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Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners —

Part 5:
Special fasteners (also including fasteners from nickel alloys) for high temperature applications

Fixations — Caractéristiques mécaniques des fixations en acier inoxydable résistant à la corrosion —

Partie 5: Fixations spéciales (incluant également les fixations en alliages de nickel) pour utilisation à hautes températures

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Foreword

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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).

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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 Technical Committee ISO/TC 2, *Fasteners.*

A list of all parts in the ISO 3506 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.

Introduction

The ISO 3506 series consists of the following parts, under the general title *Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners*:

— *Part 1: Bolts, screws and studs with specified grades and property classes*

— *Part 2: Nuts with specified grades and property classes*

— *Part 3* [1]*: Set screws and similar fasteners not under tensile stress*

— *Part 4* [1]*: Tapping screws*

— *Part 5: Special fasteners (also including fasteners from nickel alloys) for high temperature applications*

— *Part 6: General rules for the selection of stainless steels and nickel alloys for fasteners*

Complementary detailed explanations about definitions of stainless steel grades and properties are specified in ISO 3506-6.

The properties of stainless steel and nickel alloy fasteners for high temperature applications result from the chemical composition of the material, from the heat treatment process and from the manufacturing process of the fasteners. Static or dynamic properties at room temperature like tensile strength, hardness or fatigue resistance are not sufficient enough to design fasteners for high temperature applications properly.

In fact, at high temperatures e.g. above 300 °C, additional phenomena occur, for instance:

— decrease in tensile properties and hardness,

— hot oxidation and scaling,

— stress relaxation,

— creep.

All these phenomena significantly affect the durability and service life of fasteners. Therefore:

— a proper choice of material grade is essential to avoid heavy hot oxidation,

— qualification of fasteners through dedicated tests should be performed.

Different tests are currently available to assess the behaviour of machined and standardized samples (see for example ASTM E292 or ASTM E328). In addition to these tests, this document specifies test methods on finished fasteners: these are useful when requiring results as representative as possible of the actual service conditions.

All fastener categories included in this document are heat-treated (see [Clause 6](#)). Heat treatment processing is crucial to reach mechanical properties and suitable microstructure that are essential to stand phenomena described above and to get adequate durability for the fasteners and the assembled bolted joints.

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1) It is intended to revise ISO 3506-3 and ISO 3506-4 in the future in order to include the reference to ISO 3506-6.

Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners —

Part 5:
Special fasteners (also including fasteners from nickel alloys) for high temperature applications

1 Scope

This document specifies the mechanical and physical properties of bolts, screws, studs and nuts, with coarse pitch thread and fine pitch thread, made of corrosion-resistant stainless steels (i.e. martensitic stainless steels and precipitation hardening austenitic stainless steels) and nickel alloys, intended for use at high temperatures up to 800 °C.

Tests in accordance with Clause 9 are performed at the ambient temperature range of 10 °C to 35 °C, and other tests can be performed at higher temperatures, see Clause 10.

NOTE   Fasteners specified in this document are also suitable when used at low temperatures, typically down to -50 °C. For more information, see ISO 3506-6.

The term "fasteners" is used in this document when bolts, screws, studs and nuts are considered all together.

ISO 3506-6 provides general rules and additional technical information on suitable stainless steels and nickel alloys as well as their properties.

This document applies to fasteners:

— with ISO metric thread in accordance with ISO 68-1,

— with diameter/pitch combinations in accordance with ISO 261 and ISO 262,

— with coarse pitch thread M3 to M39, and fine pitch thread M8×1 to M39×3,

— with thread tolerances in accordance with ISO 965-1 and ISO 965-2, and

— of any shape but with full loadability.

Stainless steel and nickel alloy fastener symbols can be used for sizes outside the diameter limits of this document (i.e. for bolts, screws and studs with d < 3 mm or d > 39 mm and for nuts with D < 5 mm or D > 39 mm), provided that all applicable chemical, mechanical and physical requirements are met.

Fasteners with reduced loadability (i.e. thin nuts and bolts, screws and studs with head or unthreaded shank weaker than the threaded shank) are not dealt with in this document.

This document does not specify requirements for functional properties such as:

— torque/clamp force properties,

— shear strength,

— fatigue resistance,

— weldability,

or

— properties of bolted joints and fasteners in high temperature environment (see test methods at high temperature for fasteners in Clause 10).

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 1891-4, *Fasteners — Vocabulary — Part 4: Control, inspection, delivery, acceptance and quality*

ISO 3506-1, *Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners — Part 1: Bolts, screws and studs with specified grades and property classes*

ISO 3506-2, *Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners — Part 2: Nuts with specified grades and property classes*

ISO 3506-6, *Fasteners — Mechanical properties of corrosion-resistant stainless steel fasteners — Part 6: General rules for the selection of stainless steels and nickel alloys for fasteners*

ISO 6506-1, *Metallic materials — Brinell hardness test — Part 1: Test method*

ISO 6507-1, *Metallic materials — Vickers hardness test — Part 1: Test method*

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

ISO 16228, *Fasteners — Types of inspection documents*

EN 10319-2, *Metallic materials — Tensile stress relaxation testing — Part 2: Procedure for bolted joint models*

3 Terms and definitions

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

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

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
stainless steel
steel with at least 10,5 % (mass fraction) of chromium (Cr) and maximum 1,2 % (mass fraction) of carbon (C)

[SOURCE: ISO 3506-1:2020, 3.5]

3.2
martensitic stainless steel
stainless steel (3.1) with high amounts of chromium but very little nickel or other alloying elements, which can be hardened by heat treatment for increasing strength but with reduced ductility, and with highly magnetic properties

[SOURCE: ISO 3506-1:2020, 3.7]

3.3
precipitation hardening austenitic stainless steel
austenitic stainless steel that can be hardened through precipitation of intermetallic phases from its supersaturated metallic matrix

3.4
nickel alloy
alloy whose main constituent is nickel

3.5
soaking time
time that the entire part being heat-treated (throughout its cross-sections) remains at the specified set temperature

3.6
stainless steel bolt and screw with full loadability
nickel alloy bolt and screw with full loadability
bolt and screw with head stronger than the threaded and unthreaded shanks (with unthreaded shank diameter $d_s \approx d_2$ or $d_s > d_2$) or screw threaded to the head, and fulfilling the minimum ultimate tensile load

[SOURCE: ISO 3506-1:2020, 3.1 modified]

3.7
stainless steel stud with full loadability
nickel alloy stud with full loadability
stud with unthreaded shank diameter $d_s \approx d_2$ or $d_s > d_2$, and fulfilling the minimum ultimate tensile load

[SOURCE: ISO 3506-1:2020, 3.2 modified]

3.8
stainless steel nut with full loadability
nickel alloy nut with full loadability
regular nut or high nut fulfilling the requirements for proof load and with minimum height $m_{min} \geq 0,80D$ or $m_{th,design,min} \geq 0,73D$

Note 1 to entry: The limits for the minimum height $m_{min} \geq 0,80D$ (for standard nuts) or $m_{th,design,min} \geq 0,73D$ (for other nuts) are explained in 6.4.

3.9
resistance to high temperature environment
extent to which a fastener retains required functional properties (e.g. resistance against oxidation, relaxation, creep) during exposure to a specified temperature for a specified duration and/or to temperature cycles

3.10
creep
time-dependent strain that occurs after the application of a force which is thereafter maintained constant

3.11
relaxation
time-dependent stress loss for a constant strain

4 Symbols

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

A	Total elongation after fracture for full-size fastener, mm
A_T	Total elongation after fracture for full-size fastener at high temperature, mm
$A_{s,nom}$	Nominal stress area in thread, mm^2
b	Thread length, mm
d, D	Nominal thread diameter, mm
d_1	Basic minor diameter of external thread, mm
d_2	Basic pitch diameter of external thread, mm
D_2	Basic pitch diameter of internal thread, mm
d_3	Minor diameter of external thread (for nominal stress area calculation), mm
d_h	Hole diameter of the grip in tensile testing device, mm
d_s	Diameter of unthreaded shank, mm
F_{mf}	Ultimate tensile load for full-size fastener, N
$F_{mf,T}$	Ultimate tensile load for full-size fastener at high temperature, N
$F_{n,T}$	Ultimate stripping load at high temperature for the nut, N
F_P	Proof load for nut, N
F_{pf}	Load at 0,2 % non-proportional elongation for full-size fastener, N
$F_{pf,T}$	Load at 0,2 % non-proportional elongation for full-size fastener at high temperature, N
h	Thickness of the nut grip in tensile testing device, mm
H	Height of the fundamental triangle of the thread, mm
l	Nominal length of fastener, mm
L_0	Total length of fastener before tensile test, mm
L_1	Total length of fastener after fracture, mm
L_2	Clamping length before tensile test, mm
l_t	Overall length of stud, mm
l_{th}	Free threaded length of fastener in testing device, mm
m	Height of the nut, mm
$m_{th,design}$	Design thread height of the nut, mm
P	Pitch of the thread, mm
R_{mf}	Tensile strength for full-size fastener, MPa

$R_{\mathrm{mf,T}}$	Tensile strength for full-size fastener at high temperature, MPa
$R_{\mathrm{n,T}}$	Ultimate nut strength at stripping load at high temperature, MPa
R_{pf}	Stress at 0,2 % non-proportional elongation for full-size fastener, MPa
$R_{\mathrm{pf,T}}$	Stress at 0,2 % non-proportional elongation for full-size fastener at high temperature, MPa
S_{p}	Stress under proof load for nuts, MPa

5 Designation system for fasteners made from stainless steels and nickel alloys

All stainless steels and nickel alloys specified in this document belong to one of the three following categories:

— **martensitic stainless steels** (3.2): CH0, CH1, CH2, V, VH, and VW,

— **precipitation hardening austenitic stainless steels** (3.3): SD,

— **nickel alloys** (3.4): SB and 718.

The chemical composition and heat treatment of fasteners for these three material categories are specified in Clause 6.

The marking, labelling and designation with the fastener symbols of Clause 6 shall be as specified in Clause 11.

6 Materials and manufacture

6.1 Chemical composition

Tables 1 to 3 specify the limits for chemical composition of the stainless steels and nickel alloys for fasteners. The chemical composition shall be assessed in accordance with the relevant International Standards.

The final choice of the chemical composition within the specified fastener symbol is at the discretion of the manufacturer, unless otherwise agreed between the purchaser and the manufacturer.

The stainless steel or nickel alloy grade suitable for an application shall be selected in accordance with the specifications defined in ISO 3506-6 (see also Bibliography for additional material information).

