
**Steel for the reinforcement and
prestressing of concrete — Test
methods —**

**Part 3:
Prestressing steel**

*Aciers pour l'armature et la précontrainte du béton — Méthodes
d'essai —*

Partie 3: Aciers de précontrainte

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by ISO/TC 17, *Steel*, Subcommittee SC 16, *Steels for the reinforcement and prestressing of concrete*.

This third edition cancels and replaces the second edition (ISO 15630-3:2010), which has been technically revised. Changes have been introduced in the Introduction, [Clauses 1](#) and [2](#), [5.3.1](#), [5.3.2](#), 9.3, 9.4.4, 10.4.3, 11.4 (now [10.3](#), [10.4.4](#), [11.4.3](#), [12.4](#)) and [Figure 8](#). The Bibliography has been updated and the dated references have been replaced by undated references. A new [Clause 8](#) on the wrapping test has been added.

A list of all parts in the ISO 15360 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

This corrected version of ISO 15630-3:2019 incorporates the following corrections:

- in [Figure 8](#), $60^\circ \pm 12^\circ$ has been corrected to $60^\circ \pm 12'$.

Introduction

The aim of ISO 15630 (all parts) is to provide all relevant test methods for reinforcing and prestressing steels in one standard series.

This document covers standard test methods, as well as specialized test methods that are not commonly used in routine testing and that should only be considered where relevant (or specified) in the applicable product standard.

Reference is made to International Standards on the testing of metals, in general, as they are applicable. Complementary provisions have been given if needed.

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Steel for the reinforcement and prestressing of concrete — Test methods —

Part 3: Prestressing steel

1 Scope

This document specifies test methods applicable to prestressing steel (bar, wire or strand) for concrete.

This document does not cover the sampling conditions that are dealt with in the product standards.

A list of options for agreement between the parties involved is provided in [Annex A](#).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 4957, *Tool steels*

ISO 4965-1, *Metallic materials — Dynamic force calibration for uniaxial fatigue testing — Part 1: Testing systems*

ISO 4965-2, *Metallic materials — Dynamic force calibration for uniaxial fatigue testing — Part 2: Dynamic calibration device (DCD) instrumentation*

ISO 6508-1, *Metallic materials — Rockwell hardness test — Part 1: Test method*

ISO 6892-1, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature*

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

ISO 7801, *Metallic materials — Wire — Reverse bend test*

ISO 7802, *Metallic materials — Wire — Wrapping test*

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

ISO 16020, *Steel for the reinforcement and prestressing of concrete — Vocabulary*

3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in ISO 16020 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

For the purposes of this document, the following symbols apply.

Symbol	Unit	Description	Reference
a_m	mm	Rib height at the mid-point	14.3 , 15.2
a_{max}	mm	Maximum height of rib or depth of indentation	14.3
$a_{s,i}$	mm	Average height of a portion i of a rib subdivided into p parts of length Δl	15.2
$a_{1/4}$	mm	Rib height at the quarter-point	14.3 , 15.2
$a_{3/4}$	mm	Rib height at the three-quarters point	14.3 , 15.2
A	%	Percentage elongation after fracture	5.1 , 5.3
A_{gt}	%	Percentage total extension at maximum force	Clause 5
A_r	%	Percentage uniform elongation after fracture	5.3
b	mm	Width of transverse rib at the mid-point	14.3.1.6
c	mm	Rib or indentation spacing	14.3
C	mm	Groove width at nominal diameter of the mandrel, d_a , used for the deflected tensile test	12.3.4
d	mm	Nominal diameter of the bar, wire or strand	5.3.1 , 7.2 , Table 3 , 10.4.6 , Table 4
d_a	mm	Nominal diameter of the mandrel used for the deflected tensile test	12.3.4
d_b	mm	Diameter to be obtained after placing two gauge cylinders in the groove of the mandrel used for the deflected tensile test	12.3.4
d_e	mm	Diameter of the gauge cylinder used for the deflected tensile test	12.3.4
d_g	mm	Diameter of guide hole	7.2
d_i	mm	Inner diameter of the groove of the mandrel used for the deflected tensile test	12.3.4
D	%	Average coefficient of reduction of the maximum force in the deflected tensile test	12.2 , 12.4
D_c	mm	Inner diameter of the test cell in the stress corrosion test	11.3.4
D_i	%	Individual percentage of reduction of the maximum force in the deflected tensile test	12.4
D_m	mm	Diameter of the mandrel of the bending device in the bend test	Figure 2
e	mm	Average gap between two adjacent ribs or indentation rows	14.3.1.4 , 14.3.2.5
E	MPa	Modulus of elasticity	5.2 , 5.3
f	Hz	Frequency of force cycles in the axial force fatigue test	10.1 , 10.4.2
f_R	—	Relative rib area	Clause 15
$F_{a,i}$	N	Individual breaking force in the deflected tensile test	12.4
F_m	N	Maximum force in the tensile test	5.3
$\bar{F}_m$	N	Mean value of the maximum force	9.2 , 11.2 , 12.2 , 12.4
$F_{p0,1}$	N	0,1 % proof force, plastic extension	5.2 , 5.3
$F_{p0,2}$	N	0,2 % proof force, plastic extension	5.2 , 5.3
F_r	N	Force range in the axial force fatigue test	Figure 6 , 10.3 , 10.4.2
F_{rt}	N	Residual force in the test piece at time t in the isothermal stress relaxation test	9.1
ΔF_{rt}	N	Force loss in the test piece at time t in the isothermal stress relaxation test	9.1
F_R	mm ²	Area of longitudinal section of one rib	15.2

NOTE 1 MPa = 1 N/mm².

Symbol	Unit	Description	Reference
F_{up}	N	Upper force in the axial force fatigue test	Figure 6, 10.3, 10.4.2
F_0	N	Initial force in the isothermal stress relaxation test and the stress corrosion test	9.1, 9.2, 9.3, 9.4, 11.1, 11.2, 11.4.2
G	mm	Depth of the groove of the mandrel used for the deflected tensile test	12.3.4
h	mm	Distance from the top tangential plane of cylindrical supports to the bottom face of the guide	7.2
h_b	mm	Bow height in the plane of the bow	14.3.4
l	mm	Length of indentation	14.3.2.4
L_t	mm	Length of the test piece in the stress corrosion test	11.2
L_0	mm	Gauge length (without force on the test piece) in the isothermal stress relaxation test Length of the test piece in contact with the solution in the stress corrosion test	9.1, 9.3, 9.4, 11.2, 11.3.4, 11.4.1, 11.4.3, 11.4.5
L_1	mm	Length of the passive side in the deflected tensile test	12.3.2
L_2	mm	Length of the active side in the deflected tensile test	12.3.2
m, n	—	Coefficients or numbers	9.4.9, 14.3, 15.2
P	mm	Lay length of a strand	14.3.3
r	mm	Radius of cylindrical supports	7.2
R	mm	Radius at the base of the mandrel used for the deflected tensile test	12.3.4
r_1	mm	Distance between the grips and the gauge length for the manual measurement of A_{gt}	5.3
r_2	mm	Distance between the fracture and the gauge length for the manual measurement of A_{gt}	5.3
R_a	μm	Surface roughness of the mandrel used for the deflected tensile test	12.3.4
S_n	mm^2	Nominal cross-sectional area of the test piece	5.3.2
t_a	h	Maximum agreed time for the stress corrosion test	11.4.5
$t_{f,i}$	h	Individual lifetime to fracture in the stress corrosion test	11.4.5
$t_{f,m}$	h	Median lifetime to fracture in the stress corrosion test	11.4.6
t_0	s	Starting time in the isothermal stress relaxation test and in the stress corrosion test	9.4.2, 11.4
y	mm	Distance from a plane, defined by the axes of the cylindrical supports, to the nearest point of contact with the test piece	Figure 3
V_0	mm^3	Volume of test solution to fill the test cell in the stress corrosion test	11.4.3
Z	%	Percentage reduction of area	5.3.1
α	°	Angle of deviation in the deflected tensile test	12.3.2
β	°	Rib or indentation angle to the bar or wire axis	14.3
ε_{xF_m}	—	Value of the strain for a force equal to $x F_m$	5.3.2
ρ	%	Relaxation	9.4.9
$\sum e_i$	mm	Part of the circumference without indentation or rib	14.3.1.4, 14.3.2.5, 15.2

NOTE 1 MPa = 1 N/mm².

