INTERNATIONAL STANDARD

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Metallic materials — Tensile testing at elevated temperature

Matériaux métalliques — Essai de traction à température élevée

Reference number
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Contents

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Foreword

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

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 783 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals.*

It cancels and replaces Recommendation ISO/R 783 : 1968, of which it constitutes a technical revision.

Annexes A to G form an integral part of this International Standard. Annex H is for information only.

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Metallic materials — Tensile testing at elevated temperature

1 Scope

This International Standard specifies a method of tensile testing of metallic materials at elevated temperature and defines the mechanical properties which can be determined thereby.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 286-2 : 1988, *ISO system of limits and fits — Part 2: Tables of standard tolerance grades and limit deviations for holes and shafts.*

ISO 377 : 1985, *Wrought steel — Selection and preparation of samples and test pieces.*

ISO 2142 : 1981, *Wrought aluminium, magnesium and their alloys — Selection of specimens and test pieces for mechanical testing.*

ISO 7500-1 : 1986, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tensile testing machines.*

ISO 9513 : 1989, *Metallic materials — Verification of extensometers used in uniaxial testing.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 gauge length: Length of the parallel-sided portion of the test piece on which elongation is measured at any moment during the test. In particular, a distinction is made between the gauge lengths defined in 3.1.1 and 3.1.2.

3.1.1 original gauge length, L_o: Gauge length at ambient temperature before heating of the test piece and before application of force.

3.1.2 final gauge length, L_u: Gauge length after rupture, the two pieces having been carefully fitted back together so that their axes lie in a straight line. This length is measured at ambient temperature.

3.2 extensometer gauge length, L_e: Length of the parallel portion of the test piece used for the measurement of elongation by means of an extensometer. [This length may differ from L_o and has a value greater than b, d or D (see table 1) but less than L_c].

3.3 elongation: Increase in the original gauge length, L_o, under the action of the tensile force, at any moment during the test.

3.4 percentage elongation: Elongation expressed as a percentage of the original gauge length, L_o. In particular, a distinction is made between the elongations defined in 3.4.1 and 3.4.3.

3.4.1 percentage permanent elongation: Increase in the original gauge length of a test piece after removal of a specified stress (see 3.7), expressed as a percentage of the original gauge length, L_o.

3.4.2 percentage elongation after fracture, A: Difference between final gauge length and original gauge length, $L_u - L_o$, expressed as a percentage of the original gauge length, L_o.

NOTES

1 In the case of proportional test pieces, only if the original gauge length is other than $5{,}65\sqrt{S_o}$*, where S_o is the original cross-sectional area of the parallel length, the symbol A is to be supplemented by a subscript designating the coefficient of proportionality used, for example:

$A_{11,3}$ = percentage elongation on a gauge length, L_o, of $11{,}3\sqrt{S_o}$

2 In the case of non-proportional test pieces, the symbol A is to be supplemented by a subscript designating the original gauge length used, expressed in millimetres, for example:

$A_{80\ \text{mm}}$ = percentage elongation on a gauge length, L_o, of 80 mm

* $5{,}65\sqrt{S_o} = 5\sqrt{\frac{4\,S_o}{\pi}}$

3.4.3 percentage total elongation at fracture, A_t: Increase in the original gauge length of test piece at the moment of fracture, expressed as a percentage of the original gauge length, L_o.

3.5 percentage reduction of area, Z: Maximum change in cross-sectional area which has occurred during the test, $S_o - S_u$, expressed as a percentage of the original cross-sectional area, S_o.

3.6 maximum force, F_m: The greatest force which the test piece withstands during the test (see comments in annex H).

3.7 stress: Force at any moment during the test divided by the original cross-sectional area, S_o, of the test piece.

3.7.1 tensile strength, R_m: Stress corresponding to the maximum force, F_m (see figure 4).

3.7.2 yield stress: When the metallic material exhibits a yield phenomenon, a point is reached during the test at which plastic deformation occurs without any increase in the force.

A distinction is made between the stresses defined in 3.7.2.1 and 3.7.2.2.

3.7.2.1 upper yield stress, R_{eH}: Value of stress at the moment when the first decrease in force is observed (see figure 1).

3.7.2.2 lower yield stress, R_{eL}: Lowest value of stress during plastic yielding, ignoring any transient effects (see figure 1).

3.7.3 proof stress of non-proportional elongation, R_p: Stress at which a non-proportional elongation is equal to a specified percentage of the original gauge length, L_o (see figure 3). The symbol used is to be supplemented by a subscript designating the specified percentage of the original gauge length, for example: $R_{p0,2}$.