Table 1 — Chemical composition for martensitic stainless steel fasteners

Fastener symbol	Material reference	Chemical composition Mass fraction, % (maximum values unless stated otherwise)									
		C	Si	Mn	P	S	Cr	Mo	Ni	N	Other elements
CH0	4021-420-00-I [a]	0,16 to 0,25	1,00	1,50	0,040	0,030 [c]	12,0 to 14,0	—	—	—	—
	1.4021 [b]										
CH1	4028-420-00-I [a]	0,26 to 0,35	1,00	1,50	0,040	0,030 [c]	12,0 to 14,0	—	—	—	—
	1.4028 [b]										
CH2	4057-431-00-X [a]	0,12 to 0,22	1,00	1,50	0,040	0,030 [c]	15,0 to 17,0	—	1,50 to 2,50	—	—
	1.4057 [b]										
V or VH [d]	4923-422-77-E [a]	0,18 to 0,24	0,50	0,40 to 0,90	0,025	0,015	11,0 to 12,5	0,80 to 1,20	0,30 to 0,80	—	V: 0,25 to 0,35
	1.4923 [e]										
VW	1.4913 [e]	0,17 to 0,23	0,50	0,40 to 0,90	0,025	0,015	10,0 to 11,5	0,50 to 0,80	0,20 to 0,60	0,05 to 0,10	V: 0,10 to 0,30 Nb: 0,25 to 0,55 B ≤ 0,0015 Al ≤ 0,020

[a] Material reference given for information according to ISO 15510.

[b] Material reference given for information according to EN 10088-3.

[c] For machinability, a controlled sulfur mass fraction of 0,015 % to 0,030 % is recommended.

[d] Symbol V for stress at 0,2 % non-proportional elongation $R_{pf} \geq 600$ MPa, and symbol VH for $R_{pf} \geq 700$ MPa, in accordance with Table 7.

[e] Material reference given for information according to EN 10269.

Table 2 — Chemical composition for precipitation hardening austenitic stainless steel fasteners

Fastener symbol	Material reference	Chemical composition Mass fraction, % (maximum values unless stated otherwise)									
		C	Si	Mn	P	S	Cr	Mo	Ni	Ti	Other elements
SD [a]	4980-662-86-X [b]	0,080 [e]	1,00	2,00	0,040	0,030	13,5 to 16,0	1,00 to 1,50	24,0 to 27,0	1,90 to 2,35	Al ≤ 0,35 V: 0,10 to 0,50 B: 0,0010 to 0,010
	Alloy 660 UNS S66286 [c]										
	1.4980 [d]	0,030 to 0,080	1,00	1,00 to 2,00	0,025	0,015	13,5 to 16,0	1,00 to 1,50	24,0 to 27,0	1,90 to 2,30	Al ≤ 0,35 V: 0,10 to 0,50 B: 0,0030 to 0,010

[a] Secondary melting (for instance Electro-Slag Remelting) of the raw material is recommended due to the beneficial effect on the functional properties of the finished fasteners. The melting process is left to the choice of the fastener manufacturer, unless otherwise agreed.

[b] Material reference given for information according to ISO 15510.

[c] Material reference given for information according to ASTM A453/A453M.

[d] Material reference given for information according to EN 10269.

[e] A minimum carbon content may be required for specific applications.

Table 3 — Chemical composition for nickel alloy fasteners

Fastener symbol	Material reference	Chemical composition Mass fraction, % (maximum values unless stated otherwise)									
		C	Si	Mn	P	S	Cr	Mo	Ni	Ti	Other elements
SB [a]	Alloy 80A UNS N07080 [b]	0,10 [c]	1,00	1,00	—	0,015	18,0 to 21,0	—	Re-minder	1,80 to 2,70	Al: 0,50 to 1,80 Fe ≤ 3,00
	2.4952 [d]	0,040 to 0,10	1,00	1,00	0,020	0,015	18,0 to 21,0	—	≥ 65	1,80 to 2,70	Al: 1,00 to 1,80 Fe ≤ 1,50 Co ≤ 1,00 Cu ≤ 0,20 B ≤ 0,0080
718 [a]	Alloy 718 UNS N07718 [e]	0,080 [c]	0,35	0,35	0,015	0,015	17,0 to 21,0	2,80 to 3,30	50 to 55	0,65 to 1,15	Nb + Ta: 4,75 to 5,50 Al: 0,20 to 0,80 Co ≤ 1,00 Cu ≤ 0,30 B ≤ 0,0060
	2.4668 [f]	0,020 to 0,080	0,35	0,35	0,015	0,015	17,0 to 21,0	2,80 to 3,30	50 to 55	0,60 to 1,20	Nb + Ta: 4,7 to 5,5 Al: 0,30 to 0,70 Co ≤ 1,00 Cu ≤ 0,30 B ≤ 0,0020 to 0,0060

[a] Secondary melting (for instance Electro-Slag Remelting) of the raw material is recommended due to the beneficial effect on the functional properties of the finished fasteners. The melting process is left to the choice of the fastener manufacturer, unless otherwise agreed.

[b] Material references given for information according to ASTM B637.

[c] A minimum carbon content may be required for specific applications.

[d] Material references given for information according to EN 10269.

[e] Material references given for information according to ASTM A1014.

[f] Material references given for information according to EN 10302.

6.2 Heat treatment for fasteners

Fasteners shall be heat treated in order to meet the mechanical and physical properties specified in Clause 7.

Heat treatment requirements are specified in Table 4. The minimum tempering temperature for martensitic stainless steels shall be selected in accordance with Table 4, by taking into account the mechanical and physical properties required in Table 7 as well as the temperature at which the fasteners are intended to be used.

The process steps shall be as follows:

— for SD, SB and 718, solution annealing (AT) shall be carried out. In addition, it is strongly recommended to perform AT after the manufacture of the fasteners; however, for externally threaded fasteners with tensile strength R_{mf} above or equal to 1 100 MPa, AT could be performed on the raw material (before manufacturing the fasteners) subject to prior agreement between the purchaser and the manufacturer at the time of order;

— for cold and hot forged fasteners, heat treatment shall be performed after the manufacture of the fasteners;

— for fasteners machined from bars, heat treatment can be carried out on the raw material or after the manufacture of the fasteners.

For externally threaded fasteners, thread rolling can be carried out before or after heat treatment, or between solution annealing (AT) and precipitation hardening (P) steps.

Table 4 — Heat treatment for fasteners

Fastener symbol	Heat treatment condition	Temperature range for quenching/solution annealing °C [and soaking time ([3.5])]	Temperature for tempering/ precipitation hardening °C [and soaking time ([3.5])]
CH0	+QT	950 to 1 050	≥ 450 [a, b]
CH1	+QT	950 to 1 050	≥ 450 [a, b]
CH2	+QT	950 to 1 050	≥ 450 [a, b]
V	+QT	1 020 to 1 070	≥ 550 [a]
VH	+QT	1 020 to 1 070	≥ 550 [a]
VW	+QT	1 100 to 1 130	≥ 550 [a]
SD	+AT+P	970 to 990 [≥ 1 h] 890 to 910 [≥ 1 h]	704 to 760 [≥ 16 h]
SB	+AT+P	1 050 to 1 080	1st step: 840 to 860 [≥ 24h] 2nd step: 690 to 710 [≥ 16h]
718	+AT+P	940 to 1 010	1st step: 710 to 730 [≥ 8 h] 2nd step: 610 to 630 Total treatment time: 18 h minimum

QT   Quenched and Tempered.

AT   Solution annealed (Annealing Treatment).

P   Precipitation hardened.

[a]   When the intended service temperature is specified by the customer, the manufacturer shall choose a tempering temperature above this service temperature and in accordance with this [Table 4]. Otherwise, the tempering temperature is left to the choice of the manufacturer providing that the required mechanical and physical properties of the fasteners are met.

[b]   Tempering temperature between 500 °C and 600 °C should be avoided (loss of toughness and increased risk of intergranular corrosion): see information in [Annex A].

Soaking times which are not specified in [Table 4] are left to the choice of the manufacturer. Cooling media are not specified in [Table 4], they are left to the choice of the manufacturer (see e.g. EN 10269).

6.3   Finish

Unless otherwise specified, fasteners shall be supplied clean.

Fasteners are often used in bolted joints where the preload is applied by torque tightening. Lubrication of stainless steel and nickel alloy fasteners is recommended in order to avoid galling during tightening.

NOTE 1   Several parameters can increase the risk of galling for stainless steel and nickel alloy fasteners in bolted assemblies during tightening such as thread damage, high preload, high tightening speed.

NOTE 2   Requirements concerning surface discontinuities and torque/clamp force properties are not specified in International Standards for stainless steel and nickel alloy fasteners.

A controlled torque/clamp force relationship can be obtained for stainless steel and nickel alloy fasteners by means of an adequate finish, either only with a lubricant or with a coating, top coat and/ or sealer including lubricant. In this case, the designation and/or labelling should include the letters

"Lu" immediately after the fastener symbol, e.g. SD Lu. Appropriate measures and means of tightening should be selected accordingly in order to achieve the required preload.

When specific requirements shall be met, they shall be agreed between the supplier and the purchaser at the time of order.

6.4 Design of bolt/nut assemblies

Two styles of nuts are specified in accordance with their minimum heights:

a) For standard hexagon nuts (without flange and without prevailing torque feature) the styles are specified in accordance with the nut minimum height, m_{min}:

— style 1 for regular nut with $0,80D \leq m_{min} < 0,89D$,

— style 2 for high nut with $m_{min} \geq 0,89D$.

b) For other nuts (nuts with flange, nuts per drawing, etc.) the styles are specified in accordance with the minimum design thread height, $m_{th,design,min}$ [2]:

— style 1 for regular nut with $0,73D \leq m_{th,design,min} < 0,83D$,

— style 2 for high nut with $m_{th,design,min} \geq 0,83D$.

More information on basic design principles for nuts and loadability of bolted assemblies is given in ISO 3506-2.

Nuts should be mated with bolts, screws, studs (and washers) with the same fastener symbol (e.g. CH0 bolts with CH0 nuts). However, combining fasteners of different materials is possible providing that:

— an experienced fastener metallurgist shall be consulted,

— the component with the lowest corrosion resistance is always taken into account,

— the component with the lowest temperature resistance is always taken into account, and

— the risk of galling is also considered.

With regard to material properties, fasteners should be mated in accordance with the combinations specified above the stepped thick line in Table 5.

Table 5 — Recommended combinations of bolts, screws and studs with nuts

Bolts, screws and studs	Nuts						
	CH0	CH1	CH2	V, VH and VW	SD	SB	718
CH0							
CH1				**Possible mating nuts**			
CH2							
V, VH and VW							
SD							
SB							
718							

When using stainless steel and nickel alloy fasteners in bolted joints with clamped parts made of dissimilar materials, it is advised to consider the use of isolation components in order to avoid galvanic corrosion.