4 General provisions concerning test pieces

Unless otherwise agreed or specified in the product standard, the samples shall be taken from the finished product before packaging.

Special care should be taken when samples are taken from the packaged product (e.g. coil or bundle) in order to avoid plastic deformation, which could change the properties of the samples used to provide the test pieces.

Specific complementary provisions concerning the test pieces are indicated in the relevant clauses of this document, if needed.

5 Tensile test

5.1 Test piece

In addition to the general provisions given in [Clause 4](#), the free length of the test piece shall be sufficient for the determination of the percentage total extension at maximum force (A_{gt}) in accordance with [5.3.1](#).

If the percentage elongation after fracture (A) is determined manually, the test piece shall be marked in accordance with ISO 6892-1.

If the percentage total extension at maximum force (A_{gt}) is determined by the manual method for a bar or wire, equidistant marks shall be made on the free length of the test piece (see ISO 6892-1). The distance between the marks shall be 20 mm, 10 mm or 5 mm, depending on the test piece diameter.

5.2 Test equipment

The test equipment shall be verified and calibrated in accordance with ISO 7500-1 and shall be at least of class 1.

If an extensometer is used, it shall be of class 1 in accordance with ISO 9513 for the determination of E , $F_{p0,1}$ or $F_{p0,2}$; for the determination of A_{gt} , a class 2 extensometer (see ISO 9513) may be used.

Grips shall be such as to avoid breaks in or very near the grips.

5.3 Test procedure

5.3.1 General

The tensile test for the determination of the modulus of elasticity (E), 0,1 % and 0,2 % proof force ($F_{p0,1}$ and $F_{p0,2}$), maximum force (F_m), percentage total extension at maximum force (A_{gt}) and/or percentage elongation after fracture (A) and percentage reduction of area (Z) shall be performed in accordance with ISO 6892-1.

An extensometer shall be used for the determination of the modulus of elasticity (E), 0,1 % and 0,2 % proof force ($F_{p0,1}$ and $F_{p0,2}$) and percentage total extension at maximum force (A_{gt}). The extensometer gauge length shall be as specified in the relevant product standard.

Accurate values of A_{gt} can only be obtained with an extensometer. If it is not possible to leave the extensometer on the test piece to fracture or until the maximum force has been passed, the extension may be measured as follows.

- Continue loading until the extensometer records an extension just greater than the extension corresponding to $F_{p0,2}$, at which the extensometer is removed; the distance between the testing machine cross-heads is noted. The loading is continued until fracture occurs. The final distance between the cross-heads is noted.
- The difference between the cross-head measurements is calculated as a percentage of the original distance between the cross-heads and this value is added to the percentage obtained by the extensometer.

For wire and bars, it is also permissible to determine A_{gt} by the manual method. If A_{gt} is determined by the manual method after fracture, A_{gt} shall be calculated from [Formula \(1\)](#):

$$A_{gt} = A_r + R_m / 2\ 000 \quad (1)$$

where A_r is the percentage uniform elongation after fracture.

The measurement of A_r shall be made, as the measurement of A (see ISO 6892-1), on the longer of the two fractured parts of the test piece on a gauge length of 100 mm, as close as possible to the fracture but at a distance, r_2 , of at least 50 mm or $2d$ (whichever is the greater) away from the fracture. This measurement may be considered as invalid if the distance, r_1 , between the grips and the gauge length is less than 20 mm or d (whichever is the greater). See [Figure 1](#).

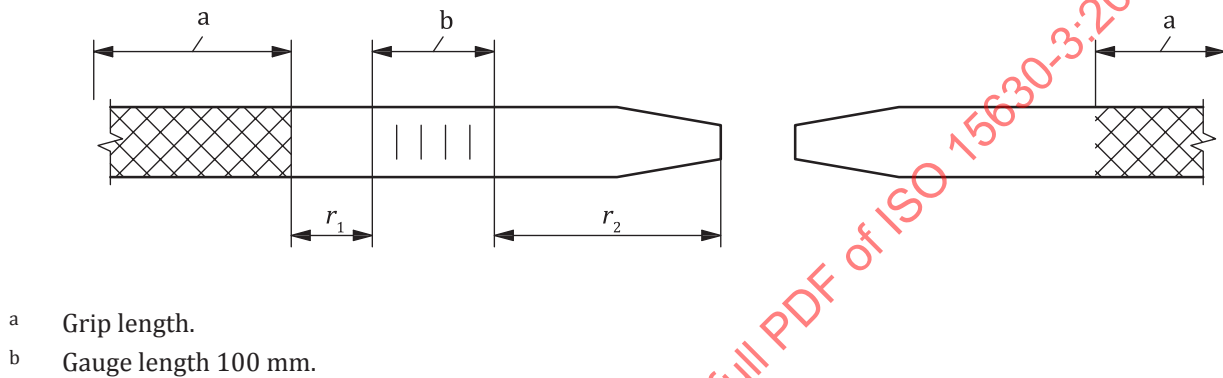


Figure 1 — Measurement of A_{gt} by the manual method

It is preferable to apply a preliminary force to the test piece, e.g. to about 10 % of the expected maximum force before placing the extensometer.

If A_{gt} is not completely determined with an extensometer, this shall be indicated in the test report.

For routine tests conducted by prestressing steel producers, the test information should be described within internal documentation.

Tensile properties ($F_{p0,1}$, $F_{p0,2}$, F_m) are recorded in force units.

For the determination of percentage elongation after fracture (A), the original gauge length shall be eight times the nominal diameter (d), unless otherwise specified in the relevant product standard. In case of dispute, A shall be determined manually.

If the fracture occurs within a distance of 3 mm from the grips, the test shall, in principle, be considered as invalid and it shall be permissible to perform a retest. However, it shall be permitted to take into account the test results if all values meet the relevant specified values.

5.3.2 Determination of the modulus of elasticity

The modulus of elasticity (E) shall be determined from the slope of the linear portion of the force-extension diagram divided by the nominal cross-sectional area of the test piece (S_n).

In general, for cold-drawn prestressing products (e.g. strands and plain wires), the slope can be determined in the range between $0,2F_m$ and $0,7F_m$, as shown by [Formula \(2\)](#):

$$E = \left[(0,7F_m - 0,2F_m) / (\epsilon_{0,7F_m} - \epsilon_{0,2F_m}) \right] / S_n \quad (2)$$

The slope may be calculated either by a linear regression of the measured data stored in a data storage facility or by a best-fit visual technique over the above-defined portion of the recorded curve.

In some special cases, e.g. hot-rolled and stretched bars, the above-mentioned method cannot be applied; a secant modulus between $0,05F_m$ and $0,7F_m$ may then be determined as shown by [Formula \(3\)](#):

$$\left[(0,7F_m - 0,05F_m) / (\varepsilon_{0,7F_m} - \varepsilon_{0,05F_m}) \right] / S_n \quad (3)$$

In addition to the provisions given in [5.3.1](#), it shall be ensured that the stress rate is not changed within the force range over which the modulus of elasticity is determined.

