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Third edition
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Plastics — Determination of tensile properties —

Part 1:
General principles

Plastiques — Détermination des propriétés en traction —

Partie 1: Principes généraux

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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.

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 documents 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).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 2, *Mechanical properties.*

This third edition cancels and replaces the second edition (ISO 527-1:2012), which has been technically revised.

The main changes compared to the previous edition are as follows:

— an error in Figure 1 concerning ε_{tM} has been removed;

— the inconsistency concerning the accuracy of the elongation used in the calculation of the tensile modulus between 5.1.5.1, Figure 1 and Annex C has been removed. For gauge lengths $L_0 \leq 50$ mm, the accuracy is set to ±1 µm;

— the normative references (see Clause 2) have been updated;

— minor editorial changes have been applied;

— language has been clarified.

A list of all parts in the ISO 527 series can be found on the ISO website.

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.

Plastics — Determination of tensile properties —

Part 1:
General principles

1 Scope

1.1 This document specifies the general principles for determining the tensile properties of plastics and plastic composites under defined conditions. Several different types of test specimen are defined to suit different types of material which are detailed in subsequent parts of ISO 527.

1.2 The methods are used to investigate the tensile behaviour of the test specimens and for determining the tensile strength, tensile modulus and other aspects of the tensile stress/strain relationship under the conditions defined.

1.3 The methods are selectively suitable for use with the following materials:

— rigid and semi-rigid moulding, extrusion and cast thermoplastic materials, including filled and reinforced compounds in addition to unfilled types; rigid and semi-rigid thermoplastics sheets and films;

— rigid and semi-rigid thermosetting moulding materials, including filled and reinforced compounds; rigid and semi-rigid thermosetting sheets, including laminates;

— fibre-reinforced thermosets and thermoplastic composites incorporating unidirectional or non-unidirectional reinforcements, such as mat, woven fabrics, woven rovings, chopped strands, combination and hybrid reinforcement, rovings and milled fibres; sheet made from pre-impregnated materials (prepregs);

— thermotropic liquid crystal polymers.

The methods are not normally suitable for use with rigid cellular materials, for which ISO 1926 is used, or for sandwich structures containing cellular materials.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 291, *Plastics — Standard atmospheres for conditioning and testing*

ISO 2602, *Statistical interpretation of test results — Estimation of the mean — Confidence interval*

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 9513:2012, *Metallic materials — Calibration of extensometer systems used in uniaxial testing*

ISO 16012, *Plastics — Determination of linear dimensions of test specimens*

ISO 23529, *Rubber — General procedures for preparing and conditioning test pieces for physical test methods*

3 Terms and definitions

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

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

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

— IEC Electropedia: available at http://www.electropedia.org/

3.1
gauge length
L_0
initial distance between the gauge marks on the central part of the test specimen

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

Note 2 to entry: The values of the gauge length that are indicated for the specimen types in the different parts of ISO 527 represent the maximum relevant gauge length.

3.2
thickness
h
smaller initial dimension of the rectangular cross-section in the central part of a test specimen

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

3.3
width
b
larger initial dimension of the rectangular cross-section in the central part of a test specimen

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

3.4
cross-section
A
product of initial *width* (3.3) and *thickness* (3.2), $A = bh$, of a test specimen

Note 1 to entry: It is expressed in square millimetres, (mm^2).

3.5
test speed
v
rate of separation of the gripping jaws

Note 1 to entry: It is expressed in millimetres per minute (mm/min).

3.6
stress
σ
normal force per unit area of the original *cross-section* (3.4) within the *gauge length* (3.1)

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: In order to differentiate from the true stress related to the actual cross-section of the specimen, this stress is frequently called “engineering stress”.

3.6.1
stress at yield
σ_y
stress at the *yield strain* (3.7.1)

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: It may be less than the maximum attainable stress (see Figure 1, curve 2).

3.6.2
strength
σ_m
stress at the first local maximum observed during a tensile test

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: This may also be the stress at which the specimen yields or breaks (see Figure 1).

3.6.3
stress at x **% strain**
σ_x
stress at which the strain, ε, reaches the specified value x expressed as a percentage

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: Stress at x % strain may, for example, be useful if the stress/strain curve does not exhibit a yield point (see Figure 1, curve 4).

3.6.4
stress at break
σ_b
stress at which the specimen breaks

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: It is the highest value of stress on the stress-strain curve directly prior to the separation of the specimen, i.e directly prior to the load drop caused by crack initiation.

3.7
strain
ε
increase in length per unit original length of the gauge

Note 1 to entry: It is expressed as a dimensionless ratio, or as a percentage (%).

3.7.1
strain at yield
yield strain
ε_y
first occurrence in a tensile test of strain increase without a stress increase

Note 1 to entry: It is expressed as a dimensionless ratio, or as a percentage (%).

Note 2 to entry: See Figure 1, curves (2) and (3).

Note 3 to entry: See Annex A for computer-controlled determination of the yield strain.

3.7.2
strain at break
ε_b
strain at the last recorded data point before the *stress* (3.6) is reduced to less than or equal to 10 % of the *strength* (3.6.2) if the break occurs prior to yielding

Note 1 to entry: It is expressed as a dimensionless ratio, or as a percentage (%).

Note 2 to entry: See Figure 1, curves (1) and (4).

3.7.3
strain at strength
ε_m
strain at which the *strength* (3.6.2) is reached

Note 1 to entry: It is expressed as a dimensionless ratio, or as a percentage (%).

3.8
nominal strain
ε_t
representation of *strain* (3.7) calculated from grip displacement and the *gripping distance* (3.11) by one of the methods in 10.2.2

Note 1 to entry: It is expressed as a dimensionless ratio, or as a percentage (%).

Note 2 to entry: It may be calculated either based on the grip displacement from the beginning of the test or based on the increase of grip displacement beyond the strain at yield, if the latter is determined with an extensometer (preferred for multipurpose test specimens).

3.8.1
nominal strain at break
ε_{tb}
nominal strain at the last recorded data point before the *stress* (3.6) is reduced to less than or equal to 10 % of the *strength* (3.6.2) if the break occurs after yielding

Note 1 to entry: It is expressed as a dimensionless ratio, or as a percentage (%).

Note 2 to entry: See Figure 1, curves (2) and (3).