4 Symbols and their meanings

Symbols used throughout this International Standard and their meanings are given in table 1.

Table 1 — Symbols and their meanings

Reference number[1)]	Symbol	Unit	Meaning
Test piece			
—	θ_i	°C	Indicated temperature
1	a	mm	Thickness of a flat test piece or wall thickness of a tube
2	b	mm	Width of the parallel-sided portion of a flat test piece or average width of the longitudinal strip taken from a tube or width of flat wire
3	d	mm	Diameter of the parallel-sided portion of a circular test piece, or diameter of round wire or internal diameter of a tube
4	D	mm	External diameter of a tube
5	L_o	mm	Original gauge length
6	L_c	mm	Parallel length
—	L_e	mm	Extensometer gauge length
7	L_t	mm	Total length of test piece
8	L_u	mm	Final gauge length after fracture
9	S_o	mm^2	Original cross-sectional area of the parallel-sided portion
10	S_u	mm^2	Minimum cross-sectional area after fracture
—	Z	%	Percentage reduction of area: $\frac{S_o - S_u}{S_o} \times 100$
11	—	—	Gripped ends
Elongation			
12	—	mm	Elongation after fracture : $L_u - L_o$
13	A[2)]	%	Percentage elongation after fracture : $\frac{L_u - L_o}{L_o} \times 100$
14	A_t	%	Percentage total elongation at fracture
15	—	%	Specified percentage permanent elongation set
16	—	%	Specified percentage non-proportional elongation
Force			
17	F_m	N	Maximum force
Yield stress — Proof stress — Tensile strength			
18	R_{eH}	N/mm^2[3)]	Upper yield stress
19	R_{eL}	N/mm^2	Lower yield stress
20	R_m	N/mm^2	Tensile strength
21	R_p	N/mm^2	Proof stress (non-proportional elongation)

1) See figures 1 to 11.
2) See 3.4.2.
3) 1 N/mm^2 = 1 MPa

5 Principle

The test consists of straining a test piece by tensile force, generally to fracture, for the purpose of determining one or more of the mechanical properties defined in clause 3.

The test is carried out at the specified temperature, which is greater than the ambient temperature.

6 Apparatus

6.1 Testing machine

The testing machine shall be calibrated in accordance with ISO 7500-1 and shall be of at least grade 1,0, unless otherwise specified in the product standard.

6.2 Extensometer

When using an extensometer to measure the elongation, the extensometer shall be of class 1 (see ISO 9513) for the upper and lower yield stresses and for the proof stress for non-proportional elongation; for the other characteristics (having higher elongations) an extensometer of class 2 (see ISO 9513) can be used.

The extensometer gauge length shall be not less than 10 mm and shall be centrally located in the mid-region of the parallel gauge length. The extensometer should be preferably of the type that is capable of measuring extension on both sides of a test piece and allowing the two readings to be averaged.

Any parts of the extensometer projecting beyond the furnace shall be designed or protected from draughts so that fluctuations in the ambient temperature have only a minimal effect on the readings. It is advisable to maintain reasonable stability of the temperature and speed of the air surrounding the testing machine.

6.3 Heating device

6.3.1 Permitted deviations of temperature

The heating device for the test piece shall be such that the test piece can be heated to the specified temperature, θ.

The permitted deviations between the specified temperature, θ, and the indicated temperatures, θ_i, are the following:

± 3 °C for $\theta \leqslant$ 600 °C

± 4 °C for 600 °C $< \theta \leqslant$ 800 °C

± 5 °C for 800 °C $< \theta \leqslant$ 1 000 °C

For specified temperatures higher than 1 000 °C, the permitted deviations shall be defined by a previous agreement between the parties concerned.

The indicated temperatures, θ_i, are the temperatures which are measured at the surface of the parallel length of the test piece.

The permitted deviations in temperature shall be complied with on the original gauge length, L_o, at least until the point corresponding to the proof stress for non-proportional elongation is reached.

6.3.2 Measurement of temperature

The temperature-measuring equipment shall have a resolution of at least 1 °C and an accuracy of ± 2 °C.

Three thermocouples, which are arranged at identical intervals along the parallel length of the test piece, are generally sufficient to guarantee uniformity of the temperature of the test piece. This number may be reduced if the general arrangement of the furnace and the test piece is such that, from experience, it is known that the variation in temperature of the test piece does not exceed the permitted deviations specified in 6.3.1.