6 Bend test

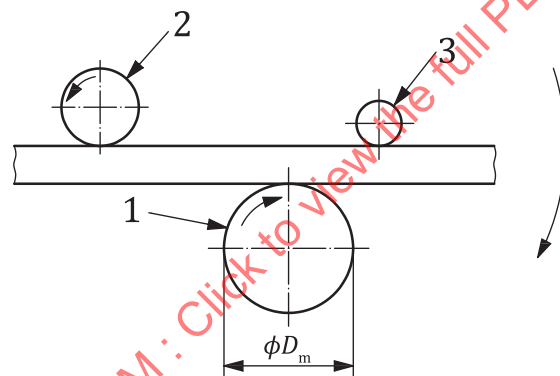
6.1 Test piece

The general provisions given in [Clause 4](#) apply.

6.2 Test equipment

6.2.1 A bending device, the principle of which is shown in [Figure 2](#), shall be used.

NOTE [Figure 2](#) shows a configuration where the mandrel and support rotate and the carrier is locked. It is also possible that the carrier rotates and the support or mandrel is locked.



Key

- 1 mandrel
- 2 support
- 3 carrier

Figure 2 — Principle of a bending device

6.2.2 The bend test may also be performed using a device with supports and a mandrel (e.g. see ISO 7438).

6.3 Test procedure

The bend test shall be performed at a temperature between 10 °C and 35 °C. The test piece shall be bent over a mandrel.

The angle of bend and the diameter of the mandrel shall be in accordance with the relevant product standard.

6.4 Interpretation of test results

The interpretation of the bend test results shall be made in accordance with the requirements of the relevant product standard.

If requirements are not specified in the relevant product standard, the absence of cracks visible to a person with normal or corrected vision shall be considered as evidence that the test piece has withstood the bend test.

A superficial ductile tear may occur at the base of the ribs or indentations and shall not be considered to be a failure. The tear may be considered superficial when the depth of the tear is not greater than the width of the tear.

7 Reverse bend test

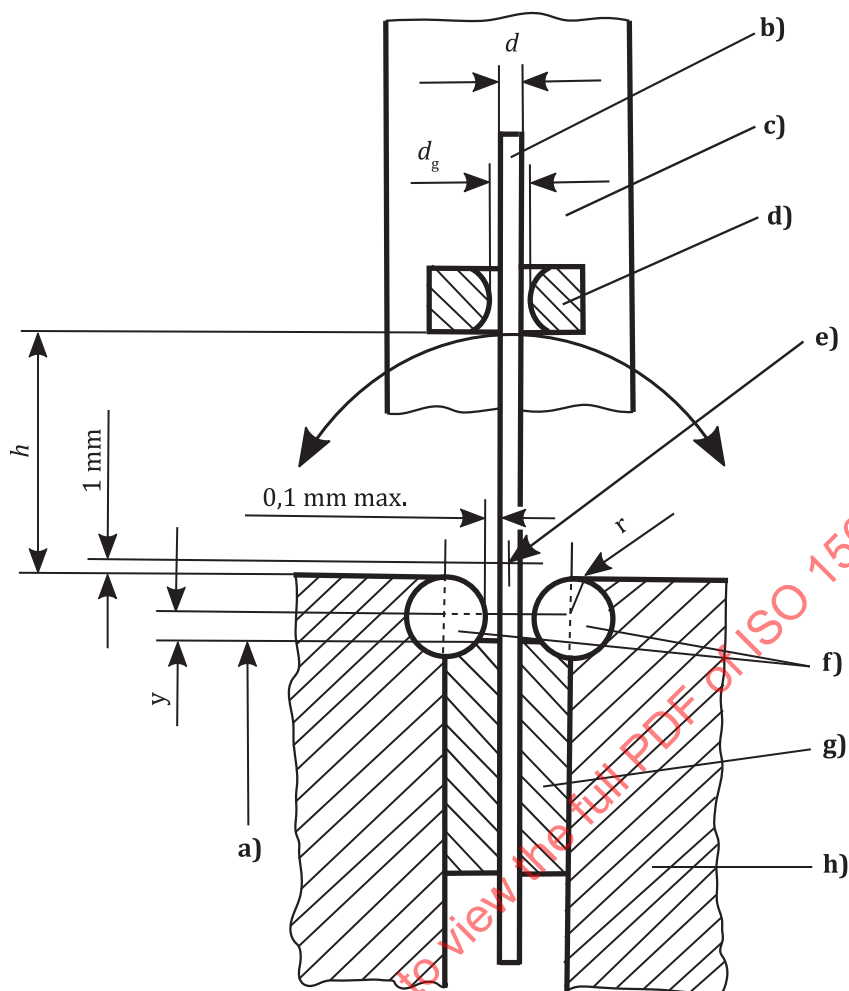
7.1 Test piece

In addition to the general provisions given in [Clause 4](#), the test piece shall conform to ISO 7801.

7.2 Test equipment

The test equipment shall conform to ISO 7801.

For wire of nominal diameter $10 \text{ mm} < d \leq 12,5 \text{ mm}$, the following conditions apply to the test equipment as defined by [Figure 3](#): $r = (30 \pm 1) \text{ mm}$, $h = 125 \text{ mm}$, $d_g = 11 \text{ mm}$ or 13 mm .



Key

- a) nearest point of contact with test piece d) guide g) gripping faces of supports
b) test piece e) pivoting axis of the bending arm h) supports
c) bending arm f) cylindrical supports

Figure 3 — Schematic of the test equipment for the reverse bend test

7.3 Test procedure

The reverse bend test shall be performed in accordance with ISO 7801.

8 Wrapping test

8.1 Test piece

In addition to the general provisions given in [Clause 4](#), the test piece shall conform to ISO 7802.

8.2 Test equipment

The test equipment shall conform to ISO 7802.

8.3 Test procedure

The wrapping test shall be performed in accordance with ISO 7802.

9 Isothermal stress relaxation test

9.1 Principle of test

The isothermal stress relaxation test consists of measuring, at a given temperature (generally fixed at 20 °C unless otherwise agreed), the variations of force of a test piece maintained at constant length ($L_0 + \Delta L_0$), from an initial force (F_0) (see Figure 4).

The loss in force is expressed as a percentage of the initial force for a given period of time.

