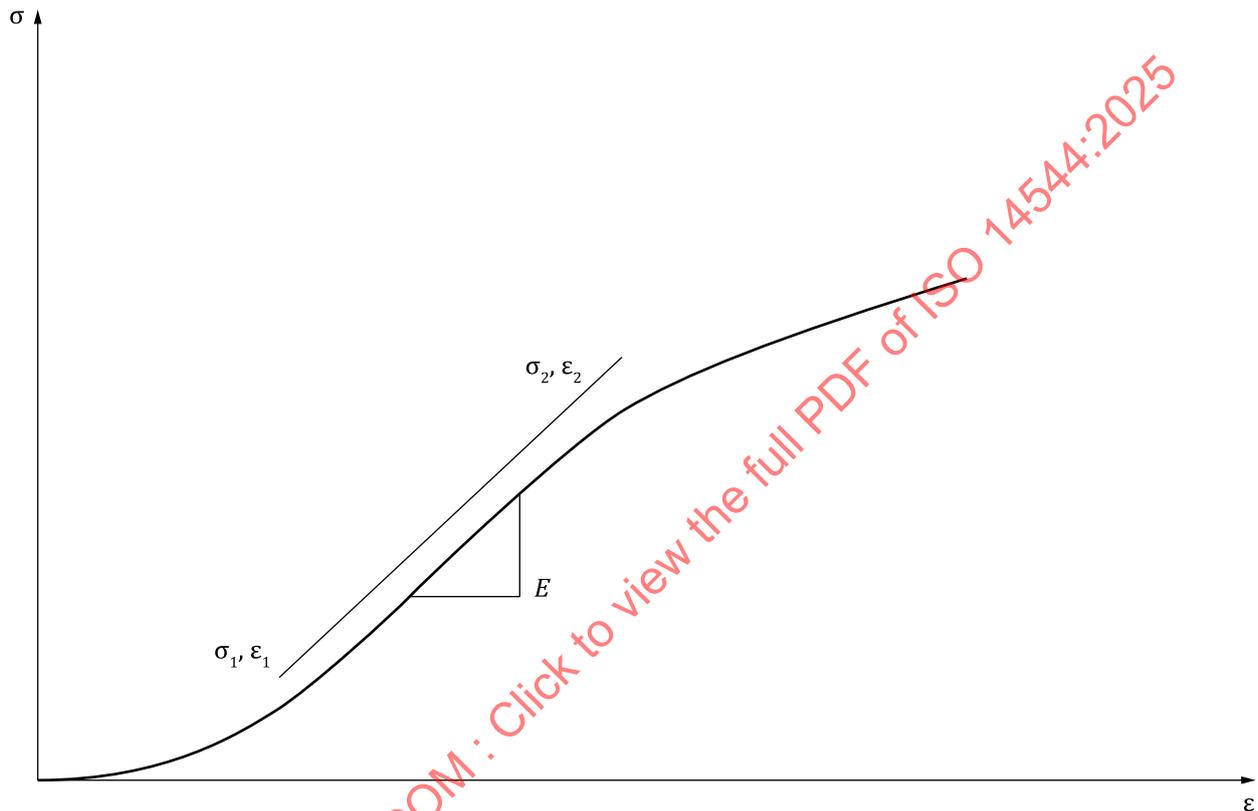
It is recommended to determine the measurement uncertainties. References and information are available in ISO 6892-1:2019, Annexes J and K.<sup>[3]</sup>

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## Annex A (informative)

### Illustration of compressive modulus

[Figure A.1](#) shows an example of a stress-strain curve that presents a toe before the first linear region bounded by  $\sigma_1, \varepsilon_1$  and  $\sigma_2, \varepsilon_2$ .

