



**International
Standard**

ISO 14574

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

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

**Second edition
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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).

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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 14574:2013), 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 tensile 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.

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

1 Scope

This document specifies procedures for determination of the tensile behaviour of ceramic matrix composite materials with continuous fibre reinforcement at elevated temperature in air, vacuum and inert gas atmospheres.

This method applies to all ceramic matrix composites with a continuous fibre reinforcement, uni-directional (1D), bidirectional (2D) and multi-directional (x D, with $x > 2$), tested along one principal axis of reinforcement or off axis conditions for 2D and x D materials. This method also applies to carbon-fibre-reinforced carbon matrix composites (also known as carbon/carbon or C/C).

NOTE In most cases, ceramic matrix composites to be used at high temperature in air are coated with an anti-oxidation coating.

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, 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 title 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

increase in the gauge length under a tensile force in the load direction

Note 1 to entry: The longitudinal deformation corresponding to the maximum tensile force is denoted as A_m .

3.7 tensile strain

ε

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

Note 1 to entry: The tensile strain corresponding to the maximum tensile force is denoted as ε_m .

3.8 tensile force

F

uniaxial force carried by the test specimen at any time during the tensile test

3.9 tensile stress

σ

tensile 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 $\sigma = F/S_0$

3.9.1

apparent tensile stress

σ_{app}

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

3.9.2

effective tensile stress

σ_{eff}

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

3.10

maximum tensile force

F_m

highest force recorded or force at failure during a tensile test

3.11

tensile strength

σ_m

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

3.11.1

apparent tensile strength

$\sigma_{m app}$

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

3.11.2

effective tensile strength

$\sigma_{m eff}$

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

3.13

tensile 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](#).

3.13.1

apparent tensile modulus

E_{app}

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

3.13.2

effective tensile modulus

E_{eff}

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

4 Principle

A test specimen of specified dimensions is heated to the test temperature, and loaded in tension. 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 tensile curve, only the tensile 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 test 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 500×10^{-6} .

The attachment fixtures shall align the test specimen axis with the applied force direction.

The grip design shall prevent the test specimen from slipping.

There are two types of gripping systems:

- hot grips where the grips are in the hot zone of the furnace;
- cold grips where the grips are outside the hot zone.

The choice of gripping system will depend on material, on test specimen design and on alignment requirements.

The hot grip technique is limited in temperature because of the nature and strength of the materials that can be used for grips.

In the cold grip technique, a temperature gradient exists between the centre which is at the prescribed temperature and the ends which are at the same temperature as the grips.

5.3 Test chamber

The test chamber shall be as gas-tight as possible and 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 the 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 of 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 as 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 ± 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 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 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 tensile 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 perpendicularly 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 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 [3].

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 tensile tests by using DIC technique, as well as for tensile tests on SiC/SiC CMCs up to 1 316 °C [3].

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 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 (Informative) [4].

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 be in accordance with ISO 3611.

6 Test specimens

6.1 General

The choice of specimen geometry depends on:

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

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

NOTE The total length L depends on furnace and gripping system. Generally, L is greater than 150 mm.

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 Test specimens commonly used

Several types of test specimens may be used, as indicated in [Figures 1 to 6](#) and [Tables 1 to 6](#). The cross-sections of the recommended test specimens may be cylindrical, square or rectangular. For cold gripping system, either type 4 or 5 shall be used to reduce thermal gradient in calibrated length.