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2) Up to now, $m_{th,design,min}$ is only specified from ISO/DIS 898-2:2021 version for steel nuts: it will be considered in ISO 3506-2 for its next revision.

6.5 Service temperatures for fasteners

Mechanical and physical properties specified in Clause 7 and test methods specified in Clause 9 are for fasteners at the ambient temperature range of 10 °C to 35 °C. Mechanical and physical properties of the fasteners decrease when used at high temperatures. The typical maximum service temperature in relation to the fastener symbol is specified in Table 6. However, depending on the service conditions, the applicable temperature may be lower.

Table 6 — Typical maximum service temperatures for fasteners

Fastener symbol	Typical maximum service temperature °C
CH0	400
CH1	400
CH2	450
V	550
VH	550
VW	550
SD	650
SB	800
718	700
NOTE SD, SB and 718 also provide a good resistance to wet corrosion.	

Above these typical maximum service temperatures, the specified mechanical or physical properties may be impaired. Particularly above 500 °C, high temperature oxidation occurs and creep (3.10) resistance is the dimensioning factor. Therefore, it is the responsibility of the user to determine the appropriate choice for a given application including resistance to high temperature environment (3.9), in consultation with an experienced fastener metallurgist.

When fastener properties have to be assessed for a specific application, it is advisable to perform tensile test at high temperature and/or stress rupture test and/or relaxation (3.11) test on the finished fasteners at the expected service temperature. Relevant test methods are specified in Clause 10.

The tests should be performed under conditions that are as near as possible to the ones of the final joint in the considered application (clamped parts, clamp force, service temperature, etc.). The contracting parties shall agree on all test conditions before the order.

7 Mechanical and physical properties

7.1 Mechanical properties of bolts, screws and studs

When tested using the methods specified in Clause 9, the bolts, screws and studs of the specified fastener symbol shall meet, at ambient temperature, all the applicable requirements specified in Tables 7 to 11, regardless of which tests are performed during manufacture or final inspection.

Table 7 — Properties at ambient temperature for bolts, screws and studs

Fastener symbol	Tensile strength R_{mf} MPa min.	Stress at 0,2 % non-proportional elongation R_{pf} MPa min.	Elongation after fracture A mm min.	Hardness HRC min. – max.	Converted hardness [a] HV ($F \geq 98$ N) min. – max.
CH0	800	600	0,20d	22 – 32	250 – 320
CH1	850	650	0,20d	26 – 39	270 – 380
CH2	860	690	0,20d	25 – 32	260 – 320
V	800	600	0,20d	22 – 32	250 – 320
VH	900	700	0,20d	28 – 38	280 – 370
VW	900	750	0,20d	28 – 38	280 – 370
SD	900	600	0,25d	22 – 37	250 – 367
SB	1 000	600	0,20d	32 – 42	320 – 417
718	1 230	1 030	0,20d	36 – 48	345 – 480

NOTE   For suitability for high temperature applications, see Table 6.

[a]   Vickers hardness are converted from HRC values by taking into account ASTM A370, ASTM A1014, ASTM F2281 and DIN 267-13.

Table 8 — Minimum ultimate tensile loads at ambient temperature – Coarse pitch thread

Thread d	Nominal stress area $A_{s,nom}$ mm²	Minimum ultimate tensile load, F_{mf} N								
		CH0	CH1	CH2	V	VH	VW	SD	SB	718
M3	5,03	4 030	4 280	4 330	4 030	4 530	4 530	4 530	5 040	6 190
M3,5	6,78	5 430	5 760	5 830	5 430	6 100	6 100	6 100	6 780	8 340
M4	8,78	7 030	7 470	7 550	7 030	7 910	7 910	7 910	8 780	10 800
M5	14,2	11 350	12 060	12 200	11 350	12 770	12 770	12 770	14 190	17 450
M6	20,1	16 100	17 110	17 310	16 100	18 120	18 120	18 120	20 130	24 760
M7	28,9	23 090	24 540	24 820	23 090	25 980	25 980	25 980	28 860	35 500
M8	36,6	29 290	31 120	31 490	29 290	32 950	32 950	32 950	36 610	45 030
M10	58,0	46 400	49 300	49 880	46 400	52 200	52 200	52 200	57 990	71 330
M12	84,3	67 420	71 630	72 470	67 420	75 840	75 840	75 840	84 270	103 700
M14	115	92 360	98 130	99 280	92 360	103 900	103 900	103 900	115 500	142 000
M16	157	125 400	133 200	134 800	125 400	141 100	141 100	141 100	156 700	192 800
M18	192	154 000	163 700	165 600	154 000	173 300	173 300	173 300	192 500	236 800
M20	245	195 900	208 100	210 600	195 900	220 400	220 400	220 400	244 800	301 100
M22	303	242 800	257 900	261 000	242 800	273 100	273 100	273 100	303 400	373 200
M24	353	282 100	299 700	303 200	282 100	317 300	317 300	317 300	352 600	433 600
M27	459	367 600	390 500	395 100	367 600	413 500	413 500	413 500	459 500	565 100
M30	561	448 500	476 500	482 200	448 500	504 600	504 600	504 600	560 600	689 600
M33	694	554 900	589 600	596 500	554 900	624 200	624 200	624 200	693 600	853 100
M36	817	653 400	694 300	702 400	653 400	735 100	735 100	735 100	816 800	1 004 600
M39	976	780 700	829 400	839 200	780 700	878 200	878 200	878 200	975 800	1 200 200

$F_{mf,min} = A_{s,nom} \times R_{mf,min}$. For the calculation of $A_{s,nom}$, see 9.1.8. The load values are calculated by using the exact data for A_s, and only at the end the values are rounded to the next upper 10 N up to 100 000 N, and to the next upper 100 N above.

Table 9 — Minimum loads at R_{pf} at ambient temperature – Coarse pitch thread

Thread d	Nominal stress area $A_{s,nom}$ mm^2	Minimum load at 0,2 % non-proportional elongation, F_{pf} N								
		CH0	CH1	CH2	V	VH	VW	SD	SB	718
M3	5,03	3 020	3 280	3 480	3 020	3 530	3 780	3 020	3 020	5 190
M3,5	6,78	4 070	4 410	4 680	4 070	4 750	5 090	4 070	4 070	6 980
M4	8,78	5 270	5 710	6 060	5 270	6 150	6 590	5 270	5 270	9 050
M5	14,2	8 510	9 220	9 790	8 510	9 930	10 640	8 510	8 510	14 610
M6	20,1	12 080	13 090	13 890	12 080	14 090	15 100	12 080	12 080	20 730
M7	28,9	17 320	18 760	19 920	17 320	20 210	21 650	17 320	17 320	29 730
M8	36,6	21 970	23 800	25 260	21 970	25 630	27 460	21 970	21 970	37 710
M10	58,0	34 800	37 700	40 020	34 800	40 600	43 500	34 800	34 800	59 730
M12	84,3	50 560	54 780	58 150	50 560	58 990	63 200	50 560	50 560	86 800
M14	115	69 270	75 040	79 660	69 270	80 810	86 580	69 270	69 270	119 000
M16	157	94 010	101 900	108 200	94 010	109 700	117 600	94 010	94 010	161 400
M18	192	115 500	125 200	132 900	115 500	134 800	144 400	115 500	115 500	198 300
M20	245	146 900	159 200	169 000	146 900	171 400	183 600	146 900	146 900	252 200
M22	303	182 100	197 300	209 400	182 100	212 400	227 600	182 100	182 100	312 600
M24	353	211 600	229 200	243 300	211 600	246 800	264 400	211 600	211 600	363 100
M27	459	275 700	298 700	317 000	275 700	321 600	344 600	275 700	275 700	473 200
M30	561	336 400	364 400	386 900	336 400	392 500	420 500	336 400	336 400	577 500
M33	694	416 200	450 900	478 600	416 200	485 500	520 200	416 200	416 200	714 400
M36	817	490 100	530 900	563 600	490 100	571 800	612 600	490 100	490 100	841 300
M39	976	585 500	634 300	673 300	585 500	683 100	731 900	585 500	585 500	1 005 100

$F_{pf,min} = A_{s,nom} \times R_{pf,min}$. For the calculation of $A_{s,nom}$, see 9.1.8. The load values are calculated by using the exact data for A_s, and only at the end the values are rounded to the next upper 10 N up to 100 000 N, and to the next upper 100 N above.

Table 10 — Minimum ultimate tensile loads at ambient temperature – Fine pitch thread

Thread $d \times P$	Nominal stress area $A_{s,nom}$ mm²	Minimum ultimate tensile load, F_{mf} N								
		CH0	CH1	CH2	V	VH	VW	SD	SB	718
M8×1	39,2	31 340	33 300	33 690	31 340	35 260	35 260	35 260	39 170	48 180
M10×1,25	61,2	48 960	52 020	52 640	48 960	55 080	55 080	55 080	61 200	75 280
M10×1,0	64,5	51 600	54 820	55 470	51 600	58 050	58 050	58 050	64 500	79 330
M12×1,5	88,1	70 510	74 910	75 790	70 510	79 320	79 320	79 320	88 130	108 400
M12×1,25	92,1	73 660	78 270	79 190	73 660	82 870	82 870	82 870	92 080	113 300
M14×1,5	125	99 640	105 900	107 200	99 640	112 100	112 100	112 100	124 600	153 200
M16×1,5	167	133 800	142 200	143 900	133 800	150 600	150 600	150 600	167 300	205 800
M18×1,5	216	173 000	183 800	186 000	173 000	194 700	194 700	194 700	216 300	266 000
M20×1,5	272	217 300	230 800	233 500	217 300	244 400	244 400	244 400	271 600	334 000
M22×1,5	333	266 500	283 100	286 500	266 500	299 800	299 800	299 800	333 100	409 700
M24×2	384	307 600	326 800	330 600	307 600	346 000	346 000	346 000	384 500	472 900
M27×2	496	396 600	421 400	426 400	396 600	446 200	446 200	446 200	495 800	609 800
M30×2	621	497 000	528 100	534 300	497 000	559 100	559 100	559 100	621 300	764 100
M33×2	761	608 700	646 700	654 300	608 700	684 800	684 800	684 800	760 800	935 800
M36×3	865	692 000	735 200	743 900	692 000	778 500	778 500	778 500	865 000	1 063 900
M39×3	1 030	822 800	874 200	884 500	822 800	925 600	925 600	925 600	1 028 400	1 265 000

$F_{mf,min} = A_{s,nom} \times R_{mf,min}$. For the calculation of $A_{s,nom}$, see 9.1.8. The load values are calculated by using the exact data for A_s, and only at the end the values are rounded to the next upper 10 N up to 100 000 N, and to the next upper 100 N above.