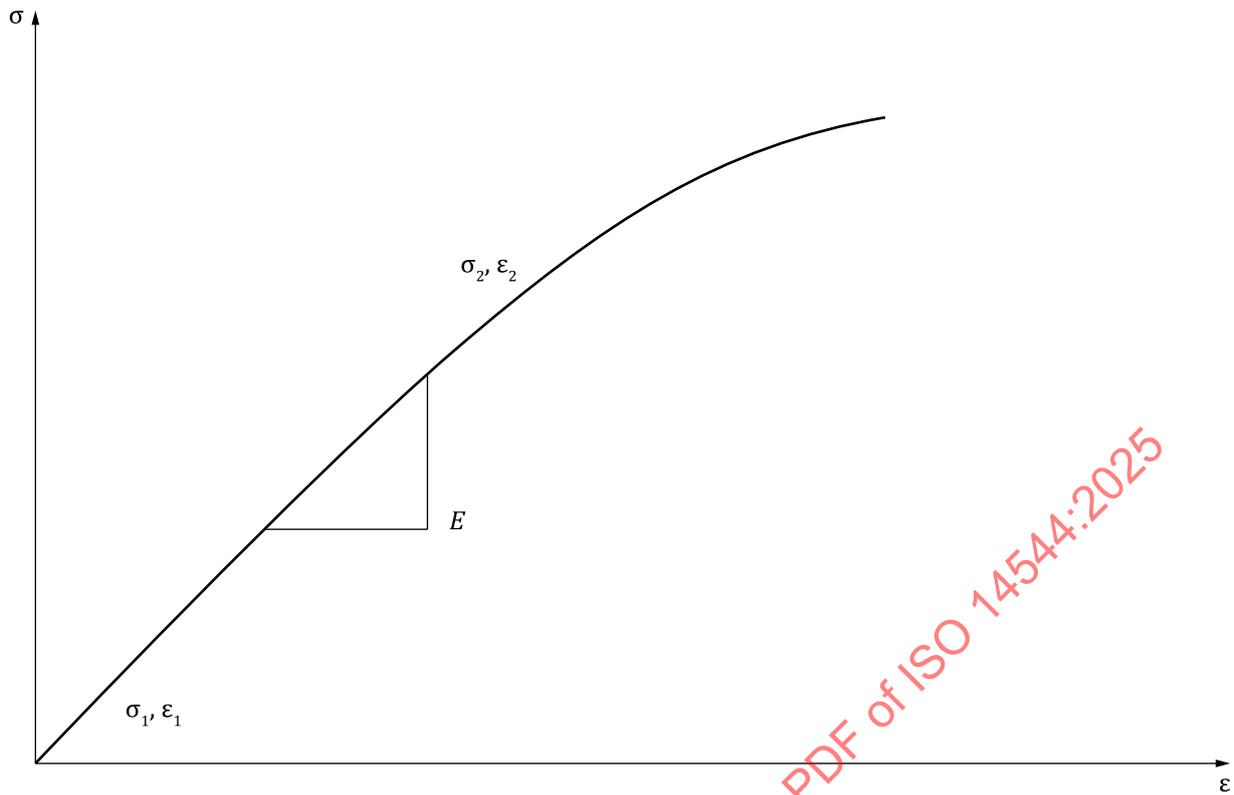


#### Key

- $\varepsilon$  compressive strain
- $\sigma$  compressive stress (apparent or effective)
- $E$  compressive modulus (apparent or effective)

**Figure A.1** — Mechanical behaviour with linear region bounded by  $\sigma_1, \varepsilon_1$  and  $\sigma_2, \varepsilon_2$

[Figure A.2](#) shows another example of a stress-strain curve where the linear part starts at the origin.