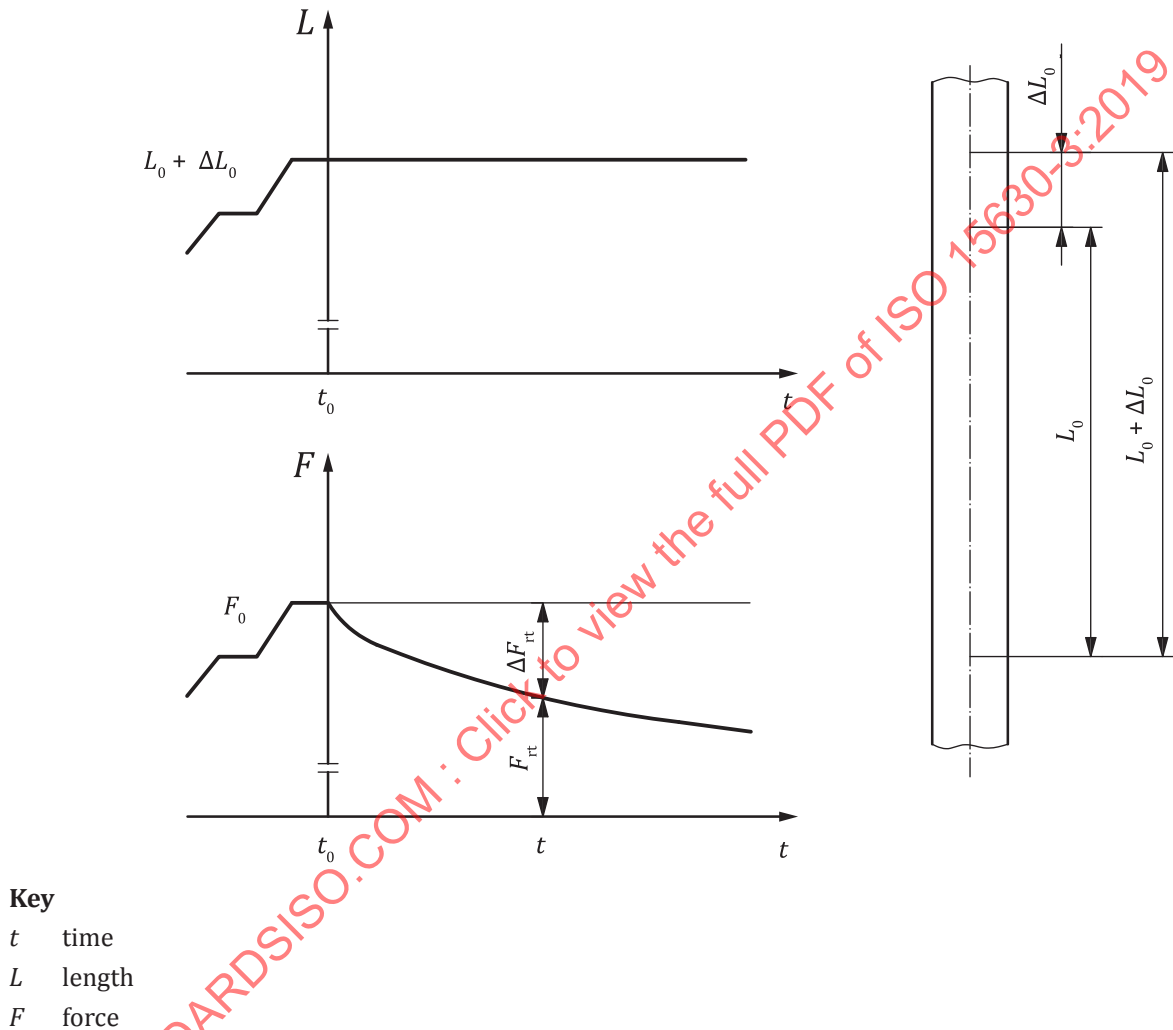


Figure 4 — Principle of the isothermal stress relaxation test

9.2 Test piece

The general provisions given in [Clause 4](#) apply.

The test piece for the isothermal stress relaxation test shall be maintained in a straight condition. The free length of the test piece between the grips shall not be subjected to any mechanical deformation or treatment of any kind.

Two test pieces adjacent to the test pieces for the stress relaxation test shall be taken for the determination of the mean value of maximum force ($\bar{F}_m$), if the initial force (F_0) is expressed as a percentage of $\bar{F}_m$, e.g. $70 \% \times \bar{F}_m$.

9.3 Test equipment

9.3.1 Frame

Any deformation of the frame shall be within such limits that it does not influence the results of the test.

9.3.2 Force-measuring device

The force shall be measured either by a coaxial force cell or another appropriate device (e.g. lever loading system).

The force cell shall be calibrated in accordance with ISO 7500-1 and have an accuracy of $\pm 1\%$ for forces up to 1 000 kN and $\pm 2\%$ for forces greater than 1 000 kN.

The other appropriate devices shall have the same accuracy as the one specified for the force cell.

The resolution of the output of the force-measuring device shall be $5 \times 10^{-4} F_0$ or better.

9.3.3 Length-measuring device (extensometer)

The gauge length (L_0) shall be not less than 200 mm. For strands, it should preferably be 1 000 mm or an integer number of the strand lay length where the actual length ($L_0 + \Delta L_0$) is measured on the same wire of the strand. The extensometer shall be of class 1 or better in accordance with ISO 9513.

NOTE The maximum permissible values for a class 1 extensometer are as follows: relative error of the gauge length $\pm 1\%$; resolution $\pm 0,5\%$ or $1\text{ }\mu\text{m}$, whichever is the greater; bias error $\pm 1,0\%$ or $\pm 3,0\text{ }\mu\text{m}$, whichever is the greater.

9.3.4 Anchoring device

The anchoring device shall be constructed in such a way that slipping during the test either is not possible or is corrected and rotation of the anchoring device is prevented.

9.3.5 Loading device

The loading device shall allow a smooth increase in loading the test piece without shock. It shall be constructed in such a way that the length ($L_0 + \Delta L_0$) can be maintained within the limits fixed in [9.4.5](#), throughout the test, by reduction of force.

9.4 Test procedure

9.4.1 Provisions concerning the test piece

The test piece shall remain at least 24 h in the testing laboratory prior to the test.

The test piece shall be securely gripped in the anchorages of the test device in order to avoid any slippage during loading and during the test.

9.4.2 Application of force

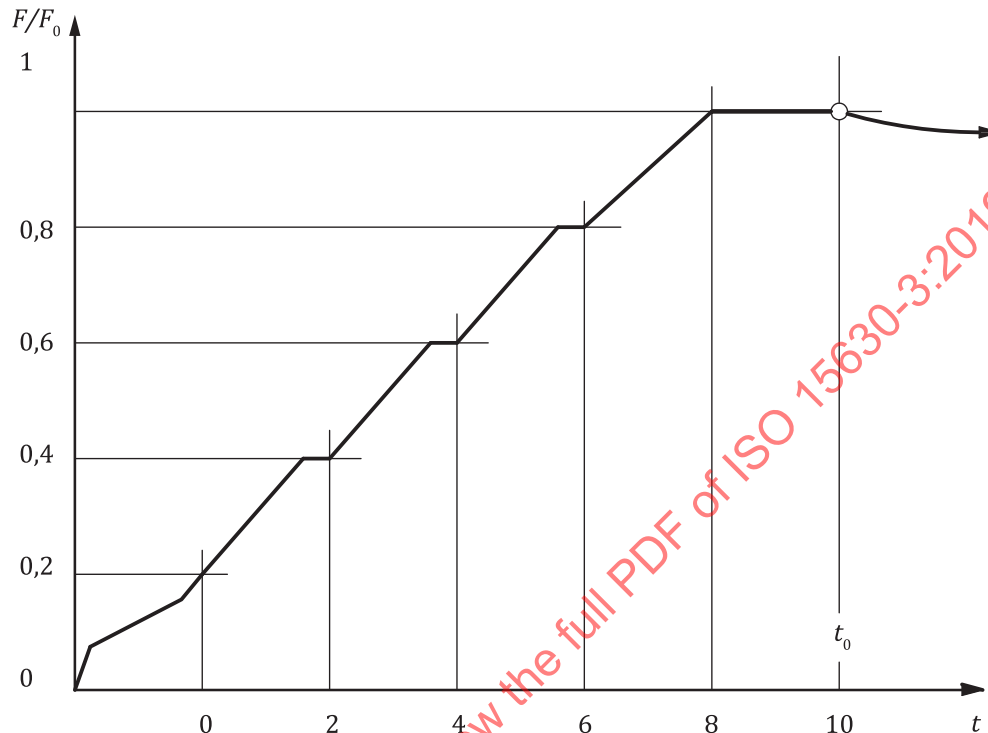
At all times, the force shall be applied uniformly and without shock.

The loading up to 20 % of the initial force (F_0) may be applied as desired. Loading of the test piece from 20 % up to 80 % of F_0 shall be applied continuously or in three or more uniform steps or with a uniform rate of loading and shall be completed within 6 min. Application of the force between 80 % and 100 % of F_0 shall be continuous and shall be completed within 2 min, after achievement of 80 % of F_0 .

NOTE A rate of loading up to F_0 of $(200 \pm 50)\text{ MPa}\cdot\text{min}^{-1}$ is considered as a uniform rate of loading.