Table 11 — Minimum loads at R_{pf} at ambient temperature – Fine pitch thread

Thread $d \times P$	Nominal stress area $A_{s,nom}$ mm²	Minimum load at 0,2 % non-proportional elongation, F_{pf} N								
		CH0	CH1	CH2	V	VH	VW	SD	SB	718
M8×1	39,2	23 510	25 460	27 030	23 510	27 420	29 380	23 510	23 510	40 350
M10×1,25	61,2	36 720	39 780	42 230	36 720	42 840	45 900	36 720	36 720	63 040
M10×1,0	64,5	38 700	41 930	44 510	38 700	45 150	48 380	38 700	38 700	66 430
M12×1,5	88,1	52 880	57 290	60 810	52 880	61 690	66 100	52 880	52 880	90 770
M12×1,25	92,1	55 250	59 850	63 530	55 250	64 460	69 060	55 250	55 250	94 840
M14×1,5	125	74 730	80 960	85 940	74 730	87 190	93 410	74 730	74 730	128 300
M16×1,5	167	100 400	108 800	115 500	100 400	117 100	125 500	100 400	100 400	172 300
M18×1,5	216	129 800	140 600	149 300	129 800	151 400	162 200	129 800	129 800	222 800
M20×1,5	272	163 000	176 500	187 400	163 000	190 100	203 700	163 000	163 000	279 700
M22×1,5	333	199 900	216 500	229 900	199 900	233 200	249 800	199 900	199 900	343 100
M24×2	384	230 700	249 900	265 300	230 700	269 100	288 400	230 700	230 700	396 000
M27×2	496	297 500	322 300	342 100	297 500	347 100	371 900	297 500	297 500	510 700
M30×2	621	372 800	403 800	428 700	372 800	434 900	466 000	372 800	372 800	639 900
M33×2	761	456 500	494 600	525 000	456 500	532 600	570 600	456 500	456 500	783 700
M36×3	865	519 000	562 300	596 900	519 000	605 500	648 800	519 000	519 000	890 900
M39×3	1 030	617 100	668 500	709 600	617 100	719 900	771 300	617 100	617 100	1 059 300

$F_{pf,min} = A_{s,nom} \times R_{pf,min}$. For the calculation of $A_{s,nom}$, see 9.1.8. The load values are calculated by using the exact data for A_s, and only at the end the values are rounded to the next upper 10 N up to 100 000 N, and to the next upper 100 N above.

7.2 Mechanical properties of nuts

When tested using the methods specified in Clause 9, the nuts of the specified fastener symbol shall meet, at ambient temperature, the requirements for proof load and hardness specified in Tables 12 to 14, regardless of which tests are performed during manufacture or final inspection.

Table 12 — Hardness for nuts at ambient temperature

Fastener symbol	Stress under proof load, S_p MPa	Hardness HRC min. – max.	Converted hardness [a] HV ($F \geq 98$ N) min. – max.
CH0	800	22 – 32	250 – 320
CH1	850	26 – 39	270 – 380
CH2	860	25 – 32	260 – 320
V	800	22 – 32	250 – 320
VH	900	28 – 38	280 – 370
VW	900	28 – 38	280 – 370
SD	900	22 – 37	250 – 367
SB	1 000	32 – 42	320 – 417
718	1 230	36 – 48	345 – 480

[a] Vickers hardness are converted from HRC values by taking into account ASTM A370, ASTM A1014, ASTM F2281 and DIN 267-13.

Table 13 — Proof load values for nuts at ambient temperature – Coarse pitch thread

Thread D	Nominal stress area $A_{s,nom}$ mm²	Proof load, F_p N								
		CH0	CH1	CH2	V	VH	VW	SD	SB	718
M5	14,2	11 350	12 060	12 200	11 350	12 770	12 770	12 770	14 190	17 450
M6	20,1	16 100	17 110	17 310	16 100	18 120	18 120	18 120	20 130	24 760
M7	28,9	23 090	24 540	24 820	23 090	25 980	25 980	25 980	28 860	35 500
M8	36,6	29 290	31 120	31 490	29 290	32 950	32 950	32 950	36 610	45 030
M10	58	46 400	49 300	49 880	46 400	52 200	52 200	52 200	57 990	71 330
M12	84,3	67 420	71 630	72 470	67 420	75 840	75 840	75 840	84 270	103 700
M14	115	92 360	98 130	99 280	92 360	103 900	103 900	103 900	115 500	142 000
M16	157	125 400	133 200	134 800	125 400	141 100	141 100	141 100	156 700	192 800
M18	192	154 000	163 700	165 600	154 000	173 300	173 300	173 300	192 500	236 800
M20	245	195 900	208 100	210 600	195 900	220 400	220 400	220 400	244 800	301 100
M22	303	242 800	257 900	261 000	242 800	273 100	273 100	273 100	303 400	373 200
M24	353	282 100	299 700	303 200	282 100	317 300	317 300	317 300	352 600	433 600
M27	459	367 600	390 500	395 100	367 600	413 500	413 500	413 500	459 500	565 100
M30	561	448 500	476 500	482 200	448 500	504 600	504 600	504 600	560 600	689 600
M33	694	554 900	589 600	596 500	554 900	624 200	624 200	624 200	693 600	853 100
M36	817	653 400	694 300	702 400	653 400	735 100	735 100	735 100	816 800	1 004 600
M39	976	780 700	829 400	839 200	780 700	878 200	878 200	878 200	975 800	1 200 200

$F_p = A_{s,nom} \times S_p$. For the calculation of $A_{s,nom}$, see 9.1.8. The proof load values are calculated by using the exact data for A_s, and only at the end the values are rounded to the next upper 10 N up to 100 000 N, and to the next upper 100 N above.

Table 14 — Proof load values for nuts at ambient temperature – Fine pitch thread

Thread $D \times P$	Nominal stress area $A_{s,nom}$ mm²	Proof load, F_p N								
		CH0	CH1	CH2	V	VH	VW	SD	SB	718
M8×1	39,2	31 340	33 300	33 690	31 340	35 260	35 260	35 260	39 170	48 180
M10×1,25	61,2	48 960	52 020	52 640	48 960	55 080	55 080	55 080	61 200	75 280
M10×1,0	64,5	51 600	54 820	55 470	51 600	58 050	58 050	58 050	64 500	79 330
M12×1,5	88,1	70 510	74 910	75 790	70 510	79 320	79 320	79 320	88 130	108 400
M12×1,25	92,1	73 660	78 270	79 190	73 660	82 870	82 870	82 870	92 080	113 300
M14×1,5	125	99 640	105 900	107 200	99 640	112 100	112 100	112 100	124 600	153 200
M16×1,5	167	133 800	142 200	143 900	133 800	150 600	150 600	150 600	167 300	205 800
M18×1,5	216	173 000	183 800	186 000	173 000	194 700	194 700	194 700	216 300	266 000
M20×1,5	272	217 300	230 800	233 500	217 300	244 400	244 400	244 400	271 600	334 000
M22×1,5	333	266 500	283 100	286 500	266 500	299 800	299 800	299 800	333 100	409 700
M24×2	384	307 600	326 800	330 600	307 600	346 000	346 000	346 000	384 500	472 900
M27×2	496	396 600	421 400	426 400	396 600	446 200	446 200	446 200	495 800	609 800
M30×2	621	497 000	528 100	534 300	497 000	559 100	559 100	559 100	621 300	764 100
M33×2	761	608 700	646 700	654 300	608 700	684 800	684 800	684 800	760 800	935 800
M36×3	865	692 000	735 200	743 900	692 000	778 500	778 500	778 500	865 000	1 063 900
M39×3	1 030	822 800	874 200	884 500	822 800	925 600	925 600	925 600	1 028 400	1 265 000

$F_p = A_{s,nom} \times S_p$. For the calculation of $A_{s,nom}$, see 9.1.8. The proof load values are calculated by using the exact data for A_s, and only at the end the values are rounded to the next upper 10 N up to 100 000 N, and to the next upper 100 N above.

8 Applicability of test methods and inspection

8.1 Applicability of test methods

The applicability of the tests is specified in Table 15.

The test methods are applicable only to stainless steel or nickel alloy bolts and screws with full loadability (3.6), stainless steel or nickel alloy studs with full loadability (3.7) and/or to stainless steel or nickel alloy nuts with full loadability (3.8).

Table 15 — Applicability of tests for fasteners at ambient temperature

Fastener symbol	Property and related test method					
	Bolts, screws and studs				Nuts	
	Minimum tensile strength [a][b][c] R_{mf}	Stress at 0,2 % non-proportional elongation [a][b] R_{pf}	Elongation after fracture [a][b] A	Hardness	Proof load	Hardness
	Tensile test 9.1			Hardness test 9.2	Proof load test 9.3	Hardness test 9.4
SD, SB, 718	$d \geq 3$ mm and $l \geq 2,5d$ and $b \geq 2d$			Applicable	Applicable	Applicable
CH0, CH1, CH2, V, VH, VW	$d \geq 3$ mm and $l \geq 2,5d$ and $b \geq 2d$			Applicable	Applicable	Applicable

[a]   For fully threaded studs, total length $l_t \geq 3,5d$.

[b]   For $l < 2,5d$ (or $l_t < 3,5d$ for fully threaded studs) testing and test conditions shall be agreed between the manufacturer and the purchaser.

[c]   Minimum tensile strength R_{mf} can also be tested by the wedge tensile test (in this case, the test method shall be as specified in ISO 3506-1).

8.2   Manufacturer's inspection

Fasteners shall conform to all applicable requirements specified in Clauses 6 and 7, when using the applicable tests specified in 8.1 and the test methods specified in Clause 9.

This document does not specify the tests to be performed on each manufacturing lot. It is the responsibility of the manufacturer to apply suitable methods of their choice, such as in-process control or final inspection, to ensure that the manufactured lot conforms to all the specified requirements. For additional information, see ISO 16426.

In case of dispute, the test methods in accordance with 8.1 and Clause 9 shall apply.

8.3   Supplier's inspection

The supplier can control and/or test the fasteners they provide using the methods of their choice (periodic evaluation of the manufacturer, checking of test results from the manufacturer, tests on the fasteners themselves, etc.), provided the chemical, mechanical and physical properties specified in Clauses 6 and 7 are met.

In case of dispute, the test methods in accordance with 8.1 and Clause 9 shall apply.

