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มอก. 2172–2547

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การทดสอบโลหะโดยการดึงที่อุณหภูมิโดยรอบ

TENSILE TESTING AT AMBIENT TEMPERATURE FOR METALLIC MATERIALS

[ISO TITLE : METALLIC MATERIALS – TENSILE TESTING AT AMBIENT TEMPERATURE]

สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

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มาตรฐานผลิตภัณฑ์อุตสาหกรรม
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สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม
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มาตรฐานผลิตภัณฑ์อุตสาหกรรม การทดสอบโลหะโดยการดึงที่อุณหภูมิโดยรอบ กำหนดขึ้นเพื่อใช้เป็นวิธีการทดสอบโลหะในกระบวนการตรวจสอบ ควบคุมคุณภาพและพัฒนาผลิตภัณฑ์อุตสาหกรรม โดยรับ ISO 6892 : 1998 Metallic materials – Tensile testing at ambient temperature มาใช้ในระดับเหมือนกันทุกประการ (identical) โดยใช้ ISO ฉบับภาษาอังกฤษเป็นหลัก

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้นเพื่อใช้ในการอ้างอิง และเพื่อให้ทันกับความต้องการของผู้ใช้มาตรฐาน ซึ่งจะได้แปลเป็นภาษาไทยในโอกาสอันสมควรต่อไป หากมีข้อสงสัยโปรดติดต่อสอบถามที่สำนักงานมาตรฐานผลิตภัณฑ์อุตสาหกรรม

คณะกรรมการมาตรฐานผลิตภัณฑ์อุตสาหกรรมได้พิจารณามาตรฐานนี้แล้ว เห็นสมควรเสนอรัฐมนตรีประกาศตามมาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511

ประกาศกระทรวงอุตสาหกรรม

ฉบับที่ 3360 (พ.ศ. 2548)

ออกตามความในพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม

พ.ศ. 2511

เรื่อง กำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม

การทดสอบโลหะโดยการดึงที่อุณหภูมิโดยรอบ

อาศัยอำนาจตามความในมาตรา 15 แห่งพระราชบัญญัติมาตรฐานผลิตภัณฑ์อุตสาหกรรม พ.ศ. 2511 รัฐมนตรีว่าการกระทรวงอุตสาหกรรมออกประกาศกำหนดมาตรฐานผลิตภัณฑ์อุตสาหกรรม การทดสอบโลหะโดยการดึงที่อุณหภูมิโดยรอบ มาตรฐานเลขที่ มอก. 2172-2547 ไว้ ดังมีรายการละเอียดต่อท้ายประกาศนี้

ประกาศ ณ วันที่ 26 พฤษภาคม พ.ศ. 2548

วัฒนา เมืองสุข

รัฐมนตรีว่าการกระทรวงอุตสาหกรรม

มาตรฐานผลิตภัณฑ์อุตสาหกรรม
การทดสอบโลหะโดยการดึงที่อุณหภูมิโดยรอบ

บทนำ

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้กำหนดขึ้นโดยการรับ ISO 6892 : 1998 Metallic materials – Tensile testing at ambient temperature มาใช้ในระดับเหมือนกันทุกประการ (identical) โดยใช้ ISO ฉบับภาษาอังกฤษเป็นหลัก

ขอบข่าย

มาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้ กำหนดวิธีทดสอบโลหะโดยการดึงและเพื่อวัดค่าสมบัติทางกลที่อุณภูมิโดยรอบ

เอกสารอ้างอิง

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 : 1997 Steel and steel products – Location and preparation of sample and test pieces for mechanical testing

ISO 2566–1 : 1984 Steel – Conversion of elongation values – Part 1 : Carbon and low ally steels

ISO 2566–2 : 1984 Steel – Conversion of elongation values – Part 2 : Austenitic steels

ISO 7500–1 : 1986 Metallic materials – Verification of static uniaxial testing machines – Part 1 : Tensile testing machines

ISO 9513–1 : 1986 Metallic materials – Verification of extensometers used in uniaxial testing

หลักการ

รายละเอียดให้เป็นไปตาม ISO 6892 : 1998 ข้อ 3

บทนิยาม

รายละเอียดให้เป็นไปตาม ISO 6892 : 1998 ข้อ 4

สัญลักษณ์และความหมาย

สัญลักษณ์และความหมายของคำที่ใช้ในมาตรฐานผลิตภัณฑ์อุตสาหกรรมนี้ ให้เป็นไปตาม ISO 6892 : 1998 ข้อ 5

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การวัดพื้นที่ภาคตัดขวางเดิม

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การวัดค่าความยืดภายหลังชิ้นทดสอบขาด

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การวัดค่าความยืดรวมที่แรงดึงสูงสุด

รายละเอียดให้เป็นไปตาม ISO 6892 : 1998 ข้อ 12

การวัดค่าความเค้นพิสูจน์ ของความยืดที่ไม่ได้สัดส่วน

รายละเอียดให้เป็นไปตาม ISO 6892 : 1998 ข้อ 13

การวัดค่าความเค้นพิสูจน์ ของความยืดรวมทั้งหมด

รายละเอียดให้เป็นไปตาม ISO 6892 : 1998 ข้อ 14

วิธีหาค่าความแข็งแรงถาวร

รายละเอียดให้เป็นไปตาม ISO 6892 : 1998 ข้อ 15

Metallic materials — Tensile testing at ambient temperature

1 Scope

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

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 377:1997, *Steel and steel products — Location and preparation of samples and test pieces for mechanical testing.*

ISO 2566-1:1984, *Steel — Conversion of elongation values — Part 1: Carbon and low alloy steels.*

ISO 2566-2:1984, *Steel — Conversion of elongation values — Part 2: Austenitic steels.*

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

ISO 9513:—[1], *Metallic materials — Verification of extensometers used in uniaxial testing.*

3 Principle

The test involves 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 4.

The test is carried out at ambient temperature between 10 °C and 35 °C, unless otherwise specified. Tests carried out under controlled conditions shall be made at a temperature of 23 °C ± 5 °C.

1) To be published. (Revision of ISO 9513:1989)

4 Definitions

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

4.1 gauge length (L)**:** Length of the cylindrical or prismatic portion of the test piece on which elongation shall be measured. In particular, a distinction is made between:

4.1.1 original gauge length (L_o)**:** Gauge length before application of force.

4.1.2 final gauge length (L_u)**:** Gauge length after rupture of the test piece (see 11.1).

4.2 parallel length (L_c)**:** Parallel portion of the reduced section of the test piece.

NOTE — The concept of parallel length is replaced by the concept of distance between grips for non-machined test pieces.

4.3 elongation: Increase in the original gauge length (L_o) at any moment during the test.

4.4 percentage elongation: Elongation expressed as a percentage of the original gauge length (L_o).

4.4.1 percentage permanent elongation: Increase in the original gauge length of a test piece after removal of a specified stress (see 4.9), expressed as a percentage of the original gauge length (L_o).

4.4.2 percentage elongation after fracture (A)**:** Permanent elongation of the gauge length after fracture ($L_u - L_o$), expressed as a percentage of the original gauge length (L_o).

In the case of proportional test pieces, only if the original gauge length is other than $5{,}65\sqrt{S_o}$ [2] where S_o is the original cross-sectional area of the parallel length, the symbol A shall be supplemented by an index indicating the coefficient of proportionality used, for example:

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

In the case of non-proportional test pieces, the symbol A shall be supplemented by an index indicating the original gauge length used, expressed in millimetres, for example:

$A_{80\ \text{mm}}$ = percentage elongation of a gauge length (L_o) of 80 mm.

4.4.3 percentage total elongation at fracture (A_t): Total elongation (elastic elongation plus plastic elongation) of the gauge length at the moment of fracture expressed as a percentage of the original gauge length (L_o).

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2) $5{,}65\sqrt{S_o} = 5\sqrt{\frac{4S_o}{\pi}}$

4.4.4 percentage elongation at maximum force: Increase in the gauge length of the test piece at maximum force, expressed as a percentage of the original gauge length (L_o). A distinction is made between the percentage total elongation at maximum force (A_{gt}) and the percentage non-proportional elongation at maximum force (A_g) (see figure 1).

4.5 extensometer gauge length (L_e)**:** Length of the parallel portion of the test piece used for the measurement of extension by means of an extensometer.

It is recommended that for measurement of yield and proof strength parameter $L_e \geqslant L_o/2$.

It is further recommended that for measurement of parameters "at" or "after" maximum force, L_e be approximately equal to L_o.

4.6 extension: Increase in the extensometer gauge length (L_e) at a given moment of the test.

4.6.1 percentage permanent extension: Increase in the extensometer gauge length, after removal of a specified stress from the test piece, expressed as a percentage of the extensometer gauge length (L_e).

4.6.2 percentage yield point extension (A_e)**:** In discontinuous yielding materials, the extension between the start of yielding and the start of uniform work hardening. It is expressed as a percentage of the extensometer gauge length (L_e).

4.7 percentage reduction of area (Z)**:** Maximum change in cross-sectional area ($S_o - S_u$), which has occurred during the test expressed as a percentage of the orignal cross-sectional area (S_o).

4.8 maximum force (F_m)**:** The greatest force which the test piece withstands during the test once the yield point has been passed.

For materials, without yield point, it is the maximum value during the test.

4.9 stress: At any moment during the test, force divided by the original cross-sectional area (S_o) of the test piece.

4.9.1 tensile strength (R_m)**:** Stress corresponding to the maximum force (F_m).

4.9.2 yield strength: 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:

4.9.2.1 upper yield strength (R_{eH})**:** Value of stress at the moment when the first decrease in force is observed (see figure 2).

4.9.2.2 lower yield strength (R_{eL})**:** Lowest value of stress during plastic yielding, ignoring any initial transient effects (see figure 2).

4.9.3 proof strength, non-proportional extension (R_p)**:** Stress at which a non-proportional extension is equal to a specified percentage of the extensometer gauge length (L_e) (see figure 3). The symbol used is followed by a suffix giving the prescribed percentage, for example: $R_{p0,2}$.

4.9.4 proof strength, total extension (R_t)**:** Stress at which total extension (elastic extension plus plastic extension) is equal to a specified percentage of the extensometer gauge length (L_e) (see figure 4). The symbol used is followed by a suffix giving the prescribed percentage for example: $R_{t0,5}$.

4.9.5 permanent set strength (R_r)**:** Stress at which, after removal of force, a specified permanent elongation or extension expressed respectively as a percentage of the original gauge length (L_o) or extensometer gauge length (L_e) has not been exceeded (see figure 5).

The symbol used is followed by a suffix giving the specified percentage of the original gauge length (L_o) or of the extensometer gauge length (L_e), for example: $R_{r0,2}$.

