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Metallic Materials – Tensile Testing Part 1: Method of Test at Room Temperature

(ISO 6892-1：2009,MOD)

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Foreword

This standard is drafted in accordance with the rules given in GB/T 1.1-2009.
GB/T 228 *Metallic Materials – Tensile Testing* consists of the following four parts:
— Part 1: Method of Test at Room Temperature;
— Part 2: Method of Test at High Temperature;
— Part 3: Method of Test at Low Temperature;
— Part 4: Method of Test in Liquid Helium.
This part is Part 1 of GB/T 228.
This part is revised from International Standard ISO 6892-1:2009 *Metallic Materials – Tensile Testing - Part 1: Method of Test at Room Temperature* (English edition).
The overall structure, hierarchical division, preparation method and technical information of this part are basically consistent with ISO 6892-1: 2009.
This part revises the International Standard in the following aspects and marks with vertical single line in the margins of clauses related to:
— In normative references, this part directly cites national standard relative to the international standard;
— *Rules for Rounding Off of Numerical Values and Expression and Judgment of Limiting Values* (GB/T 8170), *Metallic materials - Terms of Mechanical Test* (GB/T 10623) and *Evaluation for Computerized Data Acquisition Systems for Used in Static Uniaxial Testing Machines* (GB/T 22066) are added;
— Change the minimum value of three measurements of original crosssection area in Chapter 7 to the average value;
— Add basic rules for determination of the position of upper and lower yield strength in Chapter 12;
— Chapter 22 “Rounding off of the Test Results” is added;
— Annex J Determination of Plastic Extension Strength (R_p) Based on Successive Approximation Method is added;
— Informative Annex K Example for Deternination of Permanent Extension Strength ($R_{r0.2}$) Based on the Stress Relaxation Method is added;
— The detailed description of proportional and non proportional test pieces in Annex B, C, D and E are individually changed;
— The estimation method of measurement uncertainty is changed to form Annex L Estimation of the Uncertainty of Tensile Test Measurement.
The following editorial modification has been done in this part for convenience of usage:
a) “this part of standard” has been changed to “this part”;
b) Using decimal point “.” instead of comma “,”;
c) Deleting the forward of international standard.
This part is in place of GB/T 228—2002 *Metal Materials – Tension Testing at Room Temperature* and this part greatly revises the original standard in the following technical information:
— The name of the standard is revised;
— Normative references;
— Add the method of testing rates control: method A control of stain rate control;
— Rounding off of the test results;
— The estimation method of tensile test measurement uncertainty;
— Informative Annex A Recommendations Concerning the Use of Computer-controlled Ttensile Testing Machines is added;
— Informative Annex F Estimation of the Crosshead Separation Rate in Consideration of the Stiffness (or Compliance) of the Testing Machine is added.
Annex A, Annex F, Annex G, Annex H, Annex I, Annex K, Annex L and Annex M are informative annexes, while Annex B, Annex C, Annex D, Annex E and Annex J are normative annexes.

This part is provided by China Steel & Iron Industries Association.
This part is under the jurisdiction of National Technical Committee on Steel of Standardization Administration of China.
This part is drafted by (units): Iron & Steel Research Institute, Jinan Shijin Testing Machine Group Co., Ltd, China Metallurgical Information and Standardization Institute, Baoshan Iron & Steel Co., Ltd, Meitesi Industry System (China) Co., Ltd, Shougang Corporation, Shanghai Hualong Testing Instruments Co., Ltd, Shanghai Entry-Exit and Quarantine Bureau, Dalian Xiwang Equipment Co., Ltd, Shanghai Research Institute of Materials, and Beijing General Research Institute for Nonferrous Metals.
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This part supersedes the following standard:
— GB/T 228—1963, GB/T 228—1976, GB/T 228—1987, GB/T 228—2002;
—GB/T 3076—1982;
—GB/T 6397—1986.

Introduction

In this part of the standard, 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 minimize the variation of the test rates during the moment when strain rate sensitive parameters are determined and to minimize the measurement uncertainty of the test results. This part will propose the use of control mode of strain rates for tensile testing.

Metallic Materials – Tensile Testing
Part 1: Method of Test at Room Temperature

1 Scope

This part of GB/T 228 specifies the principal, definition, symbols and description, test piece and dimension measurement, test equipment, test requirement, performance determination, rounding off of results of determination and test report for the method of tensile testing of metallic materials.
This part is applicable to the determination of the tensile property of metallic materials at room temperature.
Note: Annex A indicates complementary recommendations for computer controlled testing machines.

2 Normative References

The following documents are essential for the application of this document. For dated references, only the dated edition applies. For undated references, the latest edition (including all the amendments) applies.
GB/T 2975 Steel and Steel Products - Location and Preparation of Test Pieces for Mechanical Testing (GB/T 2975—1998, eqv ISO 377:1997)
GB/T 8170 Rules for Rounding Off of Numerical Values and Expression and Judgment of Limiting Values
GB/T 10623 Metallic materials - Terms of Mechanical Test (GB/T 10623-2008, ISO 23718: 2007, MOD)
GB/T 12160 Calibration of Extensometers Used in Uniaxial Testing (GB/T 12160-2002, ISO 9513: 1999, IDT)
GB/T 16825.1 Verification of Static Uniaxial Testing Machines – Part 1: Tension/compression testing machines - Verification and Calibration of the Force-measuring System (GB/T 16825.1 - 2008, ISO 7500-1: 2004, IDT)
GB/T 17600.1 Steel Conversion of Elongation Values - Part 1: Carbon and Lowalloy Steels (GB/T 17600. 1-1998 ,eqv ISO 2566-1: 1984)
GB/T 17600.2 Steel Conversion of Elongation Values - Part 2: Austenitic Steel (GB/T 17600.2-3998, eqv ISO 2566-2: 1984)
GB/T 22066 Evaluation for Computerized Data Acquisition Systems for Used in Static Uniaxial Testing Machines

3 Terms and Definitions

The GB/T 10623 specified and the following terms and definitions are applicable to this part.

3.1
Gauge length
L
Length [1] of the cylinder or prism portion of the test piece on which elongation is measured.

3.1.1
Original gauge length
L_o
Gauge length [1] on the piece measured at room temperature before the test.

3.1.2
Final gauge length after fracture
L_u
Gauge length [1] on the test piece measured after rupture, at room temperature, the two pieces having been carefully fitted back together so that their axes lie in a straight line.

3.2

Parallel length

L_c

Length [1] of the parallel reduced section of the test piece.

Note: The concept of parallel length is replaced by the concept of distance between grips for unmachined test pieces.

3.3

Elongation

Increase in the original gauge length [1] at any moment during the test.

3.4

Percentage elongation

Elongation expressed as a percentage of the original gauge length, L_o[1].

3.4.1

Percentage permanent elongation

Increase in the original gauge lengthof a test piece after removal of a specified stress, expressed as a percentage of the original gauge length, L_o[1].

3.4.2

Percentage elongation after fracture

A

Permanent elongation of the gauge length after fracture, (L_u - L_o), expressed as a percentage [1] of the original guage length (L_o).

Note: For 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 a subscript indicating the coefficient of proportionality used, e.g. A11,3 indicates a percentage elongation of the gauge length, Lo, of $11.3\sqrt{S_o}$. For non-proportional test pieces (see Annex B), the symbol A should be supplemented by a subscript indicating the original gauge length used, expressed in millimetres, e.g. $A_{80\ mm}$ indicates a percentage elongation of an original gauge length of 80 mm.

3.5

Extensometer gauge length

L_e

Initial extensometer gauge length [1] used for measurement of extension by means of an extensometer.

Note: 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 $L_o/2$ but less than approximately $0{,}9L_C$. This should ensure that the extensometer detects all yielding events that occur in the test piece. Further, for measurement of parameters "at" or "after reaching" maximum force, L_e should be eaqual or approximately equal to L_o, but L_e shall be equal to L_o when the percentage elongation after fracture is determined.

3.6

Extension

Increase [1] in the extensometer gauge length, L_e, at any moment during the test.

3.6.1

Percentage extension

Extension expressed as a percentage of the extensometer gauge length, L_e

3.6.2

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[1].

3.6.3

Percentage yield point extension

A_e

In discontinuous yielding materials, the extension between the start of yielding and the start of uniform workhardening, expressed as a percentage of the extensometer gauge length, L_e[1]. See Figure 7.

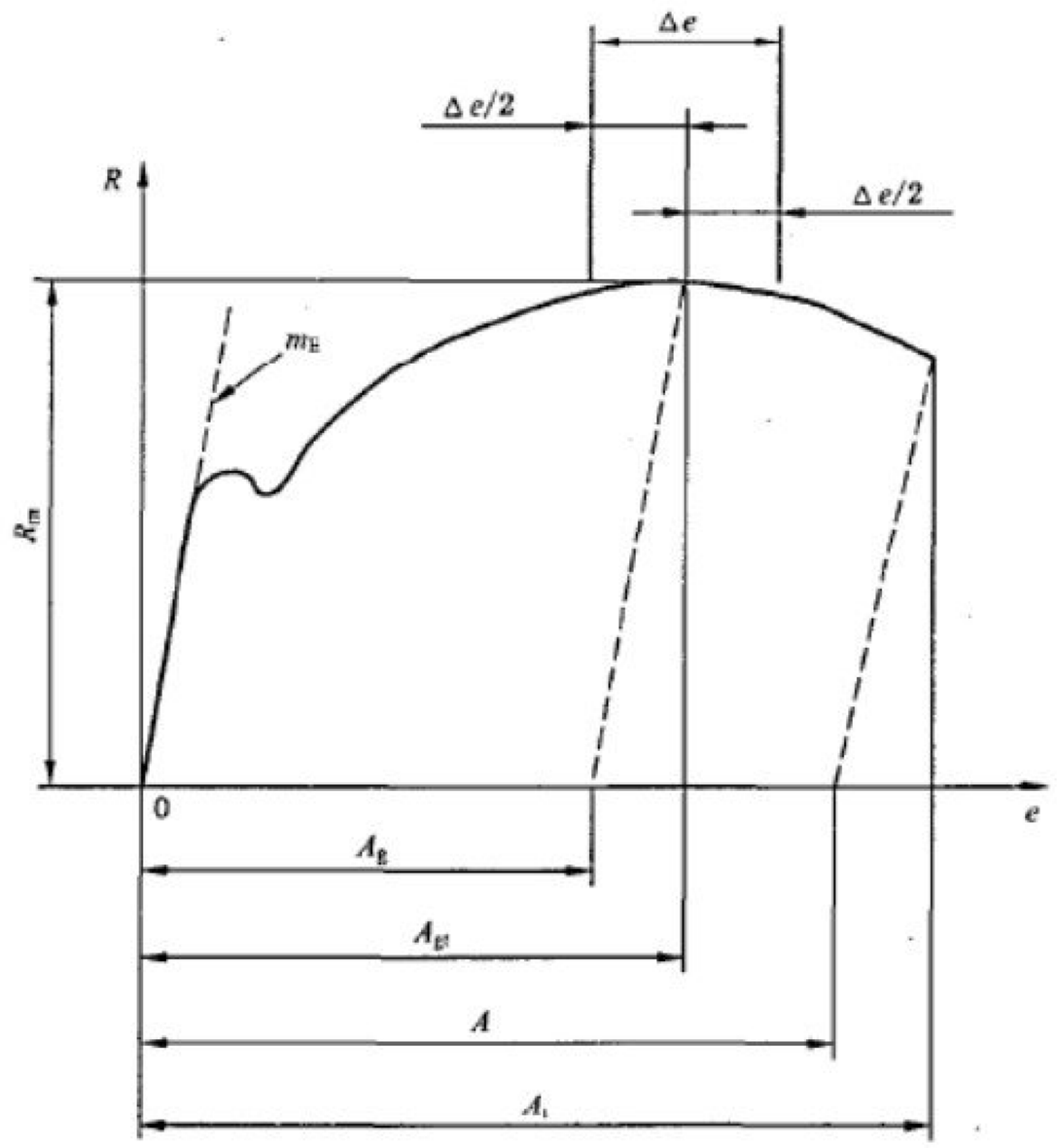
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1) $5.65\sqrt{S_o}=5\sqrt{\frac{4S_o}{\pi}}$

3.6.4
Percentage total extension at maximum force
A_{gt}
Total extension (elastic extension plus plastic extension) at maximum force, expressed as a percentage of the extensometer gauge length, L_e. See Figure 1.

3.6.5
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.

3.6.6
Percentage total extension at fracture
A_t
Total extension (elastic extension plus plastic extension) at fracture, expressed as a percentage of the extensometer gauge length, L_e. See Figure 1.



Notes:
A — percentage elongation after fracture [determined from the extensometer signal or directly from the test piece (see 20.1)];
A_g — Percentage plastic extension at maximum force;
A_{gt} — Percentage total extension at maximum force;
A_t — Percentage total extension at fracture;
E — percentage extension;
m_E — slope of the elastic part of the stress - percentage extension curve;
R — stress;
R_m — tensile strength;
Δ_e — plateau extent (for determination of A_g, see Chapter 17, for determination of A_{gt}, see Chapter 18).

Figure 1 Definitions of Extension

3.7
Testing rate
3.7.1
Strain rate
e_{Le}
Increase of strain, measured with an extensometer, in extensometer gauge length, L_e, per time.
3.7.2
Estimated strain rate over the parallel length
e_{Le}
Value of the increase of strain over the parallel length, L_e, of the test piece per time based on the crosshead separation rate and the parallel length of the test piece.
3.7.3
Crosshead separation rate
V_e
Displacement of the crossheads per time.
3.7.4
Stress rate
R
Increase of stress per time.
Note: Stress rate should only be used in the elastic part of the test (method B).
3.8
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:

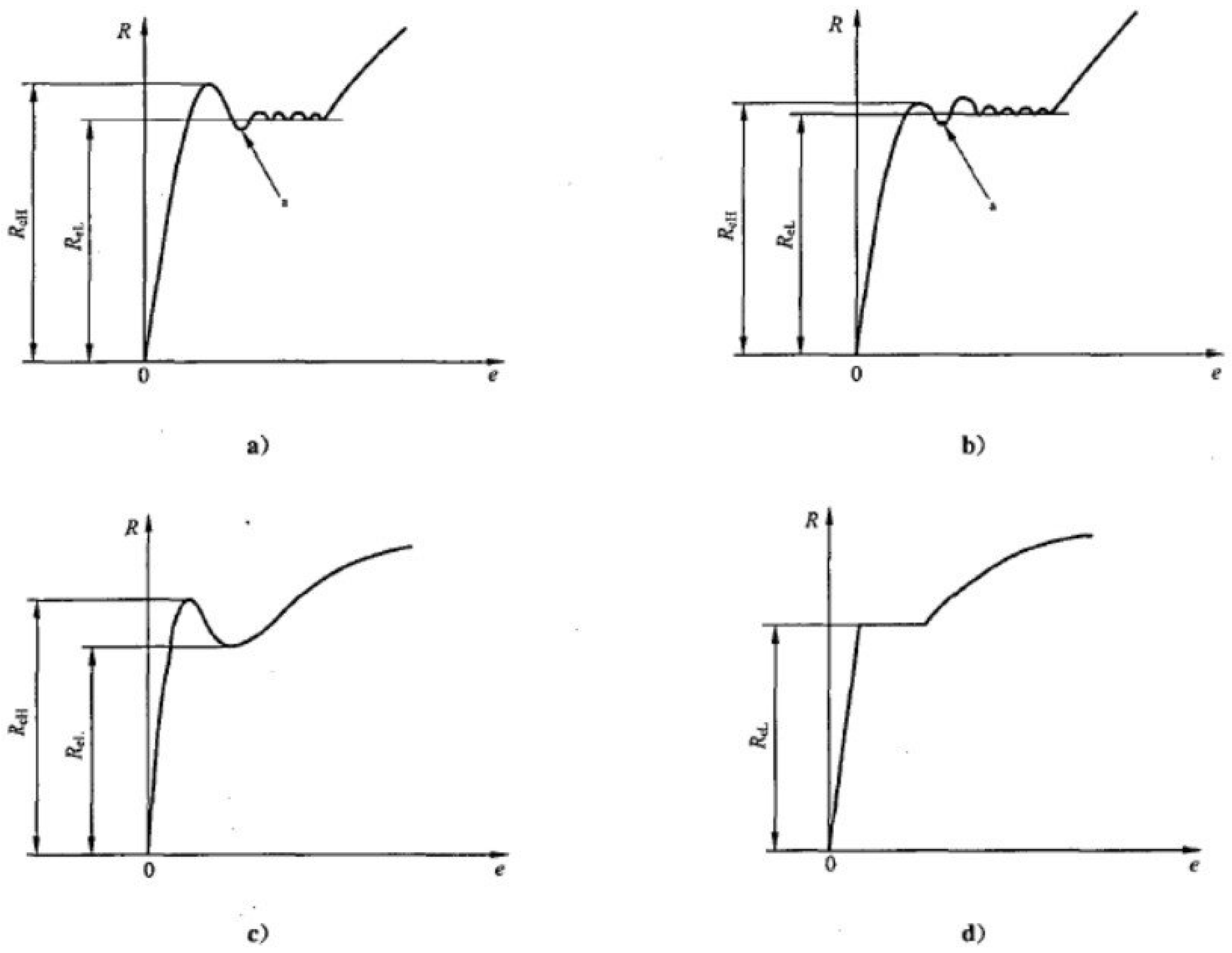
$$Z=\frac{S_o-S_u}{S_o}\times 100$$

3.9
Maximum force
Note: For materials which display discontinuous yielding, but where no workhardening can be established, F_m is not defined in this part. See footnote to Figure 8c).
3.9.1
Maximum force
F_m
(materials displaying no discontinuous yielding) highest force that the test piece withstands during the test.
3.9.2
Maximum force
F_m
(materials displaying discontinuous yielding) highest force that the test piece withstands during the test afterthe beginning of workhardening.
Note: See Figure 8a) and 8b).
3.10
Stress
R
At any moment during the test, force divided by the original cross-sectional area, S_o, of the test piece [1].
Note 1: All references to stress in this part of GB/T 228 are to engineering stress.
Note 2: In what follows, the designations “force” and “stress” or “extension”, “percentage extension” and “strain”, respectively, are used on various occasions (as figure axis labels or in explanations for the determination of different properties). However, for a general description or definition of a well-defined point on a curve, the designations “force” and “stress” or “extension”, “percentage extension” and “strain”, respectively, are interchangeable.

3.10.1
Tensile strength
R_m
Stress corresponding to the maximum force, F_m[1].

3.10.2
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. The upper yield strength and the lower yield strength [1] shall be distinguished.

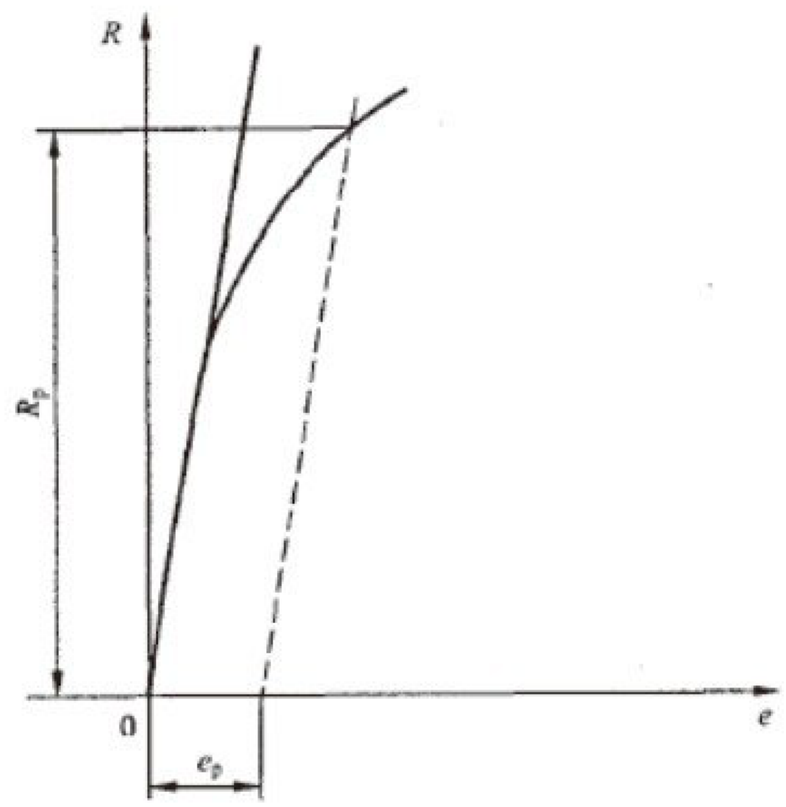
3.10.2.1
Upper yield strength
R_{eH}
Maximum value of stress [1] prior to the first decrease in force. See Figure 2.



Notes:
e — percentage extension;
R — stress;
R_{eH} — upper yield strength;
R_{eL} — lower yield strength;
A — Initial transient effect.

Figure 2 Examples of Upper and Lower Yield Strengths for Different Types of Curve

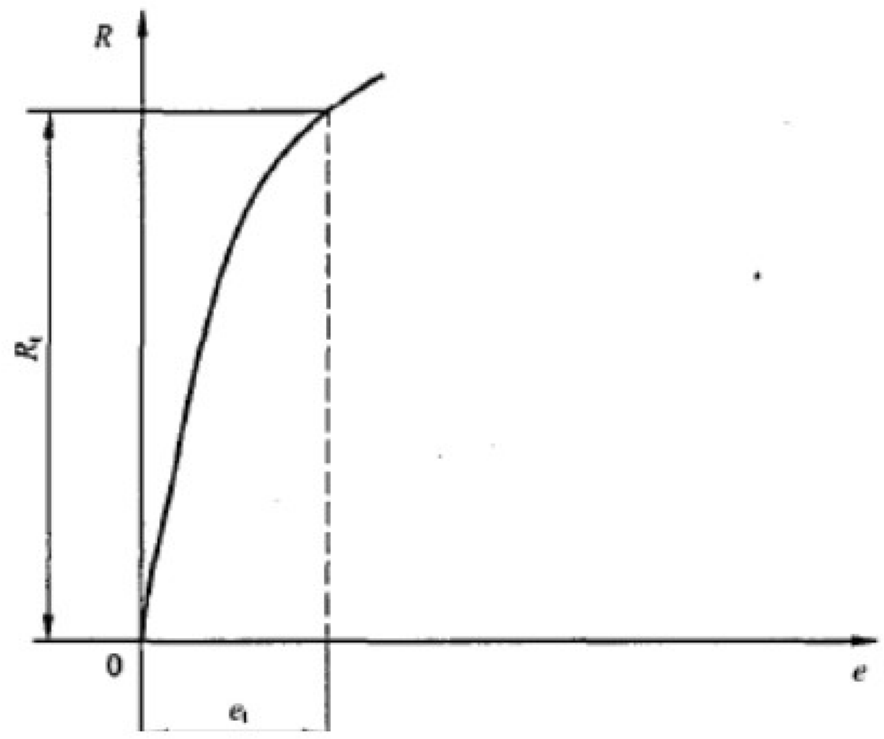
3.10.2.2
Lower yield strength
R_{eL}
Lowest value of stress [1] during plastic yielding, ignoring any initial transient effects. See Figure 2.
3.10.3
Proof strength, plastic extension
R_p
Stress at which the plastic extension is equal to a specified percentage of the extensometer gauge length, L_e[1]. See Figure 3.
Note: A suffix shall be added to the subscript to indicate the specified percentage, e.g. $R_{p0.2}$ indicates the stress when the specified percentage plastic extension is 0.2%.