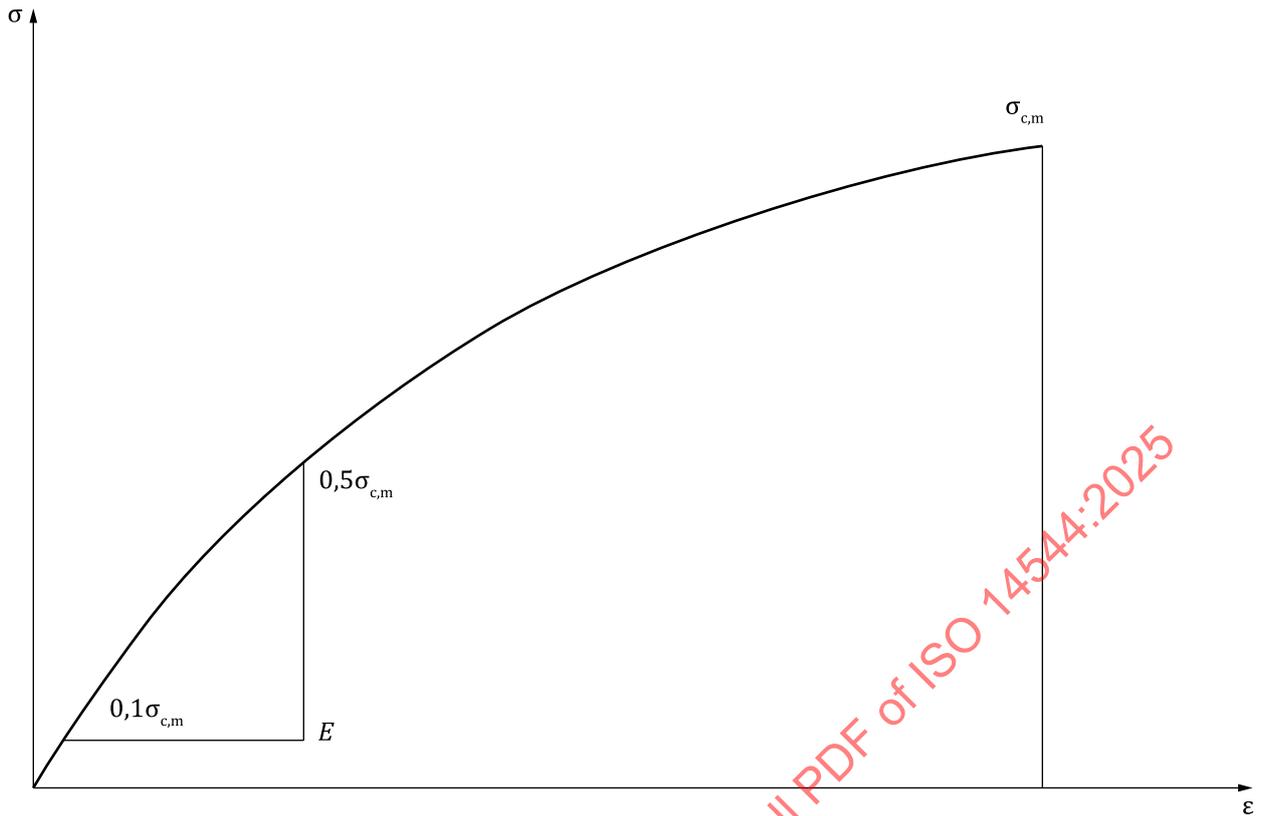


**Key**

- $\epsilon$  compressive strain
- $\sigma$  compressive stress (apparent or effective)
- $E$  compressive modulus (apparent or effective)

**Figure A.2 — Mechanical behaviour with predominantly linear region bounded by  $\sigma_1, \epsilon_1$  near the origin and  $\sigma_2, \epsilon_2$**

[Figure A.3](#) shows another example of a stress-strain curve without linear region. In this case, the couples of stress-strain values corresponding to stresses of  $0,1\sigma_{c,m}$  and  $0,5\sigma_{c,m}$  shall be used unless other couples are fixed by agreement between parties.



**Key**

- $\varepsilon$  compressive strain
- $\sigma$  compressive stress (apparent or effective)
- $E$  compressive modulus (apparent or effective)

**Figure A.3 — Mechanical behaviour without linear region**

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