3.8.2
nominal strain at strength
ε_{tm}
nominal strain at which the *strength* (3.6.2) is reached

Note 1 to entry: It is expressed as a dimensionless ratio, or as a percentage (%).

Note 2 to entry: See Figure 1, curves (2), (3) and (4).

3.9
tensile modulus
modulus of elasticity under tension
E_t
slope of the stress/strain curve σ(ε) in the interval between the two strains ε_1 = 0,05 % and ε_2 = 0,25 %

Note 1 to entry: It is expressed in megapascals (MPa).

Note 2 to entry: It may be calculated either as the chord modulus or as the slope of a linear least-squares regression line in this interval (see Figure 1, curve 4).

Note 3 to entry: This definition does not apply to films.

3.10
Poisson's ratio
μ
negative ratio of the strain change $\Delta\varepsilon_n$, in one of the two axes normal to the direction of extension, to the corresponding strain change $\Delta\varepsilon_l$ in the direction of extension, within the linear portion of the longitudinal versus normal strain curve

Note 1 to entry: It is expressed as a dimensionless ratio.

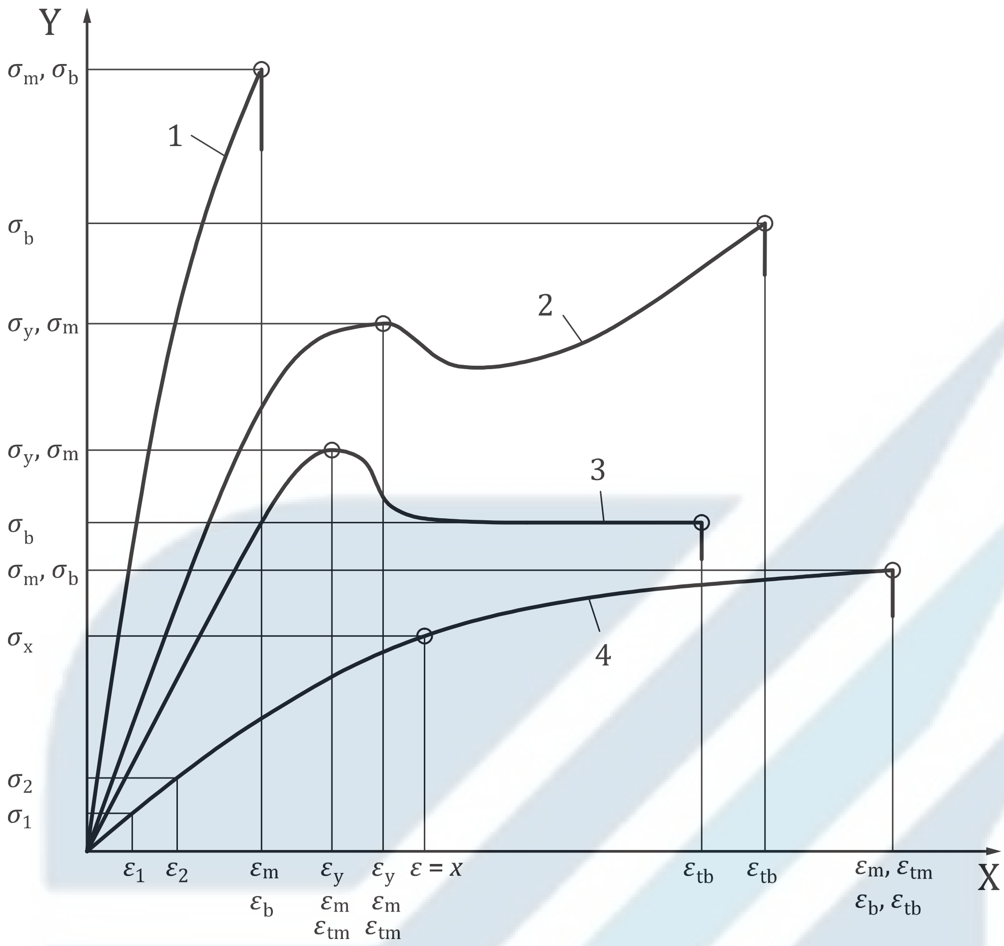
Note 2 to entry: Since the lateral strain change $\Delta\varepsilon_n$ is a negative number and the longitudinal strain change $\Delta\varepsilon_l$ is positive, the Poissons ratio as defined in 3.10 is a positive number.

3.11
gripping distance
L
initial length of the part of the specimen between the grips

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

3.12
rigid plastic
plastic that has a modulus of elasticity in flexure (or, if that is not applicable, in tension) greater than 700 MPa under a given set of conditions

3.13
semi-rigid plastic
plastic that has a modulus of elasticity in flexure (or, if that is not applicable, in tension) between 70 MPa and 700 MPa under a given set of conditions



Key

X strain and/or nominal strain

Y stress

1 Curve (1) represents a brittle material, breaking without yielding at low strains. Curve (4) represents a soft rubberlike material breaking at larger strains (>50 %).

2, 3 Curves (2) and (3) represent materials that have a yield point with (2) or without (3) stress increase after yielding. Curves (2) and (3) are curves “stress vs. strain” up to the yield point and “stress vs. nominal strain” beyond the yield point.

4 Curve (4) may be either stress vs. strain or stress vs. nominal strain depending on equipment used.

Figure 1 — Typical stress/strain curves

4 Principle and methods

4.1 Principle

The test specimen is extended along its major longitudinal axis at a constant test speed until the specimen fractures or until the stress (load) or the strain (elongation) reaches some predetermined value. During this procedure, the load sustained by the specimen and the elongation are measured.

4.2 Method

4.2.1 The methods are applied using specimens which may be either moulded to the chosen dimensions or machined, cut or punched from finished and semi-finished products, such as mouldings, laminates, films and extruded or cast sheet. The types of test specimen and their preparation are described in the relevant part of ISO 527 typical for the material. In some cases, a multipurpose test specimen may be used. Multipurpose and miniaturized test specimens are described in ISO 20753.

4.2.2 The methods specify preferred dimensions for the test specimens. Tests which are carried out on specimens of different dimensions, or on specimens which are prepared under different conditions, may produce results which are not comparable. Other factors, such as the speed of testing and the conditioning of the specimens, can also influence the results. Consequently, when comparative data are required, these factors shall be carefully controlled and recorded.