8.4   Purchaser's inspection

The purchaser can control and/or test the delivered fasteners by using the test methods specified in Clause 9.

In case of dispute, the test methods in accordance with 8.1 and Clause 9 shall apply.

8.5   Delivery of test results

If the purchaser requires test results from the supplier, the type of test report shall be agreed upon at the time of order. It shall be established in accordance with ISO 16228, unless otherwise specified. The type of test report (F2.2, F3.1 or F3.2) and any additional or specific test (for example in accordance with Clause 10) shall also be specified by the purchaser and agreed upon at the time of order.

9   Test methods at ambient temperature

9.1   Tensile test for bolts, screws and studs at ambient temperature

9.1.1   General

The purpose of this tensile test is to determine simultaneously or separately:

— the tensile strength, R_{mf}, **and**

— the stress at 0,2 % non-proportional elongation, R_{pf}, **and**

— the elongation after fracture, A.

9.1.2   Applicability

This tensile test applies to full-size bolts, screws and studs having the following specifications:

— all stainless steel and nickel alloy fasteners included in this document,

— 3 mm ≤ d ≤ 39 mm,

— bolts, screws and studs (with unthreaded shank) with nominal length l ≥ 2,5d, and thread length b ≥ 2d,

— unthreaded shank diameter $d_s > d_2$ or d_s approximately equal to d_2,

— fully threaded studs with total length l_t ≥ 3,5d.

9.1.3   Apparatus and testing device

The tensile test machine shall be in accordance with ISO 7500-1, class 1 or better. Side thrust on the fastener shall be avoided, e.g. by self-aligning grips.

The grips and adaptors shall be as follows:

— hardness of 45 HRC minimum,

— hole diameter, d_h, in accordance with Table 16,

— thread tolerance class 5H6G for the threaded adaptors.

The testing device shall be sufficiently rigid to avoid deformation that could influence the determination of the load at 0,2 % non-proportional elongation, F_{pf}, or the elongation after fracture, A.

All length measurements shall be made with an accuracy of ±0,05 mm or better.

a) Bolt

b) Screw

c) Stud with unthreaded shank

d) Fully threaded stud
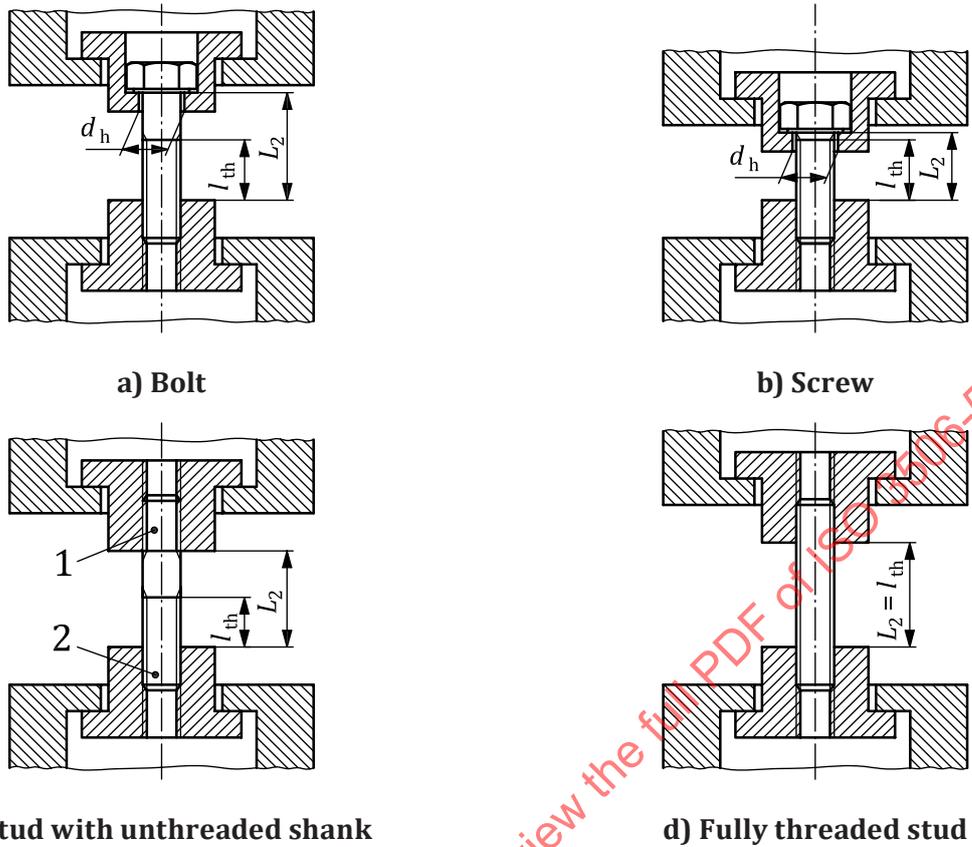
Key

1   metal-end of the stud

2   nut-end of the stud

Figure 1 — Example of testing devices for tensile test

9.1.4   General test procedure

Fasteners shall be tested as received.

The fastener shall be mounted into adaptors as shown in Figure 1. The length of thread engagement in the threaded adaptor(s) shall be $1d \pm 1P$. The free threaded length, l_{th}, subjected to the load shall be $1d$ minimum.

The tensile test shall be carried out in accordance with ISO 6892-1. The speed of testing, as determined with a free-running cross-head, shall not exceed 10 mm/min up to the load F_{pf} and 25 mm/min beyond.

Table 16 — Adaptor hole diameters for bolts, screws and stud tensile test

Dimensions in millimetres

Thread d	d_h [a,b] min.	d_h [a,b] max.	r_1 [c] nom.	Thread d	d_h [a,b] min.	d_h [a,b] max.	r_1 [c] nom.
3	3,40	3,58	0,7	16	17,50	17,77	1,3
3,5	3,90	4,08	0,7	18	20,00	20,33	1,3
4	4,50	4,68	0,7	20	22,00	22,33	1,6
5	5,50	5,68	0,7	22	24,00	24,33	1,6
6	6,60	6,82	0,7	24	26,00	26,33	1,6
7	7,60	7,82	0,8	27	30,00	30,33	1,6
8	9,00	9,22	0,8	30	33,00	33,39	1,6
10	11,00	11,27	0,8	33	36,00	36,39	1,6
12	13,50	13,77	0,8	36	39,00	39,39	1,6
14	15,50	15,77	1,3	39	42,00	42,39	1,6

[a]   Medium series in accordance with ISO 273.

[b]   For square neck bolts, the hole shall be adapted to accommodate the square neck.

[c]   The radius or chamfer r_1 is specified for austenitic stainless steel fasteners; for martensitic stainless steel fasteners, it should be in accordance with the following formula: $r_c = \dfrac{d_{a,max} - d_{s,min}}{2} + 0,2$. The tolerance on r_1 and r_c should be ±0,1 mm.

9.1.5   Test procedure for the simultaneous determination of R_{mf}, R_{pf}, and A

The load, F, shall be measured continuously and until fracture occurs, either directly by means of an adequate electronic device (e.g. microprocessor), or on the curve of load against displacement (see ISO 6892-1); the curve can be plotted either automatically or graphically.

For acceptable accurate graphical measurement, the scale of the curve shall be such that the slope in the elastic range (straight part of the curve) lies between 30° and 45° against the load axis.

Key
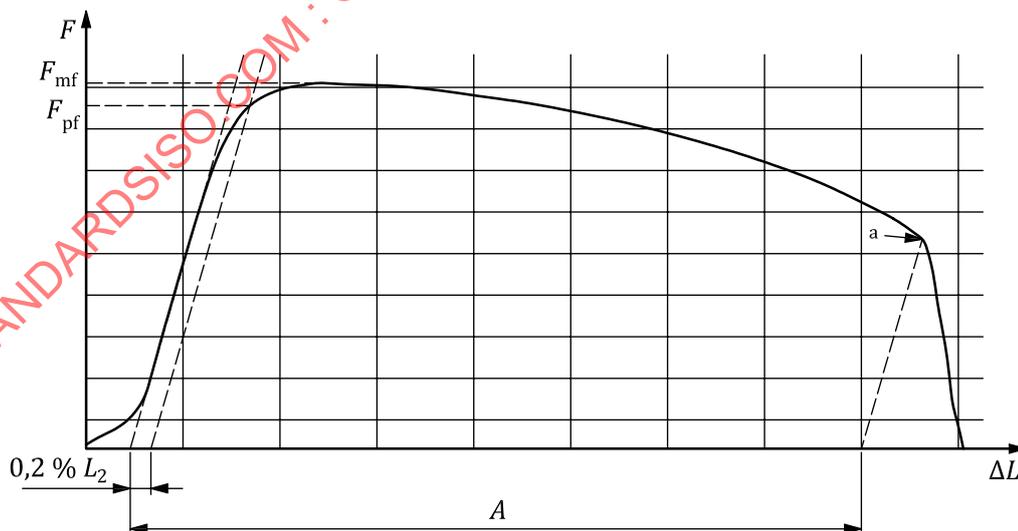
ΔL displacement, mm

F load, N

[a]   Point of fracture.

Figure 2 — Load-displacement curve

The following shall be determined in accordance with Figure 2.

a) The maximum load, F_{mf}.

b) The load at 0,2 % of non-proportional elongation, F_{pf}, directly on the load-displacement curve, as follows:

    1) the slope in the elastic range (straight part of the curve) shall be determined;

    2) a parallel line shall be drawn at a distance equal to 0,2 % of L_2 on the displacement axis ΔL;

    3) the intersection between this line and the curve corresponds to the load F_{pf}.

In case of doubt, the slope in the elastic range shall be determined by drawing a line intersecting the two points of the curve and corresponding to 0,3 F_{pf} min. and 0,6 F_{pf} min. specified in Table 9 or 11.

c) The elongation, A, as follows:

    1) a parallel line to the slope in the elastic range (straight part of the curve) shall be drawn through the point of fracture, which has an intersecting point with the displacement axis;

    2) the elongation A shall be directly determined on the displacement axis ΔL in accordance with Figure 2.

