INTERNATIONAL STANDARD

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Metallic materials — Tensile testing at low temperature

Matériaux métalliques — Essai de traction à basse température

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Foreword

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

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 15579 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of materials*, Subcommittee SC 1, *Uniaxial testing*.

Annex A of this International Standard is for information only.

Introduction

It was decided, at the ISO/TC 164/SC 1 meeting of 29th February and 1st March 1996, to define test rate by the strain rate of the parallel length of the test piece. The values taken into account correspond to testing steel products. If this International Standard is used for testing non-ferrous metallic materials, it should be verified that the test and rate values apply.

Metallic materials — Tensile testing at low temperature

1 Scope

This International Standard specifies the method of tensile testing of metallic materials at temperatures between + 10 °C and – 196 °C and defines the mechanical properties which can be determined.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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

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

3 Terms and definitions

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

3.1
gauge length
L
length of the cylindrical or prismatic portion of the test piece on which elongation shall be measured

NOTE In particular, a distinction is made between the lengths defined in 3.1.1 and 3.1.2.

3.1.1
original gauge length
L_o
gauge length before application of force measured at ambient temperature

3.1.2
final gauge length
L_u
gauge length after fracture of the test piece (see 9.3) measured at ambient temperature

3.2
parallel length
L_c
length of the parallel portion of the reduced section of the test piece

3.3
extensometer gauge length
L_e
length of the parallel portion of the test piece used for the measurement of elongation by means of an extensometer

NOTE This length may differ from L_o and has a value greater than b or d (see Table 1) but less than L_c.

3.4
elongation
increase in the original gauge length (L_o) at any moment during the test

3.5
percentage elongation
elongation expressed as a percentage of the original gauge length (L_o)

3.6
percentage permanent elongation
increase in the original gauge length of a test piece after removal of a specified stress (see 3.13), expressed as a percentage of the original gauge length (L_o)

3.7
percentage elongation after fracture
A
permanent elongation of the original gauge length after fracture ($L_u - L_o$), expressed as a percentage of the original gauge length (L_o)

NOTE In the case of proportional test pieces, only if the original gauge length is other than $5{,}65\sqrt{S_o}$ [1)] where S_o is the original cross-sectional area of the parallel length should the symbol A be supplemented by an index indicating the coefficient of proportionality used, e.g.:

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

In the case of non-proportional test pieces, the symbol A should be supplemented by an index indicating the original gauge length used, expressed in millimetres, e.g.:

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

3.8
percentage total elongation at fracture
A_t
total elongation (elastic elongation plus plastic elongation) of the gauge length at the moment of fracture expressed as a percentage of the original gauge length (L_o)

3.9
extension
increase in the extensometer gauge length (L_e) at a given moment of the test

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

3.10
percentage permanent extension
increase in the extensometer gauge length, after removal from the test piece of a specified stress, expressed as a percentage of the extensometer gauge length (L_e)

3.11
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 orignal cross-sectional area (S_o)

3.12
maximum force
F_m
the maximum force which the test piece withstands during the test after any yielding has taken place

NOTE For brittle materials, it is the maximum value during the test.

3.13
stress
force at any moment during the test divided by the original cross-sectional area (S_o) of the test piece

3.13.1
tensile strength
R_m
stress corresponding to the maximum force (F_m)

3.13.2
yield strength
when the metallic material exhibits a yield phenomenon, a point during the test at which plastic deformation occurs without any increase in the force

3.13.2.1
upper yield strength
R_{eH}
value of stress at which the first decrease in force is observed

See Figure 1.

3.13.2.2
lower yield strength
R_{eL}
lowest value of stress during plastic yielding, ignoring any transient effects

See Figure 1.

3.13.3
proof strength, non-proportional extension
R_p
stress at which the non-proportional extension is equal to a specified percentage of the extensometer gauge length (L_e)

See Figure 2.

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

4 Symbols and designations

Symbols and corresponding designations are given in Table 1.