Notes:
e — percentage extension;
e_p — specified percentage plastic extension;
R — stress;
R_p — proof strength, plastic extension.

Figure 3 Proof Strength, Plastic Extension, R_p (see 13.1)

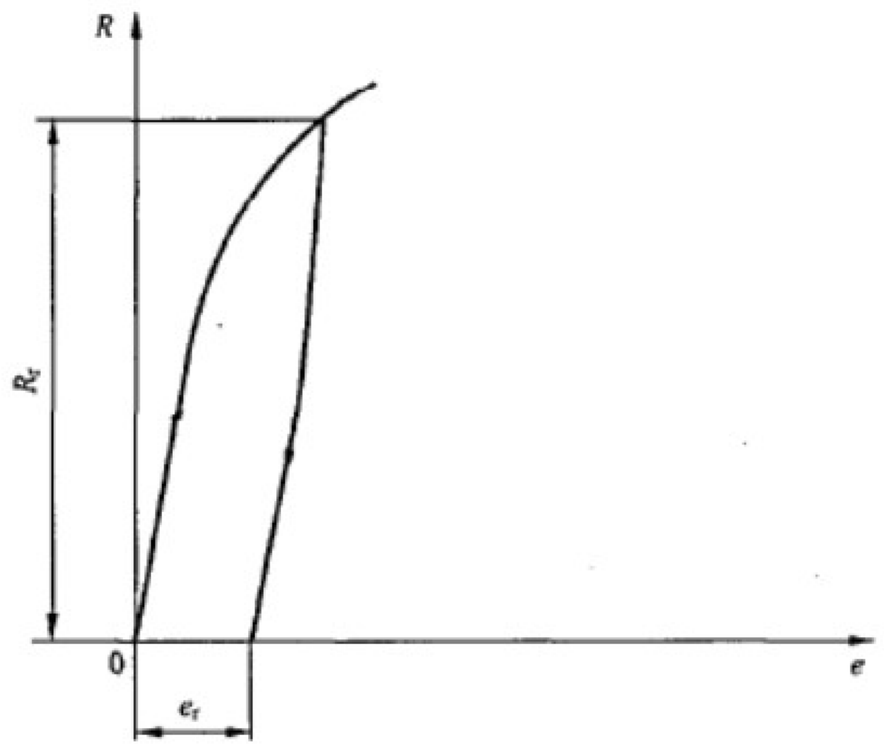
3.10.4
Proof strength, total extension
R_t
Stress at which the total extension is equal to a specified percentage of the extensometer gauge length, L_e[1]. See Figure 4.
Note: A suffix shall be added to the subscript to indicate the specified percentage, e.g. $R_{t0.5}$ indicates the stress when the specified percentage total extension is 0.5%.



Notes:
e — percentage extension;
e_t — specified percentage total extension;
R — stress;
R_t — proof strength, total extension.

Figure 4 Proof Strength, Total Extension R_t

3.10.5
Permanent set strength
R_r
Stress at which, after removal of force, a specified permanent elongation or extension, expressed respectively as a percentage of original gauge length, L_o[1], or extensometer gauge length, L_e, has not been exceeded. See Figure 5.
Note: A suffix shall be added to the subscript to indicate the specified percentage permanent extension. e.g. $R_{r0.2}$ indicates the stress when the specified percentage permanent extension is 0.2%.



Notes
e — percentage extension;
e_t — specified percentage permanent set extension;
R — stress;
R_r — permanent set strength.

Figure 5 Permanent Set Strength R_r

3.11
Fracture
Phenomenon which is deemed to occur when total separation of the test piece occurs.
Note: Criteria for fracture which may be used for computer controlled tests are given in Figure A.2 in Annex A.

4 Symbols and Description

The symbols used in this part of GB/T 228 and corresponding designations are given in Table 1.

Table 1 Symbols and Description

Symbols	Unit	Description
Test Piece		
a_o, T[a]	mm	original thickness of a flat test piece or wall thickness of a tube
b_o	mm	original width of the parallel length of a rectangular cross-section test piece or width of the longitudinal strip taken from a tube or original width of flat wire
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
D_o	mm	original external diameter of a tube
L_o	mm	Original gauge length
L'_o	mm	initial gauge length for determination of A_{wn} (see Annex I)
L_c	mm	parallel length
L_e	mm	extensometer gauge length
L_t	mm	total length of test piece
d_u	mm	minimum diameter of necking after fracture of the test piece with round cross-section
L_u	mm	final gauge length after fracture
L'_u	mm	final gauge length after fracture for determination of A_{wn} (see Annex I)
S_o	mm^2	original cross-sectional area of the parallel length
S_u	mm^2	minimum cross-sectional area after fracture
k	—	coefficient of proportionality (see 6.1.1)
Z	%	percentage reduction of area
Percentage elongation		
A	%	percentage elongation after fracture (see 3.4.2)
A_{wn}	%	percentage plastic elongation without necking (see Annex I)
percentage extension		
A_e	%	percentage yield point extension
A_g	%	percentage plastic extension at maximum force, F_m
A_{gt}	%	percentage total extension at maximum force F_m
A_t	%	percentage total extension at fracture
ΔL_m	mm	extension at maximum force
ΔL_t	mm	extension at fracture

Table 1 (continued)

Symbols	Unit	Description
Rate		
e_{Le}	s^{-1}	Strain rate
e_{Lc}	S^{-1}	Estimated strain rate over the parallel length
V_c	$mm \cdot s^{-1}$	Crosshead separation rate
R	$MPa \cdot s^{-1}$	Stress rate
Force		
F_m	N	Maximum force
Yield strength, proof strength, tensile strength		
E	MPa[b]	modulus of elasticity
m	MPa	slope of the stress-percentage extension curve at a given moment of the test
m_E	MPa	slope of the elastic part of the stress-percentage extension curve [c]
R_{eH}	MPa[b]	Upper yield strength
R_{eL}	MPa	Lower yield strength
R_m	MPa	Tensile strength
R_p	MPa	Proof strength, plastic extension
R_r	MPa	Permanent set strength
R_t	MPa	Proof strength, total extension

[a] Symbol used in steel tube product standards.
[b] 1 MPa = 1 N · mm^{-2},
[c] In the elastic part of the stress-percentage extension curve, the value of the slope may not necessarily represent the modulus of elasticity. This value 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.

5 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 Chapter 3.
The test is carried out at room 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.

6 Test piece

6.1 Shape and dimensions

6.1.1 General requirements

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 uniform cross-section (sections, bars, wires, etc.) and also as-cast test pieces (i.e. for cast iron 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 test pieces which have a $L_o = k\sqrt{S_o}$ relationship between original gauge length and the crosssectional area are 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, k = 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. For 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).

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 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 Unmachined 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 **Unit: mm**

Type of product		Corresponding Annex
Sheets – Plates – Flats  Thickness (a)	Wires – Bars – Sections  Diameter or side	
0.1≤a<3	-	B
-	<4	C
a≥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 products standards or GB/T 2975.

7 Determination of Original Cross-sectional Area

The relevant dimensions of the test piece should be measured at sufficient cross-sections perpendicular to the longitudinal axis in the central region of the parallel length of the test piece.

The original cross-sectional area, S_o, 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

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 as per GB/T 8170, 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_e, 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 GB/T 16825.1, and the accuracy shall be class 1, or better.

The accuracy of extensometer shall be in accordance with the requirement of GB/T 12160. The verification tests of determing upper yield strength, lower yield strength, yield point extension, proof strength at plastic extension, proof strength at total extension, and proof strength at permanent extension shall use the extensometer with accuracy level not less than Level 1; while for determination of other properties with larger percentage of extension, such as tensile strength, percentage total extension at maximum force and percentage plastic extension at maximum force, percentage total extension at fracture and percentage elongation after fracture, extensometer with accuracy level not less than Level 2 shall be used.

The computer-controlled tensile testing machine shall satisfy GB/T 22066 and refer to Annex A.

10 Test Requirements

10.1 Setting the force zero point

The force-measuring system shall be set to zero after the testing loading train has been assembled, but before the test piece is actually gripped at both ends. Once the force zero point has been set, the force- measuring system may not be changed in any way during the test.

Note: The use of this method ensures, that on one hand the weight of the gripping system is compensated for in the force measurement and on the other hand any force resulting from the clamping operation does not affect this measurement.

10.2 Method of gripping

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

Every endeavour should be made to ensure that test pieces are held in such a way that the force is applied as axially as possible, in order to minimize bending (more information is given in ASTM E1012, for example [2]). This is of particular importance when testing brittle materials or when determining proof strength (plastic extension), proof strength (total extension) or yield strength.

In order to obtain a straight test piece and ensure 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.

10.3 Testing rate based on strain rate control (method A)

10.3.1 General

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

Two different types of strain rate control are described in this section. The first is the control of the strain rate itself, e_{Le}, that is based on the feedback obtained from an extensometer. The second is the control of the estimated strain rate over the parallel length, e_{Le}, 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, e_{Le}, and the estimated strain rate over the parallel length, e_{Le}, 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, e_{Le}, (see 3.7.1), shall be applied. In this range, to eliminate the influence of the compliance of the tensile testing machine, the use of an extensometer clamped on the test piece is necessary to have accurate control over the strain rate. (For testing machines unable to control by strain rate, a procedure using the estimated strain rate over the parallel length, e_{Lc}, may aslo be used.)

b) During discontinuous yielding, the estimated strain rate over the parallel length, e_{Lc}, (see 3.7.2), should be applied. In this case, it is impossible to control the strain rate using the extensometer clamped on to the test piece because local yielding can occur outside the extensometer gauge length. The calculated strain rate over the parallel length range may be maintained sufficiently accurately using a constant crosshead separation rate, V_c, and in accordance with Equation (1).

$$v_c = L_c \times \dot{e}_{L_e} \qquad \cdots\cdots(1)$$

Wherein:

e_{Lc} — estimated strain rate over the parallel length;

L_c — parallel length.

C) In the range following R_P, R_t or end of yielding, e_{Le} or e_{Lc} can be used. The use of e_{Lc} is recommended to avoid any control problems which may arise if necking occurs outside the extensometer gauge length.

The strain rates specified in 10.3.2 to 10.3.4 shall be maintained during the determination of the relevant material property (see Figure 9).

During switching to another strain rate or to another control mode, no discontinuities in the stress-strain curve should be introduced which distort the values of R_m, A_g or A_{gt} (see Figure 10). This effect can be reduced by a suitable gradual switch between the rates.

The shape of the stress-strain curve in the workhardening range can also be influenced by the strain rate. The testing rate used should be documented (see 10.6).

10.3.2 Determination of the upper yield strength, R_{eH}, or proof extension strength R_P, R_t or R_r

The strain rate e_{Le} shall be kept as constant as possible up to and including the determination of R_{eH}, R_P, R_t and R_r. During the determination of these material properties the strain rate shall be in one of the two following specified ranges (see also Figure 9):

— Range 1: e_{Le} =0.00007s^{-1}, with a relative tolerance of ±20 %;

— Range 2: e_{Le} =0.00025s^{-1}, with a relative tolerance of ±20% (recommended unless otherwise specified).

If the testing machine is not able to control the strain rate directly, the estimated strain rate over the parallel length, e_{Lc}, i.e. constant crosshead separation rate, shall be used. This rate shall be calculated using Equation (1) in 10.3.1. If the compliance of the testing machine is considered, an explanation is given in Annex F.

10.3.3 Strain rate for the determination of the lower yield strength R_{eH} and percentage yield point extension A_e

Following the detection of the upper yield strength, the estimated strain rate over the parallel length, e_{Lc}, shall be maintained in one of the following two specified ranges (see Figure 9) until discontinuous yielding has ended:

— Range 2: e_{Lc} =0.00025s^{-1}, with a relative tolerance of ±20 % (recommended when determined);
— Range 3: e_{Lc} ==0.002s^{-1}, with a relative tolerance of ±20 %.

10.3.4 Strain rate for the determination of the tensile strength, R_m, percentage elongation after fracture, A, percentage total extension at the maximum force, A_{gt}, percentage plastic extension at maximum force, A_g, and percentage reduction area, Z

After determination of the required yield/proof strength properties, the estimated strain rate over the parallel length, e_{Lc}, shall be changed to one of the following specified ranges (see Figure 9):
— Range 2: e_{Lc} =0.00025s^{-1}, with a relative tolerance of ±20 %;
— Range 3: e_{Lc} =0.002s^{-1}, with a relative tolerance of ±20 %;
— Range 4: e_{Lc} =0.0067s^{-1}, with a relative tolerance of ±20% (0.4 min^{-1}, with a relative tolerance of ±20%; recommended unless otherwise specified).
If the purpose of the tensile test is only to determine the tensile strength, then an estimated strain rate over the parallel length of the test piece according to range 3 or 4 may be applied throughout the entire test.

10.4 Testing rate based on stress rate control (method B)

10.4.1 General

The testing rates shall conform to the following requirements depending on the nature of the material. Unless otherwise specified, any convenient speed of testing may be used up to a stress equivalent to half of the specified yield strength. The testing rates above this point are specified below.

10.4.2 Testing rate for the determination of yield and proof strengths

10.4.2.1 Upper yield strength R_{eH}

The rate of separation of the crossheads of the machine shall be kept as constant as possible and within the limits corresponding to the stress rates in Table 3.
Note: For information, typical materials having a modulus of elasticity smaller than 150,000 MPa include magnesium, aluminium alloys, brass, and titanium. Typical materials with a modulus of elasticity greater than 150,000 MPa include wrought iron, steel, tungsten, and nickel-based alloys.

Table 3 Stress Rate

Modulus of elasticity of the material E/MPa	Stress rate R/(MPa • s^{-1})	
	Min.	Max.
<150000	2	20
≥150000	6	60

10.4.2.2 Lower yield strength R_{eL}

If only the lower yield strength is being determined, the strain rate during yield of the parallel length of the test piece shall be between 0.00025 s^{-1} and 0.0025 s^{-1}. The strain 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 stress rate just before yield begins, the controls of the machine not being further adjusted until completion of yield.
In no case shall the stress rate in the elastic range exceed the maximum rates given in Table 3.

10.4.2.3 Upper and lower yield strengths, R_{eH} and R_{eL}

If both upper and lower yield strengths are determined during the same test, the conditions for determining the lower yield strength shall be complied with (see 10.4.2.2).

10.4.2.4 Proof strength (plastic extension), proof strength (total extension) and proof strength (permanent extension), R_P, Rt and R_r

The rate of separation of the crossheads of the machine shall be kept as constant as possible and within the limits corresponding to the stress rates in Table 3 within the elastic range.
Within the plastic range and up to the proof strength (plastic extension or total extension), the strain rate shall not exceed $0.0025s^{-1}$.

10.4.2.5 Crosshead separation rate

If the testing machine is not capable of measuring or controlling the strain rate, a crosshead separation rate equivalent to the stress rate given in Table 3 shall be used until completion of yield.

10.4.2.6 Determination of the tensile strength, R_m, percentage elongation after fracture, A, percentage total extension at the maximum force, A_{gt}, percentage plastic extension at maximum force, A_g, and percentage reduction area, Z

After determination of the required yield/proof strength properties, the test rate may be increased to a strain rate (or equivalent crosshead separation rate) no greater than $0.008s^{-1}$.
If only the tensile strength of the material is to be measured, a single strain rate can be used throughout the test which shall not exceed $0.008s^{-1}$.

10.5 Choice of the method and rates

Unless otherwise agreed, the choice of method (A or B) and test rates are at the discretion of the producer or the test laboratory assigned by the producer, provided that these meet the requirements of this part of GB/T 228.

10.6 Documentation of the chosen testing conditions

In order to report the test control mode and testing rates in an abridged form, the following system of abbreviations can be used:
GB/T 228Annn or GB/T 228Bn
where “A” defines the use of method A (strain rate control), and “B” the use of method B (stress rate based). The symbols “nnn” are a series of up to three characters that refer to the rates used during each phase of the test, as defined in Figure 9, and “n” may be added to indicate the stress rate selected during elastic loading.
EXAMPLE 1: GB/T 228A224 defines a test based on strain rate control, using ranges 2, 2 and 4.
EXAMPLE 2: GB/T 228B30 defines a test based on stress rate, performed at a nominal stress rate of 30 $MPa \cdot s^{-1}$.
EXAMPLE 3: GB/T 228B defines a test based on stress rate, performed at a nominal stress rate according to Table 3.

11 Determination of the Upper Yield Strength

The upper yield strength R_{eH} may be determined from the force-extension curve or peak load indicator and is defined as the maximum value of stress prior to the first decrease in force (see Figure 2).

12 Determination of the Lower Yield Strength

The lower yield strength R_{eL} is determined from the force-extension curve and is defined as the lowest value of stress during plastic yielding, ignoring any initial transient effects (see Figure 2).
The basic rules for determing the positions of upper and lower strength are as follows:

a) The 1st peak stain before yield (the 1st maximum stain) is determined as upper yield strength, no matter whether the following strain is larger or not;
b) If there are two or more valley stains in during the yield, the 1st one (the 1st minimum stain) shall be rounded down, and the smallest one of the valley stains shall be determined as the lower yield strength. If there is only 1 valley stain, this shall be taken as the lower yield strength;
c) If the yield point elongation exists during the yield, the elongation strain shall be determined as the lower yield strength; if there are more than one yield point elongations among which the yield point elongation of the later is higher than that of the former, the 1st elongation strain shall be taken as the lower yield strength;
d) The correct result of determination shall be that the lower yield strength must be lower than the upper yield strength.

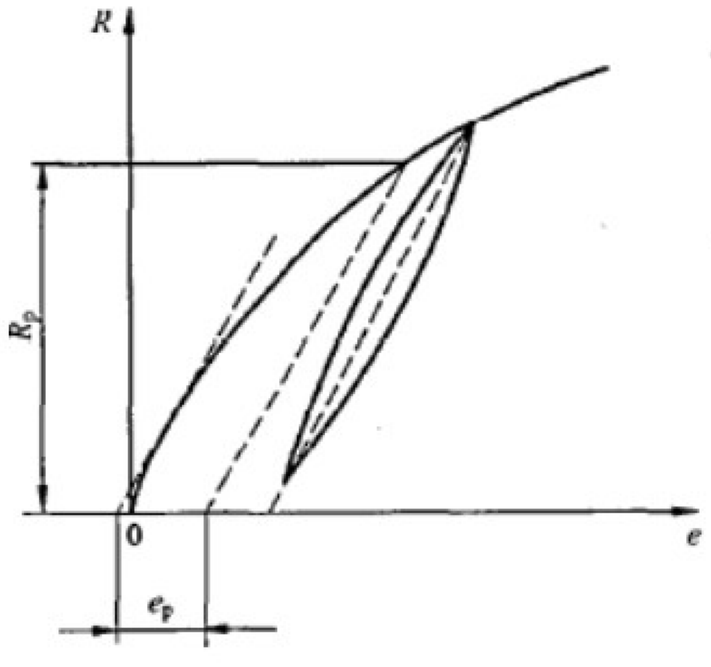
For productivity of testing, the lower yield strength may be reported as the lowest stress within the first 0.25% strain after the upper yield strength, not taking into account any initial transient effect. After determining the lower yield strength by this procedure, the test rate may be increased as per 10.3.4. Use of this shorter procedure should be recorded on the test report.

Note: This clause only applies to materials having yield phenomena and when percentage yield point extension is not to be determined.

13 Determination of Proof Strength, Plastic Extension

13.1 The proof strength, plastic extension, R_P, is determined from the force-extension curve by drawing a line parallel to the linear portion of the curve and at a distance from it equivalent to the prescribed plastic percentage extension, e.g. 0.2%. The point at which this line intersects the curve gives the force corresponding to the desired proof strength plastic extension. The latter is obtained by dividing this force by the original cross-sectional area of the test piece, S_o, (see Figure 3).

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



Notes:
E — percentage extension;
e_p — specified percentage plastic extension;
R — stress;
R_p — proof strength, plastic extension.

Figure 6 Proof Strength, Plastic Extension, R_p (see 13.1)

During test, 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 plastic percentage extension. 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 (see Figure 6).

Note 1: Several methods can be used to define the corrected origin of the force-extension curve. One of these is to construct a line parallel to that determined by the hysteresis loop so that it is tangential to the force-extension curve. The point where this line crosses the abscissa is the corrected origin of the force-extension curve (see Figure 6).

Note 2: The plastic strain at the starting point of force reduction is only slightly higher than the specified plastic extension of R_P. Starting points at much higher strain values reduce the slope of the line through the hysteresis loop.

Note 3: If not specified in product standards or agreed by the customer, it is inappropriate to determine proof strength during and after discontinuous yielding.

13.2 The property may be obtained without plotting the force-extension curve by using automatic devices (microprocessor, etc.) or automatic measuring system, see Annex A.

13.3 The successive approximation method provided in Annex J can be used to determine the proof strength, plastic extension.

14 Determination of Proof Strength, Total Extension

14.1 The proof strength, total extension R_t is determined on the force-extension curve, 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 curve by using automatic devices (microprocessor, etc.) or automatic measuring system, see Annex A.

15 Verification and Determination of Permanent Set Strength

The test piece is subjected to a force corresponding to the specified stress for 10 s to 12 s. After removing the force, it is then confirmed that the permanent set extension or elongation is not more than the percentage specified for the original gauge length, see Figure 5.