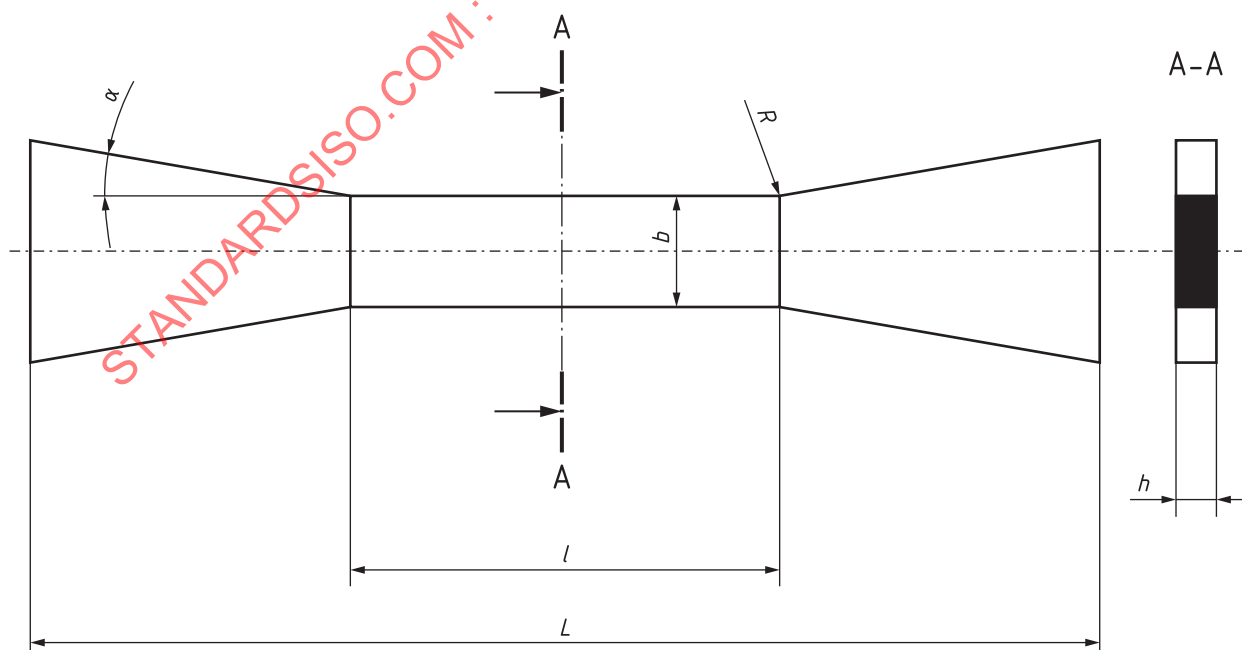


Figure 1 — Type 1 test specimen

Table 1 — Recommended dimensions for a Type 1 test specimen

Parameter	2D and xD	Tolerance
l , calibrated length	30 mm to 80 mm	$\pm 0,5$ mm
L , total length		
h , thickness	> 2 mm	$\pm 0,2$ mm
α , angle	10° to 30°	-
b , width of the calibrated length	8 mm to 20 mm	$\pm 0,2$ mm
R , radius	> 30 mm	± 2 mm
Parallelism of machined parts	0,05	-

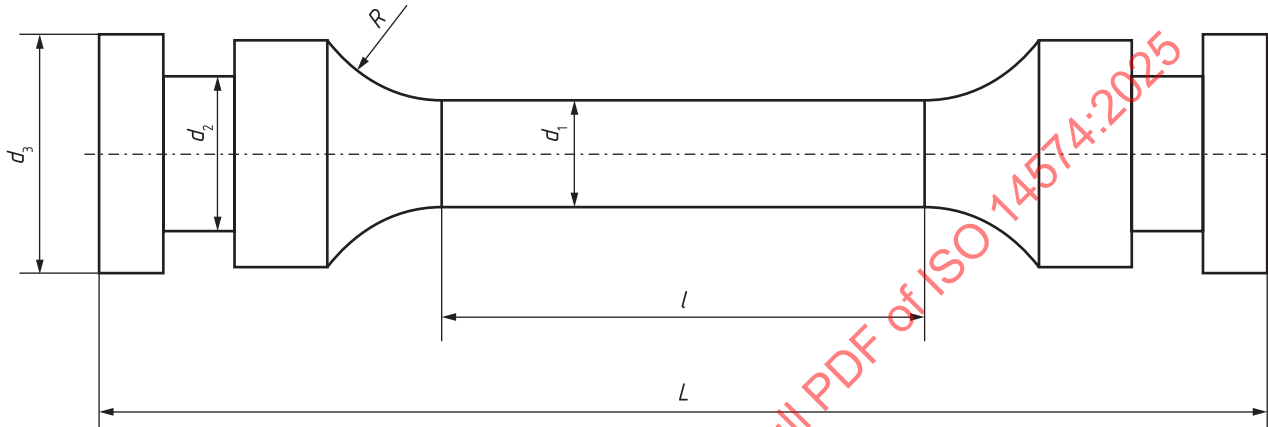


Figure 2 — Type 2 test specimen

Table 2 — Recommended dimensions for a Type 2 test specimen

Dimensions in millimetres

Parameter	xD	Tolerance
l , calibrated length	30 to 80	$\pm 0,5$
L , total length		
d_1 , diameter in calibrated length	8 to 20	$\pm 0,2$
d_2 , diameter	$d_2 = \alpha d_1$ ($\alpha = 1,2$ to 2)	$\pm 0,2$
d_3 , diameter	$d_3 = \beta d_2$ ($\beta = 1,2$ to 2)	$\pm 0,2$
R , radius	> 30	± 2
Parallelism of machined parts	0,05	-