9.1.6 Reference test procedure for the determination of stress at 0,2 % non-proportional elongation, R_{pf}

The test shall be carried out by measuring the load and elongation of the fastener when subjected to axial tensile load, see Figure 3. When this test is also used for the determination of elongation after fracture A (see 9.1.7), it shall be performed until fracture occurs. The speed of testing, as determined with a free-running cross-head, shall not exceed 10 mm/min up to the load F_{pf} and 25 mm/min beyond.
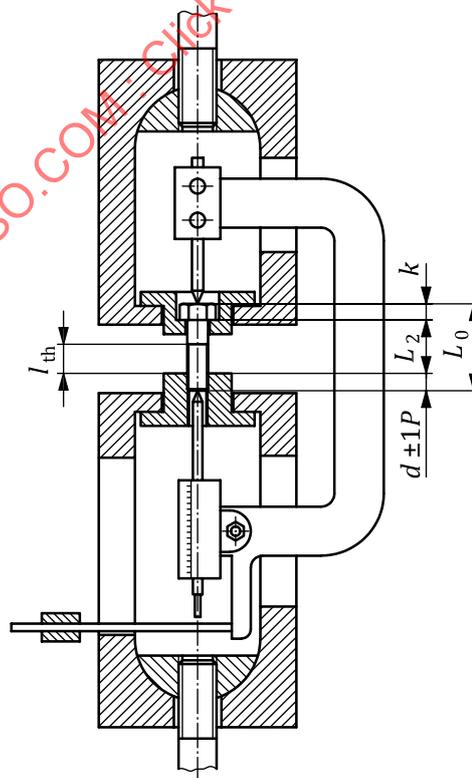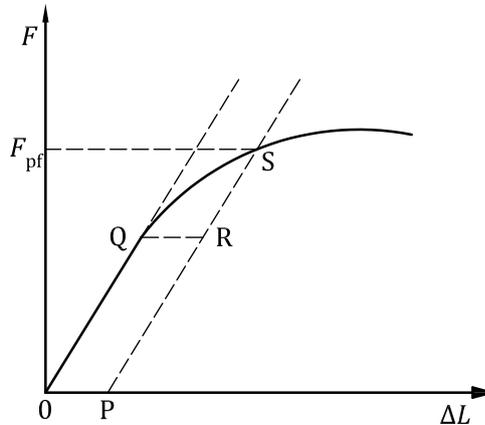

Figure 3 — Example of testing device with an extensometer

The elongation shall be determined between the top of the head and the end of the fastener or between the two ends for studs, see L_0 in Figure 3. When an extensometer is used, it shall be in accordance with ISO 9513, class 2 or better.

The curve of load against elongation shall be drawn as shown in Figure 4.

Key

ΔL elongation, mm

F load, N

Figure 4 — Load-elongation curve for determination of stress at 0,2 % non-proportional elongation, R_{pf}

The clamping length, L_2, shall be calculated as follows:

— for bolts and screws, it is the distance between the bearing surface of the head and the threaded adaptor, see Figures 1a) and 1b);

— for studs with unthreaded shank, it is the distance between the two threaded adaptors, see Figure 1c);

— for fully threaded studs, it is the distance between the two threaded adaptors, see Figure 1d).

A value equal to 0,2 % of L_2 shall be applied to scale to the horizontal axis of the load-elongation curve, 0P. The same value shall be plotted horizontally from the straight-line portion of the curve as QR. A line shall be drawn through P and R. The intersection S of this line with the load-elongation curve corresponds to the load F_{pf} on the vertical axis.

9.1.7   Alternative test procedure for the determination of elongation, A

The total length of the fastener, L_0, shall be measured, see Figure 5a). The fastener shall be mounted in the adaptors in accordance with Figure 1. It shall be axially loaded until fracture occurs. The speed of testing, as determined with a free-running cross-head, shall not exceed 10 mm/min up to the load F_{pf} and 25 mm/min beyond.

After fracture, the two broken pieces shall be fitted together and the length, L_1, shall be measured as shown in Figure 5b).
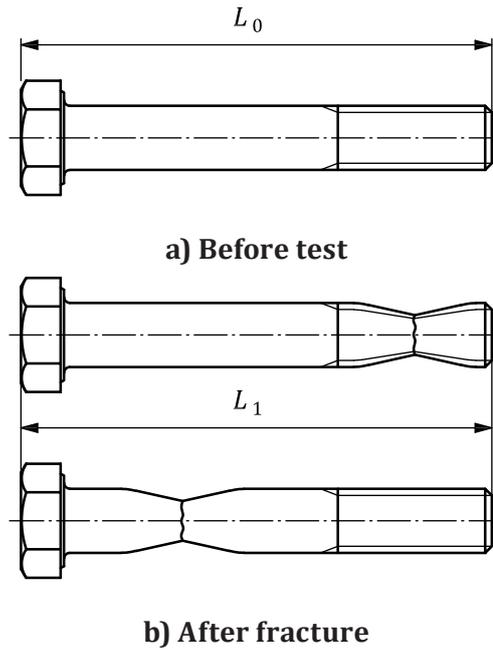
a) Before test

b) After fracture

Figure 5 — Determination of elongation after fracture, A

The elongation after fracture, A, shall be calculated using Formula (1):

$$A = L_1 - L_0 \tag{1}$$

9.1.8   Test results and requirements for tensile strength, R_{mf}

The tensile strength R_{mf} is based on the nominal stress area $A_{s,nom}$ and the ultimate tensile load F_{mf} measured during the test, and shall be calculated using the following Formulae (2) and (3):

$$R_{mf} = \frac{F_{mf}}{A_{s,nom}} \tag{2}$$

with

$$A_{s,nom} = \frac{\pi}{4}\left(\frac{d_2 + d_3}{2}\right)^2 \tag{3}$$

where

d_2 is the basic pitch diameter of external thread, see ISO 724

d_3 is the minor diameter of external thread calculated using Formula (4):

$$d_3 = d_1 - \frac{H}{6} \tag{4}$$

where

d_1 is the basic minor diameter of external thread, see ISO 724

H is the height of the fundamental triangle of the thread, see ISO 68-1.

Values of $A_{s,nom}$ given in Tables 8 and 10 have been rounded to 3 significant digits.

In order to meet the requirements:

a) for fasteners CH0, CH1, CH2, V, VH and VW, the fracture shall occur in the free threaded length;

b) for fasteners SD, SB and 718, the fracture shall occur in the free threaded length, or in the unthreaded shank providing that the ultimate tensile load is met;

c) the fracture shall not occur in the head:

— for bolts with unthreaded shank, the fracture shall not occur in the transition section between the head and the shank,

— for screws threaded to the head, the fracture which causes failure may extend or spread into the transition section between the head and the thread or into the head before separation, provided that it originates in the free threaded length.

R_{mf} shall meet the requirements specified in Table 7. The minimum ultimate tensile load F_{mf}, specified in Table 8 or 10 shall also be met.

9.1.9 Test results and requirements for stress at 0,2 % non-proportional elongation, R_{pf}

The stress at 0,2 % non-proportional elongation R_{pf}, based on the nominal stress area $A_{s,nom}$ and the load at 0,2 % F_{pf} measured during the test, shall be calculated using the following Formula (5):

$$R_{pf} = \frac{F_{pf}}{A_{s,nom}}$$ (5)

Values of $A_{s,nom}$ given in Tables 9 and 11 have been rounded to 3 significant digits.

R_{pf} shall meet the requirements specified in Table 7. The minimum loads F_{pf} specified in Table 9 or 11 shall also be met.

In case of dispute, the reference test method of 9.1.6 performed with the extensometer shall apply for the determination of the stress at 0,2 % non-proportional elongation R_{pf}.

9.1.10 Test results and requirements for elongation after fracture, A

The value for elongation after fracture, A, shall meet the requirements specified in Table 7.

In case of dispute, the reference test method in accordance with 9.1.6 with the extensometer shall apply for the determination of the elongation after fracture, A.

9.2 Hardness test for bolts, screws and studs

9.2.1 General

This test applies to bolts, screws and studs having the following specifications:

— all stainless steel and nickel alloy fasteners included in this document,

— all sizes,

— any shape.

9.2.2 Test procedure

Bolts, screws and studs shall be tested as received.

The hardness test shall be carried out in accordance with ISO 6507-1 (HV), ISO 6508-1 (HRC) or ISO 6506-1 (HBW). The Vickers hardness test shall be performed with a minimum load of 98 N. The Brinell hardness test shall be performed with a load equal to $30D^2$, expressed in newtons.

The hardness shall be determined on a transverse section through the threaded portion. The transverse section shall be taken 1d back from the end of the fastener, with a suitable process where hardness is not altered, and the surface shall be suitably prepared.

NOTE   The term "core hardness" is commonly used for hardness determined by this test method.

Hardness readings shall be performed in the area between the axis and the half-radius position in accordance with Figure 6.
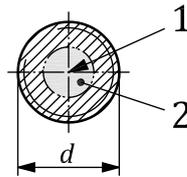
Key

1   axis of the fastener

2   half-radius area (radius of 0,25d)

Figure 6 — Half-radius area for hardness determination

Three readings spaced about 120° apart shall be performed when the size of the area allows it. The hardness value shall be the average of the readings.

9.2.3   Test results and requirements for hardness

The hardness value shall be within the limits specified in Table 7.

In case of dispute, the Vickers hardness test with HV10 shall be the reference test method.

9.3   Proof load test for nuts

9.3.1   General

The proof load test consists of two main operations:

—   application of the specified proof load by means of the test mandrel (see Figure 7), and

—   checking of the damage to the nut thread caused by the proof load, if any.

9.3.2   Applicability

This test applies to nuts having the following specifications:

—   all stainless steel and nickel alloy fasteners included in this document,

—   nominal diameters 5 mm ≤ D ≤ 39 mm,

—   any shape.

9.3.3   Apparatus and testing device

The tensile testing machine shall be in accordance with ISO 7500-1, class 1 or better. Side thrust on the nut shall be avoided, e.g. by self-aligning grips.

The grips and test mandrel shall be as follows:

— hardness of the grip: 45 HRC minimum,

— thickness of the grip, h: $1D$ minimum,

— hole diameter of the grip, d_h: in accordance with Table 17,

— steel mandrel hardened and tempered: hardness 45 HRC to 50 HRC,

— external thread tolerance class of the test mandrel: the mandrel used shall be threaded to tolerance class 5h6g except that the tolerance of the major diameter shall be the last quarter of the 6g range on the minimum material side; thread dimensions for the test mandrel are specified in ISO 3506-2.

Table 17 — Grip hole diameters for nut proof load test

Dimensions in millimetres

| Thread D	Hole diameter d_h [a]		Thread D	Hole diameter d_h [a]		Thread D	Hole diameter d_h [a]	
	min.	max.		min.	max.		min.	max.
5	5,105	5,115	14	14,050	14,160	27	27,065	27,195
6	6,105	6,115	16	16,050	16,160	30	30,065	30,195
7	7,040	7,130	18	18,050	18,160	33	33,080	33,240
8	8,040	8,130	20	20,065	20,195	36	36,080	36,240
10	10,040	10,130	22	22,065	22,195	39	39,080	39,240
12	12,050	12,160	24	24,065	24,195	—	—	—
[a] $d_h = D$ with tolerance class D11 (see ISO 286-2).								