On attainment of the initial force (F_0), the force shall be kept constant for a period of 2 min. Immediately on completion of this 2 min-period, time (t_0) is established and recorded. Any subsequent adjustment of force shall only be made in order to ensure that $L_0 + \Delta L_0$ is kept constant.

The application of force is illustrated schematically in Figure 5.



Key

t time (min)

F/F_0 ratio between the applied force and the initial force (F_0)

Figure 5 — Application of force in the isothermal stress relaxation test

9.4.3 Initial force

The initial force (F_0) shall be as specified in the appropriate product standard. The measured value of the initial force shall be within the tolerances of the specified value given in Table 1.

Table 1 — Tolerance of F_0

Value of F_0	Tolerance of F_0
$F_0 \leq 1\,000$ kN	$\pm 1\%$
$F_0 > 1\,000$ kN	$\pm 2\%$

9.4.4 Force during the test

At any time, the force shall not be permitted to exceed the initial force by more than the tolerances given in Table 1.

9.4.5 Maintenance of strain

The strain imposed by the initial force (F_0) at time (t_0) shall be measured with a suitable mechanical, electrical or optical extensometer having the accuracy defined in 9.3.3 at the selected initial

gauge length (L_0). The variation of ΔL_0 shall not exceed $5 \times 10^{-5} L_0$ between two consecutive force measurements.

9.4.6 Temperature

The temperature of the testing laboratory shall be such that the temperature of the test piece shall be maintained at the specified test temperature ± 2 °C.

9.4.7 Frequency of force recording

The loss of force shall be continuously recorded or measured at least approximately at the standard time intervals given in [Table 2](#) after starting the test and then at least once per week.

Table 2 — Standard times of force recording

Minutes	1	2	4	8	15	30	60
Hours	2	4	6	24	48	96	120

9.4.8 Frequency of strain recording

The strain measured by the extensometer shall be recorded continuously, or at least during force measurements, and twice between two consecutive force measurements (at equal time intervals).

9.4.9 Duration of the test

The duration of the test shall be not less than 120 h.

NOTE A common duration of a test is 120 h or 1 000 h.

The value of stress relaxation at 1 000 h (or more) may be extrapolated from tests terminating at not less than 120 h, where adequate evidence is provided that the extrapolated 1 000 h (or more)-value is equivalent to the actual 1 000 h (or more)-value. In this case, the extrapolation method should be described in the test report.

A current method of extrapolation is based on [Formula \(4\)](#):

$$\log \rho = m \log t + n \quad (4)$$

where

ρ is the relaxation, generally expressed in percent;

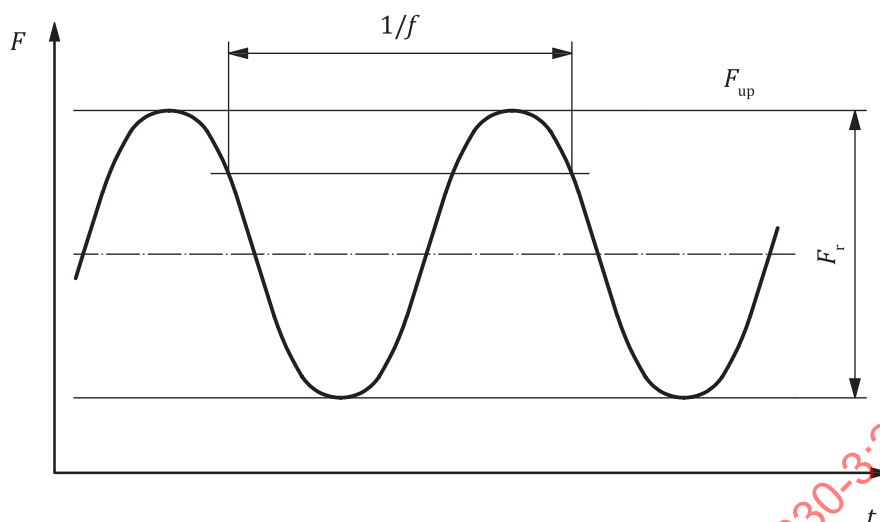
t is the time, expressed in hours;

m and n are coefficients.

10 Axial force fatigue test

10.1 Principle of test

The axial force fatigue test consists of subjecting the test piece to an axial tensile force, which varies cyclically according to a sinusoidal wave-form of constant frequency (f) in the elastic range (see [Figure 6](#)). The test is performed until failure of the test piece or until reaching, without failure, the number of force cycles specified in the relevant product standard.

**Key** F_{up} upper value of F F_r range of F per cycle $1/f$ one cycle F force t time**Figure 6 — Force-cycle diagram****10.2 Test piece**

The general provisions given in [Clause 4](#) apply.

The minimum free length shall be in accordance with [Table 3](#). The free length of the test piece between the grips shall not be subjected to treatment of any kind.

Table 3 — Minimum free length of the test piece

Wire and bar	140 mm or $14d$, whichever is the greater
Strand	500 mm or twice the lay length, whichever is the greater

10.3 Test equipment

The fatigue-testing machine shall be calibrated in accordance with either ISO 4965-1 and ISO 4965-2, or ISO 7500-1. The accuracy shall be at least ± 1 %. The fatigue-testing machine shall be capable of maintaining the upper force (F_{up}) to within ± 2 % of the specified value and the force range (F_r) to within ± 4 % of the specified value.

10.4 Test procedure**10.4.1 Provisions concerning the test piece**

The test piece shall be gripped in the test equipment in such a way that force is transmitted axially and free of any bending moment along the test piece. For strands, it is essential that all constituent wires be equally gripped and the force equally distributed among them.

10.4.2 Stability of force and frequency

The test shall be performed under conditions of stable upper force (F_{up}), force range (F_r) and frequency (f). There shall be no planned interruptions in the cyclic loading throughout the test. However, it is

permissible to continue a test which is accidentally interrupted. Any interruption shall be recorded in the test report.

10.4.3 Counting of force cycles

The number of force cycles shall be counted inclusively from the first full force-range cycle.

10.4.4 Frequency

The frequency of force cycles shall be stable during the test and shall be maintained during a series of tests with identical testing conditions. The frequency shall not exceed

- a) 120 Hz for wire and bar, or
- b) 20 Hz for strand.

10.4.5 Temperature

The temperature of the test piece shall not exceed 40 °C throughout the test. The temperature of the testing laboratory shall be between 10 °C and 35 °C, unless otherwise specified.

10.4.6 Validity of the test

If failure occurs in the grips or within a distance of $2d$ from the grips, or initiates at an exceptional feature of the test piece, the test may be considered as invalid.

11 Stress corrosion test in a solution of thiocyanate

11.1 Principle of test

The test determines the time to fracture of a test piece maintained at a constant tensile force (F_0) specified in the relevant product standard and immersed in a solution of thiocyanate (see [11.3.5](#)), at a given constant temperature.

11.2 Sample and test piece

The general provisions given in [Clause 4](#) apply to the sample which should provide not less than six test pieces for the stress corrosion test and two test pieces for the determination of $\bar{F}_m$ by a uniaxial tensile test if the initial force (F_0) is expressed as a percentage of $\bar{F}_m$, e.g. 80 % $\bar{F}_m$.

The length of a test piece (L_t) shall be sufficient to ensure that any bending from the anchorage is minimized and should be preferably twice the length (L_0).

11.3 Test equipment

11.3.1 Frame

A stiff frame shall be used. Loading shall be applied by a lever apparatus or by a hydraulic or mechanical device acting on a closed frame in either the horizontal or vertical orientation.

11.3.2 Force-measuring device

A force-measuring device with an accuracy of at least ± 2 % shall be used and calibrated in accordance with ISO 7500-1.

11.3.3 Time-measuring device

The time shall be measured with a resolution of at least 0,01 h. The time-measuring device shall be equipped with an automatic control to stop and retain or record the time at fracture with an accuracy of $\pm 0,1$ h. Alternatively, the time to fracture shall be the last manually recorded time prior to fracture.