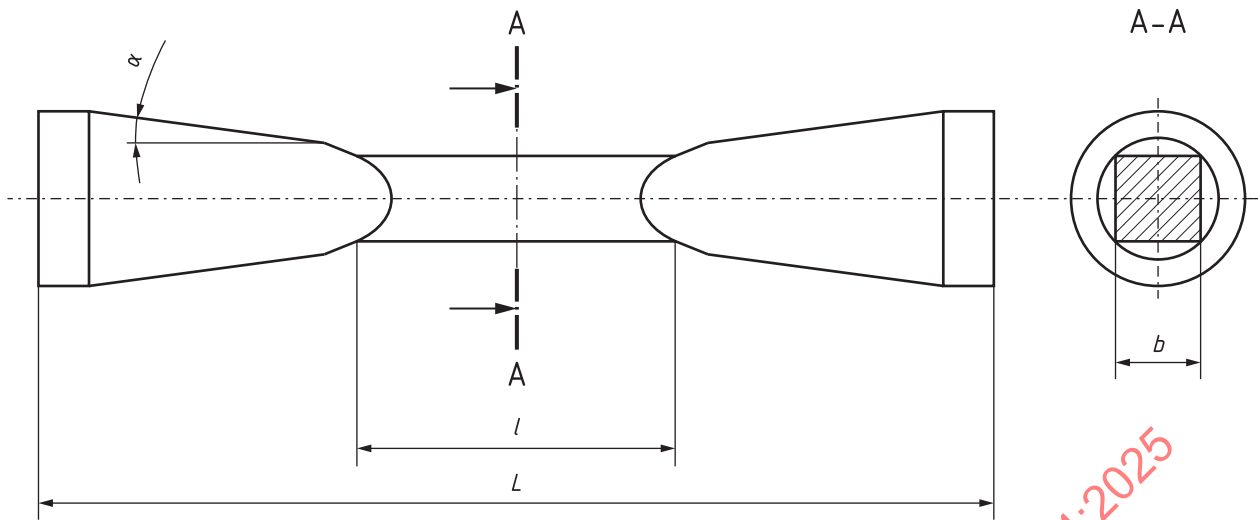


Figure 3 — Type 3 test specimen

Table 3 — Recommended dimensions for a Type 3 test specimen

Parameter	xD	Tolerance
l , calibrated length	30 mm to 80 mm	$\pm 0,5$ mm
L , total length		
b , width and thickness in the calibrated length	3 mm to 8 mm	$\pm 0,2$ mm
α , angle	7° to 30°	$\pm 2^\circ$
Parallelism of machined parts	0,05 mm	-

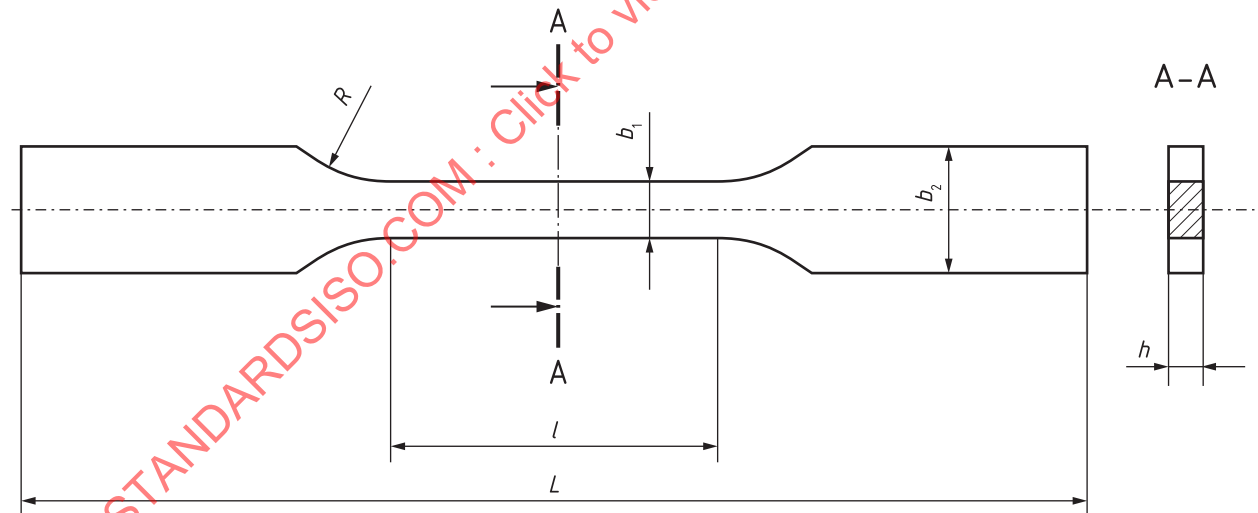


Figure 4 — Type 4 test specimen

Table 4 — Recommended dimensions for a Type 4 test specimen

Dimensions in millimetres

Parameter	2D and xD	Tolerance
l , calibrated length	30 to 80	$\pm 0,5$
L , total length		
h , thickness	> 2	$\pm 0,2$
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	$\pm 0,2$
R , radius	> 30	± 2
Parallelism of machined parts	0,05	-

Variation of material properties with temperature can lead to a multi-section test specimen (Type 5) as represented in [Figure 5](#). When used with cold grips, this multi-section specimen allows rupture in the controlled temperature zone. Recommended dimensions are given in [Table 5](#).