Thermocouple junctions shall make good thermal contact with the surface of the test piece and be suitably screened from direct radiation from the furnace wall.

6.3.3 Verification of the temperature-measuring system

The temperature-measuring system, comprising sensors and read-out equipment, shall be verified over the working temperature range at intervals not exceeding one year; the errors shall be recorded in the verification report. Verification of the temperature-measuring system shall be carried out by a method traceable to the international unit (SI unit) of temperature.

7 Test pieces

7.1 Shape and dimensions

The shape and dimensions of the test pieces depend on the shape and dimensions of the metallic products of which the mechanical properties are to be determined.

The test piece is usually obtained by machining a sample from the product or a pressed blank or casting. However, products of constant cross-section (sections, bars, wires, etc.) and cast test bars (e.g. malleable cast iron, white cast iron, non-ferrous alloys) may be subjected to test without being machined.

The cross-section of the test pieces may be circular, square, rectangular, annular or, in special cases, of some other shape.

Test pieces whose original gauge length is related to the original cross-sectional area by the equation $L_0 = k\sqrt{S_o}$ are called proportional test pieces. The internationally adopted value for k is 5,65. The original gauge length shall be not less than 20 mm. When the cross-sectional area of the test piece is too small for this requirement to be met with the coefficient k value of 5,65, a higher value (for example 11,3) for coefficient k or a non-proportional test piece may be used.

In the case of non-proportional test pieces, the original gauge length, L_o, is taken independently of the original cross-sectional area, S_o.

The dimensional tolerances of the test pieces shall be in accordance with the appropriate annexes (see 7.2).

There are other types of test pieces; if these test pieces are used, the gauge length shall be defined.

7.1.1 Machined test pieces

Machined test pieces shall incorporate a transition curve between the gripped ends and the parallel-sided portion if these have different dimensions. The dimensions of this transition radius may be important and it is recommended that they be defined in the material specification if they are not given in the appropriate annex (see 7.2).

The gripped ends may be of any shape to suit the grips of the testing machine.

The length of the parallel-sided portion, L_c, or, in the case where the test piece has no transition curve, the free length between the grips, is dependent on the original gauge length, L_o.

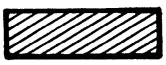
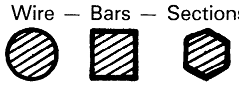
7.1.2 Non-machined test pieces

If the test piece consists of an unmachined length of the product or of an as-cast test bar, the free length between the grips shall conform to the specifications in the annexes.

7.2 Types

The main types of test piece are defined in annexes B to E according to the shape and type of product, as shown in table 2. Other types of test piece may be used if specified in product standards.

Table 2 — Product types

Type of product		Corresponding annex
Sheets — Flats  with a thickness, in millimetres, of	Wire — Bars — Sections  with a diameter or side, in millimetres, of	
0,1 ⩽ thickness < 3	—	B
—	< 4	C
⩾ 3	⩾ 4	D
Tubes		E

7.3 Preparation of test pieces

The test pieces shall be taken and prepared in accordance with the requirements of the International Standards for the different materials (ISO 377, ISO 2142, etc.).

8 Test conditions

8.1 Heating of test piece

The test piece shall be heated to the specified temperature, θ, and shall be maintained at that temperature for at least 10 min before loading. The loading shall only be started after the indications of the elongation-measuring apparatus have been stabilized.

During the heating, the temperature of the test piece shall not, at any moment, exceed the specified temperature with its tolerances, except by special agreement between the parties concerned.

When the test piece has reached the specified temperature, the extensometer shall be reset to zero.

8.2 Loading of the test piece

Force shall be applied so as to strain the test piece in a non-decreasing manner, without shock or sudden vibration. The force shall be applied along the specimen axis so as to produce minimum bending or torsion in the specimen gauge length[1)].

8.3 Rate of loading

8.3.1 Determination of yield stress (upper and lower yield stresses, proof stress for non-proportional elongation)

The strain rate of the parallel-sided length of the test piece, from the beginning of the test to the yield stress to be determined, shall be between 0,001 min^{-1} and 0,005 min^{-1}.

In the case of machines unable to achieve the required strain rate, the stress rate shall be set so that the requirement that the strain rate be smaller than 0,003 min^{-1} is complied with over the elastic range. In no case shall the stress rate in the elastic range exceed 300 N/(mm^2·min).

8.3.2 Determination of tensile strength

If only the tensile strength is to be determined, the strain rate of the test piece shall be between 0,02 min^{-1} and 0,20 min^{-1}.

