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Metallic materials — Tensile testing — Method of testing at ambient temperature

Matériaux métalliques — Essais de traction — Méthode d'essai à température ambiante

[Revision of second edition (ISO 6892:1998)]

ICS 77.040.10

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Foreword

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ISO 6892 was prepared by ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 1, and in collaboration by CEN/TC ECISS/TC 1, *Steel - Mechanical testing*.

Introduction

During discussions concerning the speed of testing in the preparation of the 1998 revision of this standard it was decided to recommend the use of strain rate control in future editions.

In this edition there are two methods of testing speeds available. The first, Method A, is based on strain rates (including crosshead separation rate) and the second, Method B, is based on stress rates. Method A is intended to minimise the variation of the test rates during the moment when strain rate sensitive parameters are determined and to minimise the measurement uncertainty of the test results.

Metallic materials — Tensile testing — Method of 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 referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

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

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

ISO 7500-1, *Metallic materials — Verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Verification and calibration of the force-measuring system*.

ISO 9513, *Metallic materials — Calibration of extensometers used in uniaxial testing*.

3 Principle

The test involves straining a test piece by tensile force, generally to fracture, for the determination of 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.

4 Terms and definitions

For the purpose of this International Standard, the following terms and definitions apply (see also Table 1):

4.1
gauge length (L)
length of the section of the test piece on which elongation is 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 fracture of the test piece (see 20.1)

4.2
parallel length (L_c)
parallel length 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
elongation after removal of a specified stress, 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)

NOTE In the case of proportional test pieces, if the original gauge length is not equivalent to 5,65 $\sqrt{S_o}$ [1)] where S_o is the original cross-sectional area of the parallel length, the symbol A should 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 (see Annex B), the symbol A should be supplemented by an index indicating the original gauge length used, expressed in millimetres, for example :

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

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

NOTE It is recommended that for measurement of yield and proof strength parameters L_e should span as much of the parallel length of the test piece as possible. Ideally, as a minimum, L_e should be greater than 0,50 L_o but less than approximately 0,9 L_c. This should ensure that the extensometer detects all yielding events that occur in the test piece. It is further recommended that for measurement of parameters "at“ or "after“ maximum force, L_e is approximately equal to L_o.

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1) $5{,}65\sqrt{S_o} = 5\sqrt{\dfrac{4S_o}{\pi}}$.

4.6
extension
increase in the extensometer gauge length (L_e) at a given moment during the test

4.6.1
percentage extension
extension expressed as a percentage of the extensometer gauge length (L_e)

4.6.2
percentage permanent extension
extension after removal of a specified stress, expressed as a percentage of the extensometer gauge length (L_e)

4.6.3
percentage yield point extension (A_e)
in discontinuous yielding materials, the extension between the start of discontinuous yielding and the start of uniform work hardening, expressed as a percentage of the extensometer gauge length (L_e) (see Figure 7)

4.6.4
percentage total extension at maximum force (A_{gt})
total extension (elastic plus plastic) at maximum force, expressed as a percentage of the extensometer gauge length (L_e) (see Figure 1)

4.6.5
percentage plastic extension at maximum force (A_g)
plastic extension at maximum force, expressed as a percentage of the extensometer gauge length (L_e) (see Figure 1)

4.6.6
percentage total extension at fracture (A_t)
total extension (elastic extension plus plastic extension) at the moment of fracture, expressed as a percentage of the extensometer gauge length (L_e) (see Figure 1)

4.7
testing rate
A distinction is made between:

4.7.1
strain rate ($\dot{e}_{Le}$)
increase of strain, measured with an extensometer of gauge length L_e, per unit time (see 4.5)

4.7.2
estimated strain rate over the parallel length ($\dot{e}_{Lc}$)
the value of the increase of strain over the parallel length (L_c) of the test piece per unit time based on the crosshead separation rate and the parallel length of the test piece

4.7.3
crosshead separation rate (v_c)
displacement of the crossheads per unit time

4.7.4
stress rate ($\dot{R}$)
increase of stress per unit time

NOTE should only be used in the elastic part of the test (Method B).

4.8
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)

4.9
maximum force (F_m)
for materials which display no discontinuous yielding, the highest force that the test piece withstands during the test

For materials which display discontinuous yielding, the highest force that the test piece withstands during the test after the beginning of work hardening (see Figures 8a and 8b).

For materials which display discontinuous yielding but where no work hardening can be established, F_m is not defined in this standard (see Figure 8c and NOTE 1).

4.10
stress (R)
force at any moment during the test divided by the original cross-sectional area (S_o) of the test piece

NOTE All references to stress in this standard are engineering stress.