Table 1 — Symbols and designations

Symbol	Unit	Designation
a	mm	Thickness of a flat test piece or wall thickness of a tube
b	mm	Width of the parallel length of a flat test piece or average width of the longitudinal strip taken from a tube or width of flat wire
d	mm	Diameter of the parallel length of a cylindrical test piece or diameter of a circular wire
L_o	mm	Original gauge length
L_u	mm	Final gauge length after fracture
L_c	mm	Parallel length
L_e	mm	Extensometer gauge length
S_o	mm^2	Original cross-sectional area of the parallel length
S_u	mm^2	Minimum cross-sectional area after fracture (final cross-sectional area)
Z	%	Percentage reduction of area: $\frac{S_o - S_u}{S_o} \times 100$
A	%	Percentage elongation after fracture: $\frac{L_u - L_o}{L_o} \times 100$
A_t	%	Percentage total elongation at fracture
F_m	N	Maximum force
R_{eH}	N/mm^2	Upper yield strength
R_{eL}	N/mm^2	Lower yield strength
R_m	N/mm^2	Tensile strength
R_p	N/mm^2	Proof strength, non-proportional extension
θ	°C	Specified temperature
θ_i	°C	Indicated temperature

5 Principle

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

The test is carried out at a specified temperature which is between + 10 °C and – 196 °C.

6 Apparatus

6.1 Testing machine

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

6.2 Extensometer

When using an extensometer to measure the extension, the extensometer shall be of class 1 (see ISO 9513) for the determination of the proof stress for non-proportional elongation; for the determination of other properties (corresponding to higher elongations) an extensometer of class 2 (see ISO 9513) can be used.

The extensometer gauge length shall be not less than 10 mm and shall be centrally located in the mid-region of the parallel length and along the centre axis. The extensometer should preferably be of the type that is capable of measuring extension on both sides of a test piece thus enabling the operator to determine the mean of the two readings.

Any part of the extensometer projecting beyond the cooling device shall be protected from air currents so that fluctuations in the ambient temperature have only a minimal effect on the readings. It is recommended that reasonable stability of the temperature and speed of the air surrounding the testing machine be maintained.

6.3 Cooling device

6.3.1 General

The cooling device shall be capable of cooling the test piece to the specified temperature θ.

The means of cooling can be, for example:

— by refrigeration unit;

— by expansion of compressed gas (e.g. CO_2 or N_2);

— by immersion in a liquid maintained at its boiling point (e.g. N_2) or in a refrigerated liquid (e.g. alcohol).

WARNING — Test personnel should use proper personal protective equipment when handling the cooling medium. Precautions should be taken to avoid damage to the test equipment or test piece.

6.3.2 Measurement of temperature

The temperature of the cooling medium or the test piece shall be measured by thermocouples or other suitable devices.

The temperature of the test piece shall be measured at the surface of the parallel length of the test piece.

NOTE 1 Use of the proper type and class of thermocouple is important to ensure accuracy of the measured temperature.

NOTE 2 When the gauge length is less than 50 mm, one thermocouple should be placed at each end of the parallel length. When the gauge length is equal to or greater than 50 mm, a third thermocouple should be placed near the centre of the parallel length.

If the test piece is in a liquid medium which can be assumed to be homogeneous, the temperature measurement may be done at a point away from the test piece.

If testing is carried out in liquid nitrogen, no temperature measurement is needed. In this case, it shall be recorded in the test report.

The temperature-measuring equipment shall have a resolution of 1 °C or better and an accuracy of ± 2 °C for the range + 10 °C to – 40 °C and ± 3 °C for the range – 41 °C to – 196 °C.

6.3.3 Permitted deviations of temperature

The permitted deviation between the specified temperature θ and the indicated temperature θ_i is ± 3 °C. The temperature gradient along the surface of the test piece shall not exceed 3 °C.