5 Symbols and designations

Symbols and corresponding designations are given in table 1.

6 Test piece

6.1 Shape and dimensions

6.1.1 General

The shape and dimensions of the test pieces depend on the shape and dimensions of the metallic product from which the test pieces are taken.

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 also as-cast test pieces (i.e. cast irons and non-ferrous alloys) may be tested 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, the original gauge length of which is related to the original cross-sectional area by the equation $L_o = k\sqrt{S_o}$ 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 (preferably 11,3) 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 6.2).

Table 1 — Symbols and designations

Reference number [1)]	Symbol	Unit	Designation
			Test piece
1	a [2)]	mm	Thickness of a flat test piece or wall thickness of a tube
2	b	mm	Width of the parallel length of a flat test piece or average width of a longitudinal strip from a tube or width of flat wire
3	d	mm	Diameter of the parallel length 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
—	L'_o	mm	Initial gauge length for determination of A_g
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
—	L'_u	mm	Final gauge length after fracture for determination of A_g (see annex H)
9	S_o	mm^2	Original cross-sectional area of the parallel length
10	S_u	mm^2	Minimum cross-sectional area after fracture
—	k	—	Coefficient of proportionality
11	Z	%	Percentage reduction of area: $\frac{S_o - S_u}{S_o} \times 100$
12	—	—	Gripped ends

Table 1 *(concluded)*

Reference number[1)]	Symbol	Unit	Designation
			Elongation
13	—	mm	Elongation after fracture: $L_u - L_o$
14	A[3)]	%	Percentage elongation after fracture: $\frac{L_u - L_o}{L_o} \times 100$
15	A_e	%	Percentage yield point extension
—	ΔL_m	mm	Extension at maximum force
16	A_g	%	Percentage non-proportional elongation at maximum force (F_m)
17	A_{gt}	%	Percentage total elongation at maximum force (F_m)
18	A_t	%	Percentage total elongation at fracture
19	—	%	Specified percentage non-proportional extension
20	—	%	Percentage total extension (see 28)
21	—	%	Specified percentage permanent set extension or elongation
			Force
22	F_m	N	Maximum force
			Yield strength — Proof strength — Tensile strength
23	R_{eH}	N/mm^2	Upper yield strength[4)]
24	R_{eL}	N/mm^2	Lower yield strength
25	R_m	N/mm^2	Tensile strength
26	R_p	N/mm^2	Proof strength, non-proportional extension
27	R_r	N/mm^2	Permanent set strength
28	R_t	N/mm^2	Proof strength, total extension
—	E	N/mm^2	Modulus of elasticity

1) See figures 1 to 13.
2) The symbol T is also used in steel tube product standards.
3) See 4.4.2.
4) 1 N/mm^2 = 1 MPa

6.1.2 Machined test pieces

Machined test pieces shall incorporate a transition curve between the gripped ends and the parallel length 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 6.2).

The gripped ends may be of any shape to suit the grips of the testing machine. The axis of the test piece shall coincide with or be parallel to the axis of application of the force.

The parallel length (L_c) or, in the case where the test piece has no transition curve, the free length between the grips, shall always be greater than the original gauge length (L_o).

6.1.3 Non-machined test pieces

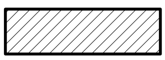
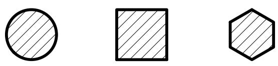
If the test piece consists of an unmachined length of the product or of an unmachined test bar, the free length between the grips shall be sufficient for gauge marks to be at a reasonable distance from the grips (see annexes A and D).

As-cast test pieces shall incorporate a transition radius between the gripped ends and the parallel length. The dimensions of this transition radius are important and it is recommended that they be defined in the product standard. The gripped ends may be of any shape to suit the grips of the testing machine. The parallel length (L_c) shall always be greater than the original gauge length (L_o).

6.2 Types

The main types of test piece are defined in annexes A to D according to the shape and type of product, as shown in table 2. Other types of test piece can be specified in product standards.

Table 2 — Main types of test piece

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	—	A
—	< 4	B
⩾ 3	⩾ 4	C
Tubes		D

6.3 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 (eg. ISO 377).

7 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 A to D for the different types of test piece.

8 Marking the original gauge length (L_o)

Each end of the original gauge length shall be marked by means of fine marks or scribed lines, 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 marked gauge length is less than 10 % of L_o. Annex F gives a nomogram for determining 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 parallel length (L_c) is much greater than the original gauge length, as, for instance, with unmachined test pieces, a series of overlapping gauge lengths may be drawn.

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 gauge lengths are drawn.

9 Accuracy of testing apparatus

The testing machine shall be verified in accordance with ISO 7500-1 and shall be of class 1 or better.

When an extensometer is used it shall be of class 1 (see ISO 9513) for the determination of upper and lower yield strengths and for proof strength (non-proportional extension); for other properties (with higher extension) a class 2 extensometer (see ISO 9513) can be used.

10 Conditions of testing

10.1 Speed of testing

Unless otherwise specified in the product standard, the speed of testing shall conform to the following requirements depending on the nature of the material.

10.1.1 Yield and proof strengths

10.1.1.1 Upper yield strength (R_{eH})

Within the elastic range and up to the upper yield strength, the rate of separation of the crossheads of the machine shall be kept as constant as possible and within the limits corresponding to the stressing rates in table 3.

Table 3 — Rate of stressing

Modulus of elasticity of the material (E) N/mm²	**Rate of stressing** N/mm²·s⁻¹	
	min.	max.
< 150 000	2	20
⩾ 150 000	6	60

10.1.1.2 Lower yield strength (R_{eL})

If only the lower yield strength is being determined, the rate of straining during yield of the parallel length of the test piece shall be between 0,000 25/s and 0,002 5/s. The straining rate within the parallel length shall be kept as constant as possible. If this rate cannot be regulated directly, it shall be fixed by regulating the rate of stressing just before yield begins, the controls of the machine not being further adjusted until completion of yield.

In no case shall the rate of stressing in the elastic range exceed the maximum rates given in table 3.

10.1.1.3 Upper and lower yield strengths (R_{eH} and R_{eL})

If the two yield strengths are determined during the same test, the conditions for determining the lower yield strength shall be complied with (see 10.1.1.2).

10.1.1.4 Proof strength (non-proportional extension) and proof strength (total extension) (R_p and R_t)

The rate of stressing shall be within the limits given in table 3.

Within the plastic range and up to the proof strength (non-proportional extension or total extension) the straining rate shall not exceed 0,002 5/s.

10.1.1.5 Rate of separation

If the testing machine is not capable of measuring or controlling the strain rate, a cross head separation speed equivalent to the rate of stressing given in table 3 shall be used until completion of yield.

10.1.2 Tensile strength (R_m)

10.1.2.1 In the plastic range

The straining rate of the parallel length shall not exceed 0,008/s.

10.1.2.2 In the elastic range

If the test does not include the determination of a yield stress (or proof stress), the rate of the machine may reach the maximum permitted in the plastic range.

10.2 Method of gripping

The test pieces shall be held by suitable means such as wedges, screwed grips, shouldered holders, etc.

Every endeavour shall be made to ensure that test pieces are held in such a way that the force is applied as axially as possible. This is of particular importance when testing brittle materials or when determining proof stress (non-proportional elongation) or proof stress (total elongation) or yield stress.

11 Determination of percentage elongation after fracture (A)

11.1 Percentage elongation after fracture shall be determined in accordance with the definition given in 4.4.2.

For this purpose, the two broken pieces of the test piece are carefully fitted 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.

Elongation after fracture ($L_u - L_o$) shall be determined to the nearest 0,25 mm with a measuring device with 0,1 mm resolution and the value of percentage elongation after fracture shall be rounded to the nearest 0,5 %. If the specified minimum percentage elongation is less than 5 %, it is recommended that special precautions be taken when determining elongation (see annex E).

This measurement is, in principle, valid only if the distance between the fracture and the nearest gauge mark is no less than one third of the original gauge length (L_o). However, the measurement is valid, irrespective of the position of the fracture, if the percentage elongation after fracture is equal to or greater than the specified value.

11.2 For machines capable of measuring extension at fracture using an extensometer, it is not necessary to mark the gauge lengths. The elongation is measured as the total extension at fracture, and it is therefore necessary to deduct the elastic extension in order to obtain percentage elongation after fracture.

In principle, this measurement is only valid if fracture occurs within the extensometer gauge length (L_e). The measurement is valid regardless of the position of the fracture cross-section if the percentage elongation after fracture is equal to or greater than the specified value.

NOTE — If the product standard specifies the determination of percentage elongation after rupture for a given gauge length, the extensometer gauge length shall be equal to this length.

11.3 If elongation is measured over a given fixed length, it can be converted to proportional gauge length, using conversion formulae or tables as agreed before the commencement of testing (for example as in ISO 2566-1 and ISO 2566-2).

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

11.4 In order to avoid having to reject test pieces in which fracture may occur outside the limits specified in 11.1, the method based on the subdivision of L_o into N equal parts may be used, as described in annex G.

12 Determination of percentage total elongation at maximum force (A_{gt})

The method consists of determining on the force-extension diagram obtained with an extensometer, the extension at maximum force (ΔL_m).

Some materials exhibit a flat plateau at maximum force. When this occurs, the percentage total elongation at maximum force is taken at the mid-point of the flat plateau (see figure 1).

The extensometer gauge length shall be recorded in the test report.

The percentage total elongation at maximum force is calculated by the following formula:

$$A_{gt} = \frac{\Delta L_m}{L_e} \times 100$$

If the tensile test is carried out on a computer controlled testing machine having a data acquisition system, the elongation is directly determined at the maximum force.

For information, a manual method is described in annex H.

13 Determination of proof strength, non proportional extension (R_p)

13.1 The proof strength (non-proportional extension) is determined from the force-extension diagram by drawing a line parallel to the straight portion of the curve and at a distance from this equivalent to the prescribed non-proportional percentage, for example 0,2 %. The point at which this line intersects the curve gives the force corresponding to the desired proof strength (non-proportional extension). The latter is obtained by dividing this force by the original cross-sectional area of the test piece (S_o) (see figure 6).

Accuracy in drawing the force-extension diagram is essential.

If the straight portion of the force-extension diagram is not clearly defined, thereby preventing drawing the parallel line with sufficient precision, the following procedure is recommended (see figure 6).

When the presumed proof strength has been exceeded, the force is reduced to a value equal to about 10 % of the force obtained. The force is then increased again until it exceeds the value obtained originally. To determine the desired proof strength a line is drawn through the hysteresis loop. A line is then drawn parallel to this line, at a distance from the corrected origin of the curve, measured along the abscissa, equal to the prescribed non-proportional percentage. The intersection of this parallel line and the force-extension curve gives the force corresponding to the proof strength. The latter is obtained by dividing this force by the original cross-sectional area of the test piece (S_o) (see figure 6).