5 Apparatus

5.1 Testing machine

5.1.1 General

The machine shall comply with ISO 7500-1 and ISO 9513, and meet the specifications given in 5.1.2 to 5.1.6.

5.1.2 Test speeds

The tensile-testing machine shall be capable of maintaining the test speeds chosen within the tolerances specified in Table 1.

Table 1 — Recommended test speeds

Test speed v mm/min	Tolerance %
0,125	±20
0,25	
0,5	
1	
2	
5	
10	
20	±10
50	
100	
200	
300	
500	

5.1.3 Grips

Grips for holding the test specimen shall be attached to the machine so that the major axis of the test specimen coincides with the direction of extension through the centre line of the grip assembly. The test specimen shall be held such that slip relative to the gripping jaws is prevented. The gripping system shall not cause premature fracture at the jaws or squashing of the specimen in the grips.

For the determination of the tensile modulus, it is essential that the strain rate is constant and does not change, for example, due to motion in the grips. This is important especially if wedge action grips are used.

NOTE For the prestress, which can be necessary to obtain correct alignment (see 9.3) and specimen seating and to avoid a toe region at the start of the stress/strain diagram, see 9.4.

5.1.4 Force indicator

The force measurement system shall comply with class 1 as defined in ISO 7500-1.

5.1.5 Strain indicator

5.1.5.1 Extensometers

Contact extensometers shall comply with ISO 9513, class 1. The accuracy of this class shall be attained in the strain range over which measurements are being made. Non-contact extensometers may also be used, provided they meet the same accuracy requirements.

The extensometer shall be capable of determining the change in the gauge length of the test specimen at any time during the test. It is desirable, but not essential, that the instrument should record this change automatically. The instrument shall be essentially free of inertia lag at the specified speed of testing.

For the determination of tensile modulus, the instrument shall be capable of measuring the change in the gauge length of the specimen with an accuracy of 1 % of the relevant value or better for all gauge lengths of 50 mm or higher, corresponding to a requirement of absolute accuracy of ±1 µm for a gauge length of 50 mm and to ±1,5 µm, in case a gauge length of 75 mm is used.

For smaller gauge lengths between 20 mm and 50 mm an absolute accuracy of ±1 µm is sufficient (see Figure 2 and Annex C.)

NOTE Depending on the gauge length used, the accuracy requirement of 1 % translates to different absolute accuracies for the determination of the elongation within the gauge length. The constant absolute accuracy for the measurement of change in gauge length leads to relative accuracies of 2 % for gauge length 25 mm and of 2,5 % for gauge length 20 mm (see Figure 2).

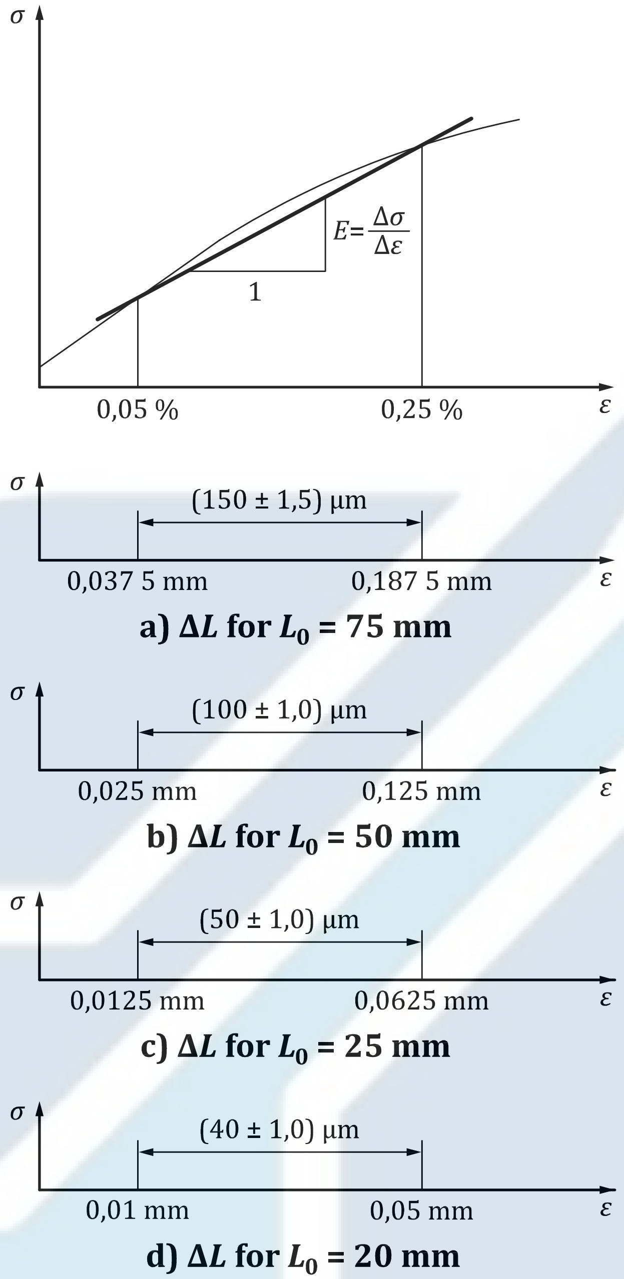


Figure 2 — Accuracy requirements for extensometers for tensile modulus determination at different gauge lengths

Commonly used optical extensometers record the deformation taken at one broad test-specimen surface: In the case of such a single-sided strain-testing method, ensure that low strains are not falsified by bending, which may result from even faint misalignment and initial warpage of the test specimen, and which generates strain differences between opposite surfaces of the test specimen. It is recommended to use strain-measurement methods that average the strains of opposite sides of the test specimen. This is relevant for tensile modulus determination, but less so for measurement of larger strains.

5.1.5.2 Strain gauges

Specimens may also be instrumented with longitudinal strain gauges; the accuracy of which shall be 1 % of the relevant value or better. This corresponds to a strain accuracy of 20×10^{-6} (20 microstrains) for the measurement of the tensile modulus. The gauges, surface preparation and bonding agents should be chosen to exhibit adequate performance on the subject material.

5.1.6 Recording of data

5.1.6.1 General

The data acquisition frequency needed for the recording of data (force, strain, elongation) shall be sufficiently high in order to meet accuracy requirements.