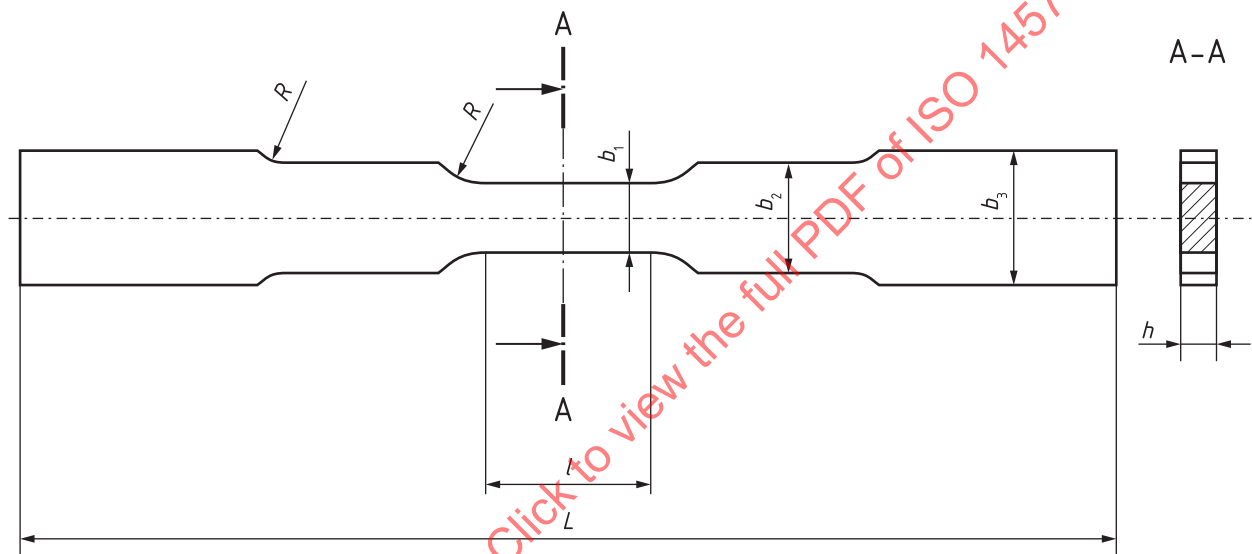


Figure 5 — Type 5 test specimen

Table 5 — Recommended dimensions for a Type 5 test specimen

Dimensions in millimetres

Parameter	2D and xD	Tolerance
l , calibrated length	30 to 80	$\pm 0,5$
L , total length		
h , thickness	> 2	$\pm 0,2$
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	> 30	± 2
Parallelism of machined parts	0,05	-

A Type 6 specimen as represented in [Figure 6](#) is easy to machine and its use allows mainly the determination of modulus, as rupture may not happen in the controlled temperature zone. Type 6 specimen cannot be used for strength measurement and for cold gripping systems.