9.3.4 Test procedure

Nuts shall be tested as received. For prevailing torque nuts, additional testing procedures specified in 9.3.5 shall apply.

The threads of the test mandrel shall be checked before each test. If the thread of the mandrel is damaged, it shall not be used within the damaged length or it shall be changed to a conforming mandrel.

The nut to be tested shall be assembled on the test mandrel in accordance with Figure 7.
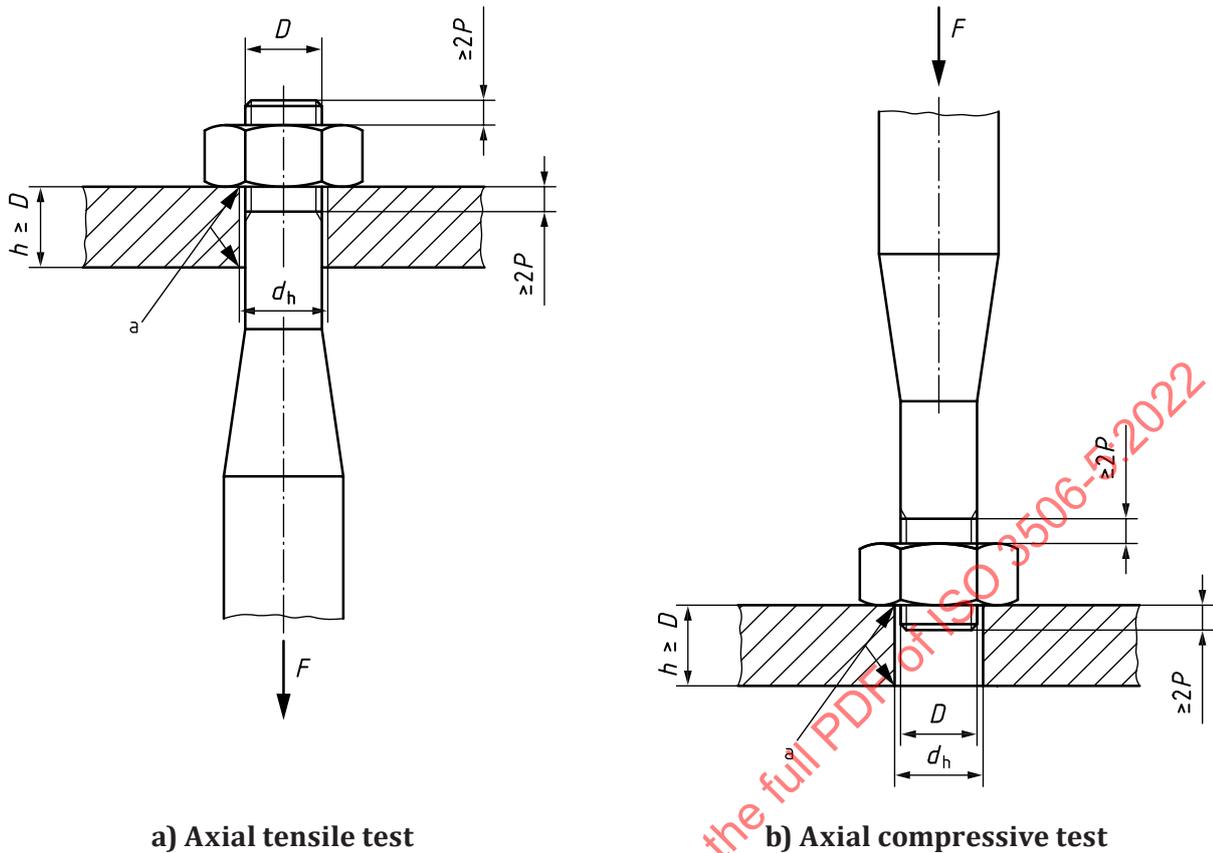
| a) Axial tensile test | b) Axial compressive test |

Key

a   No sharp edge.

F   proof load

Figure 7 — Proof load test for nuts

The axial tensile test or axial compressive test shall be carried out in accordance with ISO 6892-1. The speed of testing, as determined with a free-running cross-head, shall not exceed 3 mm/min.

The proof load value specified in Table 13 or 14 shall be applied and shall be maintained during 15 s, and then released. Exceeding the proof load value should be minimized.

The nut shall be removed from the test mandrel using the fingers. It can be necessary to use a manual wrench to start the nut in motion, but the use of such a wrench is permissible only to a half-turn.

The fact that the nut has been moved with the help of a wrench to one half-turn maximum shall be noted. The fact that nut fracture or thread stripping occurs shall be noted.

9.3.5   Additional testing procedure for prevailing torque nuts

Additionally to 9.3.4, the following shall apply for prevailing torque nuts.

The nut to be tested shall be assembled on a steel test bolt or on the test mandrel specified in 9.3.1. When a test bolt is used, it shall have rolled threads, thread tolerance class 6g, and be uncoated; it shall be in accordance with ISO 898-1, and its property class shall be chosen so that its minimum yield strength is above the proof load of the nut to be tested. For reference test purposes, the hardened steel mandrel in accordance with 9.3.1 shall be used.

The maximum prevailing torque to assemble the nut through 360° rotation shall be recorded after the first full thread of the test mandrel or test bolt has passed through the prevailing torque feature.

After releasing the load, the maximum prevailing torque occurring during disassembly of the nut after a half-turn to full disengagement, measured with the nut in motion, shall be recorded.

9.3.6 Test results and requirements for nut proof load

The nut shall resist the proof load value specified in Table 13 or 14 without failure by thread stripping or nut fracture.

For a nut without prevailing torque feature, the nut shall be removable using the fingers after the release of the proof load (and, if necessary, after a half-turn maximum with a wrench).

For prevailing torque nuts, the maximum prevailing torque occurring during disassembly shall not exceed the recorded maximum prevailing torque during assembly.

In case of dispute, the axial tensile test in accordance with Figure 7 a) shall be the reference method for acceptance.

9.4 Hardness test for nuts

9.4.1 General

This test applies to nuts having the following specifications:

— all stainless steels and nickel alloy fasteners included in this document,

— all sizes,

— any shape.

9.4.2 Test procedure

Nuts shall be tested as received.

The hardness test shall be carried out in accordance with ISO 6507-1 (HV), ISO 6508-1 (HRC) or ISO 6506-1 (HBW). The Vickers hardness test shall be performed with a minimum load of 98 N. The Brinell hardness test shall be performed with a load equal to $30D^2$, expressed in Newtons.

a)   Hardness determined on a surface

For routine inspection the hardness test shall be carried out on one bearing surface of the nut, after removal of any coating and after suitable preparation of the nut. The hardness value shall be the average of three readings spaced about 120° apart, as shown in Figure 8.


Key
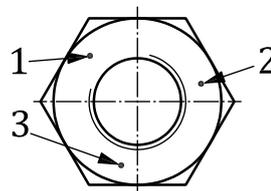
1, 2, 3   location of hardness readings

Figure 8 — Example of hardness determination on the bearing surface

b)   Hardness determined on a longitudinal section

The nut shall be longitudinally sectioned through the nut axis, with a suitable process where hardness is not altered, and the surface shall be suitably prepared.

The hardness shall be determined in accordance with Figure 9, by taking three readings as close as possible to the nominal major diameter of the thread D, at mid-height position ($m/2 \pm 1P$).

Key
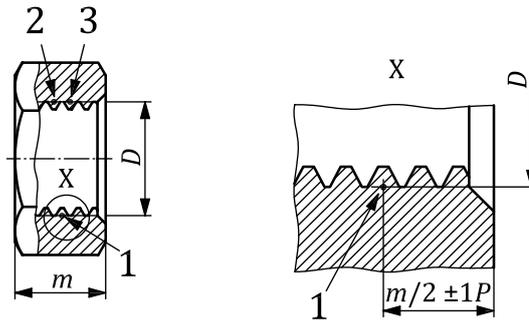
1, 2, 3 location of hardness readings

Figure 9 — Location of hardness readings (longitudinal section)

The hardness value shall be the average of the three readings.

9.4.3 Test results and requirements for nut hardness

The hardness value shall be within the limits specified in Table 12.

In case of dispute, the Vickers hardness test with HV10 on the longitudinal section shall be the reference test method.

10 Test methods at high temperature

10.1 High temperature tensile test for bolts, screws, studs and nuts

10.1.1 General

When stainless steel or nickel alloy bolts, screws, studs and nuts are subjected to tensile stresses and to high temperatures in bolted joints, data about tensile properties and fracture mode at actual service temperature can be needed by designers or end-users.

This test applies only when specifically agreed before the order between the purchaser and the supplier. It is based on ISO 6892-2, ISO 7961 and NASM 1312-18. Additional information can also be found in ASTM E21.

10.1.2 Test apparatus

The tensile testing machine, test apparatus and testing device should be as specified in ISO 7961 or NASM 1312-18.

For bolt, screw and stud testing, the properties of the reference nut shall be sufficient to ensure the failure of the tested fastener. Alternatively, a fixture with tapped hole can be used instead (see Figure 10).

For nut testing, the properties of the reference bolt/screw or test mandrel shall be sufficient to ensure the failure of the tested nut.

According to NASM 1312-18, bolt/nut combinations can also be tested. Failure of one of the mated components shall be considered as failure of the complete assembly.

The test fixture shall be designed and manufactured to withstand test loads and temperatures without permanent deformation. Examples of appropriate materials for fixtures and reference fasteners are given in Table 18.

Table 18 — Reference materials for high temperature tests

Fastener symbol and related material in accordance with Table 1	Fastener material reference	Maximum temperature for the test	Appropriate materials for fixture and reference fasteners
CH0	1.4021	400	2.4668 [a] or equivalent
CH1	1.4028	400	2.4668 [a] or equivalent
CH2	1.4057	450	2.4668 [a] or equivalent
V	1.4923	600	2.4668 [a] or equivalent
VH	1.4923	600	2.4668 [a] or equivalent
VW	1.4913	600	2.4668 [a] or equivalent
SD	1.4980	650 [b]	2.4668 [a] or equivalent
SB	2.4952	650 [b]	2.4668 [a] or equivalent
718	2.4668	650 [b]	2.4668 [a] or equivalent

[a] 2.4668 material should be solution annealed and precipitation hardened in order to provide better mechanical and physical properties.