5.1.6.2 Recording of strain data

The minimum data acquisition frequency f_{min}, needed for integral transmission from the sensor to the indicator, can then be calculated as shown in Formula (1):

$$f_{min} = \frac{v}{60} \times \frac{L_0}{L \cdot r} \quad (1)$$

where

f_{min} is the frequency, expressed in hertz (Hz);

v is the test speed, expressed in mm/min;

L_0 / L is the ratio between the gauge length L_0 and initial gripping distance L;

r is the minimum resolution, expressed in millimetre (mm), of the strain signal required to obtain accurate data. Typically, it is half the accuracy value or better.

The recording frequency of the test machine shall be at least equal to this data rate f_{min}.

5.1.6.3 Recording of force data

The required recording rate depends on the test speed, the strain range, the accuracy and the initial gripping distance. The tensile modulus, the test speed and the gripping distance determine the rise rate of force. The ratio of rise rate of force to the accuracy needed determines the recording frequency. See below for examples.

Rise rate of force is given by Formula (2):

$$\dot{F} = \frac{E_t \cdot A \cdot v}{60L} \quad (2)$$

where

$\dot{F}$ is the rise rate of force, expressed in newtons per second (N/s);

E_t is the tensile modulus, expressed in megapascals (MPa);

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

v is the test speed, expressed in millimetres per minute (mm/min);

L is the gripping distance, expressed in millimetres (mm).

Using the force difference in the tensile modulus range to define accuracy requirement in the same way as for the extensometer, Formulae (3) to (5) apply, assuming that the relevant force is to be determined to within 1 %.

Force difference in the tensile modulus determination range:

$$\Delta F = E_t \cdot A \cdot (\varepsilon_2 - \varepsilon_1) = E_t \cdot A \cdot \Delta\varepsilon \qquad (3)$$

Accuracy (half of 1 %):

$$r = 5 \cdot 10^{-3} \cdot \Delta F = 5 \cdot 10^{-3} \cdot E_t \cdot A \cdot \Delta\varepsilon \qquad (4)$$

Recording frequency:

$$f_{force} = \frac{\dot{F}}{r} = \frac{E_t \cdot A \cdot v}{E_t \cdot A \cdot \Delta\varepsilon \cdot 60 \cdot L \cdot 5 \cdot 10^{-3}} \qquad (5)$$

EXAMPLE With v = 1 mm/min, $\Delta\varepsilon = 2 \times 10^{-3}$ and L = 115 mm, a recording frequency of f_{force} = 14,5 Hz is found.

5.2 Devices for measuring width and thickness of the test specimens

See ISO 16012 and ISO 23529, where applicable. Use measurement tips/knife edges of such size and orientation as to allow the precise determination of the dimension in the desired location.

6 Test specimens

6.1 Shape and dimensions

See the part of ISO 527 relevant to the material being tested.

6.2 Preparation of specimens

See the part of ISO 527 relevant to the material being tested.

6.3 Gauge marks

See the appropriate part of ISO 527 for the relevant conditions of the gauge length.

If optical extensometers are used, especially for thin sheet and film, gauge marks on the specimen may be necessary to define the gauge length. These shall be equidistant from the midpoint (±1 mm), and the gauge length shall be measured to an accuracy of 1 % or better.

Gauge marks shall not be scratched, punched or impressed upon the test specimen in any way that may damage the material being tested. It shall be ensured that the marking medium has no detrimental effect on the material being tested and that, in the case of parallel lines, they are as narrow as possible.

Extension of the gauge marks due to stretching shall not influence the strain measurements.

6.4 Checking the test specimens

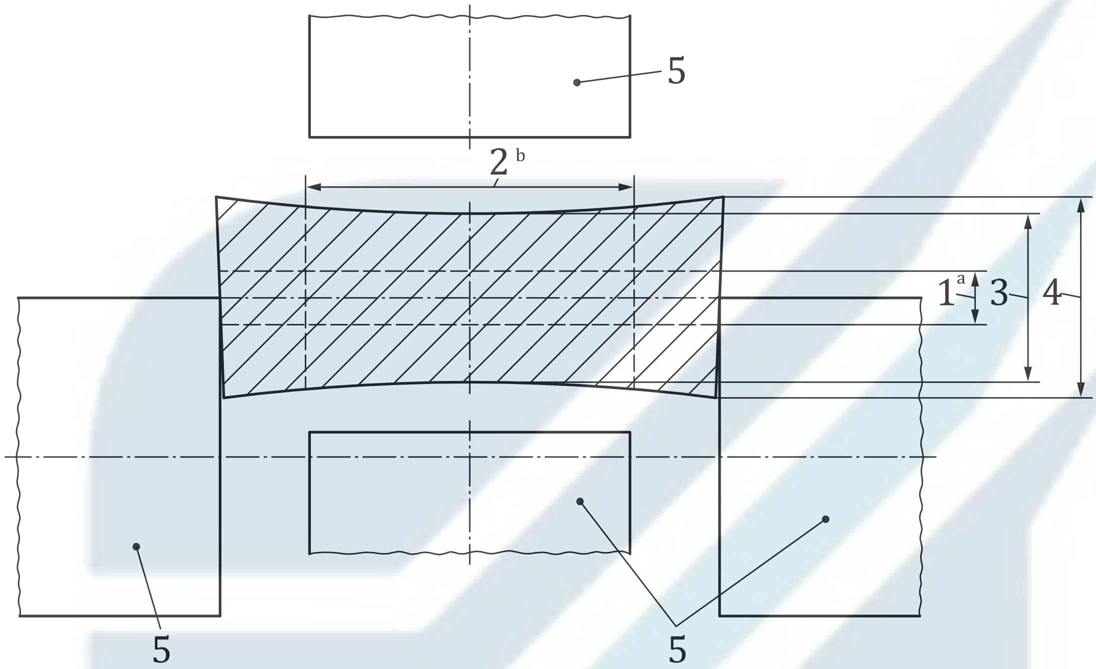
Ideally, the specimens should be free of twist and should have mutually perpendicular pairs of parallel surfaces (see NOTE 1, NOTE 2 and Figure 3). The surfaces and edges shall be free from defects that may influence the test results like scratches, pits, sink marks and flash. Draft angles of up to 2° and sink marks with a thickness difference of $\Delta h \leq 0,1$ mm are acceptable, as are purely optical effects that do not affect the test result.

