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Metallic materials — Uniaxial creep testing in tension — Method of test

Matériaux métalliques — Essai de fluage uniaxial en traction — Méthode d'essai

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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 2.

The main task of technical committees is to prepare International Standards. 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 document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 204 was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 1, *Uniaxial testing*.

This second edition cancels and replaces the first edition (ISO 204:1997), which has been technically revised.

Introduction

This International Standard is an extensive revision of the first edition of ISO 204:1997 and incorporates many recommendations developed through the European Creep Collaborative Committee (ECCC).

New annexes have been added concerning temperature measurement using thermocouples and their calibration, creep testing test pieces with circumferential Vee and blunt (Bridgman) notches, estimation of measurement uncertainty and methods of extrapolation of creep rupture life.

NOTE Information is sought relating to the influence of off-axis loading or bending on the creep properties of various materials. Consideration will be given at the next revision of this International Standard as to whether the maximum amount of bending should be specified and an appropriate calibration procedure be recommended. The decision will need to be based on the availability of quantitative data [39].

Metallic materials — Uniaxial creep testing in tension — Method of test

1 Scope

This International Standard specifies the method for the uninterrupted and interrupted creep tests and defines the properties of metallic materials which can be determined from these tests, in particular the creep elongation and the time of creep rupture, at a specified temperature.

The stress rupture test is also covered by this International Standard, as is the testing of notched test pieces.

NOTE In stress rupture testing, elongation is not generally recorded during the test, only the time to failure under a given load, or to note that a predetermined time was exceeded under a given force.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 783 [1)], *Metallic materials — Tensile testing at elevated temperature*

ISO 7500-2, *Metallic materials — Verification of static uniaxial testing machines — Part 2: Tension creep testing machines — Verification of the applied force*

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

3 Terms and definitions

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

NOTE Several different gauge lengths and reference lengths are specified in this International Standard. These lengths reflect custom and practice used in different laboratories throughout the world. In some cases, the lengths are physically marked on the test piece as lines or ridges; in other cases, the length may be a virtual length based upon calculations to determine an appropriate length to be used for the determination of creep elongation. For some test pieces, L_r, L_o and L_e are the same length (see 3.1, 3.2 and 3.5).

1) To be revised by ISO 6892-2, *Metallic materials — Tensile testing — Part 2: Method of test at elevated temperature*.

3.1
reference length
L_r
base length used for the calculation of elongation

NOTE A method to calculate this value is given in 7.5 for test pieces where the extensometer is attached to either ridges on the parallel length or to the shoulders of the test piece.

3.1.1
original reference length
L_{ro}
reference length determined at ambient temperature before the test

NOTE In general, $L_{ro} \geqslant 5D$.

3.1.2
final reference length
L_{ru}
reference length determined at ambient temperature after rupture, with the pieces carefully fitted back together with their axes in a straight line

3.2
original gauge length
L_o
length between gauge length marks on the test piece measured at ambient temperature before the test

NOTE 1 In general, $L_o \geqslant 5D$.

NOTE 2 L_o may also be used for the calculation of elongation.

3.3
final gauge length after rupture
L_u
length between gauge length marks on the test piece measured after rupture, at ambient temperature, with the pieces carefully fitted back together with their axes in a straight line

3.4
parallel length
L_c
length of the parallel reduced section of the test piece

3.5
extensometer gauge length
L_e
distance between the measuring points of the extensometer

NOTE In some cases, $L_e = L_o$ and may also be used for the calculation of elongation.

3.6
original cross-sectional area
S_o
cross-sectional area of the parallel length as determined at ambient temperature prior to testing

3.7
minimum cross-sectional area after rupture
S_u
minimum cross-sectional area of the parallel length as determined at ambient temperature after rupture, with the pieces carefully fitted back together with their axes in a straight line

3.8
initial stress
σ_o
applied force divided by the original cross-sectional area (S_o) of the test piece

3.9
elongation
ΔL_r
increase of the reference length (L_r)

NOTE See 6.2.

3.10
percentage elongation
A
elongation expressed as a percentage of the original reference length (L_{ro})

NOTE 1 See Figure 1.

NOTE 2 In the terms for elongation in 3.10 to 3.16, the symbol "ε" may replace "A".

However, when "ε" is used, the following conventions should apply:

ε % is the percentage strain or elongation;

ε is the absolute strain.