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

6.3.4 Verification of the temperature-measuring system

The temperature-measuring system, comprising sensors and read-out equipment, should be verified over the working temperature range at intervals not exceeding 90 days. If verification records demonstrate that the stability of the system's performance does not significantly affect the uncertainty of measurement, the verification period may be increased but shall not exceed one year; the errors shall be recorded in the verification report. The equipment used for the verification of the temperature-measuring system shall be traceable to national standards.

7 Test piece

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

The test piece is usually obtained by machining a sample from the product, from a pressed blank or from a casting.

The cross-section of the test pieces may be circular, square, rectangular, annular or, in special cases, of some other shape. Examples of test pieces which may be used are given in annex A.

When selecting a test piece geometry consider that, in general, the strength increases and the ductility decreases with decreasing temperature.

To ensure fracture in the gauge length, it is necessary that:

a) a sufficiently high ratio of gripped end to gauge cross-sectional area of the test piece be chosen;

b) notch effects at cross-sectional transitions, at drill holes and threads be minimized.

8 Testing conditions

8.1 Cooling of test piece

The test piece shall be cooled to the specified temperature θ. The cooling time depends on the test piece (shape, size, surface condition), on the nature of the material, on the mass of the grips and on the cooling medium. Therefore, the cooling time shall be determined by preliminary measurements.

NOTE It is understood that cooling time includes soaking time.

During the cooling process, the temperature of the test piece shall not go below the specified temperature within its tolerances, except by special agreement between the parties concerned.

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

In all cases, the application of force shall only be started when any fluctuations from the readout device of the elongation-measuring apparatus have stabilized.

8.2 Application of force on the test piece

Force shall be applied so as to increase strain on the test piece in a continual (non-stepwise) manner, without shock or sudden vibration. The force shall be applied along the specimen axis so as to minimize bending or torsion in the specimen gauge length; see Bibliography.

8.3 Test rate

Unless otherwise agreed in the product standard, the test rate based on the strain rate of the parallel length of the test piece shall comply with the requirements given in 8.3.1 and 8.3.2.

8.3.1 Yield and proof strengths

8.3.1.1 Upper yield strength, R_{eH}

Within the elastic range and up to the upper yield strength the strain rate shall be between 0,000 03/s and 0,000 3/s and shall be kept as constant as possible.

NOTE If the testing machine is not capable of measuring and controlling the strain rate, a grip head separation speed equivalent to a stress rate between 6 N/mm^2 · s^{-1} and 60 N/mm^2 · s^{-1} should be used.

8.3.1.2 Lower yield strength, R_{eL}

If the lower yield strength alone is being determined, the test rate in the elastic range shall conform to 8.3.1.1 and the strain rate during yield shall be between 0,000 03/s and 0,002 5/s and shall be kept as constant as possible.

NOTE If this rate cannot be regulated directly, the test rate should be fixed by regulating the grip separation speed just before yield begins, the controls of the machine not being further adjusted until completion of yield.

8.3.1.3 Upper and lower yield strength, R_{eH} and R_{eL}

If R_{eH} and R_{eL} are determined during the same test, the conditions for determining the lower yield strength shall be complied with (see 8.3.1.2).

8.3.1.4 Proof strength for non-proportional extension, R_p

The test rate in the elastic range shall conform to 8.3.1.1.

Within the plastic range and up to the proof strength for non-proportional extension the strain rate shall be maintained between 0,000 03/s and 0,002 5/s.

8.3.2 Tensile strength, R_m

In the plastic range the strain rate shall not exceed 0,008/s.

If the test does not include the determination of a yield strength or proof strength, the strain rate in the elastic range may reach the maximum permitted in the plastic range.

9 Procedure

9.1 Determination of original cross-sectional area, S_o

The original cross-sectional area shall be calculated from the measurements of the appropriate dimensions with an error for each dimension not exceeding ± 0,5 % or ± 0,01 mm, whichever is greater.

9.2 Marking the original gauge length, L_o

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

For proportional test pieces, the calculated value of the original gauge length may be rounded off to the nearest multiple of 5 mm, provided that the difference between the calculated and marked gauge length is less than 10 % of L_o. The original gauge length shall be marked to an accuracy of ± 1 % or ± 0,25 mm.