The specimens shall be checked for conformity with these requirements by visual observation against straight-edges, squares or flat plates, or with micrometer callipers.

Specimens showing observed or measured departure from one or more of these requirements shall be rejected. If non-conforming specimens are tested, report the reasons.

NOTE 1 Injection-moulded specimens typically have draft angles of 1° (in the gauge section) to 2° (at the shoulders) to facilitate demoulding. Also, injection-moulded test specimens are never absolutely free of sink marks. Due to differences in the cooling history, generally the thickness in the centre of the specimen is smaller than at the edge.

NOTE 2 ISO 294-1:2017, Annex D gives guidance on how to reduce sink marks in injection-moulded test specimens.



Key

1 width determination

2 thickness determination

3 smallest thickness, h_{min}

4 greatest thickness, h_{max}

5 micrometer tip

a The edge of the micrometer tip shall have contact to the specimen within ± 0,5 mm from the centre.

b The micrometer tip shall have contact to the specimen within ± 3,25 mm from the centre.

NOTE $\Delta h = h_{max} - h_{min} \leq 0{,}1$ mm.

Figure 3 — Cross-section of injection-moulded test specimen with sink marks and draft angle (exaggerated) and micrometer tips

6.5 Anisotropy

See the part of ISO 527 relevant to the material being tested.

7 Number of test specimens

7.1 A minimum of five test specimens shall be tested for each of the required directions of testing. The number of measurements may be more than five if greater precision of the mean value is required. It is possible to evaluate this by means of the confidence interval (95 % probability, see ISO 2602).

7.2 Dumb-bell specimens that break or slip inside the grips shall be discarded and further specimens shall be tested.

8 Conditioning

The test specimen shall be conditioned as specified in the appropriate standard for the material concerned. In the absence of this information, the most appropriate set of conditions from ISO 291 shall be selected and the conditioning time is at least 16 h, unless otherwise agreed upon by the interested parties, for example, for testing at elevated or low temperatures.

The preferred atmosphere is (23 ± 2) °C and (50 ± 10) % RH, except when the properties of the material are known to be insensitive to moisture, in which case humidity control is unnecessary.

9 Procedure

9.1 Test atmosphere

Conduct the test in the same atmosphere used for conditioning the test specimen, unless otherwise agreed upon by the interested parties, for example, for testing at elevated or low temperatures.

9.2 Dimensions of test specimen

9.2.1 Measure the width and the thickness of the test specimen (see 9.2.2), following the general guidance of ISO 16012 or ISO 23529, as applicable, within the limits indicated in Figure 3, to the nearest 0,1 mm for the width and to the nearest 0,01 mm for the thickness.

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

NOTE This excludes the maximum and minimum thickness, which for injection moulded test specimens usually is found at the edge and in the centre, respectively. Injection moulded test specimens prepared according ISO 294-1, will generally have thickness differences due to sink marks of $\Delta h = h_{max} - h_{min} \leq 0{,}1$ mm (see Figure 3).

For injection-moulded test specimens, it is sufficient to determine the width and thickness within 5 mm midway between the shoulders.

9.2.2 In the case of injection-moulded specimens, obtained from multiple-cavity moulds, ensure that the dimensions of the specimens do not differ by more than ±0,25 % between cavities.

For test specimens cut from sheet or film material, it is permissible to assume that the mean width of the central parallel portion of the die is equivalent to the corresponding width of the specimen. The adoption of such a procedure should be based on comparative measurements taken at periodic intervals.

For the purposes of this document, the test specimen dimensions used for calculating tensile properties are measured at ambient temperature only. For the measurement of properties at other temperatures, therefore, the effects of thermal expansion are not taken into account.

9.3 Gripping

Place the test specimen in the grips, taking care to align the longitudinal axis of the test specimen with the axis of the testing machine. Tighten the grips evenly and firmly to avoid slippage of the test specimen and movement of the grips during the test. Gripping pressure shall not cause fracture or squashing of the test specimen (see NOTE 2).

NOTE 1 Stops can be used to facilitate alignment of the test specimen, especially in manual operation.

For gripping test specimens within a temperature chamber, it is recommended to close initially only one grip and to tighten the second one only after the temperature of the test specimen is equilibrated, unless the machine is capable of continuously reducing thermal stress if it arises.

NOTE 2 Fracture in the grips can happen, for example, when testing of specimens after heat aging. Squashing can occur in tests at elevated temperatures.

9.4 Prestresses

The specimen shall not be stressed substantially prior to testing. Such stresses can be generated during centring of a film specimen, or can be caused by the gripping pressure, especially with less rigid materials. They are, however, necessary to avoid a toe region at the start of the stress/strain diagram (see 5.1.3). The prestress σ_0 at the start of a test shall be positive but shall not exceed the following value:

a) for tensile modulus measurement:

$$0 < \sigma_0 \leq E_t / 2\,000 \tag{6}$$

which corresponds to a prestrain of $\varepsilon_0 \leq 0{,}05$ %, and

b) for measuring relevant stresses σ^*, for example, $\sigma^* = \sigma_y$ or σ_m:

$$0 < \sigma_0 \leq \sigma^* / 100 \tag{7}$$

If, after gripping, stresses outside the intervals given by Formulae (6) and (7) are present in the specimen, remove these by slow movement of the crosshead, for example with 1 mm/min, until the prestress is within the allowed range.

If the tensile modulus or the stress value needed to adjust the prestress is not known, perfom a preliminary test to obtain an estimate of these values.

9.5 Setting of extensometers

After setting the prestress, set and adjust a calibrated extensometer to the gauge length of the test specimen, or provide longitudinal strain gauges, in accordance with 5.1.5. Measure the initial distance (gauge length) if necessary. For the measurement of Poisson's ratio, two elongation- or strain-measuring devices shall be provided to act in the longitudinal and transverse axes simultaneously.

For optical measurements of elongation, place gauge marks on the specimen in accordance with 6.3, if required by the system used.

Extensometers shall be positioned symmetrically about the middle of the parallel portion and on the centre line of the test specimen. Strain gauges shall be placed in the middle of the parallel portion and on the centre line of the test specimen.

9.6 Test speed

Set the test speed in accordance with the appropriate standard for the material concerned. In the absence of this information, the test speed shall be selected from Table 1 or agreed upon between the interested parties.