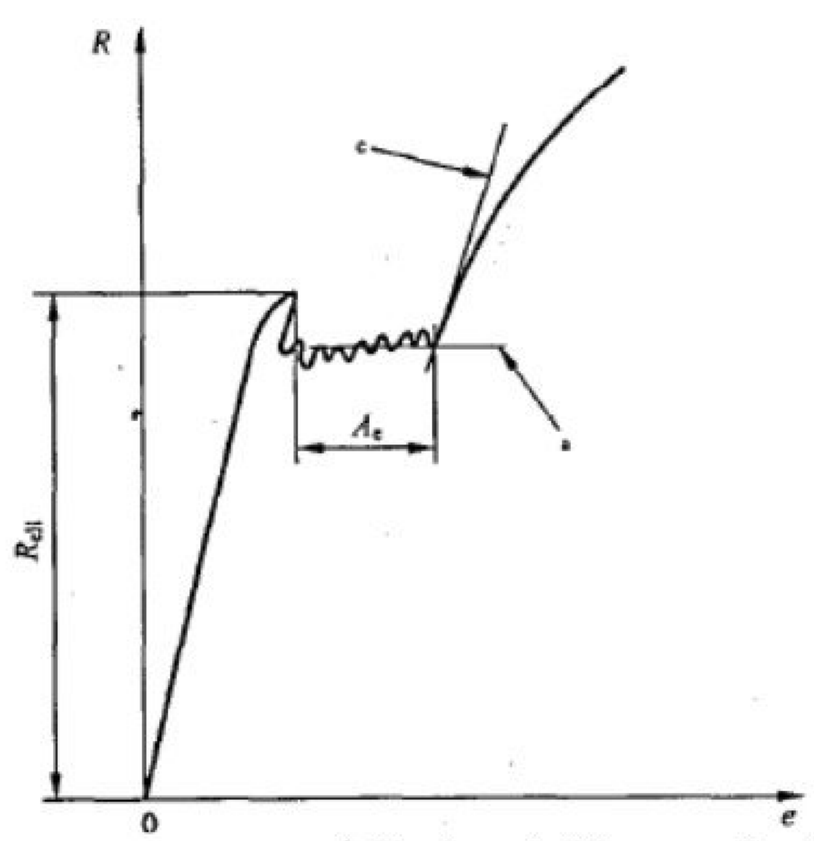
Note: This is a pass/fail test, which is not normally performed as a part of the standard tensile test. The stress applied to the test piece and the permissible permanent set extension or elongation is specified either by the product specification or the requester of the test. Example: Reporting "$R_{r0.5}$=750 MPa Pass" indicates that a stress of 750 MPa was applied to the test piece and the resulting permanent set was less than or equal to 0.5%.

For example, determination shall be carried out to obtain specified permanent extension strength. Examples are given in Annex J.

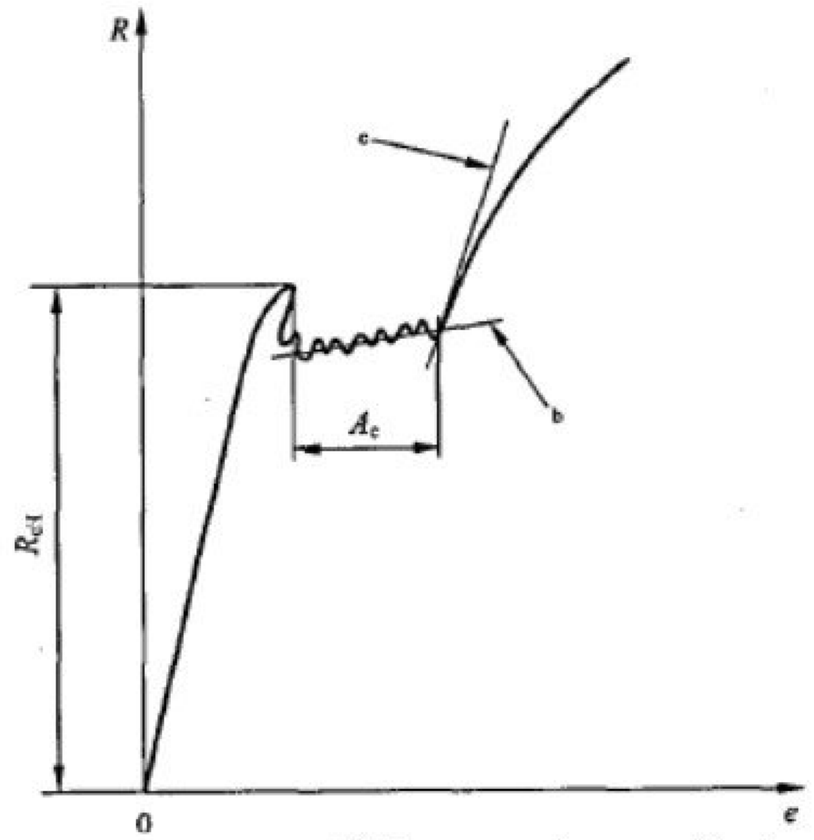
16 Determination of the Percentage Yield Point Extension

For materials that exhibit discontinuous yielding, A_e is determined from the force-extension curve by subtracting the extension at R_{eH} from the extension at the start of uniform workhardening. The extension at the start of uniform workhardening is defined by the intersection of a horizontal line through the last local minimum point, or a regression line through the range of yielding, prior to uniform workhardening and a line corresponding to the highest slope of the curve occurring at the start of uniform workhardening. It is expressed as a percentage of the extensometer gauge length, L_e (see Figure 7).

The method used [see Figure 7a) or 7b)] should be documented in the test report.



a) Horizontal line method



b) Regression method

Notes:

A_e — percentage yield point extension;

e — percentage extension;

R — stress;

R_{eH} — upper yield strength;

• Horizontal line through the last local minimum point, prior to uniform workhardening.

• Regression line through the range of yielding, prior to uniform workhardening.

• Line corresponding to the highest slope of the curve occurring at the start of uniform workhardening.

Figure 7 Different Evaluation Methods for Percentage Yield Point Extension, A_e

17 Determination of the Percentage Plastic Extension at Maximum Force

The plastic extension at maximum force is obtained by deducting the plastic extension from the total extension at maximum force in the force-extension curve drawn with extensometer, and then the percentage plastic extension at maximum force is obtained from the division of it by the extensometer gauge length.

Calculate the percentage plastic extension at maximum force, A_g, from Equation (2):

$$A_g = \left(\frac{\Delta L_m}{L_e} - \frac{R_m}{m_E}\right) \times 100 \qquad \cdots\cdots(2)$$

Wherein:

L_e — the extensometer gauge length;

m_E — slope of the elastic part of the stress - percentage extension curve;

R_m — tensile strength;

ΔL_m — the extension at maximum force.

Note: For materials which exhibit a plateau at maximum force, the percentage plastic extension at maximum force is the extension at the mid-point of the plateau, see Figure 1.

The percentage plastic extension at maximum force of some materials is not equal to the percentage plastic extension without necking. For bars, wires, rods and other long products, the method in Annex I can be used to determine the percentage plastic extension without necking A_{wn}.

18 Determination of the Percentage Total Extension at Maximum Force

The method consists of determining the extension at maximum force on the force-extension curve obtained with an extensometer. Calculate the percentage total extension at maximum force from Equation (3):

$$A_{gt} = \frac{\Delta L_m}{L_e} \times 100 \qquad \cdots\cdots(3)$$

Wherein:

L_e — the extensometer gauge length;

ΔL_m — the extension at maximum force.

Note: For materials which exhibit a plateau at maximum force, the percentage total extension at maximum force is the extension at the mid-point of the plateau, see Figure 1.

19 Determination of the Ppercentage Total Extension at Fracture

The method consists of determining the extension at fracture on the force-extension curve obtained with an extensometer. Calculate the percentage total elongation at fracture, A_t, from Equation (4):

$$A_t = \frac{\Delta L_f}{L_e} \times 100 \qquad \cdots\cdots(4)$$

Wherein:

L_c — the extensometer gauge length;

A_t — the extension at fracture.

20 Determination of Percentage Elongation after Fracture

20.1 Percentage elongation after fracture shall be determined in accordance with the definition given in 3.4.2.

For this purpose, the two broken pieces of the test piece shall be 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 for test pieces of small cross-section and test pieces having low elongation values.

Calculate the percentage elongation after fracture, A, from Equation (5):

$$A = \frac{L_u - L_o}{L_o} \times 100 \qquad \cdots\cdots(5)$$

Wherein:

L_o — the original gauge length;

L_u — the final gauge length after fracture.

Elongation after fracture, L_U-L_o, shall be determined to the nearest ±0.25 mm or better using a measuring device with sufficient resolution.

If the specified minimum percentage elongation is less than 5 %, it is recommended that special precautions be taken (see Annex G). In principle, the result of this determination is valid only if the distance between the fracture and the nearest gauge mark is not less than one third of the original guage length. However, the measurement is valid, irrespective of the position of the fracture. If the distance between the fracture and the nearest gauge mark is smaller than one third of the original guage length, the displacement method specified in Annex H can be used to determine the percentage of elongation after fracture.

20.2 When extension at fracture is measured 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. To obtain comparable values with the manual method, additional adjustments can be applied (e.g. high enough dynamic and frequency bandwidth of the extensometer, see A.3.2).

In principle, the result of this determination is valid only 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.

If the product standard specifies the determination of percentage elongation after fracture for a given gauge length, the extensometer gauge length should be equal to this length.

20.3 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 (e.g. as in GB/T 17600.1 and GB/T 17600.2).

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.

21 Determination of Percentage Reduction of Area

Percentage reduction of area shall be determined in accordance with the definition given in 3.8.

The two broken pieces of the test piece shall be carefully fitted back together so that their axes lie in a straight line. The determination of the minimum cross-sectional area after fracture shall be marked to an accuracy of ±2% (see Figure 13). The difference between the original crosssection area and the minimum crosssection area divide by the percentage of the original crosssection to obtain the percentage reduction of area, which can be calculated as per Equation (6).

$$Z = \frac{S_o - S_u}{S_o} \times 100 \qquad \cdots\cdots(6)$$

Wherein:

S_o — the original cross-sectional area of the parallel length;

S_u — minimum cross-sectional area after fracture.

Note: Measuring the cross-sectional area after fracture with an accuracy of ±2% on small diameter round test pieces, or test pieces with other crosssectional geometries, may not be possible.

22 Rounding off of the Test Results

The results of properties determined by tests shall be rounded off in accordance with the requirements of relevant product standard. The rounding off shall be performed according to the following requirements unless otherwise specified:

— the value of strength property shall be rounded off to 1 MPa;

— the percentage yield point extension shall be rounded off to 0.1%, while other percentage extension and percentage elongation after fracture shall be rounded off to 0.5%;

— the ercentage reduction of area shall be rounded off to 1%.

23 Test Report

The test report shall contain at least the following information unless otherwise agreed by the parties concerned:

a) the number of this part of national standard;

b) specifying the test condition information (as required in 10.6);

c) identification of the test piece;

d) specified material and trademark, if known;

e) Type of test piece;

f) location and direction of sampling of test pieces, if known;

g) testing control mode(s) and testing rate(s) or testing rate range(s) (see 10.6) if different from the recommended methods and values given in 10.3 and 10.4;

h) testing results.

24 Measurement Uncertainty

24.1 General

Measurement uncertainty analysis is useful for identifying major sources of inconsistencies of measured results.

Product standards and material property databases based on this part of GB/T 228 and earlier editions of GB/T 228 have an inherent contribution from measurement uncertainty. It is therefore inappropriate to apply further adjustments for measurement uncertainty and thereby risk failing product which is compliant. For this reason, the estimates of uncertainty derived by following this procedure are for information only, unless specifically instructed otherwise by the customer.

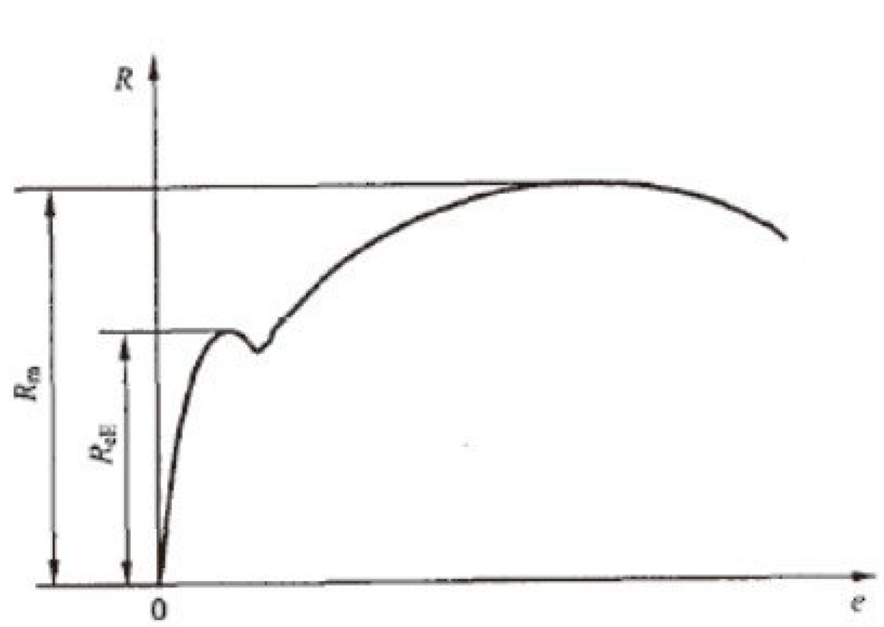
24.2 Test Conditions

The test conditions and limits defined in this part of GB/T 228 shall not be adjusted to take account of uncertainties of measurement, unless specifically instructed otherwise by the customer.

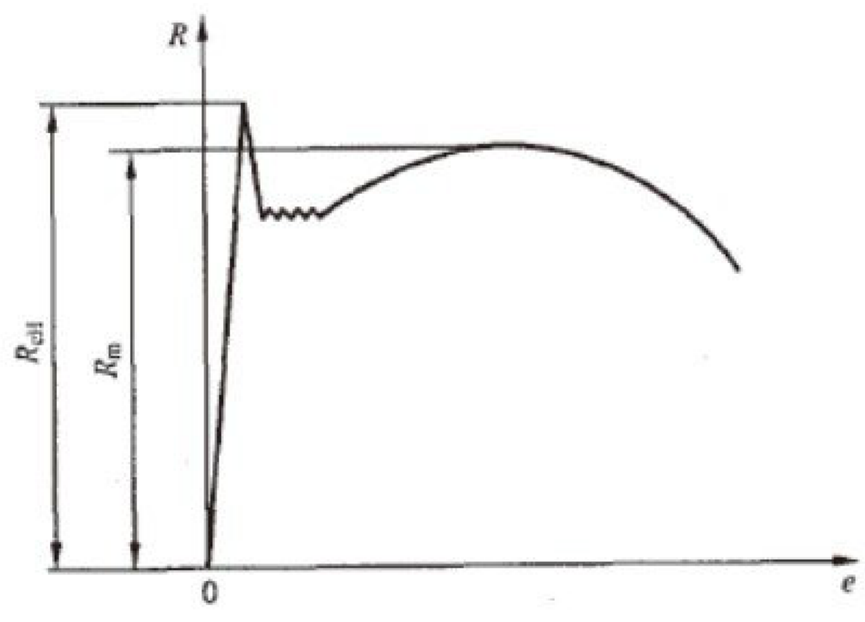
24.3 Testing results

The estimated measurement uncertainties shall not be combined with measured results to assess compliance to product specifications, unless specifically instructed otherwise by the customer.

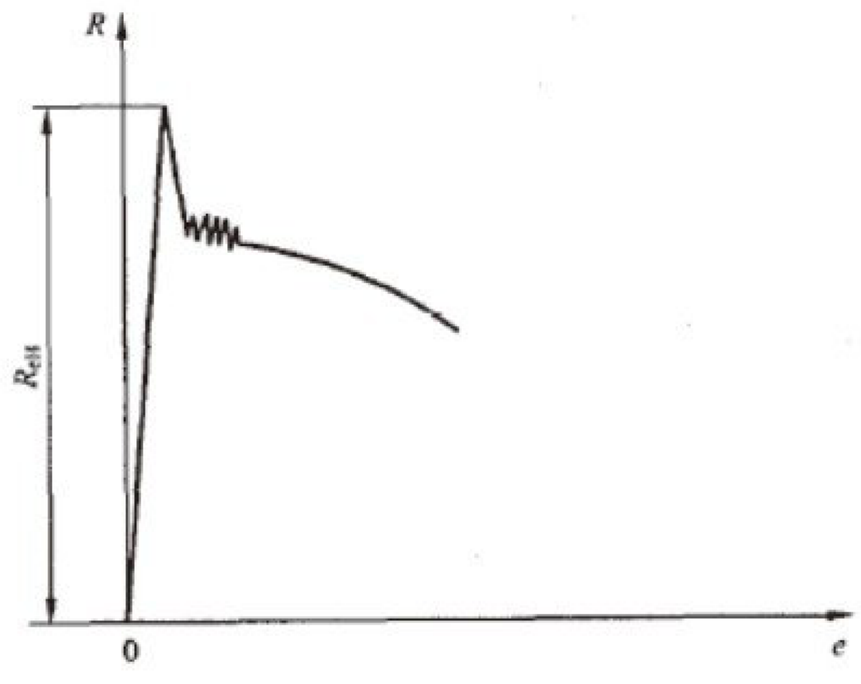
For consideration of uncertainty, see Annex L which provide the criteria of evaluation on tensile test results and Annex M which provide guidance for the determination of uncertainty related to metrological parameters and values obtained from the interlaboratory tests on a group of steels and aluminium alloys. See Bibliography [3] for the evaluation on uncertainty using tensile samples.



a) $R_{eH} < R_m$



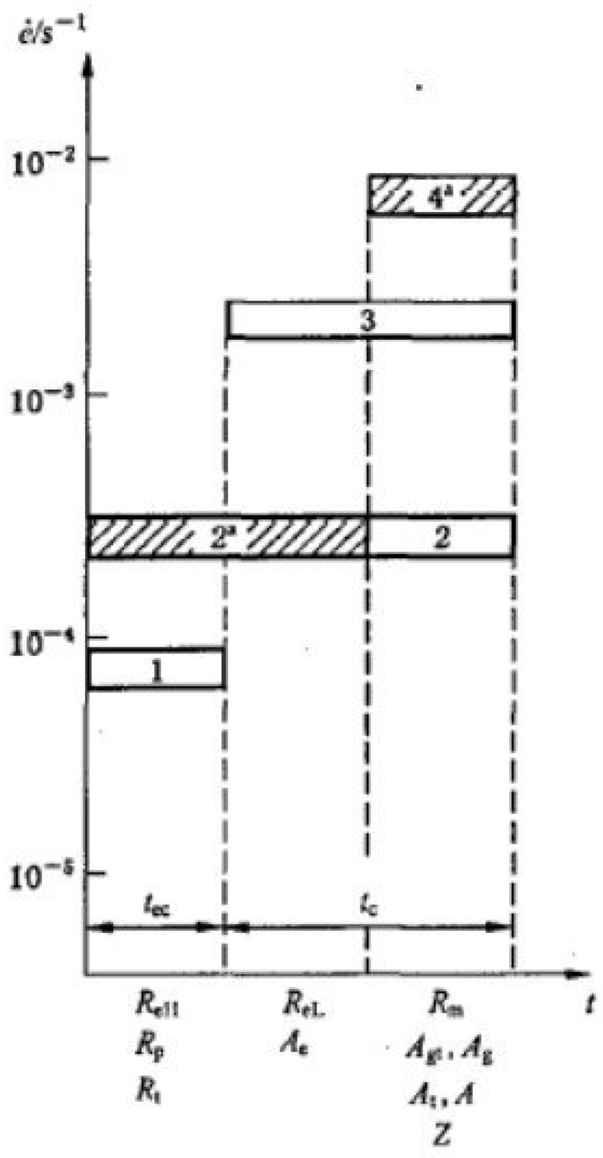
b) $R_{eH} > R_m$



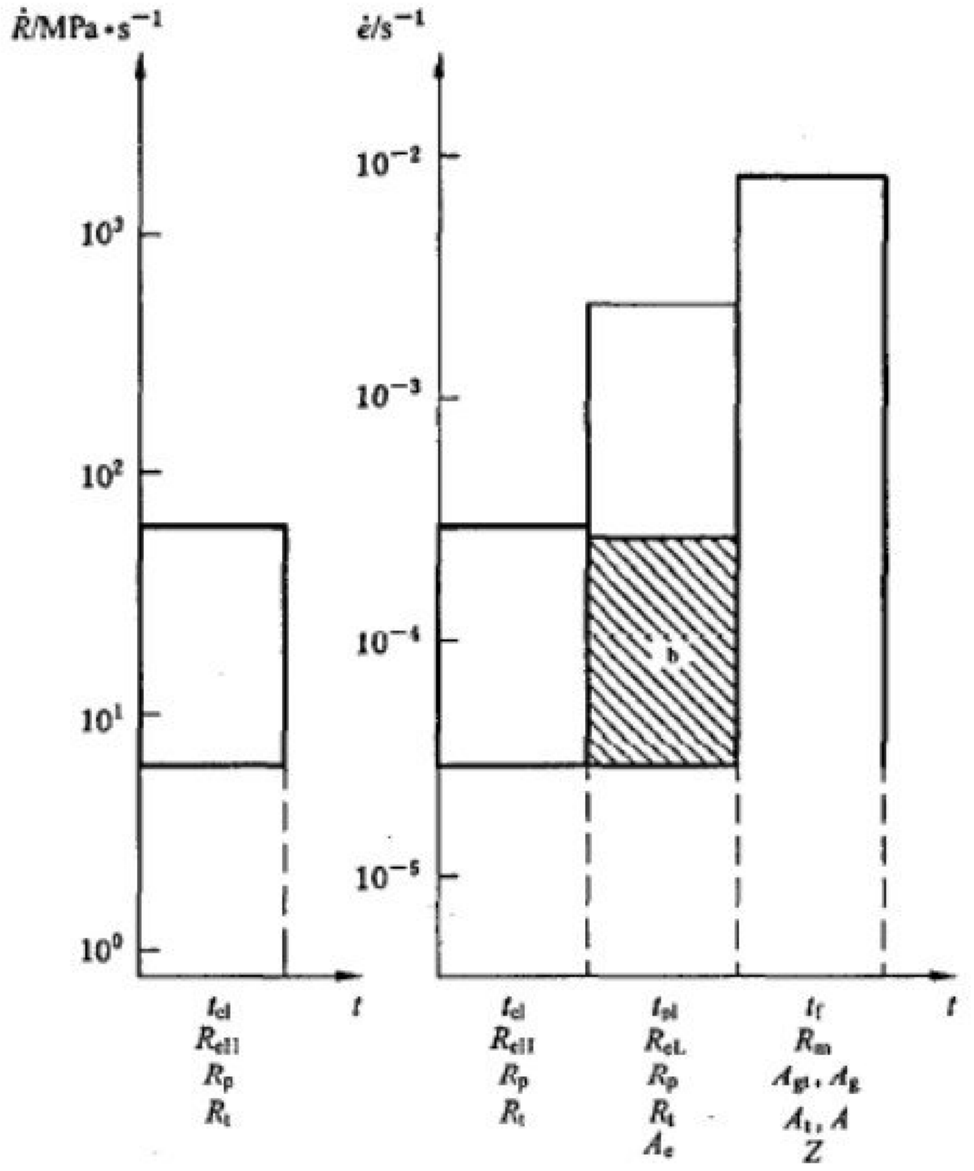
c) Special case of stress-percentage extension behaviour [a]

Notes:
e — percentage extension;
R — stress;
R_{eH} — upper yield strength;
R_m — tensile strength.
[a] For materials which display the case of percentage stress –extension in Figure 8c), no tensile strength is defined according to this standard. If necessary, separate agreements can be made between the parties concerned.