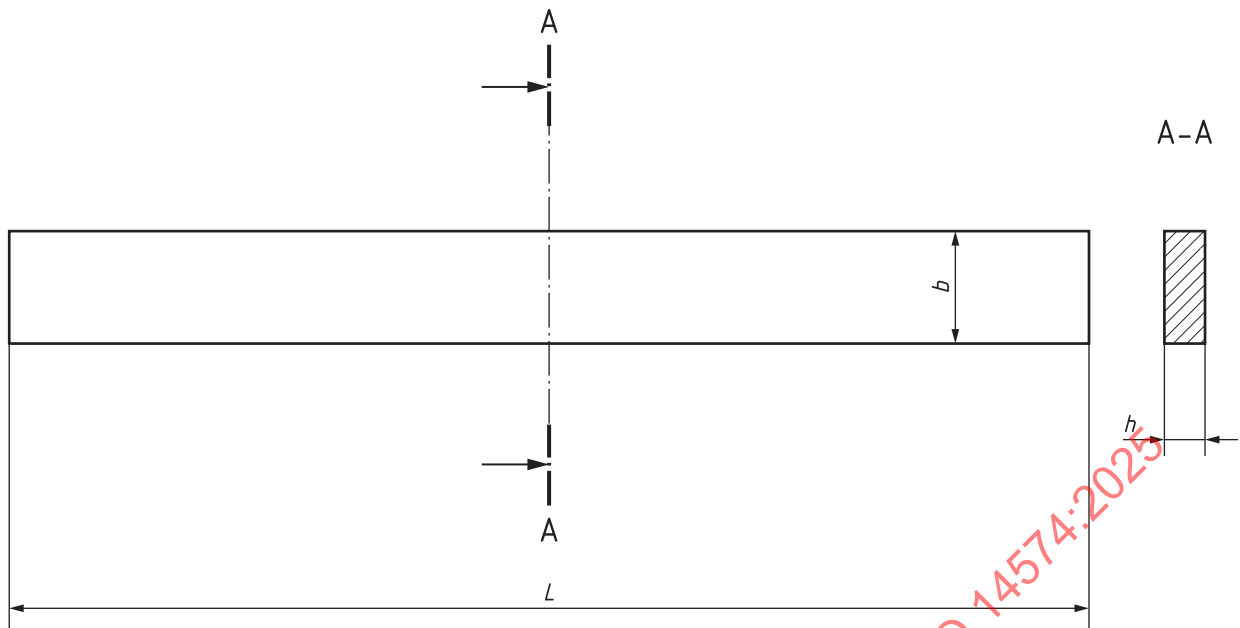


Figure 6 — Type 6 test specimen

Table 6 — Recommended dimensions for a Type 6 test specimen

Dimensions in millimetres

Parameter	1D, 2D and xD	Tolerance
L , total length		
h , thickness	> 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.

These parameters shall be adhered to during test specimen preparation.

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

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

7.2 Number of tests 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 [Annex B – 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 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.

Dimensions shall be measured to an accuracy of $\pm 0,01$ mm. The arithmetic means of the measurements shall be used for calculations.

If the test specimen is equipped with marks, the gauge length measured at room temperature, shall be known with an accuracy of ± 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 or shall be measured at the test temperature.

8.3 Testing technique

8.3.1 Specimen mounting

The test specimen shall be installed in the gripping 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 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

The test specimen temperature shall be raised to the required test temperature, and this temperature shall be maintained 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 directly measure the test specimen temperature during the test, then it is necessary to use the relationship between test specimen temperature and furnace temperature that 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 the temperature;
- load the test specimen;
- if any, cool down under inert atmosphere to a temperature where there is no more risk of material degradation of specimen and equipment before opening the test chamber;
- 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;
- change in atmosphere.

The following circumstances partially validate some tensile 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 the case of rupture outside of the gauge length the tensile modulus remains valid.

NOTE For some specific materials, the rupture outside gauge length can invalidate the tensile 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 Tensile strength

Calculate the tensile strength using one of the following formulae:

$$\sigma_{m \text{ app}} = \frac{F_m}{S_{o \text{ app}}} \quad (1)$$

$$\sigma_{m \text{ eff}} = \frac{F_m}{S_{o \text{ eff}}} \quad (2)$$

where

- $\sigma_{m \text{ app}}$ is the tensile strength at test temperature T using the apparent area $S_{o \text{ app}}$, in megapascals (MPa);
- $\sigma_{m \text{ eff}}$ is the tensile strength at test temperature T using the effective area $S_{o \text{ eff}}$, in megapascal (MPa);
- F_m is the maximum tensile force in newtons (N);
- $S_{o \text{ app}}$ is the apparent cross-section area of the specimen in square millimetres (mm²);
- $S_{o \text{ eff}}$ is the effective cross-section area of the specimen corrected to take account of the environmental barrier coating in square millimetres (mm²).

When using the effective cross-section area, the applied correction factor shall be given and justified in the test report.

9.3 Strain at maximum tensile force

Calculate the strain using [Formula \(3\)](#):

$$\epsilon_m = \frac{A_m}{L_0} \quad (3)$$

where

- ϵ_m is the strain at the maximum tensile force;
- A_m is the longitudinal deformation at the maximum tensile force in millimetres (mm) measured by the extensometer;
- L_0 is the gauge length in millimetres (mm).

9.4 Tensile modulus

9.4.1 Calculation of tensile modulus

Calculate the tensile 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](#) in [Annex A](#)), according to the following formulae:

$$E_{\text{app}}(\sigma_1, \sigma_2) = \frac{L_0}{S_{o \text{ app}}} \left(\frac{F_2 - F_1}{A_2 - A_1} \right) \times 10^{-3} \quad (4)$$

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

where

- E_{app} is the apparent tensile modulus, in gigapascals (GPa);
- E_{eff} is the effective tensile modulus, in gigapascals (GPa);
- F is the tensile force acting on the specimen, in newtons (N);
- $S_{o \text{ app}}$ is the apparent cross-section area of the specimen in square millimetres (mm²);
- $S_{o \text{ eff}}$ is the effective cross-section area of the specimen corrected to take account of the environmental barrier coating, in square millimetres (mm²);

L_0 is the gauge length, at test temperature T ; in millimetres (mm);

A is the longitudinal deformation, in mm, measured on the curve corresponding to F .