If the parallel length (L_o) is much longer than the original gauge length, a series of overlapping gauge lengths may be drawn.

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

9.3 Determination of percentage elongation after fracture, A

9.3.1 Percentage elongation after fracture shall be determined in accordance with the definition given in 3.7

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

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

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

This elongation is valid only if the distance between the fracture and the nearest gauge mark is greater than one third of the original gauge length (L_o). However, the measurement is valid, irrespective of the position of the fracture, if the percentage elongation after fracture is equal to or greater than the specified value.

NOTE If the distance between the fracture and the nearest gauge mark is less than one-third of the original gauge length, the measured elongation, although greater than the specified value, may not be representative of the material.

9.3.2 For machines capable of measuring extension at fracture using an extensometer, gauge length marks are not necessary. The elongation is measured as the total extension at fracture, and it is therefore necessary to deduce the elastic extension in order to obtain percentage elongation after fracture.

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

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

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

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

9.4 Determination of the proof stress for non-proportional extension, R_p

9.4.1 The proof strength is determined using computer software or from the force/extension diagram by constructing a line parallel to the linear portion of the curve at a distance equal to the prescribed non-proportional percentage, e.g. 0,2 %. 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 2).

Accuracy when drawing the force-extension diagram is essential.

If the straight portion of the force/extension diagram is not clearly defined, thereby preventing drawing the parallel line with sufficient precision, the following procedure is recommended (see Figure 3).

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 origin of the curve and measured along the abscissa, equal to the prescribed non-proportional percentage. The intersection of this parallel line and the force/extension curve gives the force corresponding to the proof strength. The latter is obtained by dividing this force by the original cross-sectional area of the test piece (S_o) (see Figure 3).

9.4.2 This property may be obtained by using automatic devices thus obviating plotting a force/extension curve.

9.5 Determination of percentage reduction of area, Z

The percentage reduction of area shall be determined in accordance with the definition given in 3.11.

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

10 Test report

The test report shall include at least the following information:

a) reference to this International Standard, i.e. ISO 15579;

b) identification of the test piece;