NOTE — The correction of the origin of the curve can be done by various methods. The following method is generally used: draw a line parallel to the line defined by the hysteresis loop which crosses the rising elastic part of the diagram, the slope of which is nearest to that of the loop. The point at which this line intersects the abscissa gives the corrected origin of the curve.

13.2 The property may be obtained without plotting the force-extension curve by using automatic devices (eg. microprocessor).

14 Determination of proof strength, total extension (R_t)

14.1 The proof strength (total extension) is determined on the force-extension diagram by drawing a line parallel to the ordinate axis (force axis) and at a distance from this equivalent to the prescribed total percentage extension. The point at which this line intersects the curve gives the force corresponding to the desired proof strength. The latter is obtained by dividing this force by the original cross-sectional area of the test piece (S_o) (see figure 4).

14.2 The property may be obtained without plotting the force-extension diagram by using automatic devices.

15 Method of verification of permanent set strength (R_r)

The test piece is subjected to a force for 10 s to 12 s corresponding to the specified stress and it is then confirmed, after removing the force, that the permanent set extension or elongation is not more than the percentage specified for the original gauge length.

16 Determination of percentage reduction of area (Z)

Percentage reduction of area shall be determined in accordance with the definition given in 4.7.

The two broken pieces of the test piece are carefully fitted back together so that their axes lie in a straight line. The minimum cross-sectonial area after fracture (S_u) shall be measured to an accuracy of ± 2 % (see annexes A to D). The difference between the area (S_u) and the original cross-sectional area (S_o) expressed as a percentage of the original area gives the percentage reduction of area.

17 Accuracy of the results

The accuracy of results is dependent on various parameters which may be separated into two categories:

— metrological parameters such as class of machine and extensometer and the accuracy of specimen dimensional measurements;

— material and testing parameters such as nature of material, test piece geometry and preparation, testing rate, temperature, data acquisition and analysis technique.

In the absence of sufficient data on all types of materials it is not possible, at present, to fix values of accuracy for the different properties measured by the tensile test.

Annex J provides a guideline for the determination of uncertainty related to metrological parameters.

Annex K provides values obtained from interlaboratory tests on a group of steels and aluminium alloys.

18 Test report

The test report shall contain at least the following information:

a) reference to this International Standard, i.e. ISO 6892;

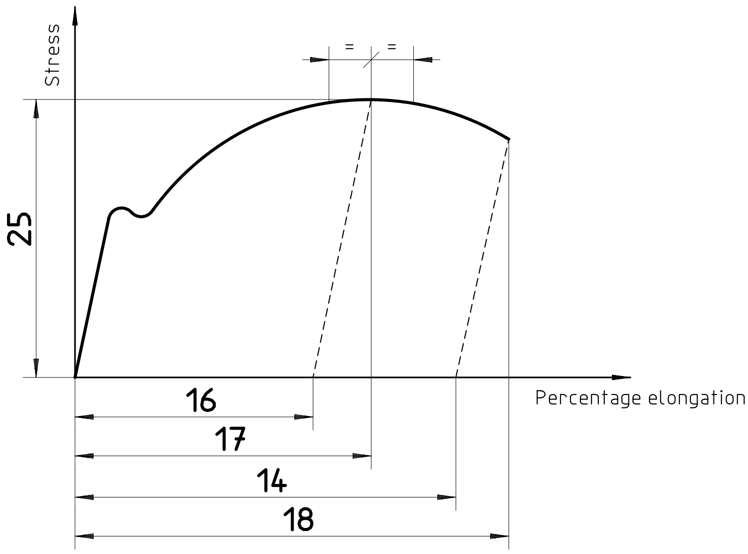
b) identification of the test piece;

c) specified material, if known;

d) type of test piece;

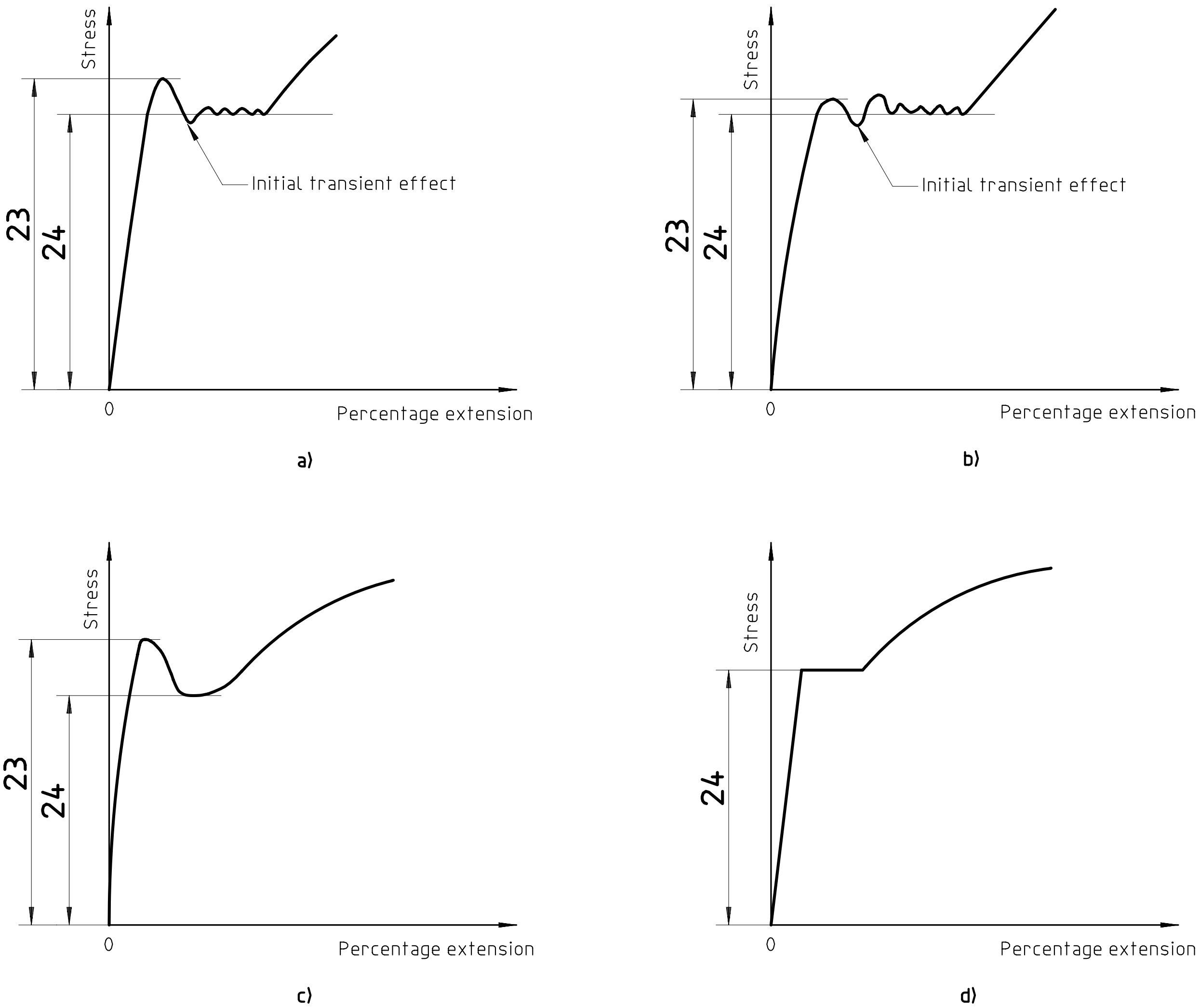
e) location and direction of sampling of test pieces;

f) measured properties and results.



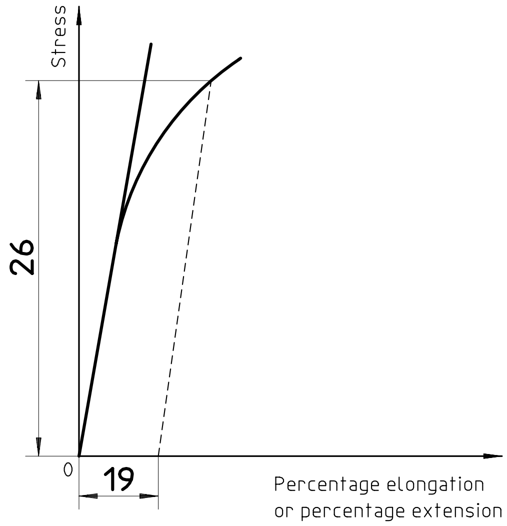
NOTE — See table 1 for explanation of reference numbers.

Figure 1 — Definitions of elongation



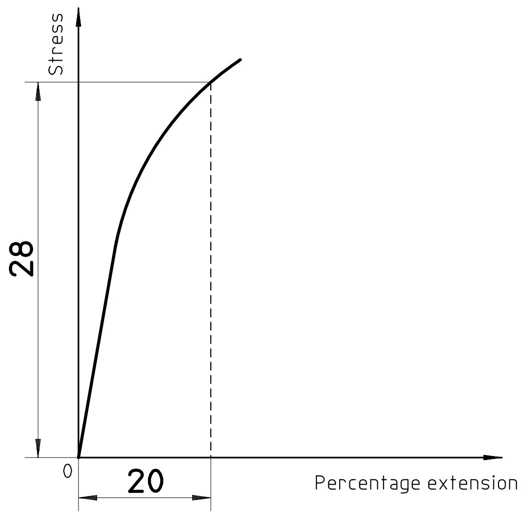
NOTE — See table 1 for explanation of reference numbers.

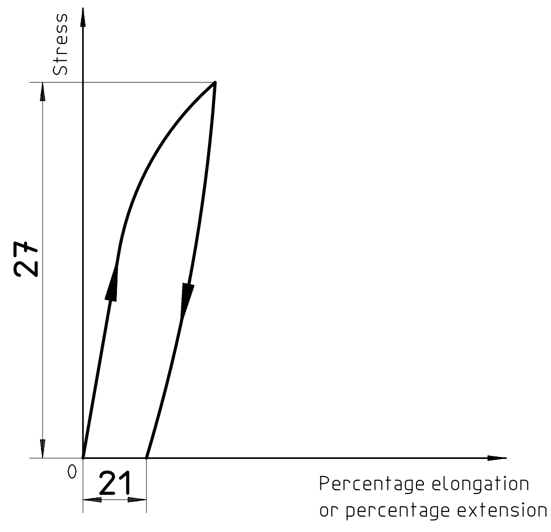
Figure 2 — Definitions of upper and lower yield strengths for different types of curves



NOTE — See table 1 for explanation of reference numbers.