For the measurement of the tensile modulus, the selected test speed shall provide a strain rate as near as possible to 1 % of the gauge length per minute. The resulting testing speed for different types of specimens is given in the part of ISO 527 that is relevant to the material being tested.

It may be necessary or desirable to adopt different speeds for the determination of the tensile modulus, of the stress/strain diagram up to the yield point, and of properties beyond the yield point. After determining stresses for the tensile modulus determination (up to the strain of $\varepsilon_2 = 0{,}25$ %), the same test specimen can be used to continue the test.

It is preferable to unload the test specimen before testing at a different speed, but it is also acceptable to change the speed without unloading after the tensile modulus has been determined. When changing the speed during the test, make sure that the change in speed occurs at strains $\varepsilon \leq 0{,}3$ %.

For any other testing purposes, separate specimens shall be used for different test speeds.

9.7 Recording of data

Preferably record the force and the corresponding values of the increase of the gauge length and of the distance between the grips during the test. This requires three data channels for data acquisition. If only two channels are available, record the force signal and the extensometer signal. It is preferable to use an automatic recording system.

10 Calculation and expression of results

10.1 Stress

Calculate all stress values, defined in 3.6, using Formula (8):

$$\sigma = \frac{F}{A} \tag{8}$$

where

- σ is the stress value in question, expressed in megapascals (MPa);
- F is the measured force concerned, expressed in newtons (N);
- A is the initial cross-sectional area of the specimen, expressed in square millimetres (mm^2).

When determining stress at x % strain, x shall be taken from the relevant product standard or agreed upon by the interested parties.

10.2 Strain

10.2.1 Strains determined with an extensometer

For materials and/or test conditions for which a homogeneous strain distribution is prevalent in the parallel section of the test specimen, i.e. for strains prior and up to a yield point, calculate all strain values, defined in 3.7, using Formula (9):

$$\varepsilon = \frac{\Delta L_0}{L_0} \tag{9}$$

where

- ε is the strain value in question, expressed as a dimensionless ratio, or as a percentage;
- L_0 is the gauge length of the test specimen, expressed in millimetres (mm);
- ΔL_0 is the increase of the specimen length between the gauge marks, expressed in millimetres (mm).

The determination of strain values using an extensometer averages strains over the gauge length. This is correct and useful, as long as the deformation of the test specimen within the gauge length is homogeneous. If the material starts necking, the strain distribution becomes inhomogeneous and strains determined with an extensometer are strongly influenced by the position and size of the neck zone. In such cases, use nominal strain to describe the strain evolution after a yield point.

10.2.2 Nominal strain

10.2.2.1 General

Nominal strain is used when no extensometer is used, for example, on miniaturized test specimens or when strain determination with extensometers becomes meaningless due to strain localization (necking) after a yield point. Nominal strain is based on the increase of distance between the grips relative to the initial gripping distance. Instead of measuring the displacement between the grips, it is acceptable to record crosshead displacement.

NOTE Depending on the type of grips used and other sources of compliance such as load cells and fixtures, crosshead displacement can be different from grip displacement especially at the beginning of the test. Where this is of concern, it is intended to correct crosshead displacement for compliance effects.

Nominal strain may be determined using Method A (see 10.2.2.2) and Method B (see 10.2.2.3).

10.2.2.2 Method A

Record the displacement between the grips of the machine from the beginning of the test. Calculate nominal strain using Formula (10):

$$\varepsilon_t = \frac{L_\mathrm{t}}{L} \qquad (10)$$

where

ε_t is the nominal strain, expressed as a dimensionless ratio or percentage;

L is the gripping distance, expressed in millimetres (mm); the gripping distance is defined in the relevant parts of ISO 527;

L_t is the increase of the gripping distance occurring from the beginning of the test, expressed in millimetres (mm).

10.2.2.3 Method B

Method B is preferred for use with multipurpose test specimens that show yielding and necking, but where the strain at yield has been precisely determined with an extensometer. Record the displacement between the grips of the machine from the beginning of the test. Calculate nominal strain using Formula (11):

$$\varepsilon_\mathrm{t} = \varepsilon_\mathrm{y} + \frac{\Delta L_\mathrm{t}}{L} \qquad (11)$$

where

ε_t is the nominal strain, expressed as a dimensionless ratio or percentage;

ε_y is the yield strain, expressed as a dimensionless ratio or percentage;

L is the gripping distance, expressed in millimetres (mm); the gripping distance is defined in the relevant parts of ISO 527;

ΔL_t is the increase of the gripping distance from the yield point onwards, expressed in millimetres (mm).

10.3 Tensile modulus

10.3.1 General

Calculate the tensile modulus, defined in 3.9, using one of the following alternatives [see Formulae (12) to (13)].

10.3.2 Chord slope

$$E_t = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - \varepsilon_1} \quad (12)$$

where

E_t is the tensile modulus, expressed in megapascals (MPa);

σ_1 is the stress, expressed in megapascals (MPa), measured at the strain value ε_1 = 0,000 5 (0,05 %);

σ_2 is the stress, expressed in megapascals (MPa), measured at the strain value ε_2 = 0,002 5 (0,25 %).

10.3.3 Regression slope

With computer-aided equipment, the determination of the tensile modulus, E_t, using two distinct stress/strain points can be replaced by a linear regression procedure applied on the part of the curve between these mentioned points.

$$E_t = \frac{d\sigma}{d\varepsilon} \quad (13)$$

where $\frac{d\sigma}{d\varepsilon}$ is the slope of a least-squares regression line fit to the part of the stress/strain curve in the strain interval $0{,}000\,5 \le \varepsilon \le 0{,}002\,5$, expressed in megapascals (MPa).

10.4 Poisson's ratio

Plot the width or thickness of the specimen as a function of the length of the gauge section, excluding the tensile modulus region, those sections that may be influenced by changes in test speed and the yield point, if present.