Figure 8 Different Types of Stress-extension Curve for Determination of Tensile Strength R_m



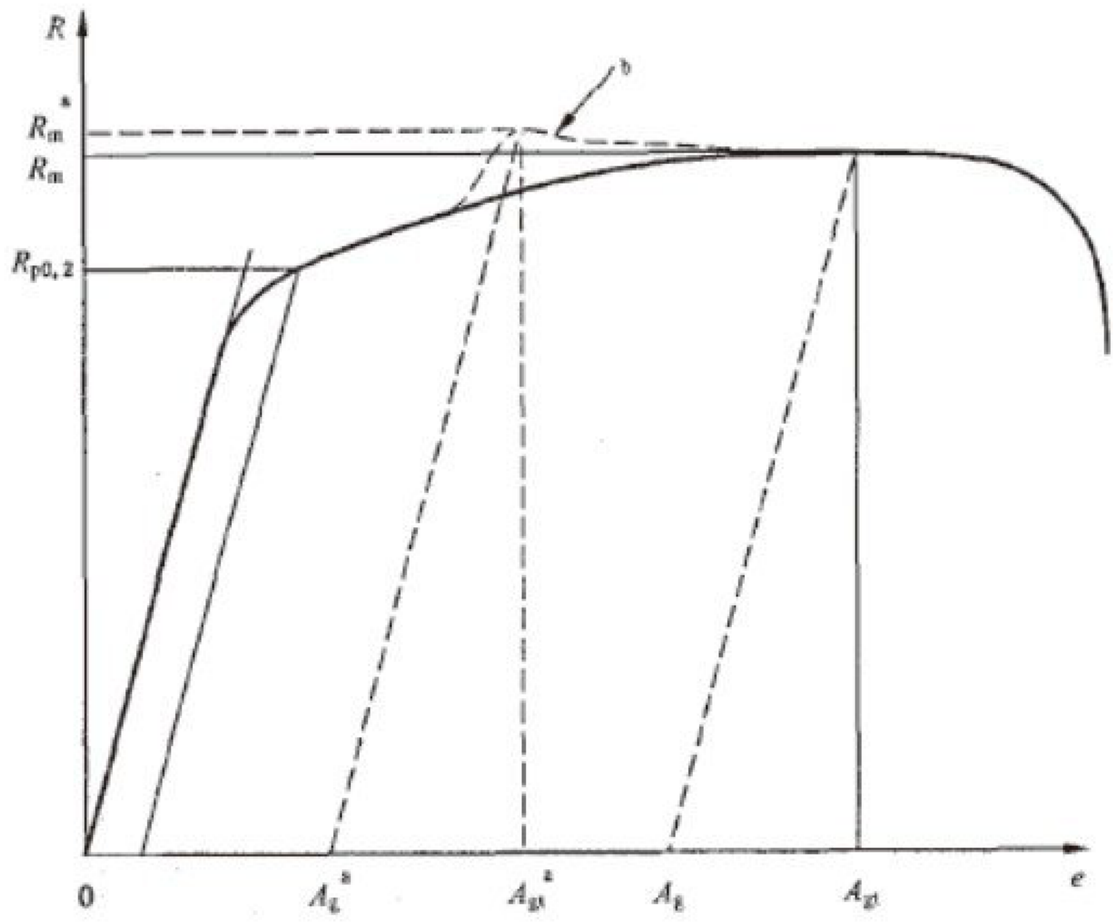
a) Method A



b) Method B

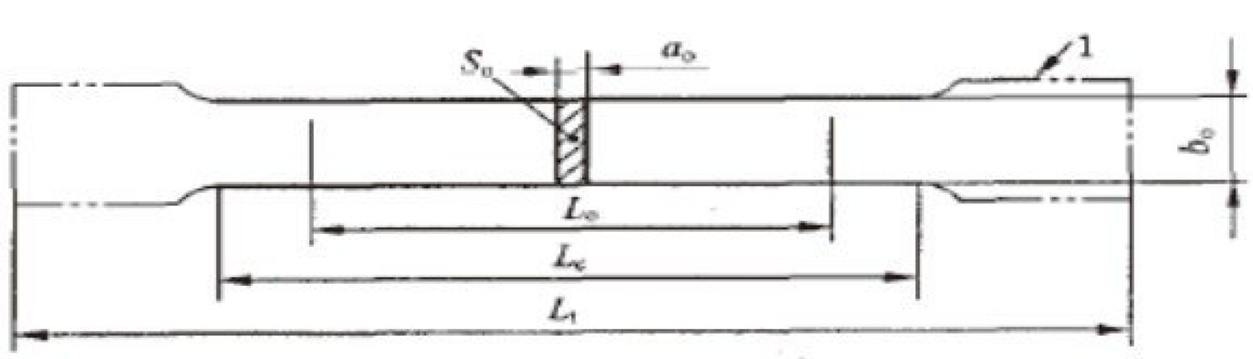
Notes:
e — strain rate;
e — stress rate;
t — time progress of the tensile test;
t_c — crosshead control time;
t_{ec}— extensometer control time or crosshead control time;
t_{el}— time range (elastic behaviour) for determination of the parameters listed (see Table 1 for designations);
t_f— time range (usually up to fracture) for determination of the parameters listed (see Table 1 for designations);
t_{pl}— time range (plastic behaviour) for determination of the parameters listed (see Table 1 for designations);
1 — Range 1: e =0.00007s^{-1}, with a relative tolerance of ±20 %;
2 — Range 2: e =0.00025 s^{-1}, with a relative tolerance of ±20 %;
3 — Range 3: e = 0.002 5 s^{-1}, with a relative tolerance of ±20 %;
4 —Range 4: e = 0.0067 s^{-1}, with a relative tolerance of ±20% (0.4 mit^{-1}, with a relative tolerance of ±20%);
5 — extensometer control or crosshead control;
6 — crosshead control.
[a] Recommended.
[b] Expanded range to lower rates, if testing machine is not capable of measuring or controlling the strain rate (see 10.4.2.5).

Figure 9 Range of strain rates to be used during the tensile test if R_{eH}, R_{eL}, A_e, R_p, R_t, R_m, A_g, A_{gt}, A, A_t and Z are determined

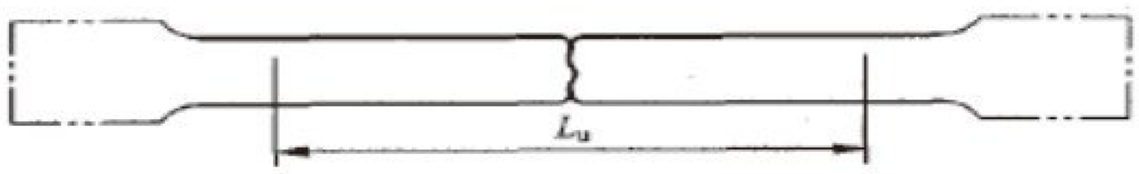


Notes:
e — percentage extension;
R — stress.
[a] False values, resulting from an abrupt strain rate increase.
[b] Stress-strain behaviour, if strain rate is abruptly increased.
Note: For parameter definitions, see Table 1.

Figure 10 Illustration of an inadmissible discontinuity in the stress-strain curve



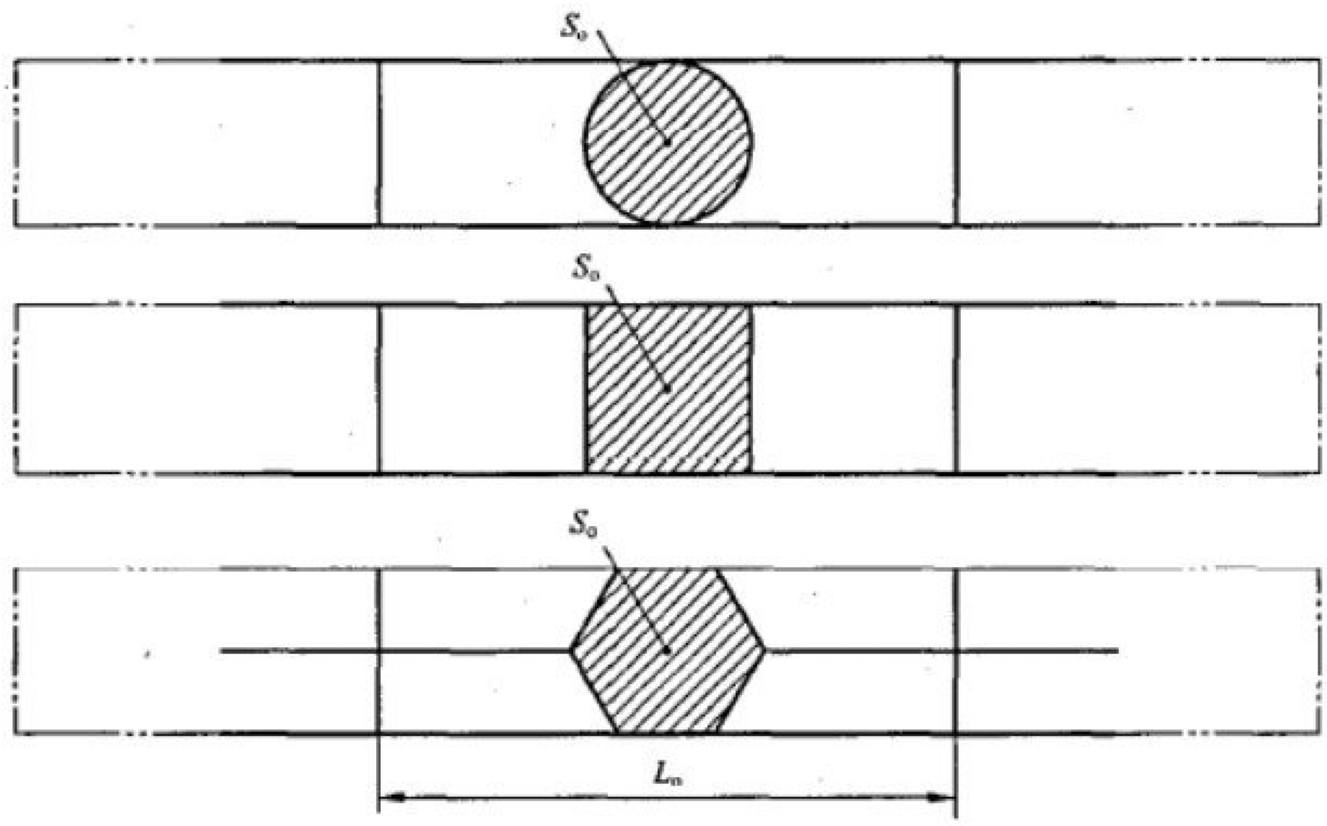
a) Before testing



b) After testing

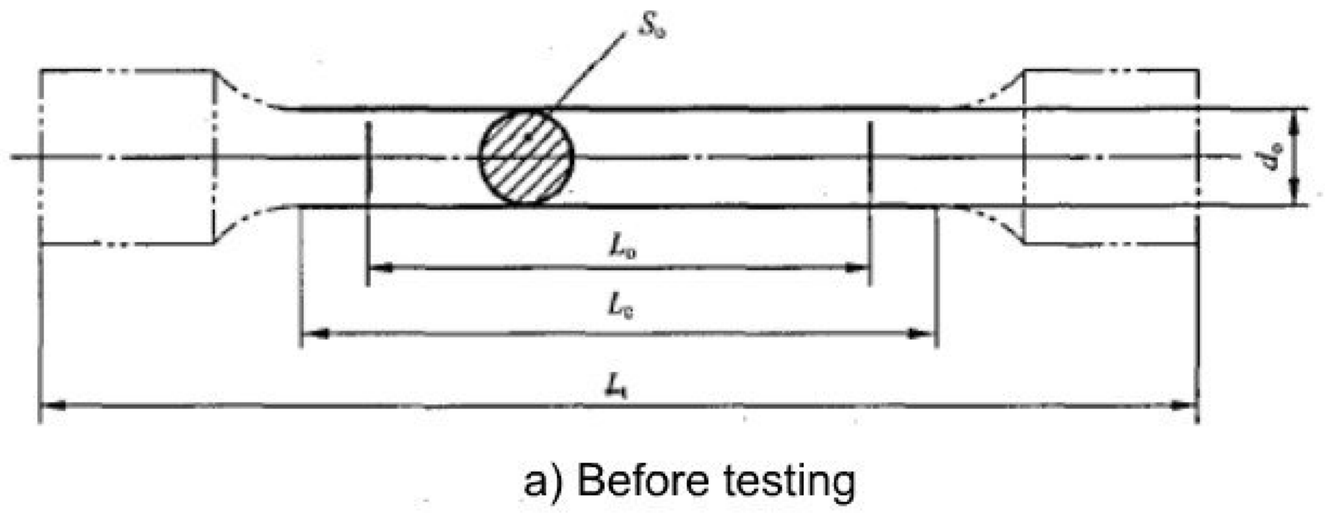
Notes:
a_o — original thickness of a flat test piece or wall thickness of a tube;
b_o — original width of the parallel length of a flat test piece;
L_o — the original gauge length;
L_c — parallel length;
L_t — total length of test piece;
L_u — the final gauge length after fracture;
S_o — the original cross-sectional area of the parallel length;
1 — gripped ends.
Note: The shape of the test piece heads is only given as a guide.

Figure 11 Machined test pieces of rectangular cross-section (see Annexes B and D)

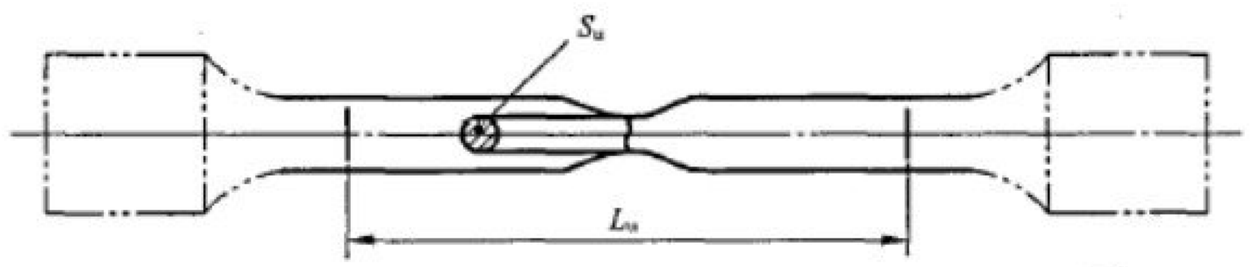


Notes:
L_o — the original gauge length;
S_o — the original cross-sectional area of the parallel length.

Figure 12 Test pieces comprising an unmachined portion of the product (see Annex C)



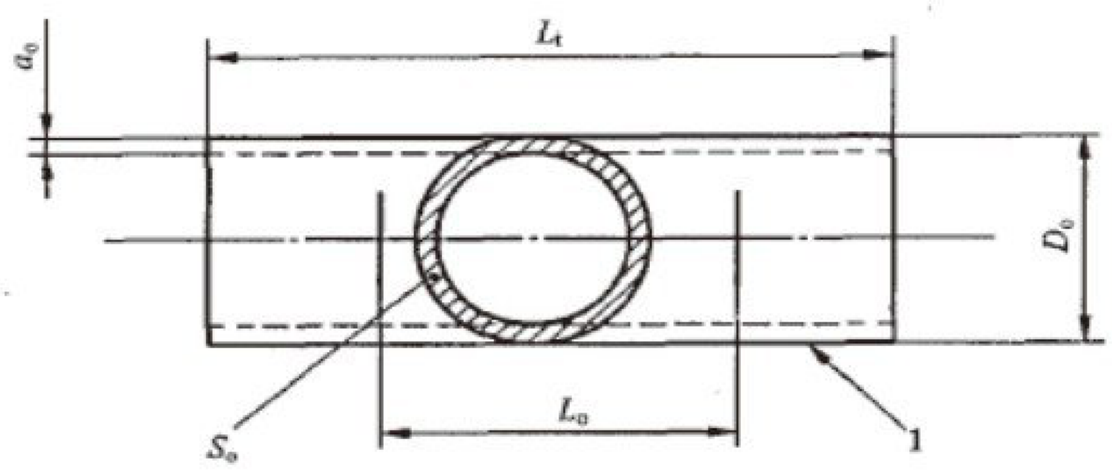
a) Before testing



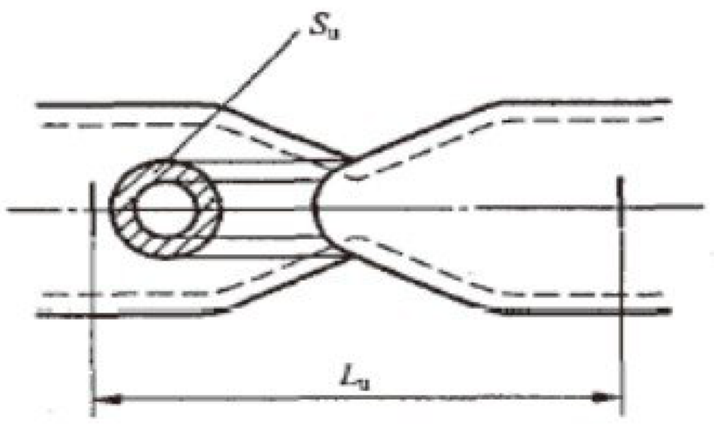
b) After testing

Notes:
d_o— original diameter of the parallel length of a circular test piece;
L_o — the original gauge length;
L_c — parallel length;
L_t — total length of test piece;
L_u — the final gauge length after fracture;
S_o — the original cross-sectional area of the parallel length;
S_u — minimum cross-sectional area after fracture.
Note: The shape of the test piece heads is only given as a guide.

Figure 13 Machined test pieces of round cross-section (see Annex D)



a) Before testing



b) After testing

Notes:

a_o — original wall thickness of a tube;

D_o — original external diameter of a tube;

L_o — the original gauge length;

L_t — total length of test piece;

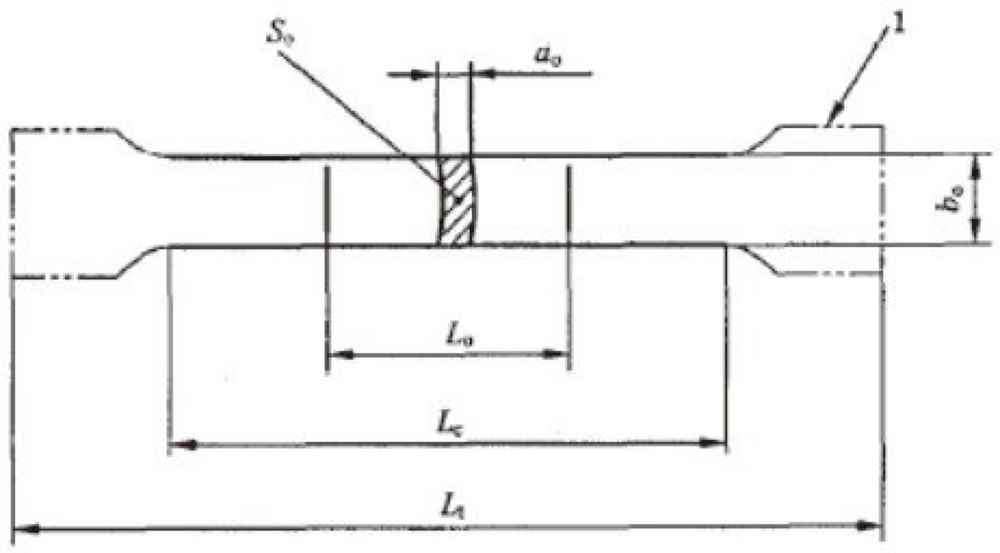
L_u — the final gauge length after fracture;

S_o — the original cross-sectional area of the parallel length;

S_u — minimum cross-sectional area after fracture;

1 — gripped ends.

Figure 14 Test pieces comprising a length of tube (see Annex E)



a) Before testing

Notes:

a_o — original wall thickness of a tube;

b_o — original average width of the longitudinal test piece taken from a tube;

L_o — the original gauge length;

L_c — parallel length;

L_t — total length of test piece;

L_u — the final gauge length after fracture;

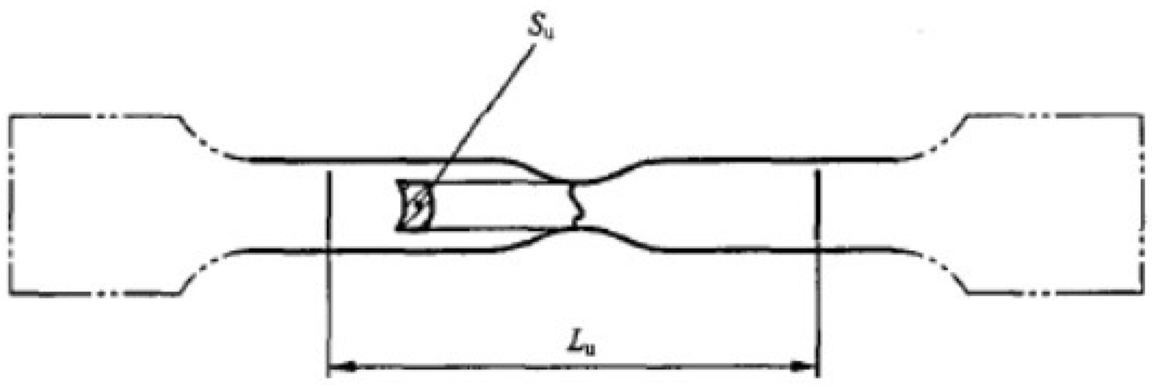
S_o — the original cross-sectional area of the parallel length;

S_u — minimum cross-sectional area after fracture;

1 — gripped ends.

Note: The shape of the test piece heads is only given as a guide.

Figure 15 Longitudinal test piece cut from the tube (see Annex E)



b) After testing

Figure 15 (continued)

Appendix A
(Informative)
Recommendations Concerning the Use of Computer-controlled Ttensile Testing Machines

A.1 General

This annex contains additional recommendations for the determination of mechanical properties by using a computer-controlled tensile testing machine. In particular it provides the recommendations that should be taken into account in the software and testing conditions.

These recommendations are related to the design, the software of the machine and its validation, and to the operating conditions of the tensile test.