3.11
percentage initial plastic elongation
A_i
non-proportional increase of the original reference length (L_{ro}) due to the application of the test force

3.12
percentage creep elongation
A_f
increase in reference length at time t (ΔL_{rt}) at a specified temperature expressed as a percentage of the original reference length (L_{ro}):

$$A_f = \frac{\Delta L_{rt}}{L_{ro}} \times 100 \quad (1)$$

NOTE 1 A_f may have the specified temperature (T) in degrees Celsius (°C) as superscript and the initial stress (σ_o) in megapascals [2)] and time t (in hours) as subscript.

NOTE 2 By convention, the beginning of creep elongation measurement is the time at which the initial stress (σ_o) is applied to the test piece (see Figure 1).

NOTE 3 Suffix f originates from "fluage", "creep" in French.

2) 1 MPa = 1 N/mm^2.

3.13
percentage plastic elongation

A_p

non-proportional increase of the original reference length (L_{ro}) at time t:

$$A_p = A_i + A_f \tag{2}$$

3.14
percentage anelastic elongation

A_k

non-proportional decrease of the original reference length (L_{ro}) at time t due to unloading

3.15
percentage permanent elongation

A_{per}

total increase of the original reference length (L_{ro}) at time t determined after unloading:

$$A_{per} = A_p - A_k \tag{3}$$

3.16
percentage elongation after creep rupture

A_u

permanent increase of the original reference length (L_{ro}) after rupture ($L_{ru} - L_{ro}$) expressed as a percentage of the original reference length (L_{ro}):

$$A_u = \frac{L_{ru} - L_{ro}}{L_{ro}} \times 100 \tag{4}$$

NOTE A_u may have the specified temperature (T) in degrees Celsius as superscript and the initial stress (σ_o) in megapascals as subscript.

3.17
percentage reduction of area after creep rupture

Z_u

maximum change in cross-sectional area measured after rupture ($S_o - S_u$) expressed as a percentage of the original cross-sectional area (S_o):

$$Z_u = \frac{S_o - S_u}{S_o} \times 100 \tag{5}$$

NOTE Z_u may have the specified temperature (T) in degrees Celsius as superscript and the initial stress (σ_o) in megapascals as subscript.

3.18
creep elongation time

t_{fx}

time required for a strained test piece to obtain a specified percentage creep elongation (x) at the specified temperature (T) and the initial stress (σ_o)

EXAMPLE $t_{f0,2}$.

3.19
plastic elongation time

t_{px}

time required to obtain a specified percentage plastic elongation (x) at the specified temperature (T) and the initial stress (σ_o)

3.20
creep rupture time
t_u
time to rupture for a test piece maintained at the specified temperature (T) and the initial stress (σ_o)

NOTE The symbol t_u may have as superscript the specified temperature (T) in degrees Celsius and as subscript the initial stress (σ_o) in megapascals.

3.21
single test piece machine
testing machine that permits straining of a single test piece

3.22
multiple test piece machine
testing machine that permits straining of more than one test piece simultaneously at the same temperature

4 Symbols and designations

The symbols and corresponding designations are given in Table 1.

Table 1 — Symbols and designations

Symbol [a]	Unit	
D	mm	Diameter of the cross-section of the parallel length of a cylindrical test piece
D_n	mm	Diameter of gauge length containing a notch
d	mm	Diameter of gauge length without a notch in a combined notched/un-notched test piece (see Figure C.1)
d_n	mm	Diameter across root of circumferential notch For a combined notched/un-notched test piece $d = d_n$
b	mm	Width of the cross-section of the parallel length of a test piece of square or rectangular cross-section
L_r	mm	Reference length
a	mm	Thickness of a test piece of square or rectangular cross-section [see Figure 2 b)]
L_{ro}	mm	Original reference length
L_{ru}	mm	Final reference length
ΔL_r	mm	Elongation
ΔL_{rt}	mm	Increase in reference length at time t
L_o	mm	Original gauge length
L_n	mm	Parallel gauge length containing a notch
L_u	mm	Final gauge length after rupture
L_c	mm	Parallel length
L_e	mm	Extensometer gauge length
R	mm	Transition radius
r_n	mm	Notch root radius
S_o	mm^2	Original cross-sectional area of the parallel length
S_u	mm^2	Minimum cross-sectional area after rupture

Table 1 (*continued*)