Figure 3 — Proof strength, non-proportional extension (R_p)





NOTE — See table 1 for explanation of reference numbers.

Figure 4 — Proof strength, total extension (R_t)

Figure 5 — Permanent set strength (R_r)

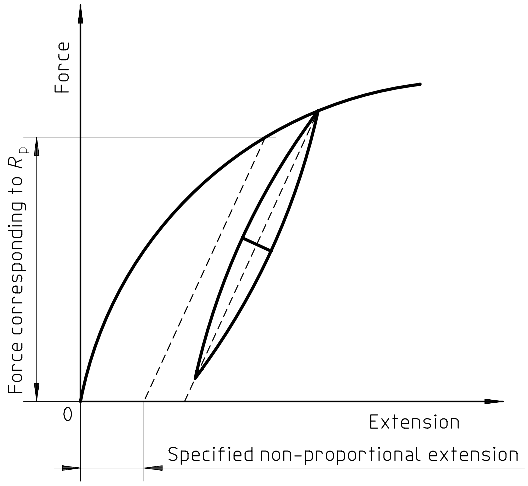
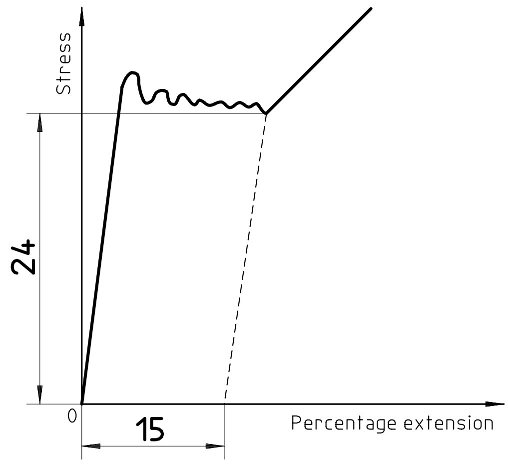
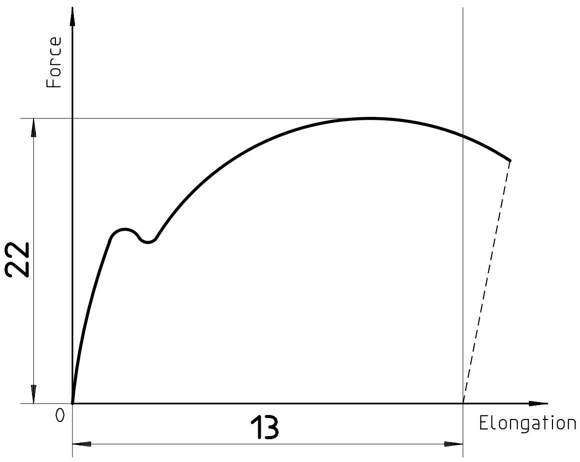


Figure 6 — Proof strength, non-proportional extension (R_p) (see 13.1)



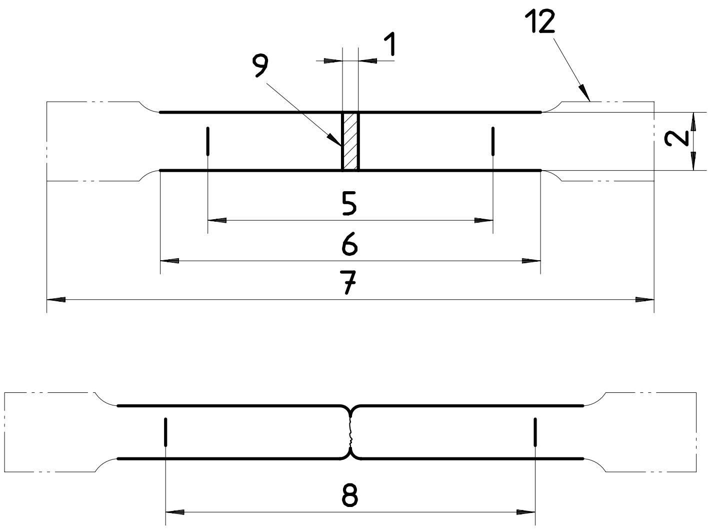
NOTE — See table 1 for explanation of reference numbers.

Figure 7 — Percentage yield point extension (A_e)



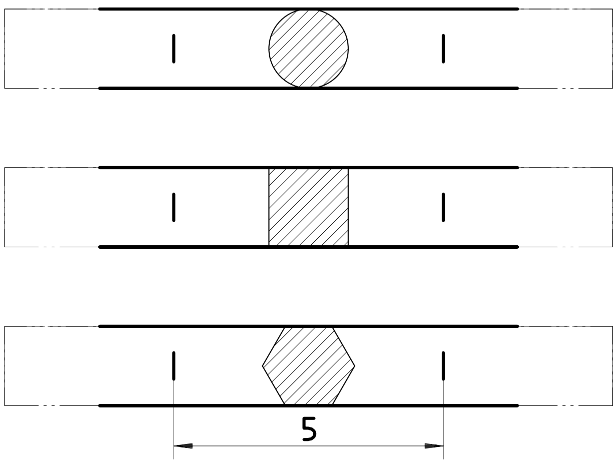
NOTE — See table 1 for explanation of reference numbers.

Figure 8 — Maximum force



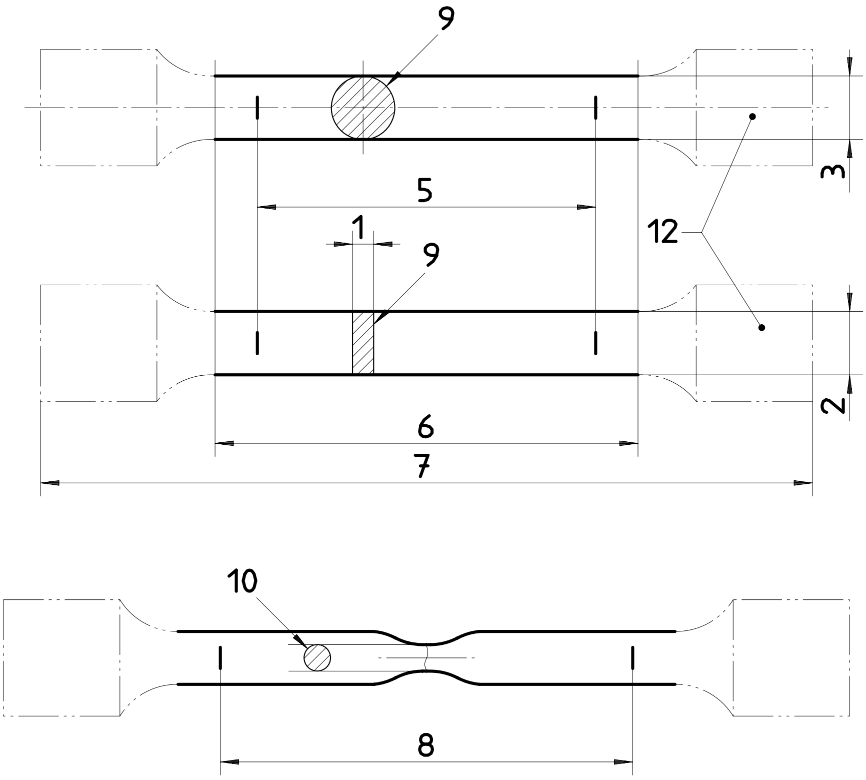
NOTES
1 The shape of the test piece heads is given only as a guide.
2 See table 1 for explanation of reference numbers.

Figure 9 — Machined test pieces of rectangular cross section
(see annex A)



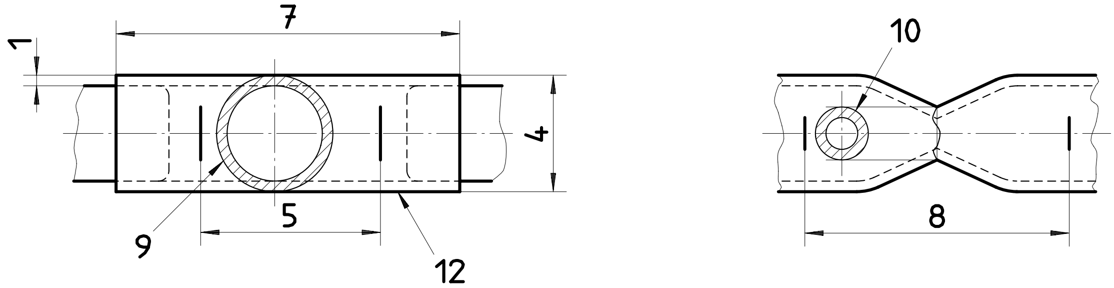
NOTES
1 The shape of the test piece heads is given only as a guide.
2 See table 1 for explanation of reference numbers.

Figure 10 — Test pieces comprising a non-machined portion of the product
(see annex B)



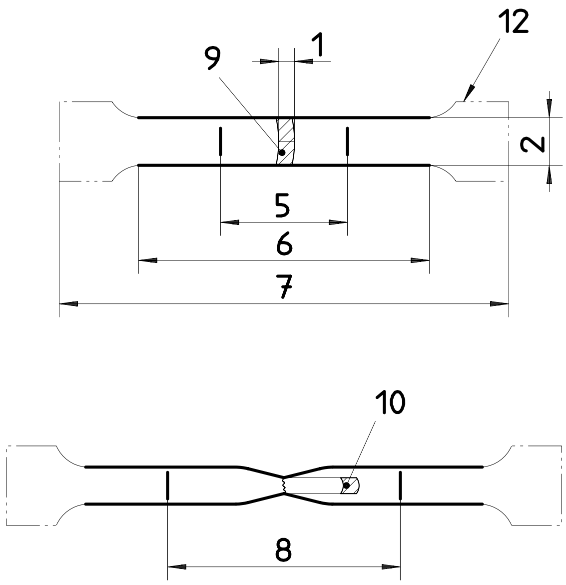
NOTES
1 The shape of the test piece heads is given only as a guide.
2 See table 1 for explanation of reference numbers.

Figure 11 — Proportional test pieces
(see annex C)



NOTE — See table 1 for explanation of reference numbers.

Figure 12 — Test pieces comprising a length of tube
(see annex D)



NOTES
1 The shape of the test piece heads is given only as a guide.
2 See table 1 for explanation of reference numbers.

Figure 13 — Test piece cut from a tube
(see annex D)

Annex A
(normative)

Types of test piece to be used for thin products: sheets, strips and flats between 0,1 mm and 3 mm thick

For products of less than 0,5 mm thickness, special precautions may be necessary.