A.2 Terms and definitions

For the purposes of this annex, the following definition applies.

A.2.1

Computer-controlled tensile testing machine

Machine for which the control and monitoring of the test, the measurements, and the data processing are undertaken by computer.

A.3 Tensile testing machine

A.3.1 Design

The machine should be designed in order to provide outputs giving analogue signals untreated by the software. If such outputs are not provided, the machine manufacturer should give raw digital data with information on how these raw digital data have been obtained and treated by the software. They should be given in basic SI units relating to the force, the extension, the crosshead separation, the time and the test piece dimensions. These data shall be corrected in case that the machines are upgraded. An example of the format of suitable data files is given in Figure A.1.

A.3.2 Data sampling frequency

The frequency bandwidth of each of the measurement channels and the data sampling frequency should be sufficiently high to record the material characteristics to be measured. For example, determine the minimum sampling frequency as per Equation (A.1) to determine R_{eH}:

$$f_{min} = \frac{\dot{e} \times E}{R_{eH} \times q} \times 100 \qquad \text{.....(A.1)}$$

Wherein:
f_{min} — the minimum sampling frequency, in reciprocal seconds (S^{-1});
e — the strain rate, in reciprocal seconds (S^{-1});
E — the modulus of elasticity, in megapascals (MPa);
R_{eH} — the upper yield strength, in megapascals (MPa);
q — the accuracy level of the dynamometric system of testing machine.
The choice of R_{eH} in Equation (A.1) is due to the fact that it corresponds to a transient characteristic during the test. If the material tested has no yield phenomena, the proof strength $R_{p0.2}$ should be used and the required minimum sampling frequency can be halved.

If method B (stress rate based) is used, the minimum sampling frequency f_{min} should be calculated using Equation (A.2):

$$f_{min}=\frac{\dot{R}}{R_{eH}\times q}\times 100 \qquad \text{(A.2)}$$

Wherein:
R — the stress rate, in megapascals per second (MPa s^{-1}).

A.4 Determination of the mechanical properties

A.4.1 General

The following requirements should be taken into account by the software of the machine.

A.4.2 Upper yield strength and lower yield strength

A.4.2.1 Upper yield strength

R_{eH} (3.10.2.1) should be considered as the stress corresponding to the highest value of the force prior to a reduction of at least 0.5% of the force, and followed by a region in which the force should not exceed the previous maximum over a strain range not less than 0.5%.

A.4.2.2 Lower yield strength

R_{eL} defined in 3.10.2.2 shall comply with the basic rules determined by the position of lower yield strength under Chapter 12.

A.4.3 Proof strength at plastic extension and proof strength at total extension

R_p (3.10.3) and R_t (3.10.4) can be determined by interpolation between adjacent points on the curve.

A.4.4 Percentage total extension at maximum force

A_{gt} (see 3.6.4 and Figure 1) should be considered as the total extension corresponding to the maximum of the stress-strain curve after yield point phenomena.

For some materials it is necessary to smooth the stress-strain curve in which case a polynomial regression is recommended. The smoothing range may have an influence on the result. The smoothed curve should be a reasonable representation of the relevant part of the original stress-strain curve.

A.4.5 Percentage plastic extension at maximum force

A_g (see 3.6.5 and Figure 1) should be considered as the plastic extension corresponding to the maximum of the stress-strain curve after yield point phenomena.

For some materials it is necessary to smooth the stress-strain curve in which case a polynomial regression is recommended. The smoothing range may have an influence on the result. The smoothed curve should be a reasonable representation of the relevant part of the original stress-strain curve.

A.4.6 Percentage total extension at fracture

A.4.6.1 Determine A_t with reference to the definition of fracture in Figure A.2.

The fracture is considered to be effective when the force between two consecutive points decreases:

a) by more than five times the difference between the value of the previous two points, followed by a decrease to lower than 2% of the maximum tensile force;

b) lower than 2% of the maximum tensile force (soft materials).

Another useful method for detecting the fracture of the test piece is to monitor the voltage or electric current through the test piece, when the values measured just before the current is interrupted are taken as those at fracture.

A
"Reference"; "ISO 6892"
"Identification"; "TENSTAND"
"Material"; "DC 04 Steel"
"Extensometer to crosshead transition" ; 0.00; "%"
"Specimen geometry"; "flat"
"Specimen thickness = ao"
"Specimen width = bo"
"Cross-sectional area = So"
"Extensometer gauge length = Le"
"Extensometer output in mm"
"Parallel length = Lc"
"Data acquisition rate 50Hz"
"Data row for start force reduction (Hysteresis) = Hs"
"Data row for end force reduction (Hysteresis) = Be"
"Data row for switch to crosshead = Cs"
"File length H data rows"
"File width M data columns"
.
.