9.4.2 Calculation of tensile modulus with linear behaviour at the origin

When the material has a linear behaviour at the origin (see [Figure A.2](#) in [Annex A](#)), calculate the tensile modulus according to the following formulae:

$$E_{\text{app}} = \frac{FL_0}{S_{\text{o app}}A} \times 10^{-3} \quad (6)$$

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

where

E_{app} is the apparent tensile modulus, in gigapascals (GPa);

E_{eff} is the effective tensile modulus, in gigapascals (GPa);

F is the tensile force acting on the specimen, in newtons (N);

$S_{\text{o app}}$ is the apparent cross-section area of the specimen in square millimetres (mm²);

$S_{\text{o eff}}$ is the effective cross-section area of the specimen corrected to take account of the environmental barrier coating, in square millimetres (mm²);

L_0 is the gauge length, at temperature T ; in millimetres (mm);

A is the longitudinal deformation, in 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 tensile modulus with non-linear behaviour

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

10 Test report

The test report shall contain the following information:

- name and address of the testing establishment;
- date of the test, unique identification of report and of each page, customer name and address and signatory;
- a reference to this document, i.e. determined in accordance with ISO 14574:2025;
- test piece drawing or reference and orientation of load versus main fibre direction;
- description of the test material (material type, manufacturing code, batch number);
- 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, sensors calibration validity;
- 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;
- k) valid results, mean value of the tensile strength, the tensile strain at maximum tensile force, the tensile modulus;
- l) value of correction factor applied when effective cross-section area is used, and method to obtain it;
- m) failure location of all the specimens used for obtaining the above results;
- n) any unusual features observed.

11 Uncertainties

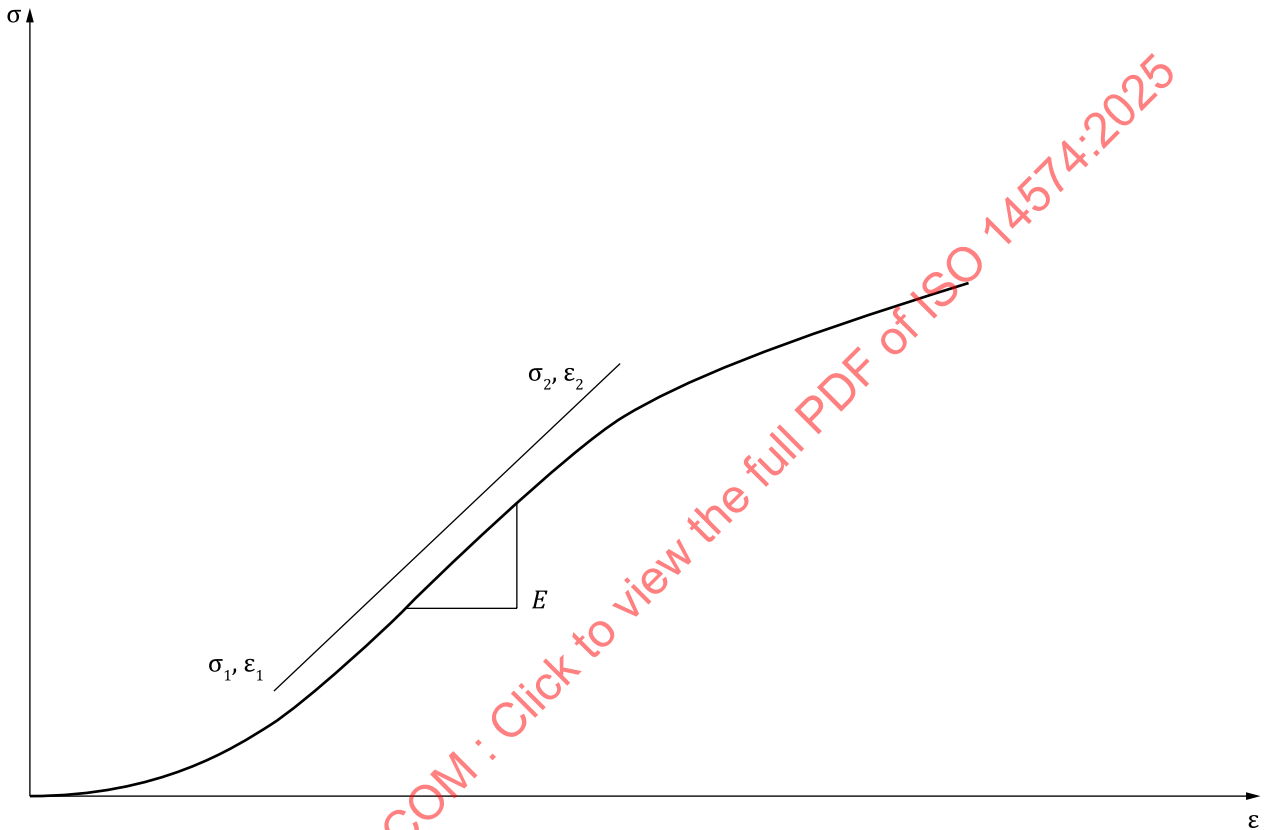
It is recommended to determine the measurement uncertainties. References and information are available in of ISO 6892-1:2019, Annexes J and K.^[4]

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Annex A (informative)

Illustration of tensile modulus

Figure A.1 shows an example of a stress-strain curve that presents a toe before the linear region bounded by the lower (σ_1, ε_1) and the upper (σ_2, ε_2) limits.