Symbol [a]	Unit	Designation
σ_o	MPa	Initial stress
A_e [b]	%	Percentage elastic elongation
A_i [b]	%	Percentage initial plastic elongation
A_k [b]	%	Percentage anelastic elongation
A_p [b]	%	Percentage plastic elongation
A_{per} [b]	%	Percentage permanent elongation
A_f [b]	%	Percentage creep elongation: $$A_f = \frac{\Delta L_{rt}}{L_{ro}} \times 100$$ NOTE As an example, the symbol may be completed as follows: $A_{f\,50/5\,000}^{375}$: percentage creep elongation with an initial stress of 50 MPa after 5 000 h at the specified temperature of 375 °C.
A_u [b]	%	Percentage elongation after creep rupture: $$A_u = \frac{L_{ru} - L_{ro}}{L_{ro}} \times 100$$ NOTE As an example, the symbol may be completed as follows: A_{u50}^{375} : percentage elongation after creep rupture with an initial stress of 50 MPa at the specified temperature of 375 °C.
Z_u	%	Percentage reduction of area after creep rupture: $$Z_u = \frac{S_o - S_u}{S_o} \times 100$$ NOTE As an example, the symbol may be completed as follows: Z_{u50}^{375} : percentage reduction of area after creep rupture with an initial stress of 50 MPa at the specified temperature of 375 °C.
t_{fx}	h	Creep elongation time
t_{px}	h	Plastic elongation time
t_u	h	Creep rupture time NOTE As an example, the symbol may be completed as follows: t_{u50}^{375} : creep rupture time with an initial stress of 50 MPa at the specified temperature of 375 °C.
t_{un}	h	Creep rupture time of a notched test piece
T	°C	Specified temperature
T_i	°C	Indicated temperature
x	%	Specified percentage creep or plastic elongation
n		Creep exponent

[a] The main subscripts (r, o and u) of the symbols are used as follows:

r corresponds to reference;

o corresponds to original;

u corresponds to ultimate (after rupture).

[b] See Note 2 in 3.10.

5 Principle

The test consists of heating a test piece to the specified temperature and of straining the test piece by means of a constant tensile force or constant tensile stress (see note) applied along its longitudinal axis for a period of time to obtain any of the following:

— a specified creep elongation (uninterrupted test);

— values of permanent elongation at suitable intervals throughout the test (interrupted test);

— the creep rupture time (uninterrupted and interrupted test).

NOTE "Constant stress" means that the ratio of the force to the instantaneous cross-section remains constant throughout the test. The results obtained with constant stress are generally different from those obtained with constant force.

6 Apparatus

6.1 Testing machine

The testing machine shall apply a force along the axis of the test piece while keeping inadvertent bending or torsion of the test piece to a minimum. Prior to test the machine should be visually examined to ensure that loading bars, grips, universal joints and associated equipment are in a good state of repair.

The force should be applied to the test piece without shock.

The machine should be isolated from external vibration and shock. The machine should be equipped with a device which minimizes shock when the test piece ruptures.

NOTE At present, there appears to be insufficient quantitative data in the literature demonstrating the influence of bending upon creep and stress rupture life. It is requested that any organization with such information forwards it to ISO/TC164 for consideration at the next revision of this International Standard.

The machine shall be verified and shall meet the requirements of at least class 1 in ISO 7500-2.

6.2 Elongation measuring device

In uninterrupted tests, the elongation shall be measured using an extensometer, which meets the performance requirements of class 1 or better of ISO 9513 or by other means which ensure the same accuracy without interruption of the test. The extensometer can either be directly attached to the test piece, or can be non-contacting (e.g. a non-contacting optical or laser extensometer).

It is recommended that the extensometer is calibrated over an appropriate range based upon the expected creep strain.

The extensometer shall be calibrated at intervals not exceeding 3 years, unless the test duration is longer than 3 years. If the predicted test exceeds the date of the expiry of the calibration certificate then the extensometer shall be recalibrated prior to commencement of the creep test.

The extensometer gauge length shall not be less than 10 mm.

The extensometer shall be able to measure the elongation either on one side or on the opposite sides of the test piece; the latter is the preferred option.

The type of extensometer used (e.g. single-sided, double-sided, axial, diametral) should be reported. When the elongation is measured on the opposite sides, the average elongation should be reported.

NOTE 1 For uninterrupted creep tests, i.e. with an extensometer attached directly to the parallel section of a test piece, the percentage creep elongation is measured over L_e.

When the elongation is measured with an extensometer attached to the grip ends of the test piece, the ends shall be of such shape and size that it can be assumed that the observed elongation has occurred completely within the reference length of the test piece. Percentage creep elongation is measured over L_r.

The extensometer gauge length should normally be as near as possible to the reference length. In the case of accurate creep measurements, a gauge length as long as possible should be used to improve the accuracy of measurements.