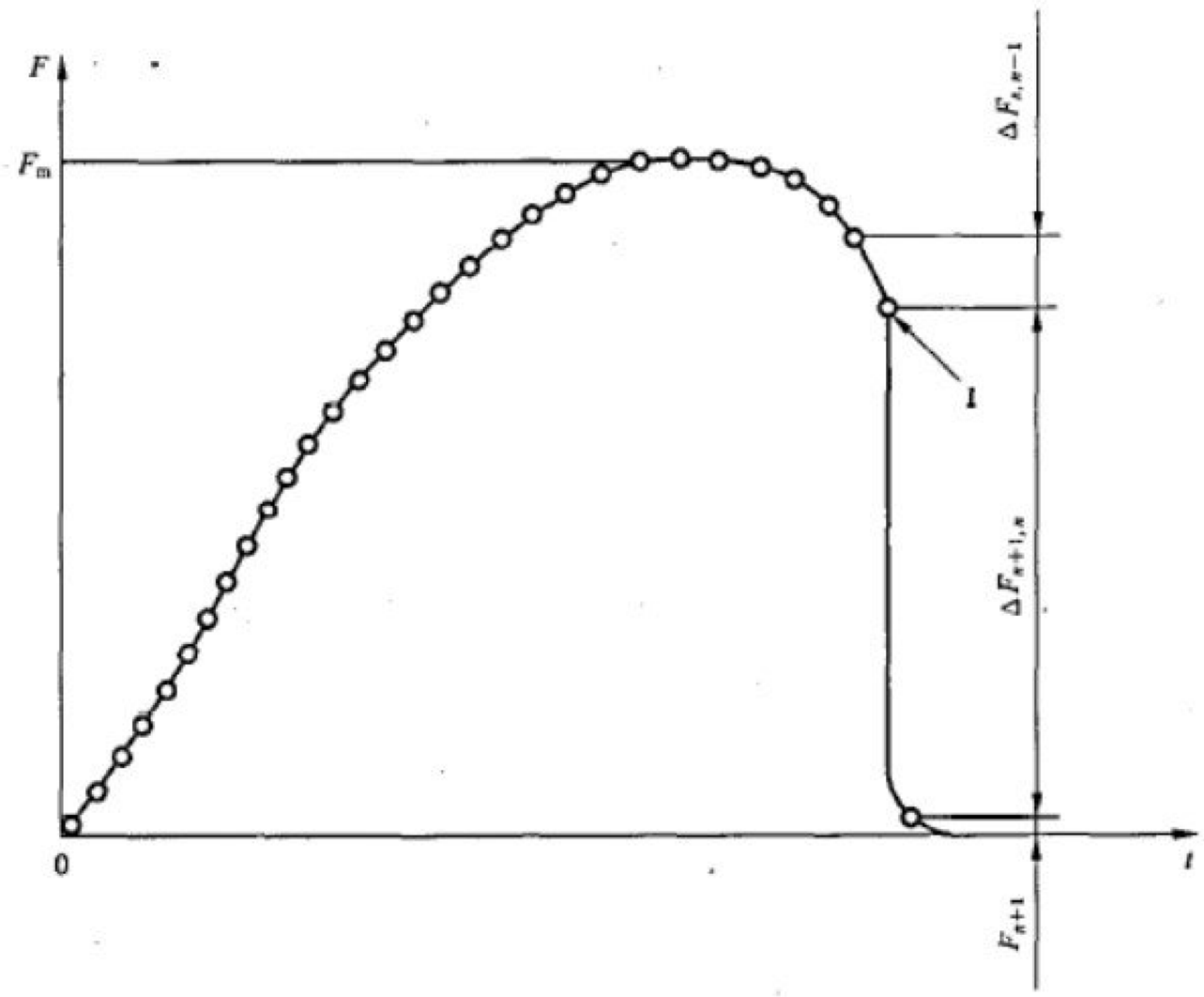
B
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"ao";0.711;"mm"
"bo";19.93;"mm"
"So";14.17;"mm2"
"Le";80.00;"mm"
"Lc";120.00;"mm"
"N";2912
"M";4
"Hs";0
"He";0
"Cs";0
```
.

"time"; "crosshead"; "extensometer"; "force" "
"s"; "mm"; "mm"; "kN"
.
.

C
```
0.40;0.0012;0.0000;0.12694
0.42;0.0016;0.0000;0.12992
0.44;0.0020;0.0001;0.13334
0.46;0.0024;0.0002;0.13699
0.48;0.0029;0.0003;0.14114
0.50;0.0035;0.0004;0.14620
0.52;0.0041;0.0006;0.15124
0.54;0.0047;0.0007;0.15669
0.56;0.0054;0.0008;0.16247
0.58;0.0060;0.0009;0.16794
0.60;0.0067;0.0012;0.17370
0.62;0.0074;0.0013;0.17980
0.64;0.0082;0.0014;0.18628
```
.
.

Notes:
A — header;
B — test parameters and sample dimensions;
C — data.

Figure A.1 Example of the format of suitable data files



Notes:

F — force;

F_m — maximum force;

F_{n+1} — force at measuring point n+1;

$\Delta F_{n,\ n-1}$ — force difference between measuring point n and n-1;

$\Delta F_{n+1,\ n}$ — force difference between measuring point n+1 and n;

t — time;

l — fracture;

O — data point.

Criteria for fracture: $|\Delta F_{n+1,\ n}| > 5|\Delta F_{n,\ n-1}|$ and/or $F_{n+1} < 0.02F_m$

Figure A.2 Schematic representation for definition of fracture of the test piece

A.4.6.2 If the extensometer is kept on and the extension is measured until the fracture, evaluate the value at point 1 in Figure A.2.

A.4.6.3 If the extensometer is removed or if the extension measurement is interrupted before fracture but after maximum force, F_m, then it is permitted to use crosshead displacement to determine the additional elongation between removal of the extensometer and fracture. The method used should be verifiable.

A.4.7 Measurement of the slope of the curve in the elastic range

In order to be valid for test pieces of unknown characteristics, the method used should not rely upon any predefined stress limit, unless this is defined in the product standard or by agreement between parties to the test.

The most convenient methods based on the calculation of the characteristics of a sliding segment are the most convenient. The parameters are:

a) the length of the sliding segment (number of points used);

b) the equation chosen as reference to define the slope of the curve.

Note: If the straight portion of the force extension curve is not clearly defined, refer to 13.1 and Annex J.

The slope of the curve in the elastic range corresponds to the mean slope in a range where the following conditions are fulfilled:

c) the slope of the sliding segment is constant;

d) the selected range is representative.

In any case, it should be recommended that pertinent limits for the range can be selected by the user in order to eliminate unrepresentative values of the slope of the curve in the elastic range.

References to these and other acceptable methods are given in References [4], [5], [6], [7].

A recommended method to determine the slope of the elastic line for evaluation of $R_{p0.2}$:

— linear regression of the linear range;

— lower limit: ≈ 10% of $R_{p0.2}$;

— upper limit: ≈ 50% of $R_{p0.2}$;

— to get more exact data for $R_{p0.2}$, the elastic line must be checked and if necessary recalculated with other limits.

A.5 Validation of the software for determination of the tensile properties

The efficiency of the methods used by the testing system to determine the various material characteristics may be checked by comparison with results determined in the traditional manner by examination/calculation from plots of analogue or digital data. Data which are derived directly from the machine transducers or amplifiers should be collected and processed using equipment with frequency bandwidth, sampling frequency and uncertainty, of at least equal to those used to provide the machine computer-calculated results.

Confidence may be placed in the accuracy of the machine computer processing if differences in arithmetic means between computer-determined values and those determined manually on the same test piece are small. For the purposes of assessing the acceptability of such differences, 5 similar test pieces should be tested and the average difference for each relevant property should lie within the limits shown in Table A.1.

Note: This procedure confirms only that the machine finds the material characteristics for the particular test piece shape, material tested and conditions used. It gives no confidence that the properties of the material tested are either correct or fit for purpose.

If other methods are used, e.g. injection of a pre-determined set of data from a known material with a recognized level of quality assurance, these should meet the requirements mentioned above and those in Table A.1.

Table A.1 Maximum permitted differences between computer-derived and manually derived results

Parameter	D[a]		S[b]	
	Relative [c]	Absolute [c]	Relative [c]	Absolute [c]
$R_{p0.2}$	≤0.5%	2 MPa	≤0.35%	2 MPa
R_{p1}	≤0.5%	2 MPa	≤0.35%	2 MPa
R_{eH}	≤1%	4 MPa	≤0.35%	2 MPa
R_{eL}	≤0.5%	2 MPa	≤0.35%	2 MPa
R_m	≤0.5% “	2 MFa	≤0.35%	2 MPa
A		≤2%		≤2%

[a] $D = \frac{1}{n}\sum_{i=1}^{n} D_i$ 。

[b] $s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(D_i - D)^2}$ 。

Wherein:

D_i — the difference between the result of manual evaluation, H_i, and the result of computer evaluation, R_i, for a test piece ($D_i = H_i - R_i$);

n — the number of identical test pieces from one sample (≥ 5).

[c] The highest of the relative and absolute values should be taken into account.

Annex B

(Normative)

Types of Test Pieces to be Used for Thin Sheets and Strips between 0.1 mm and 3 mm Thick

Note: For products of less than 0.5 mm thickness, special precautions may be necessary.

B.1 Shape of the test piece

Generally, the test piece has gripped ends which are wider than the parallel length (see Figure 11a). The parallel length shall be connected to the ends by means of transition curves with a radius of at least 20 mm. The width of these ends should be ≥1.2 b_o, where b_o is the original width.

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.

B.2 Dimensions of the test piece

Three different non-proportional test piece geometries are widely used (see Table B.1).

See Table B.2 for the dimensions of three non-proportional test pieces which are commonly used.

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

In case of dispute, the length L_o+2b_o, should be used, unless there is insufficient material.

For 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_o.

When measuring the dimensions of each test piece, the tolerances on shape given in Table B.3 shall apply.

For 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.

Table B.1 Dimensions of proportional test pieces with rectangular cross-section

b_o /mm	r/mm	K=5.65			K=11.3		
		L_o/mm	L_c/mm	Test piece No.	L_o/mm	L_c/mm	Test piece No.
10	≥20	$5.65\sqrt{S_o}$ ≥15	≥$L_o+b_o/2$ Arbitration test: L_o+2b_o	P1	$11.3\sqrt{S_o}$ ≥15	≥$L_o+b_o/2$ Arbitration test: L_o+2b_o	P01
12.5				P2			P02
15				P3			P03
20				P4			P04
NOTE 1: The proportional test piece with coefficient of proportionality k=5.65 shall be preferred. The non proportional test piece in Table B.2 shall be recommended if the proportional gauge length is less than 15 mm. NOTE 2: If necessary, small lugs can be provided on the parallel length of the test piece with thickness less than 0.5 mm to equip with the extensometer. The distance between the center lines of upper and lower lugs is the original guage length.							

Table B.2 Dimensions of non-proportional test pieces with rectangular cross-section

b_o /mm	r/mm	L_o/mm	L_c/mm		Test piece No.
			with parallel sides	Without parallel sides	
12.5	≥20	50	75	87.5	P5
20		80	120	140	P6
25		50[a]	100[a]	120[a]	P7
[a] Compared to the test pieces with width of 12.5 mm and 20 mm, the L_c/b_o and L_o/b_o with thickness of 25 mm is very low. The properties of these test pieces, especially the percentage elongation after fracture (absolute value and dispersion range), is different with those of the other two types of test pieces.					

Table B.3 Tolerances on the width of the test piece Unit: mm

Nominal width of the test piece	Tolerance on dimension [a]	Tolerance on shape [b]
12.5	± 0.05	0.06
20	± 0.10	0.12
25	± 0.10	0.12
[a] These tolerances are applicable if the nominal value of the original cross-sectional area is to be included in Table B.3 without having to measure it again. [b] Maximum deviation between the measurements of the width along the entire parallel length, L_c, of the test piece.		

B.3 Preparation of test pieces

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

These test pieces are predominantly prepared from sheet or strip. If possible, the as-rolled surfaces should not be removed.

Note: The preparation of these test pieces by punching can result in significant changes to the material properties. Especially the yield/proof strength (due to workhardening). Materials which exhibit high workhardening should, generally, be prepared by milling, grinding etc.

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

Tolerances on dimension and shape of machined test piece shall be in accordance with the requirement of Table B.3. For example, for a test piece with a nominal width of 12.5 mm, the tolerance is ±0.05 mm, which means that the width of test piece shall not exceed the range between the following two values:

12.5 mm + 0.05 mm = 12,55 mm 12.5 mm - 0.05 mm = 12.45 mm

B.4 Determination of original cross-sectional area

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%.

In order to achieve test results with a reduced measurement uncertainty it is recommended that the original cross-sectional area be determined with an accuracy of ±1% or better. For thin materials special measurement techniques may be required.

Annex C

(Normative)

Types of Test Pieces to be Uused for Wire, Bars and Sections with a Diameter or Thickness of Less Than 4 mm

C.1 Shape of the test piece

The test piece generally consists of an unmachined portion of the product (see Figure 12).

C.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+3b_o or L_o+3d_o but a minimum of L_o+ 20 mm. See Table C.1.

Table C.1 Non proportional test piece

d_o 或 a_o /mm	L_o/mm	L_c/mm	Test piece No.
≤4	100	≥120	R9
	200	≥220	R10

If the percentage elongation after fracture is not to be determined, a distance between the grips of at least 50 mm may be used.

C.3 Preparation of test pieces

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

C.4 Determination of original cross-sectional area

The error in determining the original cross-sectional area shall not exceed ± 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 in square millimetres may be determined from the mass of a known length and its density using Equation (C.1):

$$S_o = \frac{1\,000 \cdot m}{\rho \cdot L_t} \qquad \text{.....(C.1)}$$

Wherein:

m — the mass, in grams (g), of the test piece;

L_t — the total length, in millimeters (mm), of the test piece;

ρ— the density, in grams per cubic centimeter ($g \cdot cm^{-3}$), of the test piece material.

Annex D

(Normative)

Types of Test Pieces to be Used for Sheets and Flats of Thickness Eequal to or Greater Than 3 mm, and Wire, Bars and Sections of Diameter or Thickness Equal to or Greater Than 4 mm

D.1 Shape of the test piece

Usually, the test piece is machined. The parallel length shall be connected by means of transition radii to the gripped ends which may be of any suitable shape for the grips of the testing machine (see Figure 13). The minimum transition radius between the gripped ends and the parallel length shall be:

a) $\geq 0.75d_o$ for the cylindrical test pieces;

b) ≥12 mm for other test pieces.

Sections, bars, etc., may be tested unmachined, if required by relevant product specifications.

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 3 mm.

D.2 Dimensions of the test piece

D.2.1 Parallel length of machined test piece

The parallel length, L_o, shall be at least equal to:

a) $L_o+\frac{d_o}{2}$ for cylindrical test pieces;

b) $L_o+ 1.5\sqrt{S_o}$ for other test pieces.

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

D.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 least a distance of $\sqrt{S_o}$ from the grips.

D.2.3 Original gauge length

D.2.3.1 Proportional test pieces

As a general rule, proportional test pieces are used where L_o is related to the original cross-sectional area, S_o:

$L_o=k\sqrt{S_o}$

Where k is equal to 5.65, or it may also be 11.3.

Test pieces of circular cross-section should preferably have one set of dimensions given in Table D.1 and D.2.

Table D.1 Circular cross-section proportional test pieces

d_o/mm	r/mm	K=5.65			K=11.3		
		L_o/mm	L_c/mm	Test piece No.	L_o/mm	L_c/mm	Type of test piece
25	≥0.75d_o	5d_o	≥L_o + d_o/2 Arbitration test: L_o + 2d	R1	10d_o	≥L_o + d_o/2 Arbitration test: L_o + 2d	R01
20				R2			R02
15				R3			R03
10				R4			R04
8				R5			R05
6				R6			R06
5				R7			R07
3				R8			R08
Note 1: R2, R4 or R7 test piece shall be preferred unless otherwise specified by relevant product standard. Note 2: The total length of test piece shall be dependent on the method of gripping, L_t>L_e + 4d_o in principle.							

Table D.2 Rectangular cross-section proportional test pieces

d_o/mm	r/mm	K=5.65			K=11.3		
		L_o/mm	L_c/mm	Test piece No.	L_o/mm	L_c/mm	Type of test piece
12. 5	≥12	$5.65\sqrt{S_o}$	≥L_o + $1.5\sqrt{S_o}$ Arbitration test: L_o+$2\sqrt{S_o}$	P7	$11.3\sqrt{S_o}$	≥L_o + $1.5\sqrt{S_o}$ Arbitration test: L_o+$2\sqrt{S_o}$	P07
15				P8			P08
20				P9			P09
25				P10			P010
30				PII			P011
Note: Test piece with the coefficient of proportionality k=5.65 shall be preferred unless otherwise specified by relevant products standard.							

D.2.3.2 Non proportional test pieces

See Table D.3 for the dimension of non proportional test piece with rectangular cross section. Non proportional test pieces are permitted if required by relevant product standard.
The parallel length shall not be less than L_o + b_o/2. In cases of dispute, the parallel length L_c=L_o + 2b, shall be used depending on the type of test piece, unless there is insufficient material.

Table D.3 Dimensions of non-proportional test pieces with rectangular cross-section

d_o/mm	r/mm	L_o/mm	L_c/mm	Type of test piece
12.5	≥20	50	≥L_o + $1.5\sqrt{S_o}$ Arbitration test: L_o+$2\sqrt{S_o}$	P12
20		80		P13
25		50		P14
38		50		P15
40		200		P16

D.3 Preparation of test pieces

D.3.1 The tolerances on the transverse dimensions of machined test pieces are shown in Table D.4.

Examples for these are shown in D.3.2 and D.3.3:

D.3.2 Tolerance on dimensions

The value given in Table D.4 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 ±0.03 mm.

10 mm+0.03 mm=10.03 mm　　10 mm-0.03 mm=9.97 mm

D.3.3 Tolerance on shape

The value given in Table D.4 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 mm+0.04 mm=10.03 mm.

Table D.4 Tolerances on the transverse dimensions of test pieces　Unit: mm

Designation	Nominal transverse dimension	Tolerance on dimension [a]	Tolerance on shape [b]
Diameter of machined test pieces of circular cross-section and transverse dimensions of test pieces of rectangular cross-section machined on all four sides	≥3 ≤6	±0.02	0.03
	>6 ≤10	±0.03	0.04
	>10 ≤18	±0.05	0.04
	>18 ≤30	±0.10	0.05
Transverse dimensions of test pieces of rectangular cross-section machined on only two opposite sides	≥3 ≤6	±0.02	0.03
	>6 ≤10	±0.03	0.04
	>10 ≤18	±0.05	0.06
	>18 ≤30	±0.10	0.12
	>30 ≤50	±0.15	0.15

[a] If the tolerances of the test pieces comply with Table D.4, the original cross-section area can be nominal value without having to measure it. If the tolerances of test pieces do not comply with Table D.4, it is essential to measure every individual test piece.

[b] Maximum deviation between the measurements of a specified transverse dimension along the entire parallel length of the test piece.

D.4 Determination of original cross-sectional area

The nominal dimensions can be used to calculate for test pieces of circular cross-section and rectangular cross-section machined on all four sides that satisfy the tolerances given in Table D.4. For all other shapes of test pieces, the original cross-sectional area, S_o, shall be calculated from measurements of the appropriate dimensions, with an error not exceeding ±0.5% on each dimension.

Annex E
(Normative)
Types of Test Pieces to be Used for Tubes

E.1 Shape of the test piece

The test piece consists either of a length of tube, or a longitudinal test piece cut from the tube and having the full thickness of the wall tube (see Figures 14 and 15), 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 B for tube wall thickness less than 3 mm, and in Annex D for thickness equal to or greater than 3 mm.

E.2 Dimensions of the test piece

E.2.1 Longitudinal test piece

See Table E.1 for the dimensions of longitudinal test piece. Test piece dimensions other than those given in Table E.1 can be specified in the product standard. Longitudinal test piece is generally applicable to the tubes with the thickness of wall greater than 0.5 mm.

To grip on the testing machine, two ends of the longitudinal test piece can be flattened, but the parallel length part shall not be flattened.

For the test pieces without ends, the free length between the grips shall be adequate for the gauge marks to be at least a distance of 1.5 $\sqrt{S_o}$ from the grips.

Table E.1 Longitudinal test piece

D_o/mm	b_o/mm	a_o/mm	r/mm	k=5.65			k=11.3		
				L_o/mm	L_c/mm	Test piece No.	L_o/mm	L_c/mm	Type of test piece
30~50	10	Original wall thickness	≥12	$5.65\sqrt{S_o}$	≥L_o + $1.5\sqrt{S_o}$ Arbitration test: L_o+$2\sqrt{S_o}$	S1	$11.3\sqrt{S_o}$	≥L_o + $1.5\sqrt{S_o}$ Arbitration test: L_o+$2\sqrt{S_o}$	S01
>50~70	15					S2			S02
>70~100	20/19					S3/S4			S03
>100~200	25					S5			
>200	38					S6			
Note: Test piece with the coefficient of proportionality k=5.65 shall be preferred unless otherwise specified by relevant products standard.									

E.2.2 Test piece of tube

See Table E.2 for the dimension of test piece of tube. Plugs shall be added at two ends of the test piece. The distance between plug and the nearest guage mark shall be not less than D_o/4, and the distance shall be D_o in arbitration test if materials are sufficient. The extended length of the plugs in relative to the testing machine in the guage direction shall be not less than D_o, and its shape shall not influence the deformation within the guage.

The two grips of test piece of tube are permitted to be flattened and to be tested with or without flat plugs. For the unflattened arbitration test, the plugs shall be provided.

Table E.2 Test piece of tube

L_o/mm	L_c/mm	Type of test piece
$5.65\sqrt{S_o}$	$\geq L_o+D_o/2$ Arbitration test: L_o+2D_o	S7
50	≥100	S8

E.2.3 Machined transverse test pieces

For the machined transverse rectangular crosssection test piece, when the wall thickness is smaller than 3 mm, test pieces in Table B.1 or Table B.2 shall be used; when the wall thickness is greater than or equal to 3 mm, test pieces in Table D.2 or Table D.3 shall be used.
For the test pieces without ends, the free length between the grips shall be adequate for the gauge marks to be at least a distance of $1.5b_o$ from the grips.
Special measures shall be taken to correct the transverse test piece.

E.2.4 Circular cross-section test piece machined in tube wall

Machined longitudinal circular cross-section test piece shall use test pieces in Table D.1. Relevant product standard shall specify the circular cross-section dimension as per the wall thickness and select from Table E.3 if not specified.

Table E.3 Circular cross-section test piece machined in tube wall

a_o/mm	Test piece used
8~13	E7
>13~16	R5
>16	R4

E.3 Determination of original cross-sectional area

The error in determining the original cross-sectional area of test piece shall not exceed ± 1%.
The original cross-section areas of the test piece of tube, the longitudinal or transverse test piece without ends can be calculated as per Equation (E.1) after measuring the length of test piece, the quality of test piece and the density of materials:

$$S_o = \frac{1\,000 \cdot m}{\rho \cdot L_t} \qquad \text{(E.1)}$$

wherein
m — the mass, in grams (g), of the test piece;
L_t — the total length, in millimeters (mm), of the test piece;
ρ— the density, in grams per cubic centimeter (g cm^{-3}), of the test piece material.
The original cross-sectional area of a test piece consisting of a longitudinal test piece shall be calculated according to Equation (E.2):

$$S_o = \frac{b_o}{4}(D_o^2 - b_o^2)^{1/2} + \frac{D_o^2}{4}\arcsin\left(\frac{b_o}{D_o}\right) - \frac{b_o}{4}[(D_o - 2a_o)^2 - b_o^2]^{1/2} - \left(\frac{D_o - 2a_o}{2}\right)^2 \arcsin\left(\frac{b_o}{D_o - 2a_o}\right) \qquad \text{(E.2)}$$

Wherein:

a_o — the thickness of the tube wall;

b_o — the average width of the longitudinal test piece, $b_o<(D_o - 2a_o)$;

D_o — the external diameter of the tube.

The simplified Equation (E.3) and (E.4) can be used for longitudinal test pieces:

When $\frac{b_o}{D_o}<0.25$,

$$S_o=a_o b_o\left[1+\frac{b_o^2}{6D_o(D_o-2a_o)}\right] \qquad \text{(E.3)}$$

When $\frac{b_o}{D_o}<0.1$,

$$S_o=a_o b_o \qquad \text{(E.4)}$$

For length of tube, the original cross-sectional area shall be calculated from Equation (E.5):

$$S_o=a_o(D_o-a_o) \qquad \text{(E.5)}$$

Annex F
(Informative)
Estimation of the Crosshead Separation Rate in Consideration of the Stiffness (or Compliance) of the Testing Machine

Equation (1) in 10.3.1 does not consider any elastic deformation of the testing equipment (frame, load cell, grips, etc.). This means that the deformation can be separated into the elastic deformation of the testing equipment and the deformation of the test piece. Only a part of the crosshead separation rate is transferred to the test piece. The resulting strain rate at the test piece, e_m, in reciprocal seconds, is given by Equation (F.1):

$$\dot{e}_m = v_c / \left(\frac{m \times S_o}{C_M} + L_c \right) \qquad \cdots\cdots (F.1)$$

Wherein:

C_M —— the stiffness, in newtons per millimetre, of the testing equipment (around the point of interest such as $R_{p0.2}$, if stiffness is not linear, e.g. when using wedge grips);

e_m —— the strain rate occuring in test piece, in seconds (s^{-1})

L_c —— the parallel length, in millimetres (mm), of the test piece;

m —— the slope, in megapascals (MPa), of the stress-percentage extension curve at a given moment of the test (e.g. around the point of interest such as $R_{p0.2}$);

S_o —— the original cross-section area, in square millimetres (mm^2);

v_c —— the crosshead separation rate, in millimetres per second ($mm \cdot s^{-1}$).

Note: The values of m and C_M derived from the linear portion of the stress/strain curve cannot be used.

Equation (1) does not compensate for the effects of compliance (see 10.3.1). A better approximation of the crosshead separation rate, in millimetres per second ($mm \cdot s^{-1}$), necessary to produce a resulting strain rate at the test piece, e_m , around the point of interest, can be made from Equation (F.2):

$$v_c = \dot{e}_m \left(\frac{m \times S_o}{C_M} + L_c \right) \qquad \cdots\cdots (F.2)$$

Annex G
(Informative)
Measuring the percentage elongation after fracture if the specified value is less than 5%

Precautions should 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 close to each end of the parallel length.Using a pair of needle-pointed dividers set at the gauge length, an arc is scribed with the mark as a centre.After fracture, the broken test piece should be placed in a fixture and axial compressive force applied, preferably by means of a screw, sufficient to firmly hold the pieces together during measurement.A second arc of the same radius should then be scribed from the original centre closest to fracture.And the distance between the two scratches measured by means of a measuring microscope or other suitable instrument is elongation after fracture, which should be accurate to within $\pm$0,02 mm.In order to render the fine scratches more easily visible, a suitable dye film may be applied to the test piece before testing.

Note: Another method is described in 20.2 (measuring extension after fracture using an extensometer).

Annex H
(Informative)
Measurement of percentage elongation after fracture based on the displacement method

To avoid having to reject test pieces where the position of the fracture does not comply with the conditions of 20.1, the following method may be used:

a) before the test, subdivide the original gauge length into N equal lengths of 5 mm (recommended) to 10 mm;

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

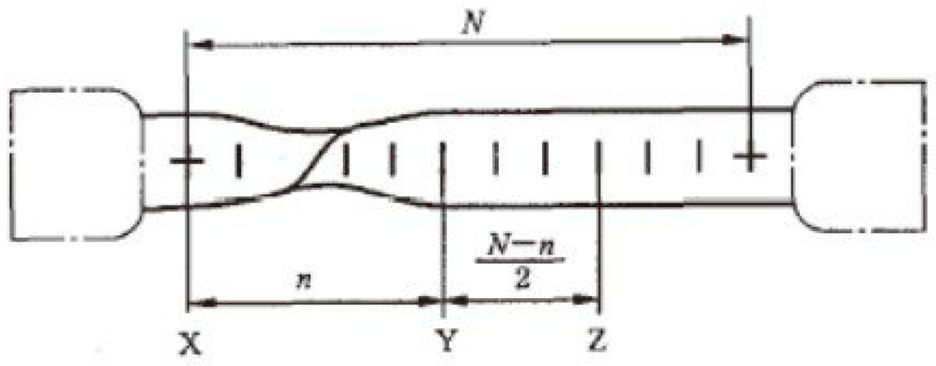
If n is the number of intervals between X and Y, the elongation after fracture is determined as follows:

1) If N-n is an even number [see Figure H.1a)], measure the distance between X and Y, l_{xy} and the distance from Y to the graduation mark Z, l_{yz}, located at $\frac{N-n}{2}$ intervals.Calculate the percentage elongation after fracture using Equation (H.1):

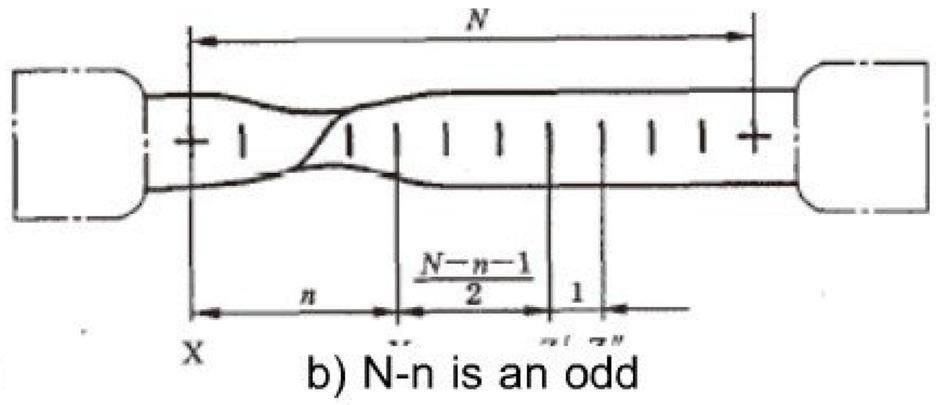
$$A=\frac{l_{XY}+2l_{YZ}-L_o}{L_o}\times 100 \qquad \cdots\cdots(H.1)$$

2) If N-n is an odd number [see Figure H.1 b)], measure the distance between X and Y and the distance from Y to the graduation marks Z' and Z", $l_{yz'}$ and $l_{yz''}$, located respectively at ½(N-n-1) and ½(N-n+1) intervals.Calculate the percentage elongation after fracture using Equation (H.2):

$$A=\frac{l_{XY}+l_{YZ'}+l_{YZ'}-L_o}{L_o}\times 100 \qquad \cdots\cdots(H.2)$$



a) N-n is an even number



b) N-n is an odd number

Notes:

n — number of intervals between X and Y;
N — number of equal lengths;
X — gauge mark on the shorter part of the test piece;
Y — gauge mark on the longer part of the test piece;
Z,Z',Z" — division marks.

Note: The shape of the test piece heads is only given as a guide.

Figure H.1 Examples of the displacement method

Annex I

(Informative)

Determination of the plastic elongation without necking, A_{wn}, for long products such as bars, wire and rods

This method is to be performed on the longer part of a tensile test piece.

Before the test, equidistant marks are made on the gauge length, the distance between two successive marks being equal to a fraction of the initial gauge length, L'_o.The marking of the initial gauge length, L'_o, should be accurate to within ±0.5 mm.The measurement of the final gauge length after fracture, L'_o, is made on the longest part of the test piece and should be accurate to within ±0.5 mm.

In order for the measurement to be valid, the following two conditions should be met:

a) the limits of the measuring zone should be located at least $5d_o$ from the fracture and at least $2.5d_o$ from the grip;

Note: If the cross section of the test piece is irregular figure, d_o is the circumscribed circle diameter of the irregular cross section.

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

The percentage plastic elongation without necking is calculated by Equation (I.1):

$$A_{wn} = \frac{L'_u - L'_o}{L'_o} \times 100 \qquad \cdots\cdots (I.1)$$

Note: For many materials, the maximum force occurs in the range where necking starts.This means that the values for A_g and A_{wn} for these materials will be nearly equal.However, large differences between A_g and A_{wn} will be found in highly cold deformed material such as double reduced tin plate or irradiated structural steel or tests performed at elevated temperatures.

Annex J
(Normative)
Determination of plastic extension strength (R_p) based on successive approximation method

J.1 Range

The successive approximation method applies to the determination of plastic extension strength of metallic materials without obvious elastic straight line segment.For metallic materials whose straight line segment height is not less than $0.5F_m$ on the force-extension curve, this method also applies to the determination of their plastic extension strength.The successive approximation method can apply to the tensile test automated test of this performance.

J.2 Methods

Determine the plastic extension strength based on force – extension curve diagram.

During the test, record the force – extension curve diagram, at least until it exceeds the expected range of plastic extension strength.On the force – extension curve, estimate any point, like A_o , as the force when the percentage of plastic extension strength is 0.2%, and determine B_1 and D_1 on the curve whose force are respectively 0.1 $F^o_{p0.2}$ and 0.5 $F^o_{p0.2}$, and draw a straight line B_1D_1.Intercept line segment OC (OC=0.2%*L_e*n, where n stands for the magnification factor of extension) from the origin O (correct the origin if neccssary) of the curve, draw a parallel line CA_1 of B_1D_1 over point C, and make CA_1 and the curve intersect at point **A_1.If A_1 and A_0 superpose each other,** $F^o_{p0.2}$ **represents the force when the percentage of plastic extension is 0.2%.**

If A_1 and A_0 do not superpose each other, further approximation in accordance with the above steps is required.At this time, take the force of point A_1, $F^1_{p0.2}$**, determine B_2 and D_2 on the curve whose force are respectively 0.1** $F^1_{p0.2}$ **and 0.5** $F^1_{p0.2}$**, and draw a straight line B_2D_2.**Draw a parallel line CA_2 of B_2D_2 over point C, and make CA_2 and the curve intersect at point A_2, use successive approximation method to make the last crosspoint A_n and the previous crosspoint A_{n-1} superpose each other (see Figure J.1).The force of A_n represents the force when the percentage of plastic extension is 0.2%.This force divided by the original cross-sectional area of the test piece equals to the determined plastic extension strength $R_{p0.2}$.

The final slope of line B_nD_n can generally be regarded as the nominal slope for determining other plastic extension strength.

Note: The successive approximation method is inappropriate when determining the plastic extension strength of low strength materials as soft aluminium.

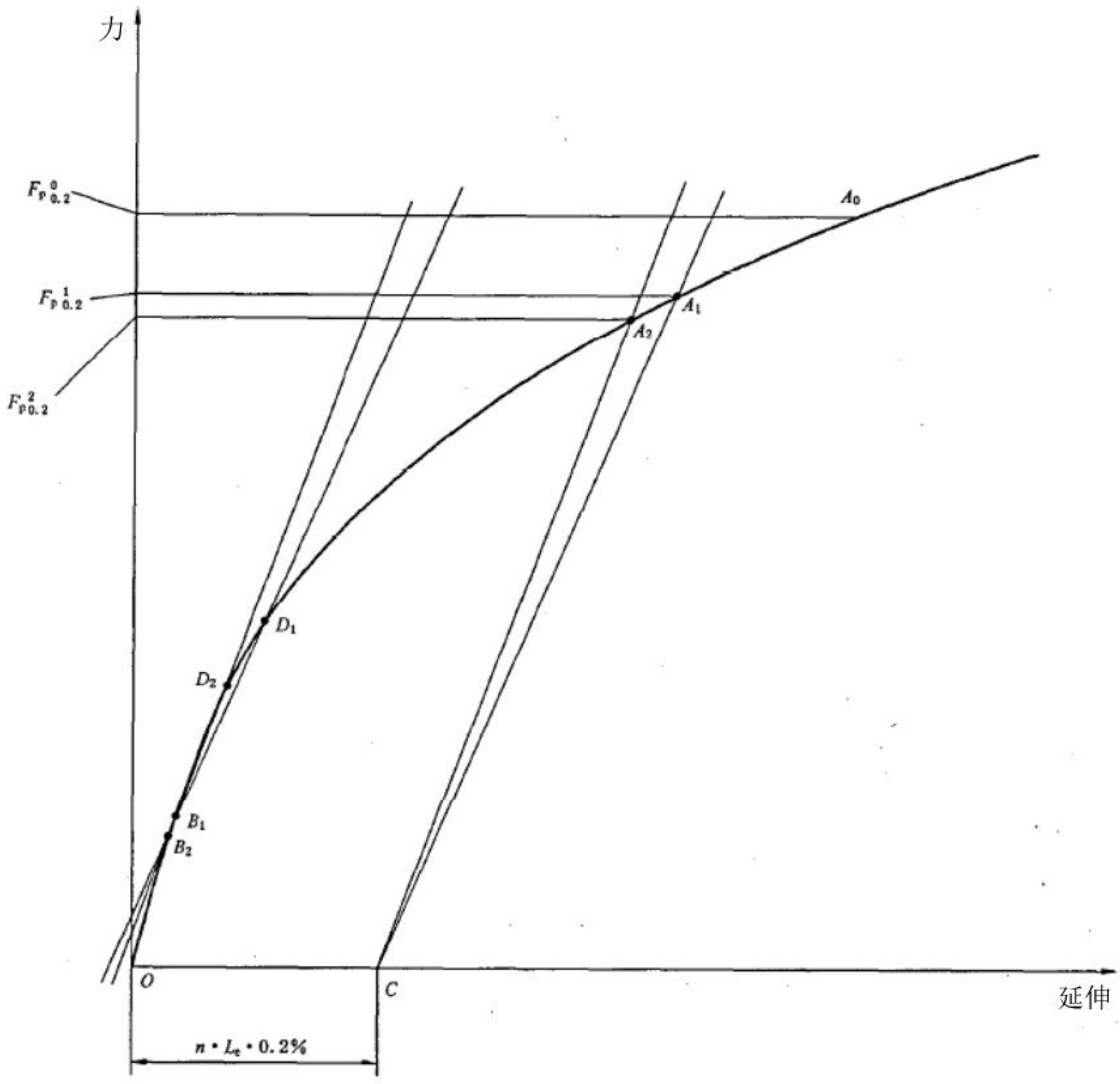


Figure J.1　Determination of plastic extension strength based on successive approximation method

Annex K
(Informative)
Example for deternination of permanent extension strength ($R_{r0.2}$) based on the stress relaxation method

Test material: steel, expected percentage permanent extension **$R_{r0.2}$≈800 MPa**
Dimension of test piece: **d=10.00 mm, S_o=78.54 mm^2;**
Extensometer: gauge extensometer, level 1 accuracy, L_e=50 mm, each division is 0.01 mm;
Testing machine: maximum measuring rage 200 kN, choosen dial is 100 kN;
Tesing rate: In accordance with the requirements specified in 10.3.2.
Calculate the prestress corresponding to the stress value of 5% in accordance with the expected permanent extension strength as the following:
$F_o=R_{r0.2}\times S_o\times 5\%=6283.2$ N, use 6000 N after roundoff. At this moment, the zeropoint of extensometer is 1 division.
The extensometer gauge length used is 50 mm, permanent extension required for determining the permanent set strength $R_{r0.2}$ shall be 50×0.2%=0.1 mm.It can be converted into divisions of extensometer as 0.1÷0.01=10.
At the first time, apply force from F_o to the test piece until it gets the total extension of 10+(1~2)=11~12 divisions within the extensometer gauge length; since the zeropoint is 1 division, the total amount is 13 divisions, maintain the force for 10s~12s and lower it to F_o, then the reading of extensometer is 2.3 divisions, which means the permanent extension is 1.3 divisions.
And the second time, apply force until the extensometer gets the readings which equal to the last reading of 13 divisions plus the difference between the permanent set extension of 10 divisions and the measured permanent extension of 1.3 divisions and plus 1~2 divisions ,that is 13+(10-1.3)+2=23.7 divisions.Maintain the force for 10s~12s and lower it to F_o, then gets the permanent extension reading of 7.3 divisions.
For the third time, apply force until the extensometer gets the readings of 23.7+(10-7.3)+1 = 27.4 divisions.
The test will not stop until the permanent extension reading arrives at or over 10 divisions, see Table K.1 for test records.
Permanent set strength $R_{r0.2}$ is calculated as the following:
According to Table K.1, the force value whose permanent strength reading is proximal to 10 divisions is 61000 N, which means the determined permanent set strength should be between 61000 N and 62000 N.The permanent set strength calculated by linear interpolation method is:

$$F_{r0.2}=\frac{(10.5-10)\times 61\,000+(10-9.7)\times 62\,000}{(10.5-9.7)}=61\,375\ \mathrm{N}$$

Results in:

$$R_{r0.2}=\frac{61\,375}{78.54}=781.4\ \mathrm{MPa}$$

According to the requirement of Chapter 22, the rounding off result is $R_{r0.2}$=781 MPa

Table K.1 Force – data record of permanent extension

Force/N	Extensometer reading/division when applying force	Extensometer reading/division when applying prestress	Permanent extension/division
6000	1.0	—	—
41000	13.0	2.3	1.3
57000	23.7	8.3	7.3
61000	27.4	10.7	9.7
62000	28.7	11.5	10.5

Annex L
(Informative)
Estimation of the uncertainty of tensile test measurement

L.1 Examples for estimation of the uncertainty of tensile test measurement

Estimate the uncertainty of low-carbon and low-alloy steel using the mean results of tensile strength and plastic index of three test pieces.

Use 10 test pieces to get the measurement list, and the outcome measurement ia as the following table L.1.

Standard deviation of the experiment is calculated as the Bessel Formula:

$$s_i = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}} \qquad \cdots\cdots(L.1)$$

Wherein:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$$

Table L.1 Measurement of repeatability test

Series No.	Diameter of the test piece d mm	Tensile strength R_m MPa	Lower yield strength R_{eL} MPa	Prescribed plastic extension strength $R_{p0.2}$ MPa	Percentage elongation after fracture A %	Percentage reduction of area Z %
1-1	10.00	767	450	450	22.5	50
1-2	10.00	767	448	449	21.0	50
1-3	10.00	771	452	453	22.0	50
1-4	10.00	769	452	452	22.0	50
1-5	10.01	763	448	450	22.5	52
1-6	10. 00	770	444	447	22.5	53
1-7	9.99	767	447	451	21.5	50
1-8	9.99	766	445	445	22.0	51
1-9	9.99	760	444	446	21.5	50
1-10	10.00	770	446	447	22.0	48
Mean value		767	447.6	449	21.95	50.4
Standard deviation S_i		3.399	2.989	2.667	0.497	1.350
Relative standard deviation		0.443%	0.668%	0.594%	2.264%	2.679%

L.2 Estimation of the uncertainty of tensile strength

Mathematical model

$$R_m = \frac{F_m}{S_o} \qquad \cdots\cdots(L.2)$$

$$u_{crel}(R_m) = \sqrt{u_{rel}^2(F_m) + u_{rel}^2(S_o) + u_{rel}^2(rep) + u_{rel}^2(R_{mV})} \qquad \cdots\cdots(L.3)$$

Wherein:

R_m — tensile strength;

F_m — maximum force;

S_o — original cross-sectional area;

rep — repeatability;

R_{mV} — effects of tensile rate on tensile strength.

L.2.1 Estimation of class A relative standard uncertainty subitem u_{rel}(rep)

This example is used for estimating the uncertainty of measured mean values of the three test pieces, so it shall be divided by$\sqrt{3}$.

$$u_{rel}(rep) = \frac{s}{\sqrt{3}} = \frac{0.443\%}{\sqrt{3}} = 0.256\% \qquad \cdots\cdots(L.4)$$

L.2.2 Estimation of class B relative standard uncertainty subitem $u_{rel}(F_m)$ of maximum force F_m

(1) Relative standard uncertainty $u_{rel}(F_1)$ caused by the indication error of the dynamometric system of testing machine

The indication error of level 1.0 tensile tesing machine is within ±1.0%, k= $\sqrt{3}$ considering the uniform distribution, then:

$$u_{rel}(F_1) = \frac{1.0\%}{\sqrt{3}} = 0.577\% \qquad \cdots\cdots(L.5)$$

(2) Relative standard uncertainty $u_{rel}(F_2)$ of standard dynamometer

Verify the testing machine using standard dynamometer of level 0.3.Repeatability R =0.3%.It can be regarded as the repeatability limit.The uncertainty of its relative standard is:

$$u_{rel}(F_2) = \frac{R}{2.83} = \frac{0.3\%}{2.83} = 0.106\% \qquad \cdots\cdots(L.6)$$

(3) Relative standard uncertainty $u_{rel}(F_3)$ caused by the Computer Data Acquisition System

Class B relative standard uncertainty introduced by the Computer Data Acquisition System is 0.2×10^{-2}:

$$u_{rel}(F_3)=0.2\% \qquad \cdots\cdots(L.7)$$

(4) Relative standard uncertainty subitem $u_{rel}(F_m)$ of maximum force

$$u_{rel}(F_m) = \sqrt{u_{rel}^2(F_1) + u_{rel}^2(F_2) + u_{rel}^2(F_3)}$$

$$= \sqrt{(0.577\%)^2 + (0.106\%)^2 + (0.2\%)^2} = 0.620\% \qquad \cdots\cdots(L.8)$$

L.2.3 Estimation of the class B relative standard uncertainty subitem $u_{rel}(F_m)$ of original cross-sectional area S_o

When estimating the original cross-sectional area, the measurement of each dimision shall be accurate to within ±0.5%.

$$S_o = \frac{1}{4}\pi d^2$$

$$u_{rel}(d) = \frac{0.5\%}{\sqrt{3}} = 0.289\%$$

$$u_{rel}(S_o) = 2 \cdot u_{rel}(d) = 2 \times 0.289\% = 0.578\%$$

L.2.4 Relative standard uncertainty subitem $u_{rel}(R_{mv})$ caused by the effects of tensile rate

According to the test, the maximum deviation of tensile strength within the variation range of tensile rate is 10 MPa, therefore the effects of tensile rate on tensile strength is within ±5 MPa considering the uniform distribution:

$$u(R_{mV}) = \frac{5}{\sqrt{3}} = 2.887 \quad \text{(L.9)}$$

$$u_{rel}(R_{mV}) = \frac{2.887}{767} = 0.376\% \quad \text{(L.10)}$$

L.2.5 Relative combined uncertainty of tensile strength (Table L.2)

Table L.2 Summary of the relative combined uncertainty subitem of tensile strength

Standard uncertainty subitem	Source of uncertainty	Relative standard uncertainty
$u_{rel}(rep)$	Measurement repeatability	0.256%
$u_{rel}(F_m)$	Maximum force	0.620%
$u_{rel}(S_o)$	original cross-sectional area of test piece	0.578%
$u_{rel}(R_{mv})$	Tensile rate	0.376%

$$u_{crel}(R_m) = \sqrt{u_{rel}^2(rep) + u_{rel}^2(F_m) + u_{rel}^2(S_o) + u_{rel}^2(R_{mV})}$$
$$= \sqrt{(0.256\%)^2 + (0.620\%)^2 + (0.578\%)^2 + (0.376\%)^2} = 0.962\% \quad \text{(L.11)}$$

L.2.6 Relative expanded uncertainty of tensile strength

Take coverage probability force p=95%, wherein k=2

$$U_{rel}(R_m) = K \cdot u_{crel}(R_m) \quad \text{(L.12)}$$

$$U_{rel}(R_m) = 2 \times 0.962\% = 1.9\% \quad \text{(L.13)}$$

L.3 Estimation of the uncertainty of lower yield strength

Mathematical model $R_{eL} = \frac{F_{eL}}{S_o}$

$$u_{crel}(R_{eL}) = \sqrt{u_{rel}^2(F_{eL}) + u_{rel}^2(S_o) + u_{rel}^2(rep) + u_{rel}^2(R_{eLV})} \quad \text{(L.14)}$$

Wherein:

R_{eL} — lower yield strength;

F_{eL} — lower yield force;

S_o — original cross-sectional area;

rep — repeatability;

R_{eLV} — effects of tensile rate on lower yield strength.

L.3.1 Estimation of class A relative standard uncertainty subitem $u_{rel}(rep)$

This example is used for estimating the uncertainty of measured mean values of the three test pieces, so it shall be divided by $\sqrt{3}$.

$$u_{rel}(rep) = \frac{s}{\sqrt{3}} = \frac{0.668\%}{\sqrt{3}} = 0.386\% \quad \text{(L.15)}$$

L.3.2 Estimation of class B relative standard uncertainty subitem $u_{rel}(F_{eL})$ of lower yield force F_{eL}

Estimation of class B relative standard uncertainty subitem $u_{rel}(F_{eL})$ of lower yield force F_{eL} is the same as the estimation of class B relative standard uncertainty subitem $u_{rel}(F_m)$ fo maximum force F_m (see L.2.2 for estimation process).

$$u_{rel}(F_{eL}) = \sqrt{u_{rel}^2(F_1) + u_{rel}^2(F_2) + u_{rel}^2(F_3)} = 0.620\% \quad \text{(L.16)}$$

L.3.3 Estimation of the class B relative standard uncertainty subitem $u_{rel}(F_m)$ of original cross-sectional area S_o

The uncetrtainty of original cross-sectional area is the same as that ot L.2.3.

$$u_{rel}(S_o)=0.578\% \quad \text{(L.17)}$$

L.3.4 Estimation of relative standard uncertainty subitem $u_{rel}(R_{eLV})$ caused by the effects of tensile rate

According to the test, the maximum deviation of lower yield strength within the variation range of tensile rate is 10MPa, therefore the effects of tensile rate on lower yield strength is within ±5MPa considering the uniform distribution:

$$u(R_{eLV}) = \frac{5}{\sqrt{3}} = 2.887 \quad \text{(L.18)}$$