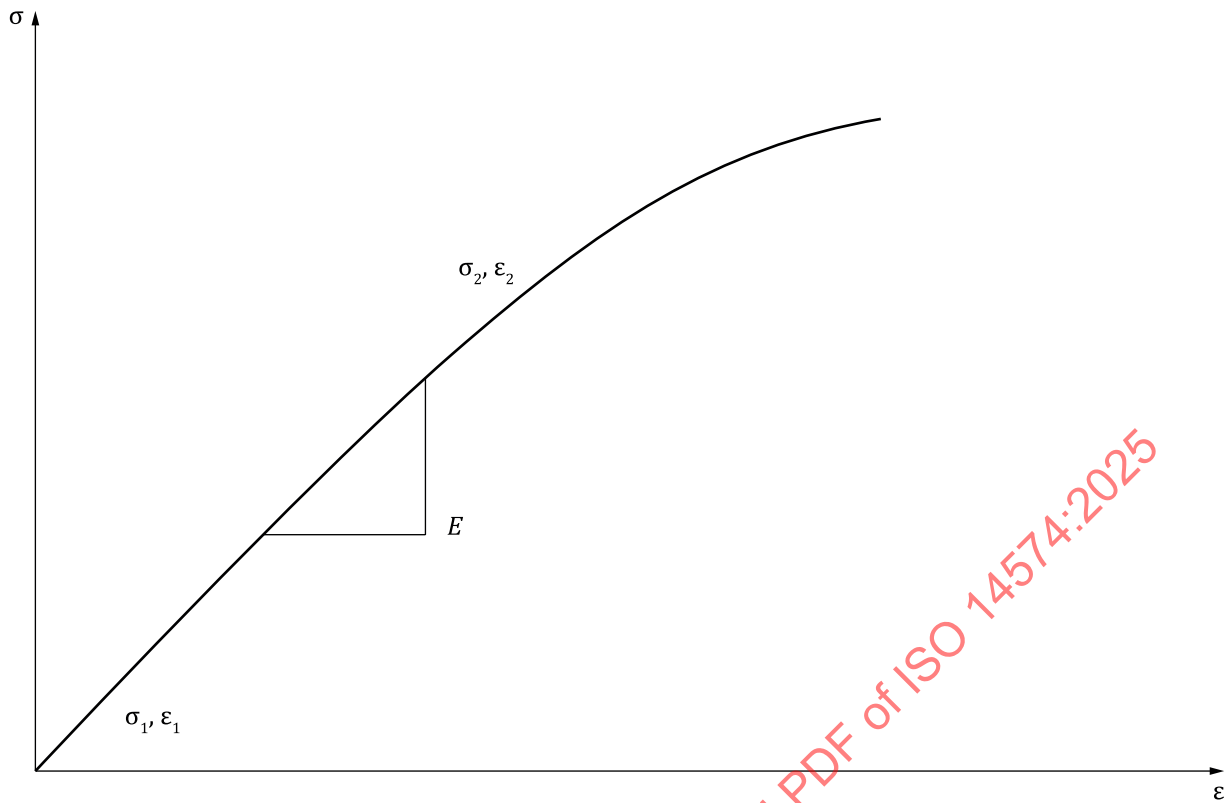


Key

- ε tensile strain
- σ tensile stress (apparent or effective)
- E tensile modulus (apparent or effective)