If a yield stress is also determined on the same piece, the change of the stress rate required in 8.3.1 to the rate defined in the paragraph above shall be monotonic.

9 Procedure

9.1 Determination of original cross-sectional area, S_o

The original cross-sectional area shall be calculated from the measurements of the appropriate dimensions. The accuracy of this calculation depends on the nature and type of the test piece. It is indicated in annexes B to E for the different types of test pieces.

9.2 Marking the original gauge length, L_o

Each end of the original gauge length shall be marked by means of fine marks, scribed lines or fine collars but not by notches which could result in premature fracture.

For proportional test pieces, the calculated value of the original gauge length may be rounded off to the nearest multiple of 5 mm provided that the difference between the calculated and

1) Examples of methods for verifying alignment can be found in ASTM E 1012, *Standard practice for verification of specimen alignment under tensile loading.*

marked gauge length is less than 10 % of L_o. Annex F gives a scale for determination of the original gauge length corresponding to the dimensions of test pieces of rectangular cross-section. The original gauge length shall be marked to an accuracy of ± 1 %.

If the length of the parallel-sided portion, L_c, is much in excess of the original gauge length, as for instance with unmachined test pieces, a series of overlapping gauge lengths shall be drawn; some of these lengths may extend up to the grips.

In some cases, it may be helpful to draw, on the surface of the test piece, a line parallel to the longitudinal axis, along which the marks are drawn.

On an automatic machine, the gauge length is defined by the distance between the two knife-edges of the extensometer.

9.3 Determination of percentage elongation after fracture, A

Percentage elongation after fracture shall be determined as defined in 3.4.2.

For this purpose, carefully fit the two broken pieces of the test piece back together so that their axes lie in a straight line.

Special precautions shall be taken to ensure proper contact between the broken parts of the test piece when measuring the final gauge length. This is particularly important in the case of test pieces of small cross-section and test pieces having low elongation values.

Measure the change in the gauge length, $L_u - L_o$, to the nearest 0,25 mm and round off the value of the percentage elongation after fracture to the nearest 1 %. If the minimum percentage elongation specified is less than 5 %, special precautions shall be taken when determining elongation (see annex A).

This measurement is, in principle, valid only if the distance between the fracture and the nearest gauge mark is not less than one-third of the original gauge length, L_o, (see annex G). However, the measurement is valid, irrespective of the position of the fracture, if the percentage elongation after fracture reaches the specified value.

If so permitted by the product standard, elongation may be measured over a fixed gauge length and converted to proportional gauge length using conversion formulae or tables.

When using an extensometer to measure the elongation after fracture and the total elongation at fracture, the extensometer gauge length, L_e, shall be equal to the original gauge length, L_o.

If machines capable of measuring elongation automatically are used, gauge marks are unnecessary. The elongation measured is the total elongation; it is therefore necessary to deduct the elastic elongation in order to obtain the percentage elongation after fracture.

NOTE — Comparisons of percentage elongation are possible only when the gauge length and the area of the cross-section are the same or when the coefficient of proportionality, k, is the same.

9.4 Determination of proof stress (non-proportional elongation), R_p

Determine the proof stress (non-proportional elongation) from the force/elongation diagram by drawing a line parallel to the straight portion of the curve and at a distance from this equivalent to the specified non-proportional percentage, e.g. 0,2 %. The point at which this line intersects the curve gives the force corresponding to the desired proof stress (non-proportional elongation). This is obtained by dividing this force by the original cross-sectional area of the test piece, S_o (see figure 3).

Accuracy in drawing the force/elongation diagram is essential. The curve may be drawn by an automatic recording or manual method.

If the straight portion of the force/elongation diagram is not clearly defined, thereby preventing the parallel line from being drawn with sufficient precision, the following procedure is recommended (see figure 6).

When the presumed proof stress has been exceeded, reduce the force to a value equal to about 10 % of the force obtained. Then increase the force again until it exceeds the value obtained originally. To determine the desired proof stress, draw a line through the hysteresis loop. Then draw a line parallel to this line, at a distance from the origin of the curve, measured along the abscissa, equal to the specified value of the non-proportional elongation. The intersection of this parallel line and the force/elongation curve gives the force corresponding to the proof stress. This is obtained by dividing this force by the original cross-sectional area of the test piece, S_o (see figure 4).

NOTE — This property may be obtained without plotting the force/elongation curve by using appropriate devices (microprocessor, etc.).