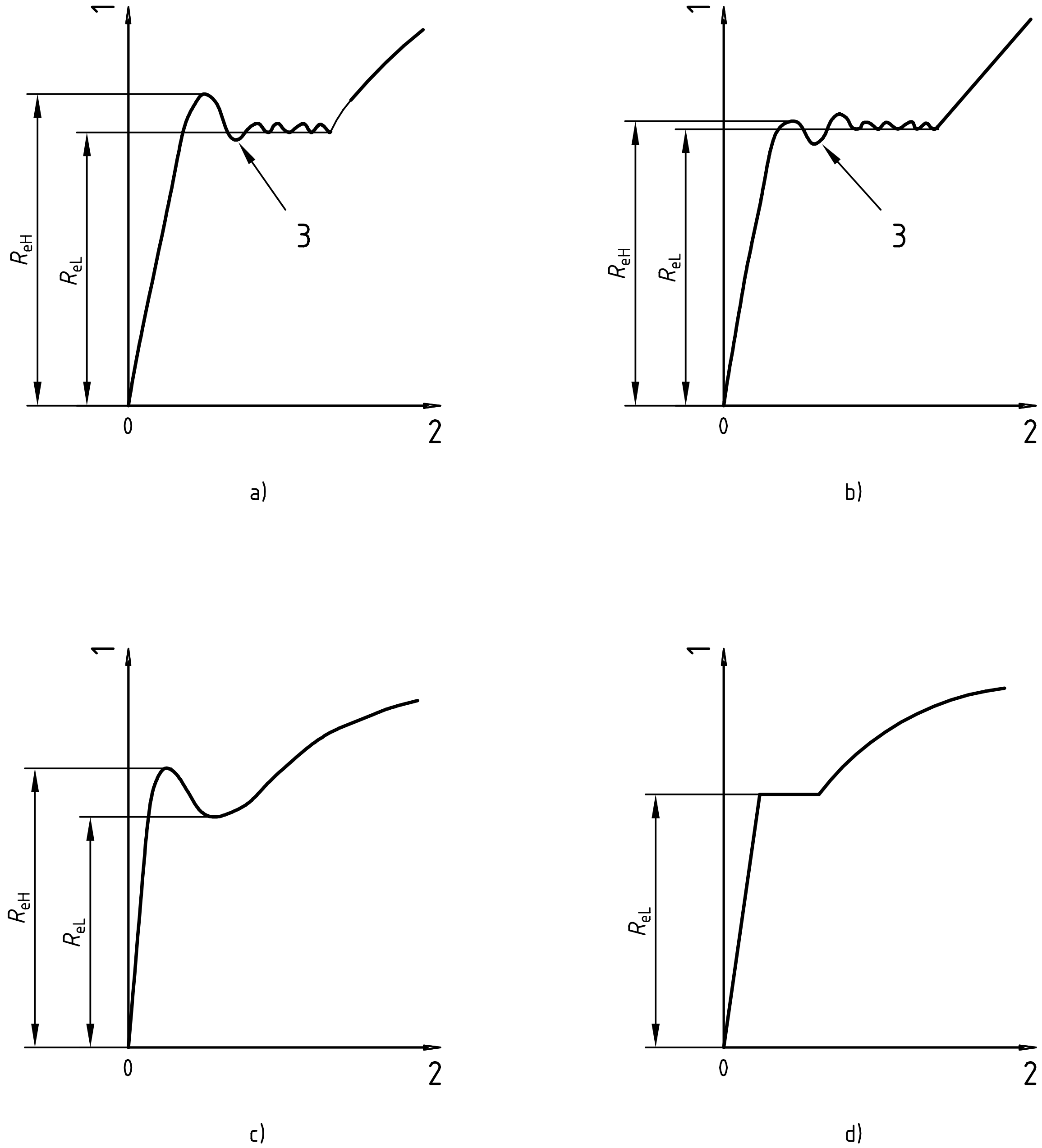
c) nature of the material, if known;

d) type of test piece;

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

f) measured properties, strain rates and results;

g) cooling medium and cooling time.



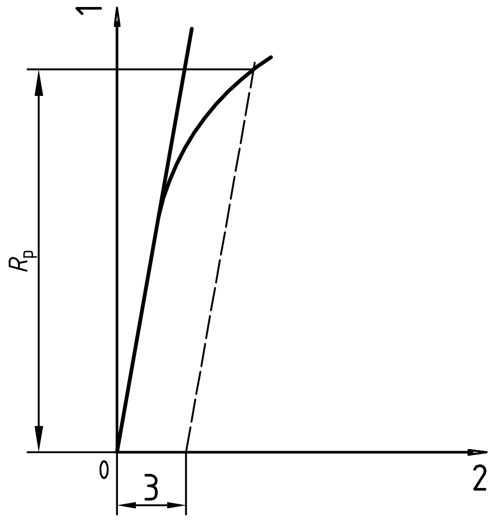
Key

1 Stress

2 Percentage extension

3 Initial transient effect

Figure 1 — Definitions of upper and lower yield strength for different types of curves



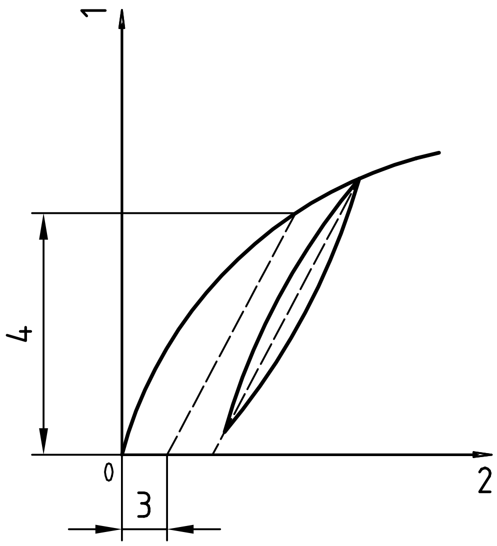
Key

1 Stress

2 Percentage elongation or percentage extension

3 Specified non-proportional extension

Figure 2 — Proof strength, non proportional extension (R_p)



Key

1 Force

2 Extension

3 Specified non-proportional extension

4 Force corresponding to R_p

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

Annex A
(informative)

Examples for test pieces for tensile testing at low temperatures

See Figures A.1 to A.3.