4.10.1
tensile strength (R_m)
stress corresponding to the maximum force (F_m) (see 4.9)

4.10.2
yield strength
when the metallic material exhibits a yield phenomenon, stress corresponding to the point reached during the test at which plastic deformation occurs without any increase in the force. A distinction is made between :

4.10.2.1
upper yield strength (R_{eH})
maximum value of stress prior to the first decrease in force (see Figure 2)

4.10.2.2
lower yield strength (R_{eL})
lowest value of stress during plastic yielding, ignoring any initial transient effects (see Figure 2)

4.10.3
proof strength, plastic extension (R_p)
stress at which the plastic extension is equal to a specified percentage of the extensometer gauge length (L_e) (see Figure 3)

NOTE The symbol used is followed by a suffix giving the prescribed percentage, for example : $R_{p0,2}$.

4.10.4
proof strength, total extension (R_t)
stress at which the total extension (elastic extension plus plastic extension) is equal to the specified percentage of the extensometer gauge length (L_e) (see Figure 4)

NOTE The symbol used is followed by a suffix giving the prescribed percentage, for example : $R_{t0,5}$.

4.10.5
permanent set strength (R_r)
applied stress which, after removal, gives a plastic deformation not exceeding the specified value of strain (see Figure 5)

NOTE 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 : $R_{r0,2}$.

4.11
fracture
phenomenon which is deemed to occur when total separation of the test piece occurs

NOTE an extended definition which may be used for computer controlled tests is given in Figure A.2.

5 Symbols and designations

Symbols and corresponding designations are given in Table 1.

Table 1 — Symbols and designations

Reference number [a]	Symbol	Unit	Designation
			Test piece
1	a_o	mm	Original thickness of a flat test piece or wall thickness of a tube [b]
2	b_o	mm	Original width of the parallel length of a flat test piece or average width of the longitudinal strip taken from a tube or width of flat wire
3	d_o	mm	Original diameter of the parallel length of a circular test piece, or diameter of round wire or internal diameter of a tube
4	D_o	mm	Original external diameter of a tube
5	L_o	mm	Original gauge length
–	L'_o	mm	Initial gauge length for determination of A_{wn} (see Annex I)
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
–	L'_u	mm	Final gauge length after fracture for determination of A_{wn} (see Annex I)
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 (see 6.1.1)
–	Z	%	Percentage reduction of area
12	–	–	Gripped ends
			Elongation
14	A	%	Percentage elongation after fracture [c]
–	A_{wn}	%	Percentage plastic elongation without necking (see Annex I)
			Extension
15	A_e	%	Percentage yield point extension
–	ΔL_m	mm	Extension at maximum force
–	ΔL_f	mm	Extension at fracture

"to be continued"

Table 1 *(end)*

Reference number [a]	Symbol	Unit	Designation
16	A_g	%	Percentage plastic extension at maximum force (F_m)
17	A_{gt}	%	Percentage total extension at maximum force (F_m)
18	A_t	%	Percentage total extension at fracture
19	–	%	Specified percentage plastic extension
20	–	%	Percentage total extension (see R_t)
21	–	%	Percentage permanent set extension or elongation
			Rates
–	$\dot{e}_{Le}$	s^{-1}	Strain rate
–	$\dot{e}_{Lc}$	s^{-1}	Average strain rate over the parallel length
–	v_c	$mm \cdot s^{-1}$	Crosshead separation rate
–	$\dot{R}$	$MPa \cdot s^{-1}$	Stress rate
			Force
22	F_m	N	Maximum force
			Yield strength - Proof strength - Tensile strength
23	R_{eH}	MPa [d]	Upper yield strength
24	R_{eL}	MPa	Lower yield strength
25	R_m	MPa	Tensile strength
26	R_p	MPa	Proof strength, plastic extension
27	R_r	MPa	Specified permanent set strength
28	R_t	MPa	Proof strength, total extension
–	E	MPa	Modulus of elasticity
–	m	MPa	Slope of the stress/percentage extension - curve at a given moment of the test
29	m_E	MPa	Slope of the elastic part of the stress/percentage extension – curve [e]

[a] See Figures 1 to 15.

[b] The symbol *T* is also used in steel tube product standards.

[c] See 4.4.2.

[d] 1 MPa = 1 N/mm^2.

[e] In the elastic part of the stress/strain curve the value of the slope can closely agree with the value of the modulus of elasticity if optimal conditions (high resolution, double-sided, averaging extensometers, perfect alignment of the test piece, etc.) are used.

6 Test piece

6.1 Shape and dimensions

6.1.1 General

The shape and dimensions of the test pieces may be constrained by 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. for 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, some other uniform cross section.

The preferred test pieces have a direct relationship between, the original gauge length and the original cross-sectional area, shown by the equation $L_o = k\sqrt{S_o}$, and are called proportional test pieces. The internationally adopted value for k is 5,65. The original gauge length shall be not less than 15 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.