Where the extensometer gauge length, L_e, differs from the original gauge length, L_o, the elongation measured shall be expressed as a percentage of the extensometer gauge length, L_e.

9.5 Verification of specified percentage permanent elongation

After the test piece has been heated to the specified temperature (see 8.1), subject it monotonically to the force specified in the product standard, if this verification is required, in accordance with the conditions defined in 8.3.1. Maintain this force, as a general rule, for 10 s to 12 s unless otherwise specified in the product standard. After the force has been removed, verify that the permanent elongation set (see 3.4.1) is not more than the percentage specified.

10 Test report

The test report shall include at least the following information:

a) reference to this International Standard;

b) identification of the test piece;

c) nature of the material, if known;

d) type of test piece;

e) specified temperature and the indicated temperatures, if outside the permitted limits;

f) measured properties and results.

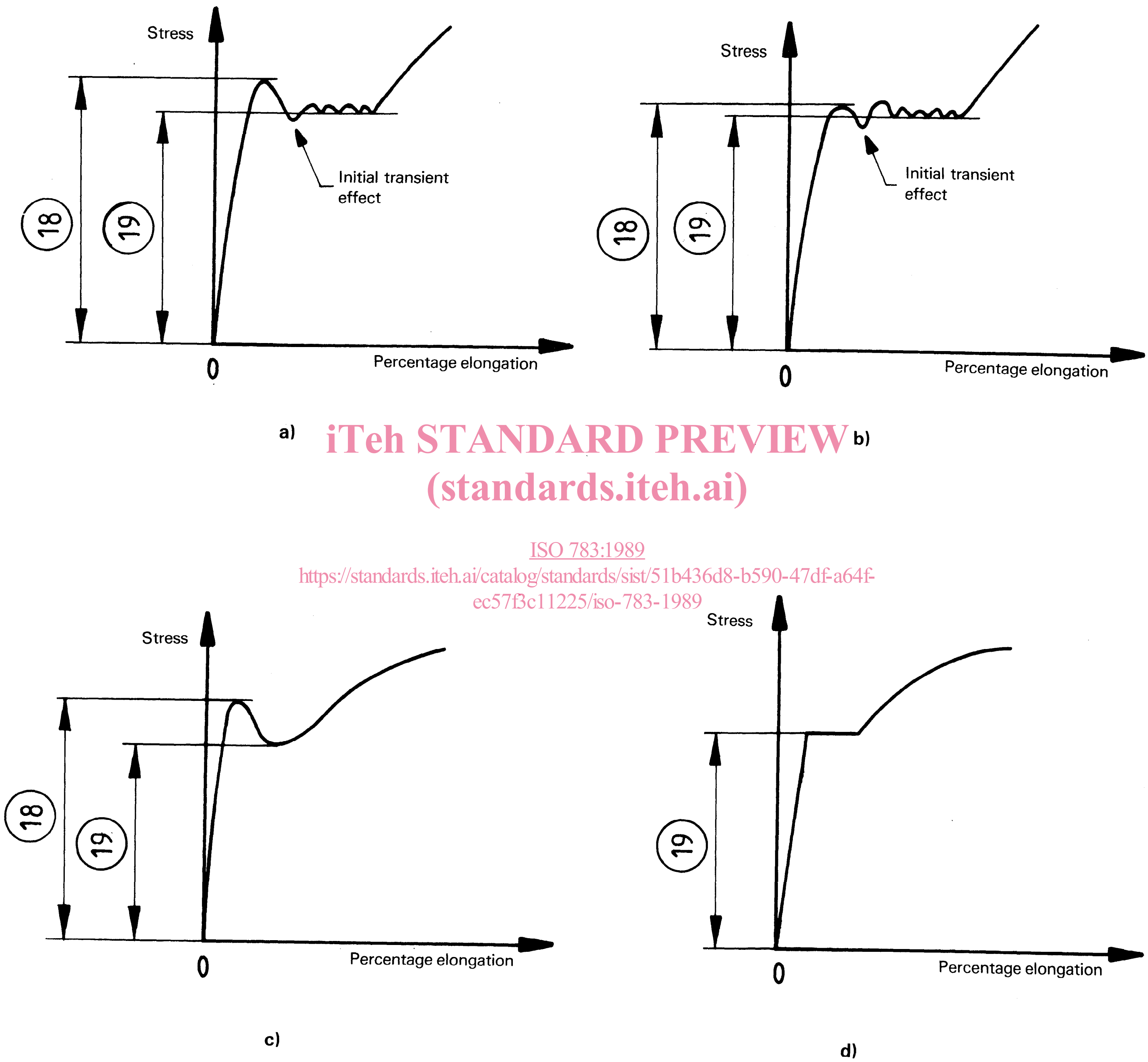

Stress
Initial transient effect
18
19
0
Percentage elongation
a)
Stress
Initial transient effect
18
19
0
Percentage elongation
b)
Stress
18
19
0
Percentage elongation
c)
Stress
19
0
Percentage elongation
d)