Determine the slope $\Delta n/\Delta L$ of the change-in-width (thickness) versus the change-in- length curve by using a linear least-squares regression analysis. Poisson's ratio is determined from Formula (14):

$$\mu = -\frac{\Delta\varepsilon_n}{\Delta\varepsilon_l} = -\frac{L_0}{n_0}\frac{\Delta n}{\Delta L} \quad (14)$$

where

μ is Poisson's ratio; it is dimensionless;

$\Delta\varepsilon_n$ is the change in strain in the selected transverse direction, while the longitudinal strain increases by $\Delta\varepsilon_l$, expressed as a dimensionless ratio or percentage;

$\Delta\varepsilon_l$ is the change in strain in the longitudinal direction, expressed as a dimensionless ratio or percentage;

L_0 is the gauge length in the longitudinal direction, expressed in millimetres (mm);

n_0 is the gauge length in the transverse direction, expressed in millimetres (mm);

Δn is the decrease of the specimen length in the transverse direction: $n = b$ (width) or $n = h$ (thickness), expressed in millimetres (mm);

ΔL is the corresponding increase of the length in the longitudinal direction, expressed in millimetres (mm).

Poisson's ratio is indicated as μ_b (width direction) or μ_h (thickness direction) according to the relevant axis.

If extensometers are used, it is recommended to determine Poisson's ratio in a strain range $0{,}3\ \% \leq \varepsilon < \varepsilon_y$ (see Annex B). The validity of the evaluation region can be determined from a plot of Δn vs. ΔL, (dimension change in transverse direction vs. dimension change in longitudinal direction within the relevant gage section). Poisson's ratio is determined from the slope of the linear part of this plot.

If strain gauges are used to determine Poisson's ratio, measurement can also be done in the strain region where the tensile modulus is determined ($0{,}05\ \% \leq \varepsilon \leq 0{,}25\ \%$).

NOTE Plastics are viscoelastic materials. As such, Poisson's ratio is dependent on the stress range where it is determined. Therefore, the width (thickness) as a function of length might not be a straight line.

10.5 Statistical parameters

Calculate the arithmetic means of the test results and, if required, the standard deviations and the 95 % confidence intervals of the mean values in accordance with the procedure given in ISO 2602.

10.6 Significant figures

Calculate the stresses and the tensile modulus to three significant figures. Calculate the strains and Poisson's ratio to two significant figures.

11 Precision

See the part of ISO 527 relevant to the material being tested.

12 Test report

The test report shall include the information specified in Items a) to q). Add the word “tensile” to individual and average properties, see Items m), n) and o):

a) a reference to the relevant part of ISO 527;

b) all the data necessary for identification of the material tested, including type, source, manufacturer's code number and history, where these are known;

c) description of the nature and form of the material in terms of whether it is a product, semi-finished product, test panel or specimen; it should include the principal dimensions, shape, method of manufacture, succession of layers and any pretreatment;

d) type of test specimen;

e) method of preparing the test specimens, and any details of the manufacturing method used;

f) if the material is in product form or semi-finished product form, the orientation of the specimen in relation to the product or semi-finished product from which it is cut;

g) number of the test specimen tested;

h) standard atmosphere for conditioning and testing, plus any special conditioning treatment, if required by the relevant standard for the material or product concerned;

i) accuracy grading of the test machine and extensometer (see ISO 7500-1, ISO 9513 and 5.1.5);

j) type of elongation or strain indicator, and the gauge length L_0;

k) type of gripping device, the gripping distance L;

l) testing speeds;

m) for each test specimen width, thickness and test results of the properties defined in Clause 3;

n) mean value(s) of width, thickness and of the measured property(ies);

o) standard deviation, and/or coefficient of variation, and/or confidence limits of the mean, if required;

p) statement as to whether any test specimens have been rejected and replaced, and, if so, the reasons, and reasons for testing non-conforming specimens;

q) date of measurement.

Annex A
(informative)

Determination of strain at yield

Historically, strain at yield was determined by drawing a horizontal tangent to a continuously recorded stress-strain curve. With the advent of computer-controlled machines, the evaluation of stress/strain curves had to use a set of discrete data points sampled according to the properties of the recording electronics. Due to signal noise (electronic as well as mechanical), there is always some scatter in the data set available and this should be taken into account when deriving properties.

For the determination of the yield point, the following items are important.

a) Plastic materials show a wide range of different stress/strain behaviours. The yielding region may be a narrow peak (e.g. for ASA) or a wide plateau (e.g. POM, moist PA6).

b) Determination of the strain at yield involves identifying the highest data point within the yielding region (necessary condition).

c) However, the point selected should be physically meaningful: Signal noise may cause selection of unsuitable points.

d) The point should allow meaningful design decisions. For example, for a material showing a yielding plateau, a useful design limit would be close to its beginning rather than in the centre.

Determining such points from digital data can be done by different methods.

— Point-to-point comparison for a maximum value. This is a simple procedure, but it needs additional checks to prevent selecting noise-related maximum values erroneously. This may, for example, involve employing a moving evaluation interval, the width of which will be system dependent. System in this sense means the combined effects of material behaviour and experimental set-up.

— Slope method: This would be a method involving a higher amount of calculation, but feasible within the computing power provided by current PCs. A slope criterion would also involve a moving evaluation interval within which the regression slope of the stress/strain curve is calculated. This method has a smoothing /filtering effect and reduces noise influence. Additionally, a criterion should be defined for which slope would be indicative of having found a yield point, for example:

  — centre-point of the evaluation interval for which the slope becomes negative for the first time;

  — centre-point of the evaluation interval for which the slope attains some limiting positive value for the first time;

  Formula (A.1) is a proposed criterion, applied to the centre-point of a moving interval, for which the slope becomes equal to or smaller than the stress value at this point:

$$\varepsilon_y = \varepsilon\left[\frac{d\sigma}{d\epsilon} \leq \sigma\right] \quad \text{(A.1)}$$

  The advantage of such a criterion would be to identify only such yield strains that are close to the first major slope change of the stress/strain curve. Yield strain values, however, would be smaller than with the current methods. This method is less useful for broad yielding peaks.

  Also, for a slope method, the correct width of the evaluation interval is again system dependent and identifying it requires the user to have a thorough understanding of the test method and the material.

These examples show that there are multiple ways to determine strain at yield. Selecting and imposing one of them for the sake of comparability of test results would, in principle, be possible but, considering existing machines and the different software packages, this would be a futile attempt.

One solution could be a verification system. This verification system would involve reference data sets (stress/strain curves) for which the relevant properties are agreed on by experts. These data sets can be fed to any evaluation software and used to check whether, or under which parameters, the software returns the “correct values”. This system would ensure comparability of test results while allowing different evaluation procedures.