A.1 Shape of the test piece

Generally, the test piece has gripped ends which are wider than the parallel length. The parallel length (L_c) shall be connected to the ends by means of transition curves with a radius of at least 20 mm. The width of these ends shall be at least 20 mm and not more than 40 mm.

By agreement, the test piece may also consist of a strip with parallel sides. For products of width equal to or less than 20 mm, the width of the test piece may be the same as that of the product.

A.2 Dimensions of the test piece

The parallel length shall not be less than $L_o + \frac{b}{2}$.

In case of dispute, the length $L_o + 2b$ shall always be used unless there is insufficient material.

In the case of parallel side test pieces less than 20 mm wide, and unless otherwise specified in the product standard, the original gauge length (L_o) shall be equal to 50 mm. For this type of test piece, the free length between the grips shall be equal to $L_o + 3b$.

There are two types of non-proportional test pieces, with dimensions as given in table A.1.

When measuring the dimensions of each test piece, the tolerances on shape given in table A.2 shall apply.

In the case of test pieces where the width is the same as that of the product, the original cross-sectional area (S_o) shall be calculated on the basis of the measured dimensions of the test piece.

The nominal width of the test piece may be used, provided that the machining tolerances and tolerances on shape given in table A.2 have been complied with, to avoid measuring the width of the test piece at the time of the test.

Table A.1 — Dimensions of test pieces

Dimensions in millimetres

Test piece type	Width b	Original gauge length L_o	Parallel length L_c	Free length between the grips for parallel sided test piece
1	12,5 ± 1	50	75	87,5
2	20 ± 1	80	120	140

Table A.2 — Tolerances on the width of the test piece

Dimensions and tolerances in millimetres

Nominal width of the test piece	Machining tolerance [1)]	Tolerance on shape [2)]
12,5	± 0,09	0,043
20	± 0,105	0,052

1) Tolerances js 12 in accordance with ISO 286-2. These tolerances are applicable if the nominal value of the original cross-sectional area (S_o) is to be included in the calculation without having to measure it.

2) Tolerances IT 9 (see ISO 286-2). Maximum deviation between the measurements of the width along the entire palallel length (L_c) of the test piece.

A.3 Preparation of test pieces

The test pieces are prepared so as not to affect the properties of the metal. Any areas which have been hardened by shearing or pressing shall be removed by machining.

For very thin materials, it is recommended that strips of identical widths be cut and assembled into a bundle with intermediate layers of a paper which is resistant to the cutting oil. It is recommended that each small bundle of strips be assembled with a thicker strip on each side, before machining to the final dimensions of test piece.

The value given in A.2, for example ± 0,09 mm for a nominal width of 12,5 mm, means that no test piece shall have a width outside the two values given below, if the nominal value of the original cross-sectional area (S_o) is to be included without having to measure it:

12,5 + 0,09 = 12,59 mm
12,5 – 0,09 = 12,41 mm.

A.4 Determination of the original cross-sectional area (S_o)

The original cross-sectional area shall be calculated from measurements of the dimensions of the test piece.

The error in determining the original cross-sectional area shall not exceed ± 2 %. As the greatest part of this error normally results from the measurement of the thickness of the test piece, the error in measurement of the width shall not exceed ± 0,2 %.

Annex B
(normative)

Types of test piece to be used for wire, bars and sections with a diameter or thickness of less than 4 mm

B.1 Shape of the test piece

The test piece generally consists of an unmachined portion of the product (see figure 10).

B.2 Dimensions of the test piece

The original gauge length (L_o) shall be taken as 200 mm ± 2 mm or 100 mm ± 1 mm. The distance between the grips of the machine shall be equal to at least L_o + 50 mm, i.e. 250 mm and 150 mm respectively, except in the case of small diameter wires where this distance can be taken as equal to L_o.

NOTE — In cases where the percentage elongation after fracture is not to be determined, a distance between the grips of at least 50 mm may be used.

B.3 Preparation of test pieces

If the product is delivered coiled, care shall be taken in straightening it.

B.4 Determination of the original cross-sectional area (S_o)

The original cross-sectional area (S_o) shall be determined to an accuracy of ± 1 %.

For products of circular cross-section, the original cross-sectional area may be calculated from the arithmetic mean of two measurements carried out in two perpendicular directions.

The original cross-sectional area may be determined from the mass of a known length and its density.

Annex C
(normative)

Types of test piece to be used for sheets and flats of thickness equal to or greater than 3 mm, and wire, bars and sections of diameter or thickness equal to or greater than 4 mm

C.1 Shape of the test piece

In general, the test piece is machined and the parallel length shall be connected by means of transition curves to the gripped ends which may be of any suitable shape for the grips of the test machine (see figure 11). The minimum transition radius between the gripped ends and the parallel length shall be:

— 0,75 d (d being the diameter of the gauge length) for the cylindrical test pieces;

— 12 mm for the prismatic test pieces.

Sections, bars, etc., may be tested unmachined, if required.

The cross-section of the test piece may be circular, square, rectangular or, in special cases, of another shape.

For test pieces with a rectangular cross-section it is recommended that the width to thickness ratio should not exceed 8:1.

In general, the diameter of the parallel length of machined cylindrical test pieces shall be not less than 4 mm.

C.2 Dimensions of the test piece

C.2.1 Parallel length of machined test piece

The parallel length (L_c) shall be at least equal to:

a) $L_o + \frac{d}{2}$ in the case of test pieces with circular cross-section;

b) $L_o + 1{,}5\sqrt{S_o}$ in the case of prismatic test pieces.

Depending on the type of test piece, the length $L_o + 2d$ or $L_o + 2\sqrt{S_o}$ shall be used in cases of dispute, unless there is insufficient material.

C.2.2 Length of unmachined test piece

The free length between the grips of the machine shall be adequate for the gauge marks to be at a reasonable distance from these grips.

C.2.3 Original gauge length (L_o)

C.2.3.1 Proportional test pieces

As a general rule, proportional test pieces are used where the original gauge length (L_o) is related to the original cross-sectional area (S_o) by the equation

$$L_o = k\sqrt{S_o}$$

where k is equal to 5,65.

Test pieces of circular cross-section preferably have the dimensions given in table C.1.

The scale given in annex F makes it easier to determine the original gauge length (L_o) corresponding to the dimensions of test pieces of rectangular cross-section.

C.2.3.2 Non-proportional test pieces

Non-proportional test pieces may be used if specified by the product standard.

Table C.1 — Circular cross-section test pieces

k	**Diameter** d mm	**Original cross-sectional area** S_o mm²	**Original gauge length** $L_o = k\sqrt{S_o}$ mm	**Minimum parallel length** L_c mm	**Total length** L_t
5,65	20 ± 0,15 10 ± 0,075 5 ± 0,040	314 78,5 19,6	100 ± 1 50 ± 0,5 25 ± 0,25	110 55 28	Depends on the method of fixing the test piece in the machine grips In principle: $L_t > L_c + 2d$ or $4d$

C.3 Preparation of test pieces

The tolerances on the transverse dimensions of machined test pieces are given in table C.2.

An example of the application of these tolerances is given below:

a) Machining tolerances

The value given in table C.2, for example ± 0,075 mm for a nominal diameter of 10 mm, means that no test piece shall have a diameter outside the two values given below, if the nominal value of the original cross-sectional area (S_o) is to be included in the calculation without having to measure it:

10 + 0,075 = 10,075 mm
10 – 0,075 = 9,925 mm

b) Tolerances on shape

The value given in table C.2 means that, for a test piece with a nominal diameter of 10 mm which satisfies the machining conditions given above, the deviation between the smallest and largest diameters measured shall not exceed 0,04 mm.

Consequently, if the minimum diameter of this test piece is 9,99 mm, its maximum diameter shall not exceed 9,99 + 0,04 = 10,03 mm

C.4 Determination of the cross-sectional area (S_o)

The nominal diameter can be used to calculate the original cross-sectional area of test pieces of circular cross-section which satisfy the tolerances given in table C 2. For all other shapes of test pieces, the original cross-sectional area shall be calculated from measurements of the appropriate dimensions, with an error not exceeding ± 0,5 % on each dimension.

Table C.2 — Tolerances relating to the transverse dimensions of test pieces

Dimensions and tolerances in millimetres

Designation	Nominal transverse dimension	Machining tolerance on the nominal dimension 1)	Tolerance on shape
Diameter of machined test pieces of circular cross-section	3	± 0,05	0,025 2)
	> 3 ⩽ 6	± 0,06	0,03 2)
	> 6 ⩽ 10	± 0,075	0,036 2)
	> 10 ⩽ 18	± 0,09	0,043 2)
	> 18 ⩽ 30	± 0,105	0,052 2)
Transverse dimensions of test pieces of rectangular cross-section machined on all four sides		Same tolerance as on the diameter of test pieces of circular cross-section	
Transverse dimensions of test pieces of rectangular cross-section machined on only two opposite sides	3		0,14 3)
	> 3 ⩽ 6		0,18 3)
	> 6 ⩽ 10		0,22 3)
	> 10 ⩽ 18		0,27 3)
	> 18 ⩽ 30		0,33 3)
	> 30 ⩽ 50		0,39 3)

1) Tolerances js 12 in accordance with ISO 286-2. These tolerances are applicable if the nominal value of the original cross-sectional area (S_o) is to be included in the calculation without having to measure it.

2) Tolerances IT9
3) Tolerances IT13
} Maximum deviation between the measurements of a specified transverse dimension along the entire parallel length (L_c) of the test piece.

Annex D
(normative)

Types of test piece to be used for tubes

D.1 Shape of the test piece

The test piece consists either of a length of tube or a longitudinal or transverse strip cut from the tube and having the full thickness of the wall tube (see figures 12 and 13), or of a test piece of circular cross-section machined from the wall of the tube.

Machined transverse, longitudinal and circular cross-section test pieces are described in annex A for tube of wall thickness less than 3 mm and in annex C for thicknesses equal to or greater than 3 mm. The longitudinal strip is generally used for tubes with a wall thickness of more than 0,5 mm.

D.2 Dimensions of the test piece

D.2.1 Length of tube

The length of tube may be plugged at both ends. The free length between each plug and the nearest gauge marks shall exceed $D/4$. In cases of dispute, the value D shall be used, as long as there is sufficient material.

The length of the plug projecting relative to the grips of the machine in the direction of the gauge marks shall not exceed D, and its shape shall be such that it does not interfere with the gauge length deformation.

D.2.2 Longitudinal or transverse strip

The parallel length (L_c) of the longitudinal strips shall not be flattened but the gripped ends may be flattened for gripping in the testing machine.