11.3.4 Test cell containing the test solution

The test cell containing the test solution should preferably be cylindrical and sealed at both ends. It shall have an inner diameter (D_c) in accordance with [Formula \(5\)](#):

$$D_c \geq \sqrt{(200 + d) \times d} \quad (5)$$

where all dimensions are given in millimetres.

Recommended inner diameters (D_c) are given in [Table 4](#).

Table 4 — Recommended inner diameters (D_c) of the test cell

Dimensions in millimetres

Nominal diameter of the test piece, d	Recommended values of D_c
$d \leq 19$	≥ 70
$19 < d \leq 50$	≥ 100

The test cell length shall be sufficient to accommodate a test length (L_0) of at least 200 mm.

The test cell shall be fabricated from a material which is chemically resistant to the test solution at 50 °C.

The test cell shall be kept closed during the test, and admission of air shall be avoided.

11.3.5 Test solution

The test solution can be selected from one of the two solutions specified below, which present a high and a low concentration of thiocyanate, respectively.

- Solution A: aqueous solution of ammonium thiocyanate prepared by dissolving 200 g of NH_4SCN in 800 ml of distilled or demineralized water. The ammonium thiocyanate shall be of analytical grade containing at least 99 % of NH_4SCN and a maximum of 0,005 % Cl^- , 0,005 % SO_4^{2-} and 0,001 % S^{2-} .
- Solution B: aqueous solution of potassium sulfate (K_2SO_4), potassium chloride (KCl) and potassium thiocyanate (KSCN) prepared with distilled or demineralized water. Test solution B shall contain 5 g/l of SO_4^{2-} , 0,5 g/l of Cl^- and 1 g/l of SCN^- .

The electrical conductivity of the water used for the preparation of solutions A and B shall not exceed 20 $\mu\text{S}/\text{cm}$.

Attention is drawn to the fact that these two solutions give different results which are not comparable. The solution(s) to be used should be as specified in the product standard.

WARNING — Relevant material safety data sheet (MSDS) information on handling dangerous chemicals and disposal of these chemicals after use shall be taken into account for the chemicals used in this test.

11.4 Test procedure

11.4.1 Provisions concerning the test pieces

The test pieces shall be cleaned by wiping with a soft cloth and degreased, e.g. with acetone (CH_3COCH_3), and dried in air.

The test piece shall be protected from corrosion by varnish or similar means in the zones where the test piece enters the test cell and for at least 50 mm into the inner part of the test cell. The test length (L_0) is the length of the test piece in contact with the solution.

11.4.2 Application and maintenance of force

The test piece is placed in the tensioning frame and the test cell is placed on the test piece. Force shall be applied to the test piece until F_0 is reached.

The indicated force for F_0 shall be maintained within $\pm 2\%$ for the duration of the test.

The value for F_0 shall be recorded at time (t_0) and shall be confirmed and, if necessary, adjusted at appropriate intervals during the test.

11.4.3 Filling of the test cell

Upon completion of loading, the test cell shall be sealed to prevent leakage and a volume (V_0) of test solution, which shall be a new one for each test, preheated to a temperature between $50\text{ }^\circ\text{C}$ and $55\text{ }^\circ\text{C}$ poured into the test cell. V_0 shall be at least 5 ml per cm^2 of surface area of the test piece along the test length (L_0). Filling of the test cell shall be completed within 1 min for wire and strands or 5 min for bars and then the time-measuring device shall be set to the starting time (t_0).

Inside the test cell, the test piece shall be completely immersed in the test solution.

The solution shall not be circulated during the test.

11.4.4 Temperature during the test

Within the time interval t_0 and $t_0 + 5\text{ min}$, the temperature of the test solution shall be adjusted to $(50 \pm 1)\text{ }^\circ\text{C}$ for wires and strands and $(50 \pm 2)\text{ }^\circ\text{C}$ for bars and shall be maintained in the relevant range throughout the test.

11.4.5 Termination of the test

The test shall be considered to have reached completion either on fracture of the test piece or at an agreed time (t_a).

In the case of strands, the test shall be considered to have reached completion if at least one wire is fractured. If fracture of the test piece occurs outside the test length (L_0), the test shall be considered as invalid.

The time to fracture ($t_{f,i}$) shall be measured and recorded to the nearest 0,1 h. If fracture has not occurred within the time (t_a), the result shall be recorded as $t_{f,i} > t_a$.

11.4.6 Determination of median lifetime to fracture

When all the test pieces in the series have been tested, the results $t_{f,i}$ shall be ordered according to the values of lifetime to fracture. The median value ($t_{f,m}$) is that in the middle of this ordered series, or the arithmetic mean of the two in the middle if there is an even number of test results.

12 Deflected tensile test

12.1 Principle of test

The test consists of determining the reduction coefficient of the maximum force in uniaxial tension due to a deviation of 20° around a specified mandrel, for five test pieces of a sample of strand with a nominal diameter equal to or greater than 12,5 mm.

12.2 Sample and test pieces

The general provisions given in [Clause 4](#) apply to a sample of sufficient length to provide at least 12 test pieces.

One test piece taken from each end of the sample shall be used in the uniaxial tensile tests to determine $\bar{F}_m$.

The remainder of the test sample shall be cut into at least 10 test pieces for deflected tensile tests.

Five valid test results are sufficient to calculate the *D*-value (see [12.4](#)). But as invalid tests can occur, it is suggested that at least 10 available test pieces be provided.

The length of each test piece shall be appropriate to the testing and anchoring device.

The test pieces shall not be subjected to any treatment or preparation other than cutting.

12.3 Test equipment

12.3.1 General description

The testing machine shall have a stiff frame and shall conform to the requirements specified in [12.3.2](#) to [12.3.5](#). The testing machine consists of a fixed passive anchorage, a movable active anchorage to which a force-measuring device is attached, a loading device and a fixed grooved mandrel of specified dimensions.

12.3.2 Dimensions

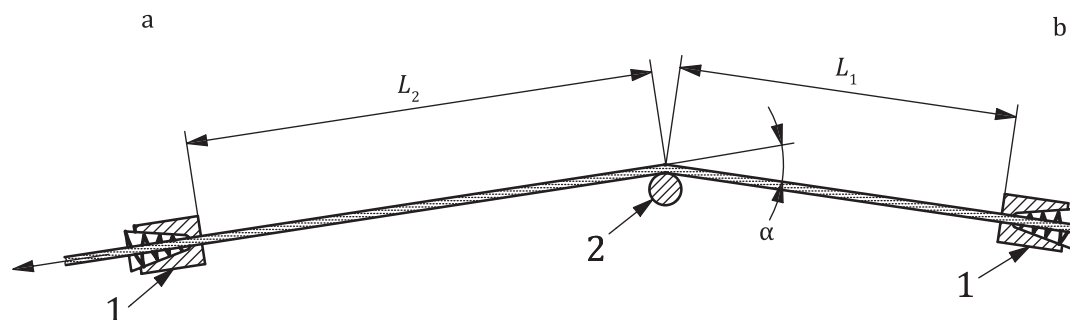
The dimensions of the test device shown in [Figure 7](#) shall be as follows:

L_1 : (700 ± 50) mm;

L_2 : ≥ 750 mm;

α : 20° ± 0,5°.

The axis of the mandrel shall be perpendicular to the plane formed between the active and the passive anchorage sides and the centre of the mandrel.

**Key**

- 1 anchorage
 2 central mandrel
 a Active side.
 b Passive side.

Figure 7 — Main dimensions of the deflected tensile test device

12.3.3 Anchorages

The longitudinal axis of both ends of the test piece shall be perpendicular to the plane of bearings for the anchorages. An inadequate geometrical position can cause incorrect test results.