A similar system for tensile testing of metals was worked out. More information on this may be found under Reference [5].

For the estimation of the width of strain intervals, Formula (A.3) can be used.

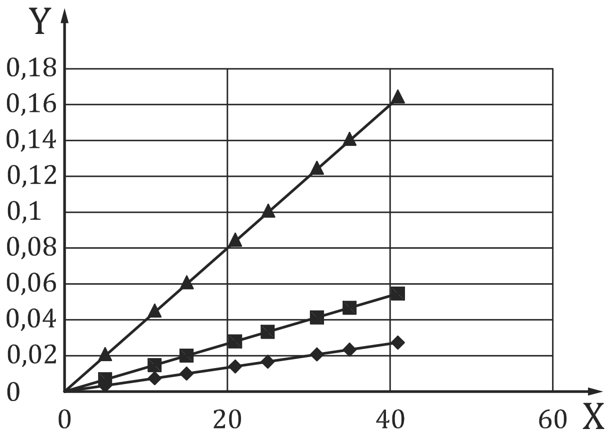
$$n = f\Delta t = f\frac{\Delta\varepsilon}{\dot{\varepsilon}} \tag{A.2}$$

$$\Delta\varepsilon = \dot{\varepsilon}\frac{n}{f} = \frac{v}{60L}\frac{n60Lr}{vL_0} = \frac{nr}{L_0} \tag{A.3}$$

where

n	is the number of data points;
f	is the data rate of the machine, see Formula (1) in s^{-1};
$\Delta\varepsilon$	is the strain interval;
ε	is the strain rate, in s^{-1};
v	is the crosshead rate, in mm/min;
L	is the gripping distance, in mm;
L_0	is the gauge length, in mm;
r	is the resolution, in mm.

The strain interval according to Formula (A.2) is shown in Figure A.1 as a function of the number of data points with the resolution r as parameter.



Key

X number of data points

Y strain interval, %

—◆— r = 0,5 µm

—■— r = 1 µm

—▲— r = 3 µm

Figure A.1 — Strain interval according to Formula (A.2)

Annex B
(informative)

Extensometer accuracy for the determination of Poisson's ratio

It is not recommended to determine Poisson's ratio in the strain region used for the tensile modulus determination.

In the tensile modulus region, the elongation of the gauge length is determined with an accuracy of 1 %, i.e. using a multipurpose test specimen, the extensometer should be capable of measuring the elongation to within 1,5 µm (see 5.1.5 and Figure 2) when a gauge length of 75 mm is used. Assuming a Poisson's ratio of 0,4, which is typical for most thermoplastics, and a gauge length of 75 mm, the length of the gauge section increases by 150 µm while the width decreases by 8 µm. In order to have the same relative accuracy of 1 % as for the longitudinal direction, the measurement system for determining the transverse deformation should be capable of measuring within 0,1 µm, which is a severe condition.

Assuming that Poisson's ratio is determined in a range of 0,3 % $< \varepsilon <$ 1,5 %, the decrease in width will be 50 µm, requiring a resolution of 0,5 µm for a 1 % accuracy in lateral contraction.

Annex C
(normative)

Calibration requirements for the determination of the tensile modulus

C.1 General

The general requirements for extensometer verification are described in 5.1.5. If the equipment is intended to perform measurements of tensile modulus E_t, the extensometer shall satisfy an additional, more stringent, accuracy requirement. This annex specifies the procedures used and the performance of the calibration equipment required to verify that the extensometer meets this additional accuracy requirement.

NOTE ISO 9513 allows the user to define different measuring ranges for which extensometers are calibrated. These ranges are defined by the ratio of the measured deformation in each range. Range a) is defined for $l_{max}/l_{min} \leq 10$, and range b) for $10 < l_{max}/l_{min} \leq 100$. Range a) applies to the determination of the tensile modulus ($l_{max}/l_{min} = 5$) and range b) applies to measurements up to about 25 % (at 50 mm gauge length).

C.2 Calibration procedure

C.2.1 General

It is expected that the additional verification will take place at the same time as the verification to ISO 9513; however, the verification can be carried out independently. Unless otherwise stated, the conditions of calibration shall be the same as described in ISO 9513.

Perform the procedure described in ISO 9513 to prepare the system for the verification.

Follow the procedure described in ISO 9513, using two additional measurements in the increasing travel direction corresponding to 0,05 % and 0,25 % of the required gauge length. The average value of the difference between the two readings from two runs shall then be compared to the difference in the applied displacements. In order to comply with the requirements of this document, the relative error between the applied displacement and the indicated displacement shall be less than or equal to ±1 % of the displacement for gauge lengths of 50 mm or above or less than or equal to ±1 µm for gauge lengths less than 50 mm.

Table C.1 — Extensometer accuracy requirements

Gauge length mm	First displacement µm	Second displacement µm	Change in displacement µm	Accuracy requirement (see 5.1.5) ±µm
75	37,5	187,5	150	1,5
50	25	125	100	1
25	12,5	62,5	50	1
20	10	50	40	1

NOTE The extensometer error limits apply to the change in reading between the first and second displacement.

Because of the difficulty in achieving the extensometer performance required at gauge lengths below 50 mm, it is recommended that tensile modulus measurements are made on specimens with gauge lengths of 50 mm and greater.

C.2.2 Calibration-apparatus accuracy requirements

The calibration apparatus shall conform to the requirements given in ISO 9513:2012, Table 2, for class 0,2.

C.2.3 Calibration report

The calibration report shall contain the following information:

a) a reference to this annex of this document, i.e. ISO 527-1:2019, Annex C;

b) the name and address of the owner of the extensometer system;

c) all other information required to be reported in ISO 9513;

d) the result of the calibration.

Bibliography

[1] ISO 294-1:2017, *Plastics — Injection moulding of test specimens of thermoplastic materials — Part 1: General principles, and moulding of multipurpose and bar test specimens*

[2] ISO 1926, *Rigid cellular plastics — Determination of tensile properties*

[3] ISO 20753, *Plastics — Test specimens*

[4] ASTM D638, *Standard Test Method for Tensile Properties of Plastics*

[5] RIDES M., LORD J. TENSTAND final report: *Computer-controlled tensile testing according to EN 10002-1: Results of a comparison test programme to validate a proposal for an amendment of the standard*. National Physical Laboratory, Teddington, 2005

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