Transverse or longitudinal test piece dimensions other than those given in annexes A and C can be specified in the product standard.

Special precautions shall be taken when straightening the transverse test pieces.

D.2.3 Circular cross-section test piece machined in tube wall

The sampling of the test pieces is specified in the product standard.

D.3 Determination of the original cross-sectional area (S_o)

The original cross-sectional area of the test piece shall be determined to the nearest ± 1 %.

The original cross-sectional area of the length of tube or longitudinal or transverse strip may be determined from the mass of the test piece, the length of which has been measured, and from its density.

The original cross-sectional area (S_o) of a test piece consisting of a longitudinal or transverse strip shall be calculated according to the following equation

$$S_o = \frac{b}{4}(D^2 - b^2)^{1/2} + \frac{D^2}{4}\arcsin\frac{b}{D} - \frac{b}{4}[(D-2a)^2 - b^2]^{1/2} - \left(\frac{D-2a}{2}\right)^2 \arcsin\frac{b}{D-2a}$$

where

a is the thickness of the tube wall;

b is the average width of the strips;

D is the external diameter.

The following simplified equations can be used for longitudinal or transverse test pieces:

$$S_o = ab\left[1 + \frac{b^2}{6D(D-2a)}\right] \text{ when } \frac{b}{D} < 0{,}25;$$

$$S_o = ab \text{ when } \frac{b}{D} < 0{,}17.$$

In the case of a length of tube, the original cross-sectional area (S_o) shall be calculated as follows:

$$S_o = \pi a(D - a).$$

Annex E
(informative)

Precautions to be taken when measuring the percentage elongation after fracture if the specified value is less than 5 %

One of the recommended methods is as follows:

Prior to the test a very small mark should be made near one of the ends of the parallel length. Using a pair of needle-pointed dividers set at the gauge length, an arc is scribed with the mark as the centre. After fracture, the broken test piece should be placed in a fixing clamp and axial compressive force applied, preferably by means of a screw, sufficient to hold the pieces firmly together during measurement. A second arc of the same radius should then be scribed from the original centre, and the distance between the two scratches measured by means of a measuring microscope or other suitable instrument. In order to render the fine scratches more easily visible, a suitable dye film may be applied to the test piece before testing.

Annex F
(informative)

Nomogram for calculating the gauge lengths of test pieces of rectangular cross-section

This nomogram has been constructed by using the alignment method.

F.1 Method of use

Carry out the following steps:

a) on the outside scales, select points a and b representing the thickness and the width of the rectangular test piece;

b) join these two points with a line (length of thread or edge of a ruler);

c) read off the corresponding gauge length from the left hand graduation, at the intersection of this line with the central scale.

Example of use

b = 21 mm a = 15,5 mm L_o = 102 mm

NOTES

1 An error in reading L_o is less than ± 1 % means that this nomogram can be used in all cases without further calculation.

2 An error in reading L_o greater than 1 %, means that in some cases the desired accuracy is not obtained; it is then preferable to calculate the product of a and b directly.

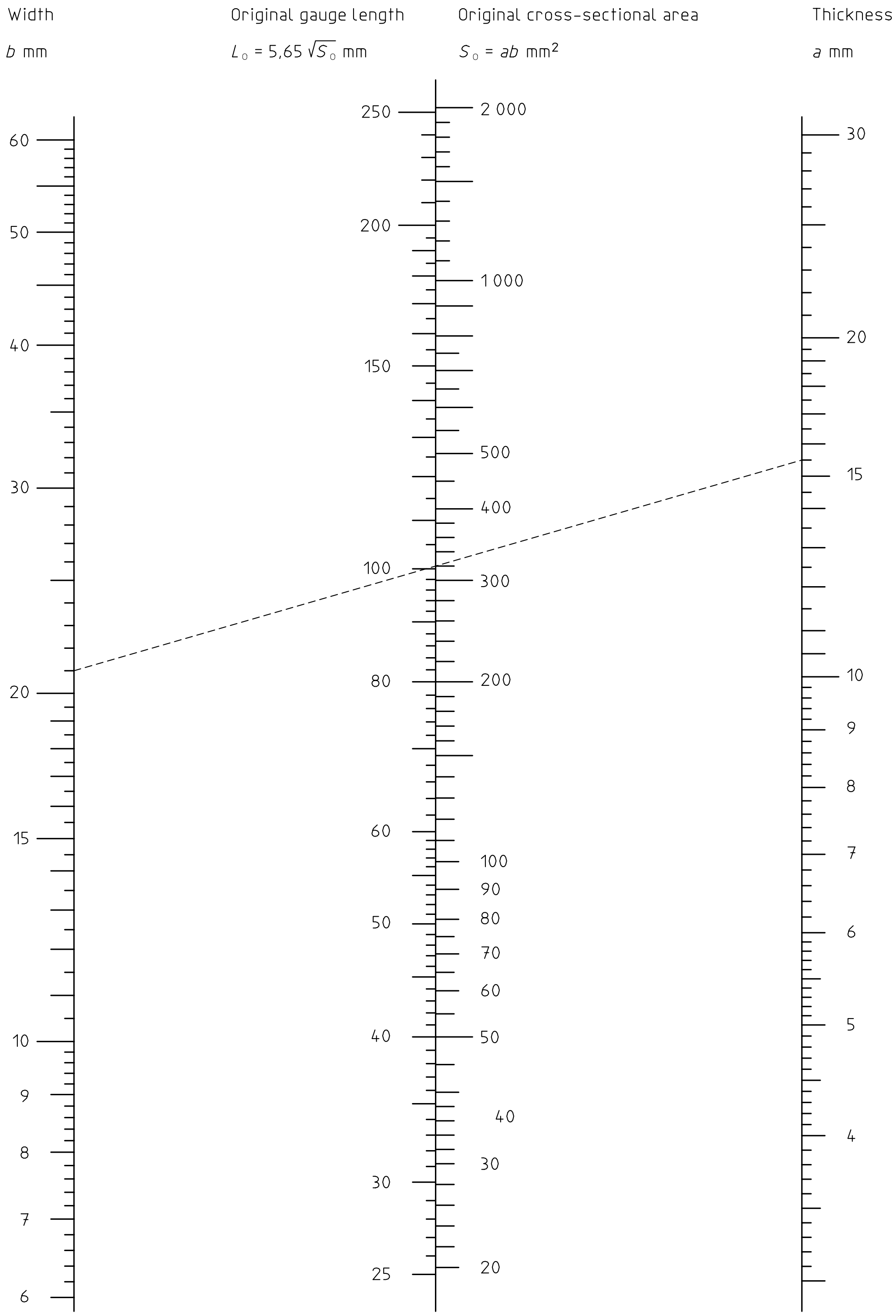
F.2 Construction of the nomogram

Draw three parallel equidistant lines which will be the ordinates for the logarithmic graduations. These shall be graduated logarithmically such that lg 10 is represented by 250 mm; the three scales increase towards the top of the page. The points (20) and (10) should be placed approximately in the centre of the page on the lateral scales. Join the two points (10) of the lateral scales.

The intersection of this line and the central scale gives the point 56,5 of the left hand centre graduation L_o.

The area scale S_o is on the right hand side of the central line. This same point 56,5 is the point 100 on the scale of areas; the graduation should be drawn to a scale which is half the preceding one, namely:

lg 10 = 125 mm.


Width
b mm
Original gauge length
$L_o = 5,65\sqrt{S_o}$ mm
Original cross-sectional area
$S_o = ab$ mm²
Thickness
a mm
60
50
40
30
20
15
10
9
8
7
6
250
200
150
100
80
60
50
40
30
25
2 000
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Annex G
(informative)

Measurement of percentage elongation after fracture based on subdivision of the original gauge length

To avoid having to reject test pieces where the position of the fracture does not comply with the conditions of 11.1, the following method may be used, by agreement:

a) before the test, sub-divide the original gauge length (L_o) into N equal parts;

b) after the test, use the symbol X to denote the gauge mark on the shorter piece and the symbol Y to denote it on the longer piece, the subdivision of which is at the same distance from the fracture as mark X.

If n is the number of intervals between X and Y, the elongation after fracture is determined as follows:

1) if $N - n$ is an even number [see figure G.1 a)], measure the distance between X and Y and the distance from Y to the graduation mark Z located at

$\frac{N-n}{2}$ intervals beyond Y;

calculate the percentage elongation after fracture using the equation

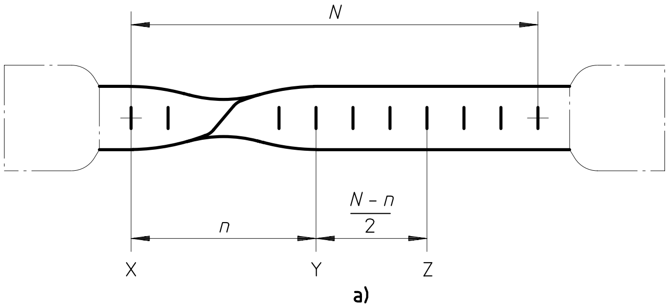
$$A = \frac{\text{XY} + 2\text{YZ} - L_o}{L_o} \times 100$$

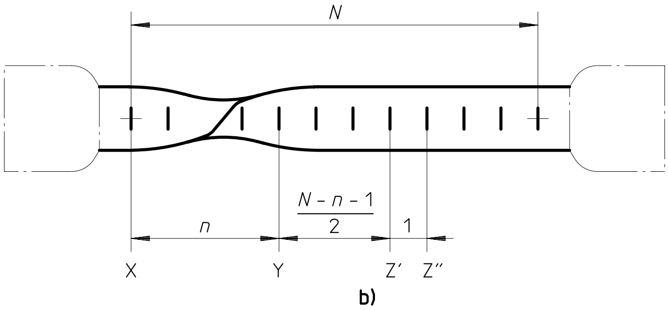
2) if $N - n$ is an odd number [figure G.1 b)], measure the distance between X and Y and the distance from Y to the graduation marks Z' and Z" located respectively at

$\frac{N-n-1}{2}$ and $\frac{N-n+1}{2}$ intervals beyond Y;

calculate the percentage elongation after fracture using the equation

$$A = \frac{\text{XY} + \text{YZ'} + \text{YZ''} - L_o}{L_o} \times 100$$





NOTE — The shape of the test piece heads is given only as a guide.

Figure G.1

Annex H
(informative)

Manual method of determination of percentage total elongation at maximum force for long products such as bars, wire, rods

The extensometer method defined in clause 12 may be replaced by the following manual method. In case of dispute, the extensometer method shall be used.