The anchorages shall conform to the following requirements:

- uniaxial tensile tests with the anchorages (wedges and dies) used in the deflected tensile tests shall provide at least 95 % of the maximum force in the uniaxial tensile test performed in accordance with [Clause 5](#);
- axial displacement of the centre wire in relation to the outer wires of the strand shall be less than 0,5 mm at 90 % of the maximum force in the uniaxial tensile test;
- displacement of the wedges in the anchorage body shall be less than the values given in [Table 5](#);
- the contact between the conical part of the die and wedges shall be secured during the test;
- the toothed part of the wedges shall have a minimum length of 2,5 times the nominal strand diameter.

Table 5 — Displacement of wedges

Percentage of maximum force	Admissible maximum displacement ^a mm
from 0 % to fracture	5
from 50 % to fracture	2,5

^a Bedding-in of the wedges prior to the beginning of the test shall be disregarded.

12.3.4 Mandrel

The mandrel shall be made of tool steel in accordance with ISO 4957. The chemical composition, microstructure and heat treatment shall be such that the mandrel is ductile and has a high wear resistance.

The surface hardness shall be 58 HRC to 62 HRC measured in accordance with ISO 6508-1.

The surface finish of the fresh mandrel groove shall have a roughness (Ra) of maximum 1,6 μm . Ra is defined in ISO 4287.

The dimensions of the mandrel (see [Figure 8](#)) are given in [Table 6](#).

The mandrel shall be rigidly fixed in such a way that there is no rotation or other movement.

Table 6 — Dimensions of the mandrel

Parameter	Nominal strand diameter (mm)		
	12,5 to 13,0	15 to 16	17 to 18
Nominal mandrel diameter, d_a (mm)	40	49	59
Angle of the groove flanks	$60^\circ \pm 12'$	$60^\circ \pm 12'$	$60^\circ \pm 12'$
Radius at the base of the groove, R (mm)	$2 \pm 0,2$	$2 \pm 0,2$	$2 \pm 0,2$
Depth of the groove, G (mm)	7,6	9,5	12
Groove width, C , at nominal mandrel diameter, d_a (mm)	14,4	17,9	21,9
Inner diameter, d_i , of the groove (mm)	$24,7 \pm 0,1$	$29,9 \pm 0,1$	$34,9 \pm 0,1$
Diameter to be obtained after placing two cylinders in the groove, d_b (mm)	$57,0 \pm 0,1$	$72,0 \pm 0,1$	$81,0 \pm 0,1$
Diameter of the gauge cylinder, d_e (mm)	44	18	20

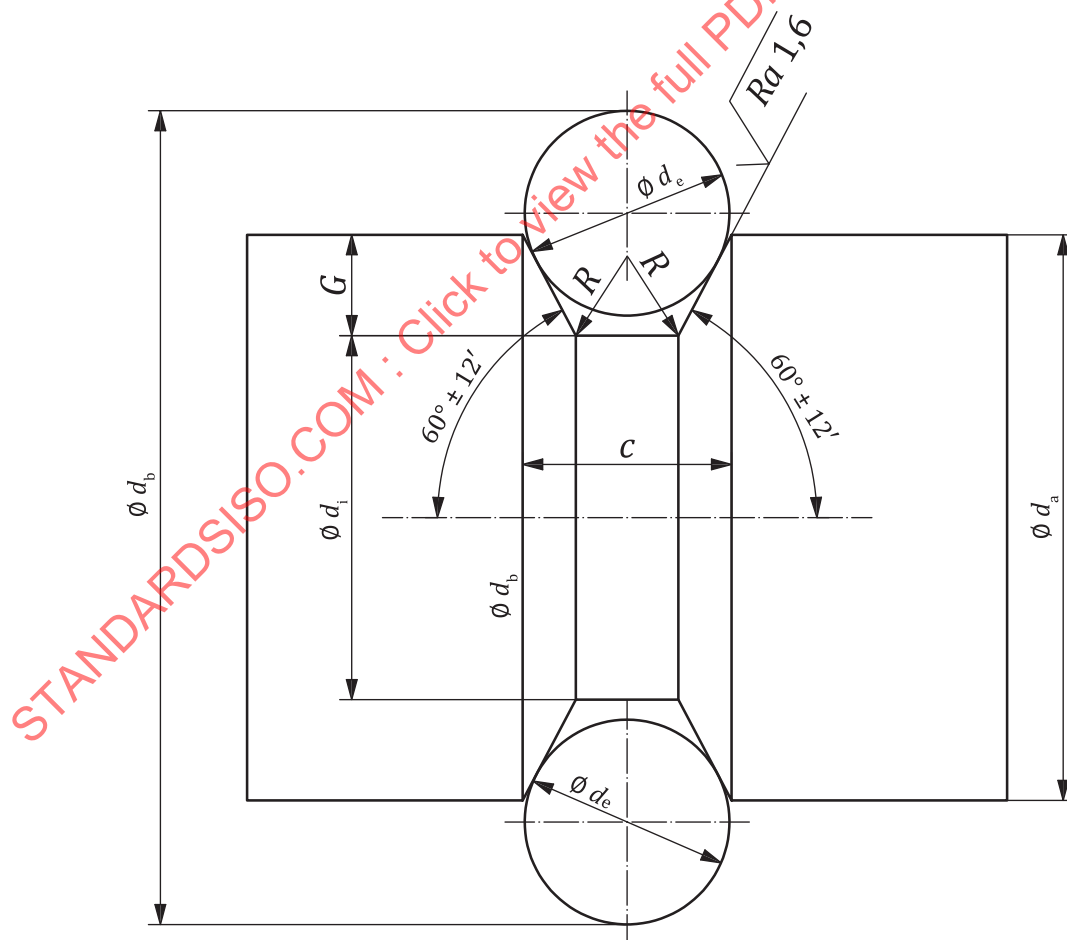


Figure 8 — Mandrel

12.3.5 Loading device

The loading equipment, preferably using a force cell, shall be calibrated in accordance with ISO 7500-1. Accuracy shall be at least ± 1 % of the indicated force for forces ≥ 10 % of the total force range.

The loading rate shall be adjustable. This rate shall be controlled during the test so that, when the force increases to 50 % of the anticipated breaking force, the rate shall be in the range $30 \text{ MPa}\cdot\text{s}^{-1}$ to $60 \text{ MPa}\cdot\text{s}^{-1}$ (or in the strain rate range of $15 \times 10^{-5} \text{ s}^{-1}$ to $30 \times 10^{-5} \text{ s}^{-1}$ if the test is strain-controlled). This rate shall then be maintained until fracture occurs.

12.4 Test procedure

The surface of the mandrel groove shall be carefully cleaned (see [11.4.1](#)) before starting any test. If the strand is slightly curved, the test piece shall be laid into the groove in such a way that the curvature is in the same direction as the deflection during the test.

Proper alignment of the test piece shall be verified after installation in the anchorages and before application of any force. During loading, the grip efficiency of the anchorages shall be checked to verify that there is no slippage between the strand and the anchorage grips.

The loading rate shall conform to [12.3.5](#).

A test shall be considered as invalid if the fracture of one or more wires of the strand does not occur at the contact with the mandrel.

The value of $F_{a,i}$ for a valid test shall be recorded with the accuracy indicated in [12.3.5](#). The corresponding value D_i shall be calculated from $F_{a,i}$ as shown by [Formula \(6\)](#), expressed in percentage, and shall be reported:

$$D_i = (1 - F_{a,i} / \bar{F}_m) \times 100 \quad (6)$$

The D -value shall be calculated as the average of the five D_i values, as shown by [Formula \(7\)](#):

$$D = \frac{1}{5} \sum_{i=1}^5 D_i \quad (7)$$

13 Chemical analysis

In general, the chemical composition is determined by spectrometric methods.