$$u_{rel}(R_{eLV}) = \frac{2.887}{447.6} = 0.645\% \quad \text{(L.19)}$$

L.3.5 Relative combined uncertainty of lower yield strength

See Table L.3 for summary of relative standard uncertainty subitem of lower yield strength

Table L.3 Summary of relative standard uncertainty subitem of lower yield strength

Standard uncertainty subitem	Source of uncertainty	Relative standard uncertainty
$u_{rel}(rep)$	Measurement repeatability	0.386%
$u_{rel}(F_{eL})$	Lower yield force	0.620%
$u_{rel}(S_o)$	original cross-sectional area of test piece	0.578%
$u_{rel}(R_{eLV})$	Tensile rate	0.645%

$$u_{crel}(R_{eL}) = \sqrt{u_{rel}^2(rep) + u_{rel}^2(F_{eL}) + u_{rel}^2(S_o) + u_{rel}^2(R_{eLV})}$$
$$= \sqrt{(0.386\%)^2 + (0.620\%)^2 + (0.578\%)^2 + (0.645\%)^2} = 1.133\% \quad \text{(L.20)}$$

L.3.6 Relative expanded uncertainty of lower yield strength

Take coverage probability force p=95%, wherein k=2

Relative expanded uncertainty ..... $U_{rel}(R_{eL})=K\times u_{crel}(R_{eL})$ (L.21)

$$U_{rel}(R_{eL})=2\times 1.133\%=2.3\% \quad \text{(L.22)}$$

L.4 Estimation of the uncertainty of prescribed plastic extension strength

Mathematical model

$$R_p = \frac{F_p}{S_o}$$

$$u_{crel}(R_p) = \sqrt{u_{rel}^2(F_p) + u_{rel}^2(S_o) + u_{rel}^2(rep) + u_{rel}^2(R_{pV})} \quad \text{(L.23)}$$

Wherein:

R_p — prescribed plastic extension strength;

R_p — prescribed plastic extension force;

S_o — original cross-sectional area;
rep — repeatability;
R_{pv}— effects of tensile rate on prescribed plastic extension strength.

L.4.1 Estimation of class A relative standard uncertainty subitem u_{rel}(rep)

This example is used for estimating the uncertainty of measured mean values of the three test pieces, so it shall be divided by$\sqrt{3}$.

$$u_{rel}(\mathrm{rep}) = \frac{s}{\sqrt{3}} = \frac{0.594\%}{\sqrt{3}} = 0.343\% \quad \text{(L.24)}$$

L.4.2 Estimation of class B relative standard uncertainty subitem $u_{rel}(F_p)$ of prescribed plastic extension force F_p

Prescribed plastic extension force is calculated as the following: on the force-extension curve, draw a line parallel to the linear portion of the curve and at a distance from it equivalent to the plastic percentage extension of 0.2%.The point at which this line intersects the curve gives the force corresponding to the prescribed plastic extension strength.

Unable to get the mathematical expression of force-extension curve, therefore, we cannot determine accurately the relation between the relative standard uncertainty $u_{rel}(\triangle L_e)$ of extensometer measurement strain and the relative standard uncertainty $u_{rel}(F_e)$ of force value.To get the approximate relationship between them, draw a tangent of the curve through the intersection point and the intersection angle with abscissa is α.The approximate relationship between the relative standard uncertainty $u_{rel}(\triangle L_e)$ of extensometer measurement strain and the relative standard uncertainty $u_{rel}(F_e)$ of force value caused by extensometer meet the following expression:

$$u_{rel}(F_e)=\tan\alpha \cdot u_{rel}(\triangle L_e) \quad \text{(L.25)}$$

The reltative deviation of level 1 extensometer is within ±1% considering the uniform distribution.

$$u_{rel}(\Delta L_e) = \frac{1\%}{\sqrt{3}} = 0.577\% \quad \text{(L.26)}$$

Then

In actual operation, angle α is related to the proportion of coordinate axis, $\tan\alpha = \frac{\Delta F}{\Delta L}$, which is intersection point $\frac{\Delta F}{\Delta L} \approx 0$ in this example.

Then $u_{rel}(F_e) = \frac{\Delta F}{\Delta L} \cdot u_{rel}(\Delta L_e) \approx 0$

$$u_{rel}(F_p) = \sqrt{u_{rel}^2(F_1) + u_{rel}^2(F_2) + u_{rel}^2(F_3) + u_{rel}^2(F_e)} = 0.620\% \quad \text{(L.27)}$$

L.4.3 Estimation of the class B relative standard uncertainty subitem $u_{rel}(F_m)$ of original cross-sectional area S_o

The uncetrtainty of original cross-sectional area is the same as that ot L.2.3:

$$u_{rel}(S_o)=0.578\% \quad \text{(L.28)}$$

L.4.4 Estimation of relative standard uncertainty subitem $u_{rel}(R_{pv})$ caused by the effects of tensile rate

According to the test, the maximum deviation of prescribed plastic extension strength within the variation range of tensile rate is 10 MPa, therefore the effects of tensile rate on prescribed plastic extension strength is within ±5 MPa considering the uniform distribution:

$$u(R_{pv}) = \frac{5}{\sqrt{3}} = 2.887 \quad \text{(L.29)}$$

$$u_{rel}(R_{pv}) = \frac{2.887}{449} = 0.643\% \quad \text{(L.30)}$$

L.4.5 Relative combined uncertainty of prescribed plastic extension strength (Table L.4)

Table L.4 Summary of the relative combined uncertainty subitem of prescribed plastic extension strength

Standard uncertainty subitem	Source of uncertainty	Relative standard uncertainty
u_{rel}(rep)	Measurement repeatability	0.343%

Table L.4 (continued)

Standard uncertainty subitem	Source of uncertainty	Relative standard uncertainty
$u_{rel}(F_p)$	prescribed plastic extension force	0.620%
$u_{rel}(S_o)$	original cross-sectional area of test piece	0.578%
$u_{rel}(R_{pv})$	Tensile rate	0.643%

Relative combined uncertainty:

$$u_{crel}(R_p)=\sqrt{u_{rel}^2(F_p)+u_{rel}^2(S_o)+u_{rel}^2(\mathrm{rep})+u_{rel}^2(R_{pV})}$$
$$=\sqrt{(0.343\%)^2+(0.620\%)^2+(0.578\%)^2+(0.643\%)^2}=1.12\% \quad \text{(L.31)}$$

L.4.6 Relative expanded uncertainty of prescribed plastic extension strength

Take coverage probability force p=95%, wherein k=2

Relative expanded uncertainty ..... $U_{rel}(R_p)=k\times u_{crel}(R_p)=2\times 1.12\%=2.2\%$ (L.32)

L.5 Estimation of the uncertainty of percentage elongation after fracture

Mathematical model

$$A=\frac{L_u-L_o}{L_o} \quad \text{(L.33)}$$

Wherein:

A — Percentage elongation after fracture;

L_o — the original gauge length;

L_u — the final gauge length after fracture.

The measurement of elongation after fracture （L_u—L_o） shall be accurate to within 0.25mm.The formula is expressed as the following when estimating the meansurement uncertainty:

$$A=\frac{L_u-L_o}{L_o}=\frac{\Delta L}{L_o} \quad \text{(L.34)}$$

△L and L_o are not related to each other, then:

$$u_{crel}(A)=\sqrt{u_{rel}^2(L_o)+u_{rel}^2(\Delta L)+u_{rel}^2(\mathrm{rep})+u_{rel}^2(\mathrm{off})} \quad \text{(L.35)}$$

L.5.1 Estimation of class A relative standard uncertainty subitem u_{rel}(rep)

This example is used for estimating the uncertainty of measured mean values of the three test pieces, so it shall be divided by$\sqrt{3}$

$$u_{rel}(\mathrm{rep})=\frac{s}{\sqrt{3}}=\frac{2.264\%}{\sqrt{3}}=1.307\% \quad \text{(L.36)}$$

L.5.2 Estimation of class B relative standard uncertainty subitem $u_{rel}(L_o)$ of original gauge length

Accordint to the standard specification, the original gauge length L_o shall be accurate to within ±1%.k=$\sqrt{3}$ considering the uniform distribution, then:

$$u_{rel}(L_o)=\frac{1\%}{\sqrt{3}}=0.577\% \quad \text{(L.37)}$$

L.5.3 Estimation of class B relative standard uncertainty subitem $u_{rel}(\triangle L)$ of elongation after fracture

The measurement of (L_u—L_o) shall be accurate to within ±0.25mm.The average elongation of this test is 10.975mm, k=$\sqrt{3}$ considering the uniform distribution, then:

$$u_{rel}(\Delta L)=\frac{0.25}{10.975\times\sqrt{3}}=1.315\% \quad \text{(L.38)}$$

L.5.4 Relative standard uncertainty subitem u_{rel}(off) caused by rounding off

The rounding off interval of percentage elongation after fracture is 0.5%.Considering the uniform distribution, relative standard uncertainty subitem caused by rounding off is:

$$u_{rel}(\text{off})=\frac{0.5\%}{2\cdot\sqrt{3}\cdot 21.95\%}=0.658\% \quad \text{(L.39)}$$

L.5.5 Relative combined uncertainty of percentage elongation after fracture (Table L.5)

Table L.5 Summary of the standard uncertainty subitem of percentage elongation after fracture

Standard uncertainty subitem	Source of uncertainty	Relative standard uncertainty	Mean value
u_{rel}(rep)	Measurement repeatability	1.307%	21.95%
$u_{rel}(L_o)$	Original gauge length of test piece	0.577%	$\overline{L_o}$=50mm
$u_{rel}(\triangle L)$	Elongation after fracture	1.315%	$\overline{\Delta L}$=10.975mm
u_{rel}(off)	Rounding off	0.658%	

Relative combined uncertainty:

$$u_{crel}(A)=\sqrt{u_{rel}^2(L_o)+u_{rel}^2(\Delta L)+u_{rel}^2(\text{rep})+u_{rel}^2(\text{off})} \quad \text{(L.40)}$$

$$=\sqrt{(0.577\%)^2+(1.315\%)^2+(1.307\%)^2+(0.658\%)^2}$$

$$=2.05\%$$

L.5.6 Relative expanded uncertainty of percentage elongation after fracture

Take coverage probability force p=95%, wherein k=2

$$U_{rel}(A)=k\times u_{crel}(A)=2\times 2.05\%=4.1\% \quad \text{(L.41)}$$

L.6 Estimation of the uncertainty of percentage reduction of area

Mathematical model

$$Z=\frac{S_o-S_u}{S_o} \quad \text{(L.42)}$$

Wherein:

Z — percentage reduction of area;

S_o — original cross-sectional area;

S_u — minimum cross-sectional area after fracture.

In the formula, S_u is not independent, but significantly related to S_o.Consider the correlation coefficient as 1 between S_o and S_u.In accordance with the following expression:

$$u_c^2(y)=\left[\sum_{i=1}^{N}c_i u(x_i)\right]^2=\left[\sum_{i=1}^{N}\frac{\partial f}{\partial x_i}u(x_i)\right]^2 \quad \text{(L.43)}$$

$$u_c(S_o,S_u)=\left|\frac{S_u}{S_o^2}\cdot u(S_o)-\frac{1}{S_o}\cdot u(S_u)\right|$$

$$u_c(Z)=\sqrt{u_c^2(S_o,S_u)+u^2(\mathrm{rep})+u^2(\mathrm{off})}$$

L.6.1 Estimation of class A standard uncertainty subitem u(rep)

This example is used for estimating the uncertainty of measured mean values of the three test pieces, so it shall be divided by$\sqrt{3}$

$$u(\mathrm{rep})=\frac{s}{\sqrt{3}}=\frac{1.350\%}{\sqrt{3}}=0.779\% \quad \text{(L.44)}$$

L.6.2 Estimation of standard uncertainty subitem u(S_o) of original cross-sectional area

The measurement of each dimision shall be accurate to within ±0.5%.

Nominal diameter of test piece: d=10mm, $S_o=\frac{1}{4}\pi d^2$ =78.54mm^2.

$$u_{\mathrm{rel}}(d)=\frac{0.5\%}{\sqrt{3}}=0.289\%$$

$u_{rel}(S_o)=2\cdot u_{rel}(d)=0.578\%$

$u(S_o)=78.54\times 0.578\%=0.454\mathrm{mm}^2$

L.6.3 Estimation of standard uncertainty subitem u(S_u) of cross-sectional area after fracture

Determination of minimum cross-sectional area after fracture in this standard shall be accurate to ±2% considering the uniform distribution:

$$u_{\mathrm{rel}}(S_u)=\frac{2\%}{\sqrt{3}}=1.155\ \% \quad \text{(L.45)}$$

Accrording to the calculation, the average cross-sectional area at minimum diameter of necking after fracture is S_u=38.96mm^2

$u(S_u)=-38.96\times 1.155\%=0.450\mathrm{mm}^2$ (L.46)

L.6.4 Relative standard uncertainty subitem caused by rounding off

According to the specification of Article 22 of this part, the rounding off interval of percentage reduction of area is 1%, considering the uniform distribution, standard uncertainty subitem caused by rounding off is:

$$u(\mathrm{off})=\frac{1\%}{2\cdot\sqrt{3}}=0.289\% \quad \text{(L.47)}$$

L.6.5 Relative combined uncertainty of percentage reduction of area

See Table L.6 for the summary of standard uncertainty subitem of percentage reduction of area.

Table L.6 Summary of standard uncertainty subitem of percentage reduction of area

Standard uncertainty subitem	Source of uncertainty	Standard uncertainty	Mean value
u(rep)	Measurement repeatability	0.758%	$\overline{Z}$=50.4%
u(S_u)	Cross-sectional area after fracture	0.457mm^2	$\overline{S_u}$ =38.96mm^2
u(S_o)	original cross-sectional area of test piece	0.454mm^2	$\overline{S_o}$ =78.54mm^2
u(off)	Rounding off	0.289%	

$$u_c(S_o, S_u) = \left| \frac{S_u}{S_o^2} \cdot u(S_o) - \frac{1}{S_o} \cdot u(S_u) \right|$$

$$= \left| \frac{38.96}{78.54^2} \times 0.450 - \frac{0.457}{78.54} \right| = 0.298\% \quad \text{(L.48)}$$

$$u_c(Z) = \sqrt{u_c^2(S_o, S_u) + u^2(\text{rep}) + u^2(\text{off})}$$

$$= \sqrt{(0.298\%)^2 + (0.758\%)^2 + (0.289\%)^2} = 0.861\% \quad \text{(L.49)}$$

L.6.6 Relative expanded uncertainty of percentage reduction of area

Take coverage probability force p=95%, wherein k=2

Relative expanded uncertainty ..... $U(Z)=K\times u_c(Z)=2\times 0.861\%=1.7\%$ (L.50)

$U_{rel}(Z)=3.4\%$

L.7 Summary of relative expanded uncertainty

See Table L.7 for summary of relative expanded uncertainty.

Table L.7 Summary of relative expanded uncertainty

Tensile strength $U_{rel}(R_m)$	Lower yield strength $U_{rel}(R_{eL})$	Prescribed plastic extension strength $U_{rel}(R_p)$	Percentage elongation after fracture $U_{rel}(A)$	percentage reduction of area $U_{rel}(Z)$
1.9%	2.3%	2.2%	4.1%	3.4%

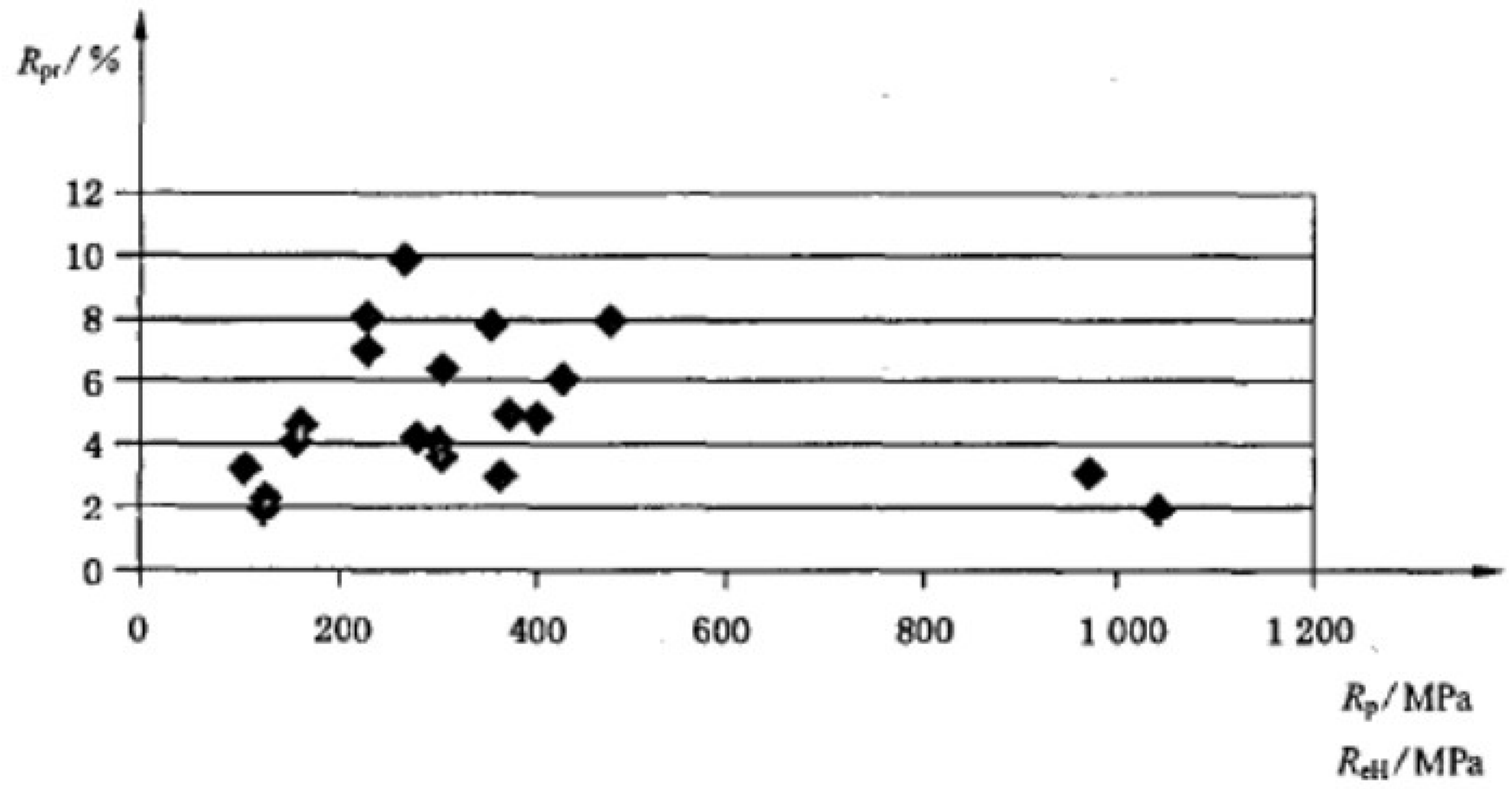
Annex M
(Informative)
Precision of tensile testing – Results from interlaboratory programmes

M.1 Interlaboratory scatter

An indication of the typical scatter in tensile test results for a variety of materials that have been reported during laboratory intercomparison exercises, which include both material scatter and measurement uncertainty, are shown in Tables M.1 to M4.Graphic presentation of the values in Tables M.1 to M.4 is given in Figures M.1 to M.4.The results for the reproducibility are expressed as percentages calculated by multiplying by 2 the standard deviation of the respective parameter, e.g R_p, R_m and A, and dividing the result by the mean value of the parameter.Thereby giving values of reproducibility which represent the 95 % confidence level in accordance with GUM, and which may be directly compared with the expanded uncertainty values calculated by alternative methods.

Table M.1 Yield strengths (0.2% prescribed plastic extension strength or upper yield strengths) - Reproducibility from laboratory intercomparison exercises

Material	Code	Yield strength MPa	Reproducilibity %	Bibliography
Aluminium plate	AA5754	105.7	3.2	[4]
	AA5182-O	126.4	1.9	[5]
	AA6016-T4	127.2	2.2	[5]
	EC-H 19	158.4	4.1	[6]
	2024-T 351	362.9	3.0	[6]
steel				
sheet	DX56	162.0	4.6	[4]
Low carbon steel plate	HR3	228.6	8.2	[7]
sheet	ZStE 180	267.1	9.9	[4]
AISI 105	P245GH	367.4	5.0	[7]
	C22	402.4	4.9	[6]
plate	S355	427.6	6.1	[4]
Austenitic stainless steel				
	SS316L	230.7	6.9	[4]
	X2CrNi18-10	303.8	6.5	[7]
AISI 316	X2CrNiMo18-10	353.3	7.8	[7]
Martensitic stainless steel	X5CrNiMo17-12-2	480.1	8.1	[6]
High strength steel	X12Cr13	967.5	3.2	[6]
	30NiCrMo16	1039.9	2.0	[7]
Nickel alloy				
INCONEL 600	NiCr15Fe8	268.3	4.4	[6]
Nimonic 75	(BCR-661)	298.1	4.0	[8]
Nimonic 75	(BCR-661)	302.1	3.6	[4]



Notes:

R_{eH} — upper yield strength;

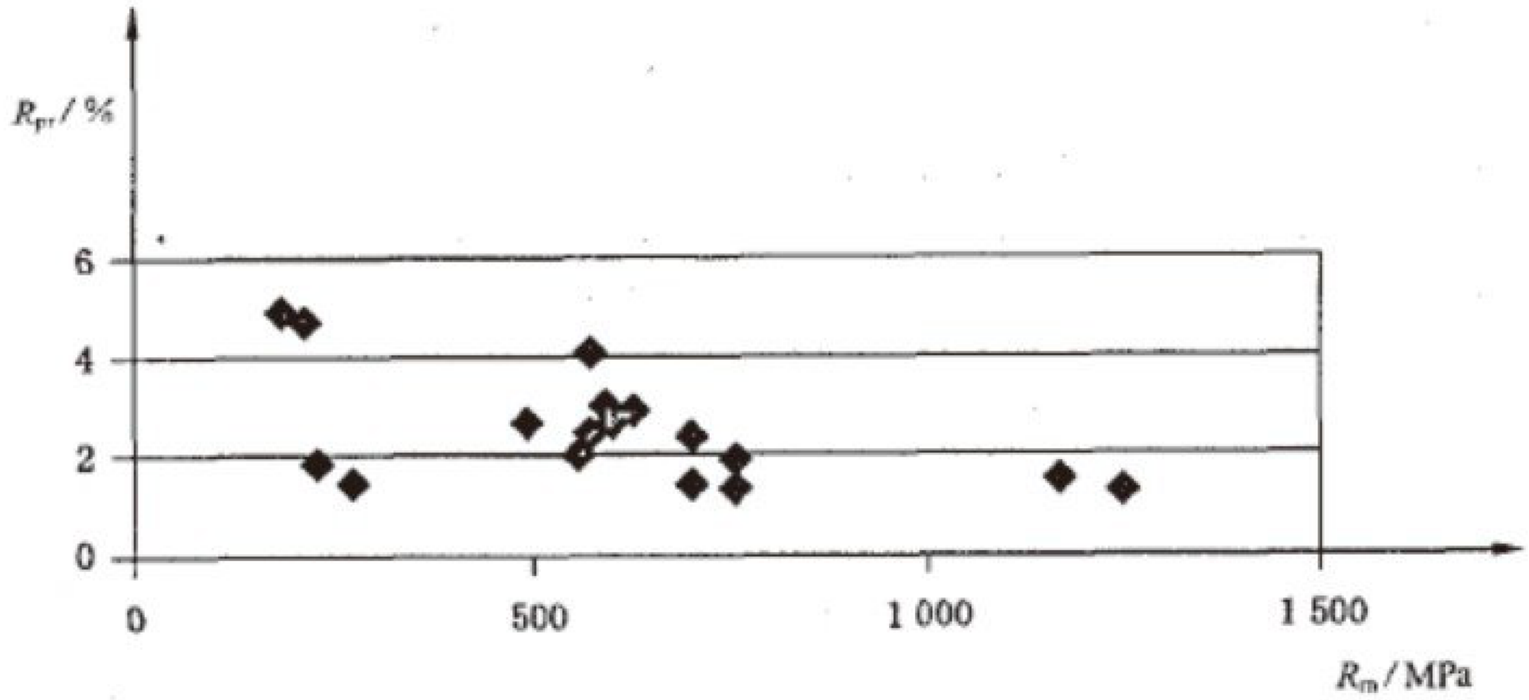
R_p— plastic extension strength;

R_{pr} — reproducibility

Figure M.1 Graphic presentation of the values given in Table M.1

Table M.2 Tensile strength R_m – Reproducibility from laboratory intercomparison exercises

Material	Code	Tensile strength MPa	Reproducilibity %	Bibliography
Aluminium plate	AA5754	212.3	4.7	[4]
	AA5182-0	275.2	1.4	[5]
	AA6016-T4	228.3	1.8	[5]
	EC-H 19	176.9	4.9	[6]
	2024-T 351	491.3	2.7	[6]
steel				
sheet	DX56	301.1	5.0	[4]
Low carbon steel plate	HR3	335.2	5.0	[7]
sheet	ZStE 180	315.3	4.2	[4]
AISI 105	Fe510C	552.4	2.0	[7]
	C22	596.9	2.8	[6]
plate	S355	564.9	2.4	[4]
Austenitic stainless steel	SS316L	568.7	4.1	[4]
	X2CrNi18-10	594.0	3.0	[7]
AISI 316	X2CrNiMo18-10	622.5	3.0	[7]
	X7CrNiMo17-12-2	694.6	2.4	[6]
Martensitic stainless steel	X12Cr13	1253.0	1.3	[6]
High strength steel	30NiCrMo16	1167.8	L5	[7]
Nickel alloy				
INCONEL 600	NiCr15Fe8	695.9	L4	[6]
Nimonic 75	(BCR-661)	749.6	1.9	[8]
Nimonic 75	(BCR-661)	754.2	L3	[4]



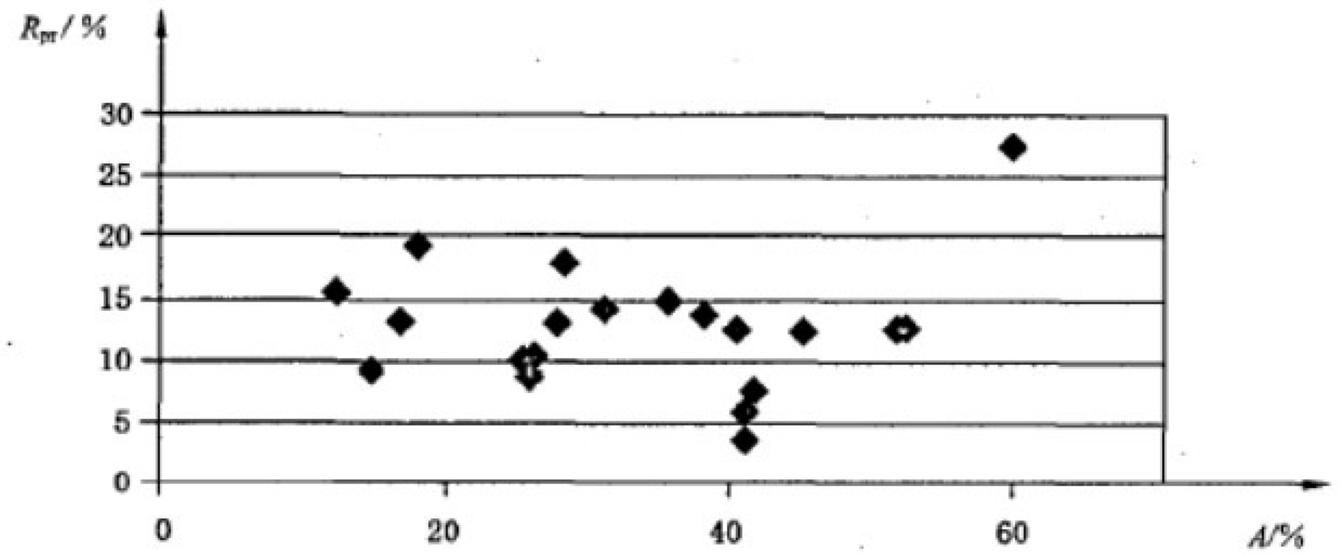
Notes:
R_m — tensile strength;
R_{pr} — reproducibility.

Figure M.2 Graphic presentation of the values given in Table M.2

Table M.3 Percentage elongation after fracture – Reproducibility from laboratory intercomparison exercises

Material	Code	Percentage elongation after fracture A %	Reproducilibity[a] %	Bibliography
Aluminium plate	AA5754	27.9	13.3	[4]
	AA5182-0	26.6(A_{80mm})	10.6	[5]
	AA6016-T4	25.9(A_{80mm})	8.4	[5]
	EC-H 19	14.6	9.1	[6]
	2024-T 351	18.0	18.9	[6]
steel				
sheet	DX56	45.2	12.4	[4]
Low carbon steel plate	HR3	38.4	13.8	[7]
sheet	ZstE 180	40.5	12.7	[4]
AISI 105	Fe510C	31.4	14.0	[7]
	C22	25.6	10. 1	[6]
plate	S355	28.5	17.7	[4]
Austenitic stainless steel	SS316L	60.1	27.6	[4]
Austenitic stainless steel	X2CrNi18-10	52.5	12.6	[7]
Austenitic stainless steel	X2CrNiMo18-10	51.9	12.7	[7]
AISI 316	X5CrNiMo17-12-2	35.9	14.9	[6]
Martensitic stainless steel	X12Cr13	12.4	15.5	[6]
High strength steel	30NiCrMo16	16.7	13.3	[7]
Nickel alloy				
INCONEL 600	NiCr15Fe8	41.6	7.7	[6]
Nimonic 75	(BCR-661)	41.0	3.3	[8]
Nimonic 75	(BCR-661)	41.0	5.9	[4]

[a] The reproducibility is expressed as a percentage of the respective mean value of A for the given material; thus for 2024-T351 alumnium alloy, the absolute value of A is (18.0±3.4)%.



Notes:
A Percentage elongation after fracture;
R_{pr} — reproducibility.

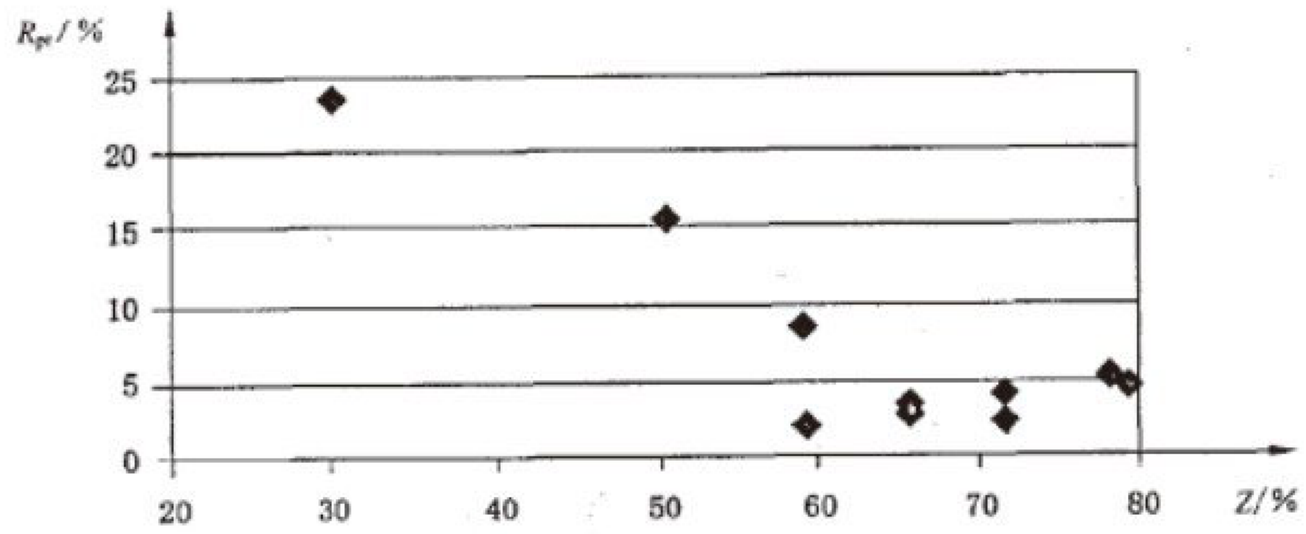
Figure M.3 Graphic presentation of the values given in Table M.3

Table M.4 Percentage reduction of area Z – Reproducibility from laboratory intercomparison exercises

Material	Code	percentage reduction of area Z %	Reproducilibity[a] %	Bibliography
Aluminium	EC-H 19	79.1	5.1	[6]
	2024-T 351	30.3	23.7[b]	[6]
steel				
Low carbon steel plate	HR3			
AISI 105	Fe510C	71.4	2.7	[7]
	C22	65.6	3.8	[6]
Austenitic stainless steel	X2CrNi18-10			
Austenitic stainless steel	X2CrNiMo18-10	77.9	5.6	[7]
AISI 316	X5CrNiMo17-12-2	71.5	4.5	[6]
Martensitic stainless steel	X12Cr13	50.5	15.6[b]	[6]
High strength steel	30NiCrMo16	65.6	3.2	[7]
Nickel alloy				
INCONEL 600	NiCr15Fe8	59.3	2.4	[6]
Nimonic 75	(BCR-661)	59.0	8.8	[8]

[a] The reproducibility is expressed as a percentage of the respective mean value of Z for the given material; thus for 2024-T351 alumnium alloy, the absolute value of Z is (30.3±7.2)%.

[b] Some of the values of reproducibility may appear to be relatively high; such values probably indicate the difficulty of reliably measuring the dimensions of the test piece in the necked region of the fracture.For thin sheet test pieces the uncertainty of measurement of the thickness of the test piece may be large.Likewise the measurement of the diameter or thickness of the test piece in the necked region is highly dependent upon the skill and experience of the operator.



Notes:
R_{pr} — reproducibility;
Z — percentage reduction of area.

Figure M.4 Graphic presentation of the values given in Table M.4

Bibliography

[1] GB/T 24182 — 2009 Mechanical testing of metals – Symbols and definitions in published standards
[2] ASTM E1012, Standard practice for verification of test frame and specimen alignment under tensile and compressive axial force application
[3] Li He-ping, Zhou Xing. The method to evaluate the measurement uncertainty of tensile test by quasi – reference materials [J]. Physical Testing and Chemical Analysis Part A, 2005, 41 (6): 289-300.
[4] KLINGELHÖFFER, H.， LEDWORUSKI, S.， BROOKES, S. , MAY, T. Computer controlled tensile testing according to EN 10002-1 —Results of a comparison test programme to validate a proposal for an amendment of the standard —Final report of the European project TEN- STAND —Work Package 4. Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin, 2005. 44 p. (Forschurngsbericht [Technical report] 268.) Available (2008-07-01) at:http://www.bam.de/de/service/publikationen/publikationen_medien/fb268_vt, pdf
[5] AEGERTER, J., KELLER,S. ,WIESER,D. Prüfvorschrift zur Durchführung und Auswer- tung des Zugversuches fur Al-Werkstoffe [Test procedure for the accomplishment and evaluation of the tensile test for aluminium and aluminium alloys], In: Proceedings of Werkstoffprüfung [Materials testing] 2003 ,pp, 139-150. Stahleisen, Düsseldorf
[6] ASTM Research Report E 28 1004 : 1994,Round robin results of interlaboratory tensile tests
[7] ROESCH,L' ,COUE,N. , VITALI, J. , DI FANT,M. Results of an interlaboratory test programme on room temperature tensile properties -Standard deviation of the measured values. (IRSID Report,NDT 93310.)
[8] INGELBRECHT,C D. ,LOVEDAY,M. S. The certification of ambient temperature tensile properties of a reference material for tensile testing according to EN 10002-1 : CRM 661. EC, Brussels,2000. (BCR Report EUR 19589 EN.)