The method consists of measuring, on the longer part of a test piece which has been submitted to a tensile test, the non-proportional elongation at maximum force, from which the percentage total elongation is calculated.

Before the test, equidistant marks are made on the measuring gauge length, the distance between 2 successive marks being equal to a submultiple of the initial gauge length (L'_o). The marking of the initial gauge length (L'_o) should be accurate to within ± 0,5 mm. This length which is a function of the value of the percentage total elongation should be defined in the product standard.

The measurement of the final gauge length after fracture (L'_u) is made on the longest broken part of the test piece and should be accurate to within 0,5 mm.

In order that the measurement is valid, the two following conditions should be respected:

— the limits of the measuring zone should be located at least 5 d from the fracture section and at least 2,5 d from the grip;

— the measuring gauge length should be at least equal to the value specified in the product standard.

The percentage non-proportional elongation at maximum force is calculated by the following formula:

$$A_g = \frac{L'_u - L'_o}{L'_o} \times 100$$

The percentage total elongation at maximum force is calculated by the following formula:

$$A_{gt} = A_g + \frac{R_m}{E} \times 100$$

Annex J
(informative)

An "Error Budget" approach to the estimation of the uncertainty of measurement in tensile testing

J.1 Introduction

An approach for estimating the uncertainty of measurements is outlined based upon the "error budget" concept using the measurement tolerances specified in the testing and calibration standards. It should be noted that it is not possible to calculate a single value for the measurement uncertainty for all materials since different materials exhibit different response characteristics to some of the specified control parameters, e.g. straining rate or stressing rate [3]. The error budget presented here could be regarded as an upper limit to the measurement uncertainty for a laboratory undertaking testing in compliance with this International Standard (class 1 machine and extensometer).

It should be noted that when evaluating the total scatter in experimental results the uncertainty in measurement should be considered in addition to the inherent scatter due to material inhomogeneity. The statistical approach to the analysis of intercomparison exercises (Round Robin experiments) given in appendix K does not separate out the two contributing causes of the scatter. Another useful approach for estimating interlaboratory scatter is to employ a Certified Reference Material (CRM) which has certified material properties. The selection of candidate materials for use as a room temperature tensile CRM has been discussed elsewhere [3] and a 1 tonne batch of a material (Nimonic 75) in the form of 14 mm diameter bar is in the process of being certified in a project under the supervision of the Community Bureau of Reference (BCR).

J.2 Estimation of uncertainty

J.2.1 Material independent parameters

The manner in which errors from a variety of sources should be added together has been treated in considerable detail [4] and more recently guidance has been given on assessing precision and uncertainty in two ISO documents, ISO 5725-2 and the Guide to the expression of uncertainty in measurement.

In the following analysis the conventional least mean squares approach has been used.

The tolerances for the various testing parameters for tensile properties are given in table J.1 together with expected uncertainty. Because of the shape of the stress-strain curve, some of the tensile properties in principle can be determined with a higher degree of precision than others, e.g., the upper yield strength R_{eH} is only dependent on the tolerances for measurement of force and cross sectional area, whilst proof strength, R_p, is dependent on force, strain (displacement), gauge length and cross-sectional area. In the case of reduction in area, Z, the measurement tolerance for cross-sectional area both before and after fracture needs to be considered.

Table J.1 — Summary of maximum admissible measurements uncertainties for determining tensile test data

Parameter	Tensile properties, % error					
	R_{eH}	R_{eL}	R_m	R_p	A	Z
Force	1	1	1	1		
Strain 1) (displacement)	—	—	—	1	1	
Gauge length, L_o 1)	—	—	—	1	1	
S_o	1	1	1	1	—	1
S_u	—	—	—	—	—	2
Expected uncertainty	$\pm\sqrt{2}$	$\pm\sqrt{2}$	$\pm\sqrt{2}$	$\pm\sqrt{4}$	$\pm\sqrt{2}$	$\pm\sqrt{5}$
(error summation using least-mean squares)						
1) Assuming a class 1 extensometer calibrated in accordance with ISO 9513.						

J.2.2 Material dependent parameters

For room temperature tensile testing, the only tensile properties significantly dependent upon the materials response to the straining rate (or stressing rate) control parameters are R_{eH}, R_{eL} and R_p. Tensile strength, R_m, can also be strain rate dependent, however in practice it is usually determined at a much higher straining rate than R_p and is generally less sensitive to variations in strain rate.

In principle, it will be necessary to determine any material's strain rate response before the total error budget can be calculated. Some limited data are available and the following examples may be used to estimate uncertainty for some classes of materials.

Typical examples of data sets used to determine materials' response over the strain rate range specified in this International Standard are shown in tables J.2 and J.3 and a summary of materials' response for proof stress for a number of materials measured under strain rate control is given in table J.2. Earlier data on a variety of steels measured under a set stressing rate are given in the seminar paper[5].

Table J.2 — Examples of variation in room temperature proof stress over the strain rate range permitted in this International Standard

Material	Nominal composition	$R_{p0,2}$ Mean value MPa	Proof stress strain rate response %	Equivalent tolerance ± %
Ferritic steel				
Pipe steel	Cr-Mo-V-Fe(bal)	680	0,1	0,05
Plate steel (Fe 430)	C-Mn-Fe(bal)	315	1,8	0,9
Austenitic steel				
(X5 Cr Ni Mo 17-12-2)	17Cr, 11Ni-Fe(bal)	235	6,8	3,4
Nickel Base Alloys				
Ni Cr 20 Ti	18Cr, 5Fe, 2Co-Ni(bal)	325	2,8	1,4
Ni Cr Co Ti Al 25-20	24Cr, 20Co, 3Ti, 1,5Mo, 1,5Al-Ni(bal)	790	1,9	0,95

J.2.3 Total measurement uncertainty

The material-dependent response of proof strength over the permitted strain rate range specified in table J.2 may be combined with the material independent parameters specified in table J.1 to give a total estimate of uncertainty for the various materials indicated, as shown in table J.3.

For the purpose of this analysis, the total value of the variation in proof strength over the strain rate range permitted in the standard has been halved and expressed as an equivalent tolerance, i.e. for X5 Cr Ni Mo 17-12-2 stainless steel, the proof strength can vary by 6,8 % over the permitted strain rate range so it is equivalent to a tolerance of ± 3,4 %. Therefore for X5 Cr Ni Mo 17-12-2 stainlesss steel, the total uncertainty is given by:

$$\pm\sqrt{2^2 + 3{,}4^2} = \pm\sqrt{15{,}6} = \pm 3{,}9\,\%$$

Table J.3 — Examples of total expected measurement uncertainty for room temperature proof strength determined in accordance with this International Standard

Material	$R_{po,2}$ Mean value MPa	Values from table J.1 ± %	Values from table J.2 %	Total expected measurement uncertainty ± %
Ferritic steel				
Pipe steel	680	2	0,05	$\sqrt{4{,}0} = 2{,}0$
Plate steel	315	2	0,9	$\sqrt{4{,}8} = 2{,}2$
Austenitic steel				
X5 Cr Ni Mo 17-12-2	235	2	3,4	$\sqrt{15{,}6} = 3{,}9$
Nickel base alloys				
Ni Cr 20 Ti	325	2	1,4	$\sqrt{6{,}0} = 2{,}4$
Ni Cr Co Ti Al 25-20	790	2	0,95	$\sqrt{4{,}9} = 2{,}2$

J.3 Concluding remarks

A method of calculating the measurement uncertainty for room temperature tensile testing using an "Error Budget" concept has been outlined and examples given for a few materials where the material response to the testing parameters is known. It should be noted that the calculated uncertainties may need to be modified to include a weighting factor in accordance with the guide to the expression of uncertainty in measurement [2] and this will be undertaken when the Eurolab and ISO working parties finalise their recommendations on the optimum approach to be adopted. In addition, there are other factors that can affect the measurement of tensile properties such as test piece bending, methods of gripping the test piece, or the testing machine control mode, i.e., extensometer control or load/crosshead control which may affect the measured tensile properties [6]. However since there is insufficient quantitative data available it is not possible to include their effects in error budgets at present. It should also be recognised that this error budget approach only gives an estimate of the uncertainty due to the measurement technique and does not make an allowance for the inherent scatter in experimental results attributable to material inhomogeneity.

Finally, it should be appreciated that when suitable reference materials become avaiblable they will offer a useful means of measuring the total measurement uncertainty on any given testing machine including the influence of grips, bending, etc, which at present have not been quantified.

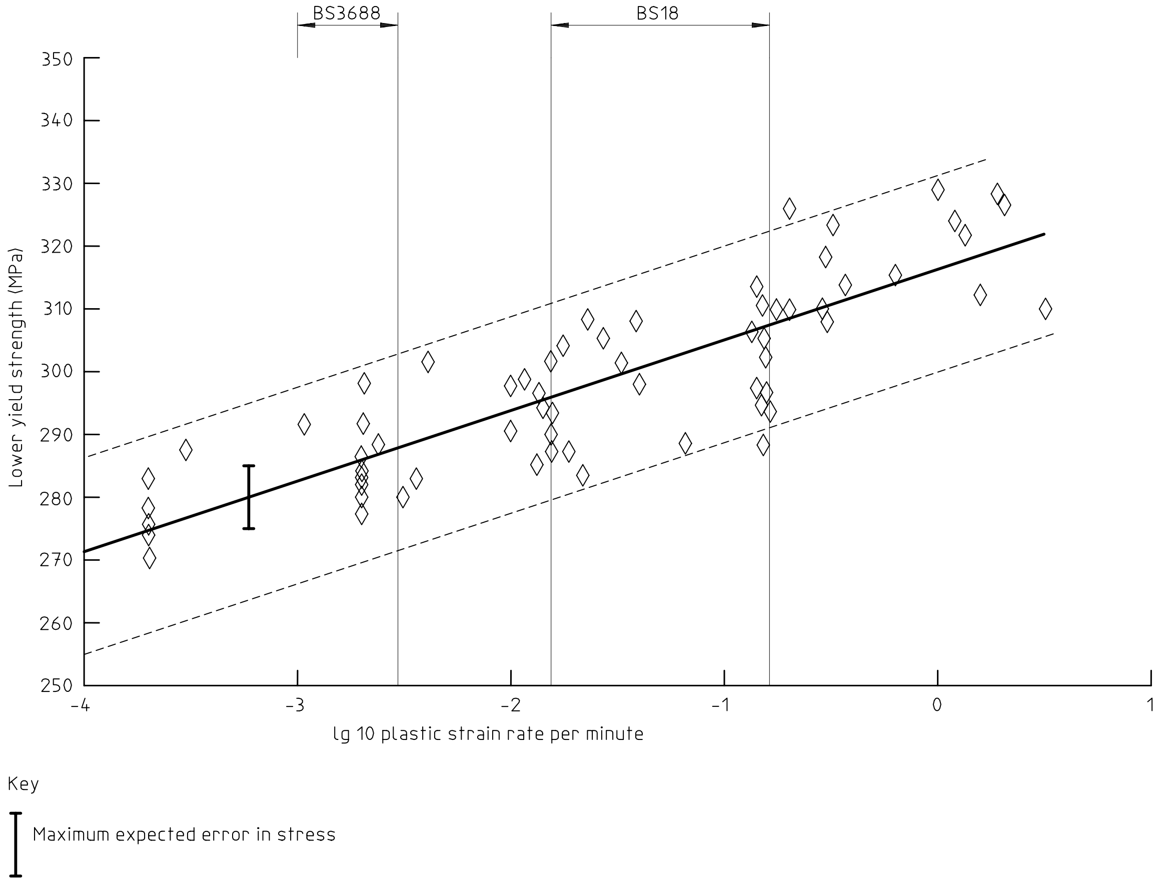


Figure J.1 — Variation of lower yield strength (R_{eL}) at room temperature as a function of strain rate, for plate steel [6]