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

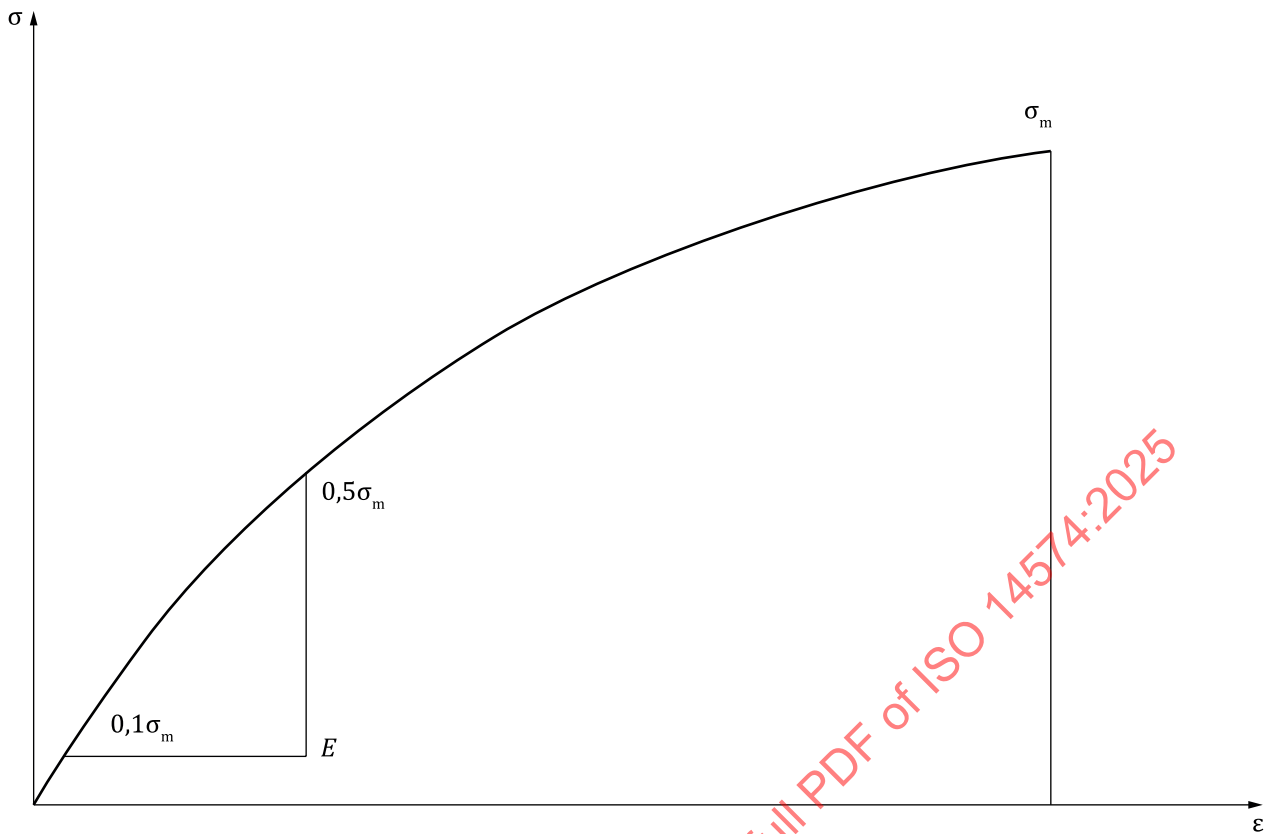
Figure A.2 shows another example of a stress-strain curve where the linear part starts at the origin.

**Key**

- ε tensile strain
 σ tensile stress (apparent or effective)
 E tensile modulus (apparent or effective)

Figure A.2 — Mechanical behaviour with predominantly linear region bounded by σ_1, ε_1 near the origin and σ_2, ε_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 $0,1\sigma_m$ and $0,5\sigma_m$ shall be used unless other couples are fixed by agreement between parties



Key

- ϵ tensile strain
- σ tensile stress (apparent or effective)
- E tensile modulus (apparent or effective)

Figure A.3 — Mechanical behaviour without linear region

Annex B (informative)

Calibration method of test temperature by using a cartographic specimen equipped with thermocouples

B.1 Principle

To determine the heating device regulation temperature that will guarantee along all the test duration that a ceramic matrix composite test specimen will be tested at the specified temperature, this method uses:

- a thermal cartography test specimen equipped with thermocouples to measure exactly the temperatures at various points of the specimen according to the device regulation temperature;
- exploitation rules of these temperature measurements versus time, based on:
 - a criterion for the temperature regulation allowing the achievement of the desired test temperature in every location of the test specimen;
 - time stability criteria of the test specimen temperature of each thermocouple, so as to guarantee the stability of test temperature during test.

B.2 Thermal cartography test specimen

In order to use the temperature regulation setting issued from this procedure on the specimen to be tested, the thermal cartography test specimen shall be identical at all points. It shall be made out of the same material and same geometry.

Depending on the mechanical test considered, the cartography specimen shall be equipped with one or more thermocouples placed on the free length of the specimen in order to indicate the core temperature of the test specimen.

For this, the thermal cartography test specimen shall be drilled with blind holes, with a suitable diameter for the used thermocouples and depth equal to the half-width of the specimen.

Thermocouples shall be pressed to the bottom of holes, adjustment shall be tight to ensure a good thermal contact.

If the test to achieve requires a measure of deformation using an extensometer, or a correlation image system, the gauge length will be equipped with at least three thermocouples, one in the centre and one at each end of the gauge length. Additional thermocouples can be added to the free length of the specimen for a better knowledge of the temperature gradient on the test specimen (see [Figure B.1](#)).

NOTE If necessary, graphite glue can be used to ensure a good contact between the thermocouple and the thermal cartography test specimen.