NOTE By using an original gauge length smaller than 20 mm the measurement uncertainty is increased.

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

The dimensional tolerances of the test pieces shall be in accordance with the Annexes B to E (see 6.2).

Other test pieces are specified in relevant product standards and national standards e. g. ASTM E8M, ASTM A370, ISO 3183 (API 5L), ISO 11960 (API 5CT), JIS Z2201, IACS Requirements concerning MATERIALS AND WELDING, see [1] in Bibliography.

6.1.2 Machined test pieces

Machined test pieces shall incorporate a transition radius between the gripped ends and the parallel length if these have different dimensions. The dimensions of the transition radius are 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 radii, the free length between the grips, shall always be greater than the original gauge length (L_o).

6.1.3 Non-machined test pieces

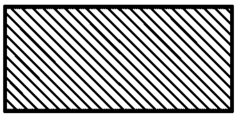
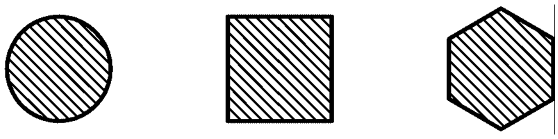
If the test piece consists of an unmachined length of the product or of an unmachined test bar, the free length between the grips shall be sufficient for gauge marks to be at a reasonable distance from the grips (see Annexes B to E).

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 pieces are defined in Annexes B to E according to the shape and type of product, as shown in Table 2. Other types of test pieces can be specified in product standards.

Table 2 — Main types of test piece according to the product type

Type of product		Corresponding Annex
Sheets – Plates – 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

6.3 Preparation of test pieces

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

7 Determination of original cross-sectional area (S_o)

The relevant dimensions of the test piece should be measured at sufficient points in the central region of the parallel length of the test piece.

NOTE A minimum of three points is recommended.

The original cross-sectional area is the average cross-sectional area and 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. Annexes B to E describe methods for the evaluation of S_o for different types of test pieces and contain specifications for the accuracy of measurement.

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 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. 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 marked.

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 marked.

9 Accuracy of testing apparatus

The force-measuring system of the testing machine shall be calibrated in accordance with ISO 7500-1 and shall be class 1 or better.

For the determination of proof strength (plastic or total extension) the used extensometer shall be class 1 or better in the relevant range (according to ISO 9513). For other properties (with higher extension) a class 2 extensometer in the relevant range (according to ISO 9513) can be used.

10 Conditions of testing

10.1 Method of gripping

The test pieces shall be gripped by suitable means such as wedges, screwed grips, parallel jaw faces, shouldered holders, etc.

Every endeavour should be made to ensure that test pieces are held in such a way that the tension is applied as axially as possible, in order to minimize bending. This is of particular importance when testing brittle materials or when determining proof strength (plastic extension), proof strength (total extension) or yield strength.

NOTE In order to obtain a straight test piece and assure the alignment of the test piece and grip arrangement, a preliminary force may be applied provided it does not exceed a value corresponding to 5 % of the specified or expected yield strength. A correction of the extension should be carried out to take into account the effect of the preliminary force.

10.2 Testing rate based on strain rate control (Method A)

10.2.1 General

This method A is intended to minimise the variation of the test rates during the moment when strain rate sensitive parameters are determined and to minimise the measurement uncertainty of the test results.

Two different types of strain rate control are described in this section. The first is strain rate ($\dot{e}_{Le}$) that is based on the feedback obtained from an extensometer. The second is the estimated strain rate over the parallel length ($\dot{e}_{Lc}$), which is achieved by controlling the crosshead separation rate at a velocity equal to the desired strain rate multiplied by the parallel length.

If a material shows homogeneous deformation behaviour and the force remains nominally constant, the strain rate ($\dot{e}_{Le}$) and the estimated strain rate over the parallel length ($\dot{e}_{Lc}$) are approximately equal. Differences exist if the material exhibits discontinuous or serrated yielding, (e.g. some steels and AlMg alloys in the yield point elongation range, or materials which show serrated yielding like the Portevin-Le Chatelier effect) or if necking occurs. If the force is increasing, the estimated strain rate may be substantially below the target strain rate due to the compliance of the testing machine.

The testing rate shall conform to the following requirements:

a) In the range up to and including the determination of R_{eH}, R_p or R_t, the specified strain rate ($\dot{e}_{Le}$) (see 4.7.1) shall be applied. In this range the use of an extensometer clamped on the test piece is necessary to have accurate control over the strain rate.

NOTE 1 This is to eliminate the influence of the compliance of the tensile testing machine.

NOTE 2 For testing machines unable to control by strain rate a procedure using the estimated strain rate over the parallel length ($\dot{e}_{Lc}$) may be used.