In case of dispute about analytical methods, the chemical composition shall be determined by an appropriate reference method specified in one of the relevant International Standards.

NOTE A list of the relevant International Standards for the determination of the chemical composition is given in the Bibliography.

14 Measurement of the geometrical characteristics

14.1 Test piece

The general provisions given in [Clause 4](#) apply.

The length of the test piece shall be sufficient to perform the measurements in accordance with [14.3](#).

14.2 Test equipment

The geometrical characteristics shall be measured with an instrument of an accuracy of at least the following:

- 0,01 mm for the height of ribs (for bars or quenched and tempered wire) and the depth of indentations (for indented cold-drawn wire and strand);
- 0,05 mm for the gap between the ribs or indentations of two adjacent rib or indentation rows;
- 0,5 mm for the measurement of the distance between ribs or indentations when determining the rib or indentation spacing (see [14.3.1.3](#) and [14.3.2.3](#)), the length of indentations (see [14.3.2.4](#)) or of the lay length for strands (see [14.3.3](#));
- one degree for the inclination between the rib or indentation and the longitudinal axis of the wire or bar.

14.3 Test procedures

14.3.1 Rib measurements

14.3.1.1 Height at the highest point ($a_{\max}$)

The rib height at the highest point ($a_{\max}$) shall be determined by measuring the height of n ($n \geq 5$) individual ribs in each row at their highest point and calculating the mean of all obtained individual values.

14.3.1.2 Rib height at a given position

The rib height at a given position, e.g. at the quarter-point or at the mid-point or at the three-quarters point, respectively designated $a_{1/4}$, a_m and $a_{3/4}$, shall be determined by measuring the height of n ($n \geq 3$) individual ribs in each row and calculating the mean of all obtained individual values.

14.3.1.3 Rib spacing (c)

The rib spacing (c) shall be determined from the length of the measured distance divided by the number of rib gaps.

The measured distance is deemed to be the interval between the centre of a rib and the centre of another rib on the same row of the test piece determined in a straight line and parallel to the longitudinal axis of the test piece. The measured distance shall include at least 10 rib gaps.

14.3.1.4 Part of the circumference without ribs ($\sum e_i$)

The part of the circumference without ribs ($\sum e_i$) shall be determined as the sum of the average gap (e) between ribs of two adjacent rib rows, for each rib row. The average gap (e) shall be determined from at least three measurements.

14.3.1.5 Rib inclination angle (β)

The rib inclination angle (β) shall be determined as the mean of the individual angles measured for each row of ribs with the same angle.

14.3.1.6 Width of transverse rib (b)

The width of transverse rib (b), see [Figure 10](#), section M-M, shall be determined as the mean of three measurements on each row, at the mid-point of the rib, made normal to the axis of the rib.

14.3.2 Indentation measurements

14.3.2.1 General

Measurements for indented strand shall be made on each individual indented wire before stranding. Single-wire test pieces that are not straightened in the production process shall be straightened, prior to measurement, without a change to the wire surface.

14.3.2.2 Depth at the deepest point ($a_{\max}$)

The indentation depth at the deepest point ($a_{\max}$) shall be determined by measuring the depth of n ($n \geq 5$) individual indentations in each row at their deepest point and calculating the mean of the individual values obtained.

14.3.2.3 Indentation spacing (c)

The indentation spacing (c) shall be determined from the length of the measured distance divided by the number of protrusions between indentations included in it.

The measured distance is deemed to be the interval between the side of an indentation and the corresponding side of another indentation on the same row of the test piece, determined along a line crossing the indentations in their centres and parallel to the longitudinal axis of the test piece, at the surface level of the wire. The measured distance shall include at least 10 protrusions between indentations.

14.3.2.4 Length of indentation (l)

The length of indentation (l) shall be determined as the mean of three measurements on each row made parallel to the longitudinal axis of the wire along a line crossing the indentation in its centre, at the surface level of the wire.

14.3.2.5 Part of the circumference without indentations ($\sum e_i$)

The part of the circumference without indentations ($\sum e_i$) shall be determined as the sum of the average gap (e) between indentations of two adjacent indentation rows, for each indentation row. The average gap (e) shall be determined from at least three measurements.

14.3.2.6 Indentation angle (β)

The indentation angle (β) shall be determined as the mean of the individual angles measured for each indentation row.

14.3.3 Lay length of strand (P)

The lay length of strand (P) shall be determined as the distance between two consecutive corresponding points of the same wire.

It is recommended that this distance be measured on paper onto which an impression of the strand is made by rubbing.

14.3.4 Straightness

The bow height (h_b) which indicates the straightness of the test piece shall be determined by measuring in the plane of the bow the distance between the prestressing steel and the line joining the ends of a rule of 1 m long in contact with the prestressing steel lying on a flat horizontal surface with a measurement tolerance of 1 mm (see [Figure 9](#)).

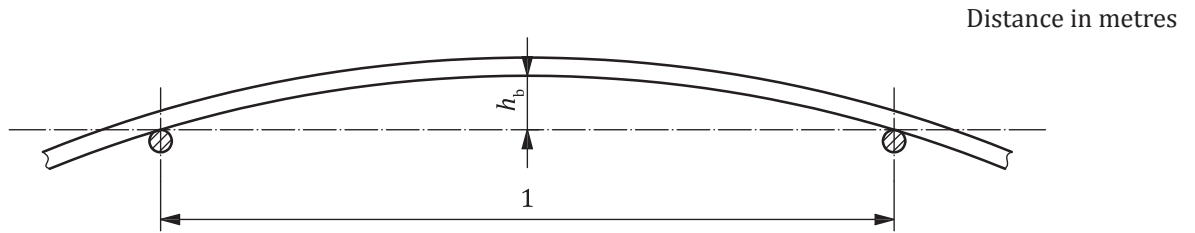


Figure 9 — Measurement of bow height

15 Determination of the relative rib area (f_R)

15.1 General

The determination of the relative rib area (f_R) for ribbed prestressing steel shall be based on the results of measurements made in accordance with [14.3.1](#).

15.2 Calculation of f_R

15.2.1 Relative rib area

The relative rib area is defined by [Formula \(8\)](#):

$$f_R = \frac{1}{\pi d} \sum_{i=1}^n \frac{\frac{1}{m} \sum_{j=1}^m F_{R,i,j} \sin \beta_{i,j}}{c_i} \quad (8)$$

where

n is the number of rows of transverse ribs on the circumference;

m is the number of different transverse rib inclinations per row.

$F_R = \sum_{i=1}^p (a_{s,i} \Delta l)$ is the area of the longitudinal section of one rib (see [Figure 10](#)) where $a_{s,i}$ is the average height of a portion i of a rib subdivided into p parts of length Δl .

15.2.2 Simplified formulae

Where [Formula \(8\)](#) is not strictly applied by using devices taking into account this formula, a simplified formula may be used.

Examples of simplified formulae are given in [Formulae \(9\)](#) to [\(12\)](#).

a) Trapezium formula:

$$f_R = (a_{1/4} + a_m + a_{3/4})(\pi d - \sum e_i) \frac{1}{4\pi d c} \quad (9)$$

b) Simpson's rule formula:

$$f_R = (2a_{1/4} + a_m + 2a_{3/4})(\pi d - \sum e_i) \frac{1}{6\pi dc} \quad (10)$$

c) Parabola formula:

$$f_R = \frac{2a_m}{3\pi dc} (\pi d - \sum e_i) \quad (11)$$

d) Empirical formula:

$$f_R = \lambda \frac{a_m}{c} \quad (12)$$

where λ is an empirical factor that may be shown to relate f_R to a particular wire profile

The values $a_{1/4}$, a_m , $a_{3/4}$ shall be determined in accordance with [14.3.1.2](#). $\sum e_i$ shall be determined as indicated in [14.3.1.4](#).