Figure 1

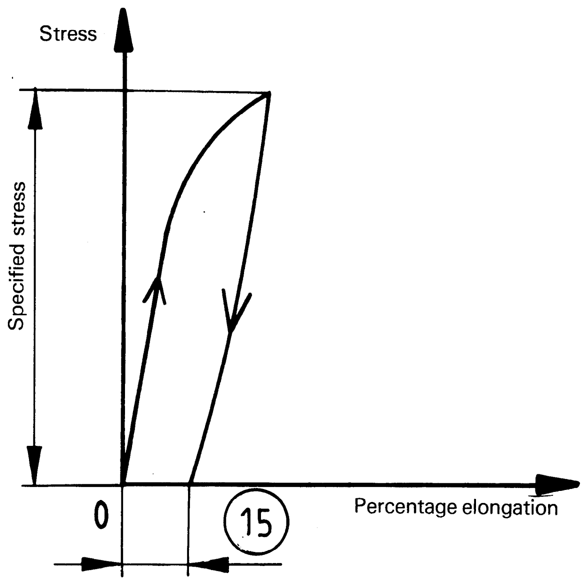


Figure 2

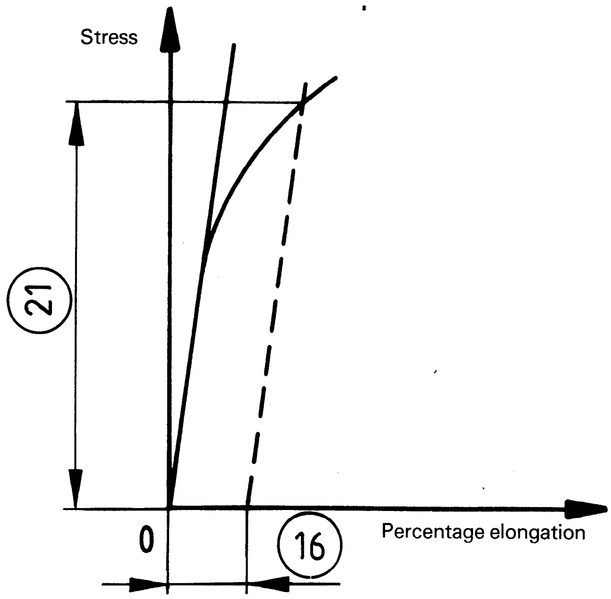


Figure 3

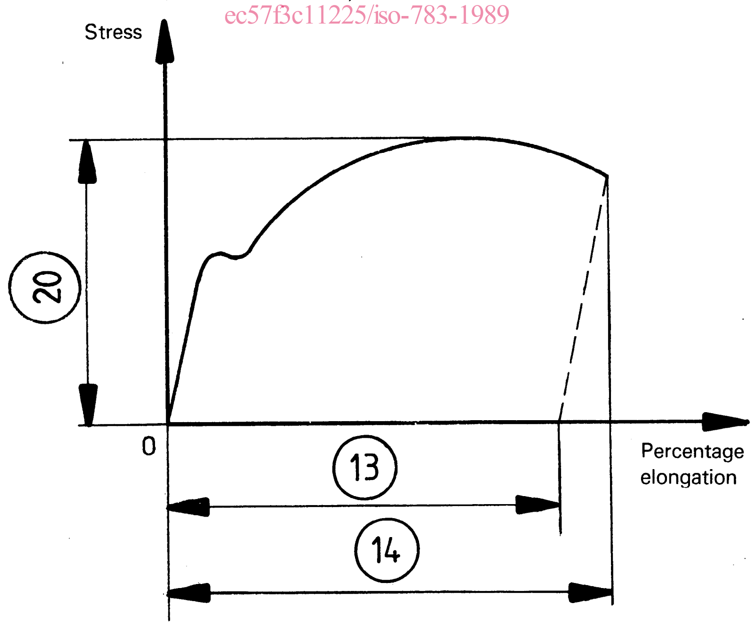


Figure 4