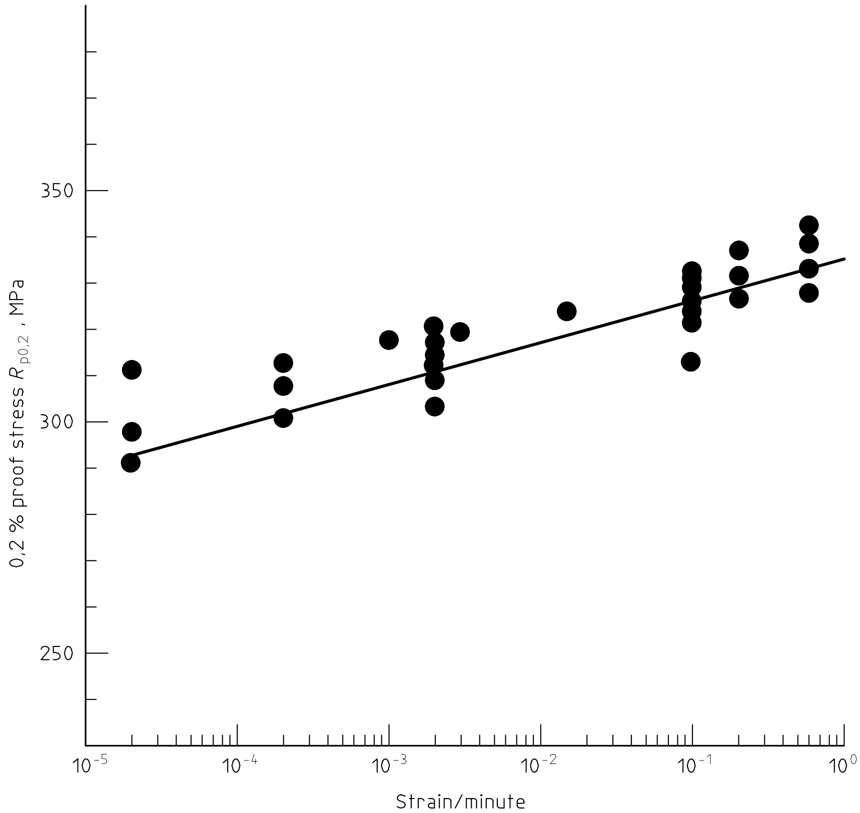


Figure J.2 — Tensile test data at 22 °C for Ni Cr 20 Ti

Annex K
(informative)

Precision of tensile testing — Results from interlaboratory test programmes

K.1 Causes of uncertainty in tensile testing

The precision of the results of tensile tests is limited by factors related to material, test piece, testing equipment, test procedure and method of calculation of the mechanical properties.

More specifically, the following causes of uncertainty can be mentioned:

— some degree of inhomogeneity, which exists even within a processing batch obtained from a single heat of material;

— test piece geometry, preparation method and tolerances;

— gripping method and axiality of force application;

— testing machine and associated measuring systems (stiffness, drive, control, method of operation);

— measurements of test piece dimensions, gauge length marking, extensometer initial gauge length, measurement of force and extension;

— test temperature and loading rates in the successive stages of the test;

— human or software errors associated with the determination of the tensile properties.

The requirements and tolerances of this International Standard do not permit quantification of the effect of all these factors. Interlaboratory tests can be used for an overall determination of the uncertainty of the results under conditions close to the industrial practice of the test. They do not, however, permit separation of effects related to the material from errors due to the test method.

K.2 Procedure

The results of two interlaboratory test programmes (programme A, reference [7] and programme B, reference [8]) are given as examples of the type of uncertainties, which are typically obtained when testing metallic materials.

For each material included in the programme, a fixed number of specimen blanks are randomly selected from the stock. A preliminary study checks the homogeneity of this stock and provides data on the "intrinsic" scatter of the mechanical properties within the stock. The blanks are sent to the participating laboratories, where the test pieces are machined to the drawings they normally use. The only requirement for the test pieces and the testing itself are the compliance with the requirements of the relevant standards. As much as possible, it is recommended that the tests be made in a short period of time, by the same operator using the same machine.

In tables K.1 and K.2, these three kinds of error are expressed in terms of a relative uncertainty coefficient:

$$\mathrm{UC}_r = \pm 2 s_r / \bar{x}\ (\%)$$

$$\mathrm{UC}_L = \pm 2 s_L / \bar{x}\ (\%)$$

$$\mathrm{UC}_R = \pm 2 s_R / \bar{x}\ (\%)$$

where

$\bar{x}$ is the general average;

s_r is the estimated repeatability standard deviation within laboratories;

s_L is the estimated variability between laboratories;

s_R is the estimated precision of the test method: reproducibility standard deviation.

These quantities are close to the 95 % confidence interval of $\bar{x}$. They are calculated for each material tested and each property.

K.3 Results of programme A

Details can be found in the report, reference [7]. The materials are a soft aluminium, a heat-treated aluminium alloy, a low alloy steel, an austenitic stainless steel, a nickel-base alloy and a high-alloy heat treated steel. For each material, six tests were carried out by the six participants. In all cases, 12,5 mm diameter cylindrical test pieces were used. The results are summarized in table K.1. In the case of the low-alloy steel having a yield point behaviour, only the 0,2 % proof strength is reported. The elongation values are relative to a gauge length equal to five diameters.

K.4 Results of programme B

Details can be found in the report, reference [8]. The materials are:

— two sheet materials: a low carbon malleable steel and an austenitic stainless steel (thickness 2,5 mm);

— three grades of bars: a constructional steel, an austenitic stainless steel, a heat treated high strength steel (diameter 20 mm).

Tests were carried out using flat test pieces for the first two materials (18 participants, 5 tests for each material) and 10 mm diameter cylindrical test pieces for the bars (18 participants, 5 tests for each material). The width of the flat test piece was 20 mm and the initial gauge length 80 mm. The results are summarized in table K.2. No distinction is made between lower yield strength (R_{eL}) and proof strength ($R_{\mathrm{p0,2}}$) in the case of materials with yield points. For the cylindrical test pieces, the elongation values correspond to a gauge length equal to five diameters.

Table K.1 — Results from interlaboratory tensile tests: Test programme A

Material	Aluminium	Aluminium	Carbon steel	Austenitic stainless steel	Nickel alloy	Martensitic stainless steel
	EC-H 19	2024-T 351	C 22	X 7 Cr Ni Mo 17-12-02	Ni Cr 15 Fe 8	X 12 Cr 13

Yield strength with 0,2 % offset, MPa

Grand average	158,4	362,9	402,4	480,1	268,3	967,5
UC_r (%)	4,12	2,82	2,84	2,74	1,86	1,84
UC_L (%)	0,42	0,98	4,04	7,66	3,94	2,72
UC_R (%)	4,14	2,98	4,94	8,14	4,36	3,28

Tensile strength, MPa

Grand average	176,9	491,3	596,9	694,6	695,9	1 253,0
UC_r (%)	4,90	2,48	1,40	0,78	0,86	0,50
UC_L (%)	—	1,00	2,40	2,28	1,16	1,16
UC_R (%)	4,90	2,66	2,78	2,40	1,44	1,26

Elongation in 5 diameters gauge length, %

Grand average	14,61	18,04	25,63	35,93	41,58	12,39
UC_r (%)	8,14	6,94	6,00	3,96	3,22	7,22
UC_L (%)	4,06	17,58	8,18	14,36	7,00	13,70
UC_R (%)	9,10	18,90	10,12	14,90	7,72	15,48

Reduction of area, %

Grand average	79,14	30,31	65,59	71,49	59,34	50,49
UC_r (%)	4,86	13,80	2,56	2,78	2,28	7,38
UC_L (%)	1,46	19,24	2,88	3,54	0,68	13,78
UC_R (%)	5,08	23,66	3,84	4,50	2,38	15,62

Table K.2 — Results from interlaboratory tensile tests: Test programme B

Material	**Low carbon steel**	**Austenitic stainless steel**	**Constructional steel**	**Austenitic stainless steel**	**High strength steel**
Steel type	HR 3 (ISO)	X 2 Cr Ni 18-10	Fe 510 C (ISO)	X 2 Cr Ni Mo 18-10	30 Ni Cr Mo 16
Test piece	Flat	Flat	Cylindrical	Cylindrical	Cylindrical

Yield strength (0,2 % offset or lower yield strength), MPa

Grand average	228,6	303,8	367,4	353,3	1 039,9
UC_r (%)	4,92	2,47	2,47	5,29	1,13
UC_L (%)	6,53	6,06	4,42	5,77	1,64
UC_R (%)	8,17	6,54	5,07	7,83	1,99

Tensile strength, MPa

Grand average	335,2	594,0	552,4	622,5	1 167,8
UC_r (%)	1,14	2,63	1,25	1,36	0,61
UC_L (%)	4,86	2,88	1,42	2,71	1,32
UC_R (%)	4,99	2,98	1,90	3,03	1,45

Elongation after fracture, %

L_o = 80 mm			L_o = 5 d		
Grand average	38,41	52,47	31,44	51,86	16,69
UC_r (%)	10,44	3,81	6,41	3,82	7,07
UC_L (%)	7,97	12,00	12,46	12,04	11,20
UC_R (%)	13,80	12,59	14,01	12,65	13,26

Reduction of area, %

Grand average			71,38	77,94	65,59
UC_r (%)			2,05	1,99	2,45
UC_L (%)			1,71	5,26	2,11
UC_R (%)			2,68	5,62	3,23

Annex L
(informative)

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