NOTE 2 If only the percentage elongation after creep rupture or the percentage creep elongation for a specified test duration is determined, the use of an extensometer is not necessary.

In interrupted tests, periodically unload the test piece and cool it to ambient temperature and measure the permanent elongation on the gauge length with an appropriate device. The precision of this device shall be 0,01 ΔL_r or 0,01 mm, whichever is the greater. After this measurement the test piece may be first reheated and then reloaded.

NOTE 3 For low creep strain measurements, e.g. $\leqslant$ 1% strain, on test pieces with short gauge lengths, careful consideration needs to be given to ensure that the measuring device used has sufficient resolution.

NOTE 4 Information on the long-term stability of transducers used for creep testing and accreditation issues are given in References [35] and [36] in the Bibliography.

Care should be taken to avoid spurious negative creep when using nickel base alloy extensometers. See the Code of Practice by Loveday and Gibbons (2007) [38].

6.3 Heating device

6.3.1 Permissible temperature deviations

The heating device shall heat the test piece to the specified temperature (T).The permitted deviations between the indicated temperature, (T_i) and the specified temperature, (T), and the permitted maximum temperature variation along the test piece shall be as given in Table 2.

Table 2 — Permitted deviations between T_i and T and maximum permissible temperature variation along the test piece

Specified temperature, T °C	Permitted deviation between T_i and T °C	Maximum permissible temperature variation along the test piece °C
$T \leqslant 600$	± 3	3
$600 < T \leqslant 800$	± 4	4
$800 < T \leqslant 1\,000$	± 5	5
$1\,000 < T \leqslant 1\,100$	± 6	6

For specified temperatures greater than 1 100 °C, the permitted values shall be defined by agreement between the parties concerned.

The indicated temperatures (T_i) are the temperatures measured at the surface of the parallel length of the test piece, errors from all sources being taken into account and any systematic errors having been corrected.

NOTE Instead of measuring the temperature at the surface of the test piece, it is permitted to carry out indirect measurement of the temperature of each heating zone of the furnace provided that it is demonstrated that the tolerance defined above is fulfilled.

If an extensometer is used, the parts of this instrument outside the furnace shall be designed and protected in such a way that the temperature variations in the air around the furnace do not significantly affect the measurements of the variations in length.

Variations in temperature of the air surrounding the test machine should not exceed ± 3 °C.

In the interrupted test, the variation of the room temperature during all measurements of the gauge length should not exceed ± 2 °C. If this range is exceeded, corrections for ambient temperature variations shall be applied.

6.3.2 Temperature measurement

6.3.2.1 General

The temperature indicator shall have a resolution of at least 0,5 °C and the temperature measuring equipment shall have an accuracy equal to or better than ± 1 °C.

6.3.2.2 Single test piece machines

In single test piece machines, for test pieces with a parallel length less than or equal to 50 mm, at least two thermocouples should be used. For test pieces with a parallel length greater than 50 mm, at least three thermocouples should be used. In all cases, a thermocouple should be placed at each end of the parallel length and, if a third thermocouple is used, it should be placed in the middle region of the parallel length.

The number of thermocouples may be reduced to one if it can be demonstrated that the conditions of the furnace and the test piece are such that the variation of temperature of the test piece does not exceed the values specified in 6.3.1.

6.3.2.3 Multiple test piece machines

In multiple test piece machines, it is recommended that at least one thermocouple be used for each test piece. If only one thermocouple is used it shall be positioned at the middle of the parallel length. Three thermocouples may only be used if located at appropriate positions within the furnace, and if there is supporting data to demonstrate that for all test pieces the temperature conforms to the requirements of 6.3.1.

In the case of indirect temperature measurement, regular control measurements are required to determine differences between the thermocouple(s) of each heating zone and a significant number of test pieces within a given zone. The non-systematic components of the temperature differences shall not exceed ± 2 °C up to 800 °C and ± 3 °C above 800 °C.

6.3.2.4 Notched test pieces

Temperature measurement of notched test pieces shall be in accordance with either 6.3.2.2 or 6.3.2.3. It is recommended that one thermocouple is placed close to the notch.

6.3.2.5 Thermocouples

The thermocouple junctions shall make good thermal contact with the surface of the test piece and shall be screened from direct radiation from the heating source. The remaining portions of the wires within the furnace shall be thermally shielded and electrically insulated.

NOTE This clause is not applicable in the case of indirect temperature measurement.