Dimensions in millimetres

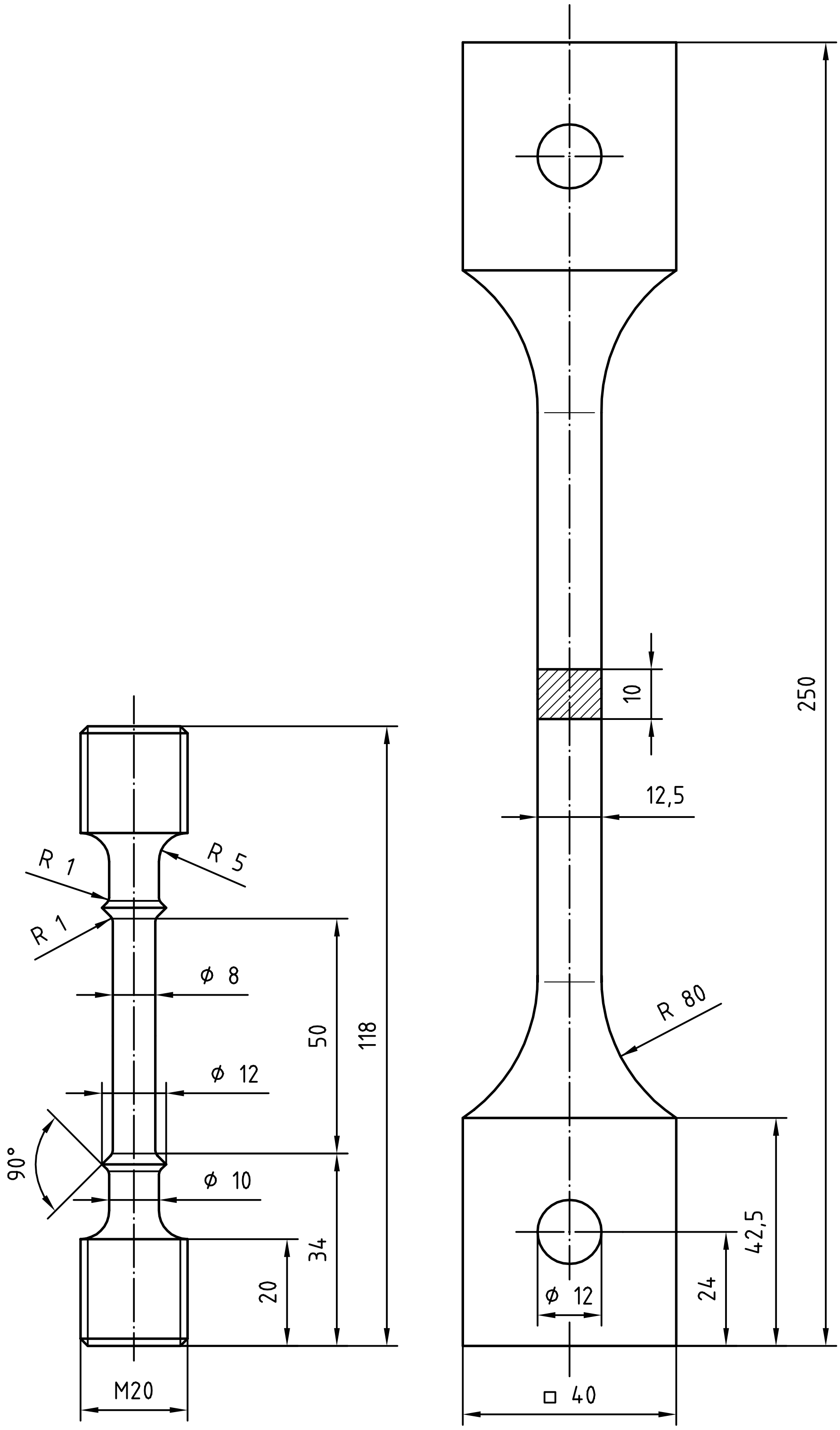


Figure A.1

Dimensions in millimetres,
surface roughness on micrometres

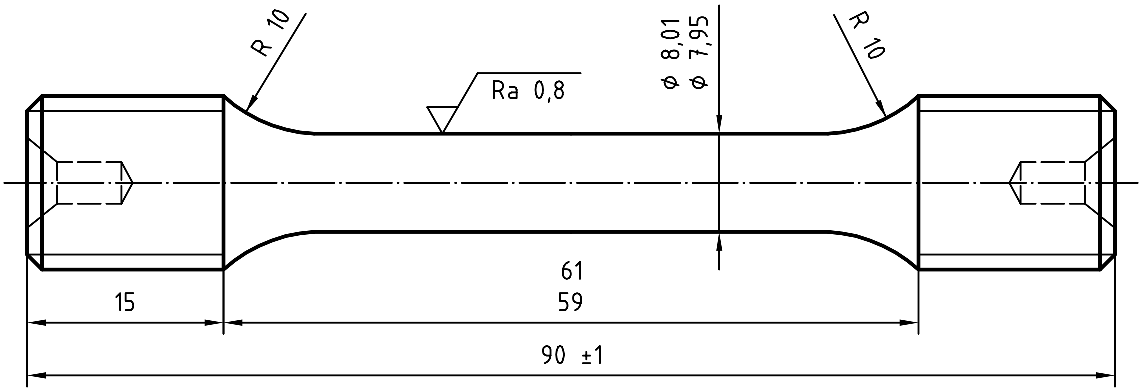


Figure A.2

Dimensions in millimetres,
surface roughness in micrometres

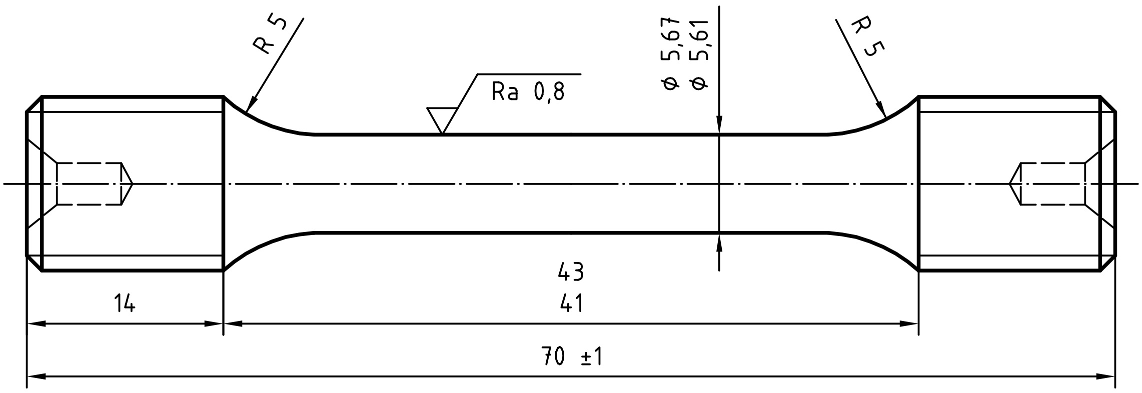


Figure A.3

Bibliography

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

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

An example of a method of checking the alignment of test pieces is given in:

[3] ASTM E 1012:1999, *Standard Practice for Verification of Specimen Alignment Under Tensile Loading.*

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