[b] High temperature tests are usually performed up to a temperature of 650 °C unless otherwise agreed, see e.g. ASTM A453/A453M or ASTM A1014/A1014M. If fasteners are requested to be tested at higher temperatures, the material for the fixture and reference fastener should be 2.4676 or equivalent, which can be used up to 1 200 °C.
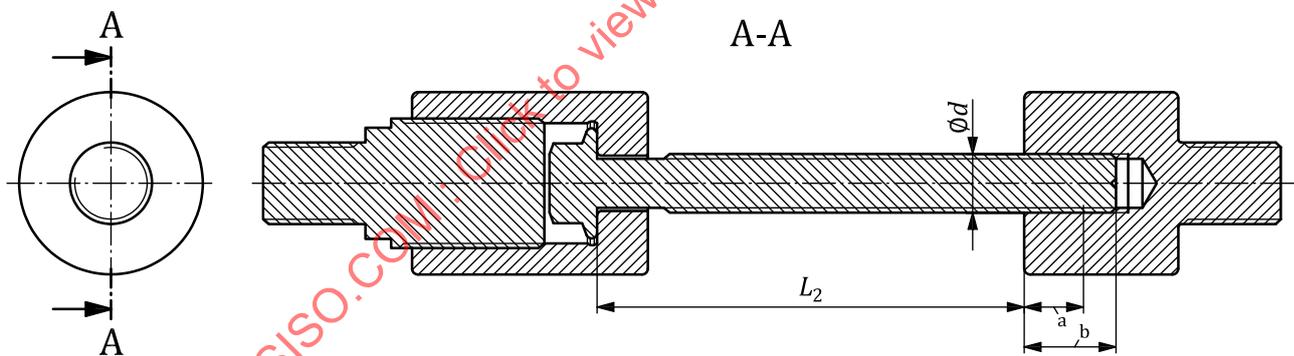
[a] Engaged length ≥ 1d of full threads
[b] Grip length

Figure 10 — Example of testing device for high temperature tensile testing

For bolt, screw and stud testing, the engaged length into the grip shall be at least 1d of full threads. For nut testing, the incomplete threads at the end of the reference bolt/screw or test mandrel shall protrude outside the nut.

10.1.3 Test procedure

At least the following shall be agreed between the supplier and the purchaser before testing:

— the specified test temperature, in relation to the expected service temperature,

— the clamped length L_2 (distance between the bolt, screw or nut bearing surface and the grip).

Additionally, the following should be agreed between the supplier and the purchaser.

a) For externally threaded fasteners:

— the minimum tensile strength at this temperature, $R_{\mathrm{mf,T}}$

— the minimum stress at 0,2 % non-proportional elongation, $R_{\mathrm{pf,T}}$,

— the minimum elongation after fracture, A_{T}.

b) For nuts:

— the ultimate stripping load $F_{\mathrm{n,T}}$ and/or the corresponding ultimate nut strength $R_{\mathrm{n,T}}$.

The test shall be performed as follows.

1) The thermocouples should be attached as specified in ISO 7961. The number of thermocouples shall be chosen to ensure uniformity of the temperature in the whole fastener, depending on the clamped length (usually three thermocouples are used, but it could be reduced to two for nuts and short bolts/screws).

2) The fastener to be tested shall be fitted into the test fixture as specified in Figure 10, and the actual clamped length and grip length shall be recorded.

3) The test fixture shall be heated to the specified test temperature, the time to reach this temperature shall be minimum 60 min per 25 mm of fastener diameter.

4) The test temperature shall be maintained for 30 min before applying the load, to ensure uniform test fixture heating and temperature equilibrium prior to loading.

5) The load shall then be applied in a continuous manner; the loading rate should be as specified in ISO 7961, but the speed of the running cross-head should not exceed 3 mm/min.

6) The test shall at least be performed until ultimate tensile load has been exceeded or, when elongation shall be determined, it should be stopped just before fracture occurs (avoiding possible damage of the thermocouples).

10.1.4 Test report

The test report shall contain at least the following information:

— the fastener full designation, and part number if any;

— the manufacturing lot number;

— the manufacturer identification and/or name;

— the material and heat treatment designation;

— the clamped length and grip length;

— the reference to this document, and/or other standard or technical specification for high temperature tensile test as relevant;

— the test temperature;

— the test results:

— for each externally threaded fastener: the ultimate tensile load $F_{\mathrm{mf,T}}$, the ultimate tensile strength $R_{\mathrm{mf,T}}$, the load and stress at 0,2 % non-proportional elongation $F_{\mathrm{pf,T}}$ and $R_{\mathrm{pf,T}}$, and the fastener elongation A_{T},

— for each nut: the ultimate stripping load $F_{\mathrm{n,T}}$ and the corresponding ultimate nut strength $R_{\mathrm{n,T}}$,

— for each bolt/nut assembly, the test results shall be expressed either as for the bolt or as for the nut (depending on the failed component), but load or stress at 0,2 % non-proportional elongation is not relevant;

— the failure mode and location of the failure;

— any specific conditions or comments to the test;

— the conclusion of the test.

10.2 High temperature stress rupture test for bolts, screws, studs and nuts

10.2.1 General

When stainless steel or nickel alloy bolts, screws, studs and nuts are subjected to tensile stresses and to high temperatures in bolted joints, a creep effect occurs usually above 400 °C. Therefore, creep phenomena should be taken into consideration when designing a bolted joint in addition to classical static load calculations, because they can significantly reduce the life time of the joint.

Since creep tests are long and expensive, the purpose of this high temperature stress rupture test for fasteners is to get quicker understanding of the behaviour of the fasteners.

This test covers the determination of the time to rupture of fasteners under conditions of constant load and temperature. Recommended practice for such test on full-size fasteners is specified in ISO 6892-2, ISO 7961, NASM 1312-10, and additional information can also be found in ASTM E292.

NOTE   Other creep or relaxation tests can be performed for specific bolted joints, but this is not in the scope of this document.

This test applies only when specifically agreed before the order between the purchaser and the supplier.

10.2.2 Test apparatus and testing device

The tensile testing machine, test apparatus and testing device should be in accordance with ISO 7961 or NASM 1312-10.

For bolt, screw and stud testing, the properties of the reference nut shall be specifically chosen to be able to withstand the test temperature and duration with a stress rupture resistance far above the stress rupture resistance of the fasteners to be tested. Alternatively, a fixture with a tapped hole can be used (see Figure 10).

For nut testing, the properties of the reference bolt/screw or test mandrel shall be specifically chosen to be able to withstand the test temperature and duration with a stress rupture resistance far above the stress rupture resistance of the nuts to be tested.

According to NASM 1312-10, bolt/nut combinations can also be tested. Failure of one of the mated components shall be considered as failure of the complete assembly.

The test fixture shall be designed and manufactured to withstand test loads and temperatures without permanent deformation. Examples of appropriate materials for fixtures and reference fasteners are given in Table 18.

For bolt, screw and stud testing, the engaged length into the grip shall be at least 1d of full threads. For nut testing, the incomplete threads at the end of the reference bolt/screw or test mandrel shall protrude outside the nut.

10.2.3 Test procedure

At least the following shall be agreed between the supplier and the purchaser before testing:

— the test load, in relation to the expected service load: this test load should not exceed 65 % of minimum load at 0,2 % non-proportional elongation F_{pf} specified in Table 9 or 11,

— the clamped length L_2 (distance between the tested bolt, screw or nut bearing surface and the grip),

— the grip length,

— the specified test temperature, in relation to the expected service temperature,

— if the test shall be stopped after a minimum specified duration, or if it shall be further carried out until fracture occurs.

Additionally, the following should be agreed between the supplier and the purchaser:

— the duration of the test (expected duration before rupture, 24 h minimum is usually considered).

The test shall be performed as follows.

1) The thermocouples should be attached as specified in ISO 7961. The number of thermocouples shall be chosen to ensure uniformity of the temperature in the whole fastener, depending on the clamped length (usually three thermocouples are used, but it could be reduced to two for nuts and short bolts).

2) The fastener to be tested shall be fitted into the test fixture as specified in Figure 10, and actual clamped length and grip length shall be recorded.

3) The test fixture shall be heated to the specified test temperature, the time to reach this temperature shall be minimum 60 min per 25 mm of fastener diameter.

4) The test temperature shall be maintained for 30 min before applying the load to ensure uniform test fixture heating and temperature equilibrium prior to loading.

5) The test load shall then be applied in a time not exceeding 1 min (if no other loading rate has been specified), and overloading and shocks shall be avoided. The test duration is counted from the time at which the specified load is reached.

6) The test load and test temperature shall be constantly maintained during the specified test duration (e.g. 24 h) or until fracture occurs.

7) The tested bolt, screw or stud shall be left to cool naturally to ambient temperature again, and the elongation shall be determined either on the non-broken or on the broken fastener.

8) As an option and when no failure occurs at the specified duration, a stepped load can be applied until fracture occurs (the load increase as well as time in hours between each step shall be previously agreed).

10.2.4 Test report

The test report shall contain at least the following information:

— the fastener full designation, and part number if any;

— the manufacturing lot number;

— the manufacturer identification and/or name;

— the material and heat treatment designation;

— the clamped length and grip length;

— the reference to this document, and/or other standard or technical specification for stress rupture test at high temperature as relevant;

— the test temperature and the time to reach this temperature;

— the test load and the loading rate (or loading time);

— the test results:

— when fracture occurs before the specified test duration, time to failure and (for externally threaded fasteners only) elongation after fracture A_T,

— when fracture does not occur before the specified test duration and only for externally threaded fasteners, elongation determined after the fastener is naturally left cooled back to ambient temperature,

— when increased stepped loads have been applied, breaking load, total duration from reaching the test temperature, and (for externally threaded fasteners only) elongation after fracture A_T,

— for bolt/nut assemblies, test results shall be expressed either as for the bolt or as for the nut (depending on the failed component);

— any specific conditions or comments to the test;

— the conclusion of the test.

10.3 Relaxation test for bolts, screws, studs and nuts

10.3.1 General

When stainless steel or nickel alloy bolts, screws, studs and nuts are subjected tensile stresses and to high temperatures in bolted joints, relaxation can occur usually above 400 °C. This relaxation induces slackening, thus resulting in a loss of stresses in the joint.

The purpose of this test is to determine the stress relaxation of bolts, screws, studs and nuts, when tensioned in a bolted joint model subjected throughout the test to overall strain and constant temperature conditions, according to EN 10319-2 or other relevant specifications such as NASM 1312-17 or ASTM E328.

This test applies only when specifically agreed before order between the purchaser and the supplier.

10.3.2 Bolted joint models

For the purpose of fasteners, the property of the reference parts and clamped pieces shall be specifically chosen to be able to withstand the test temperature and duration with relaxation properties far above the relaxation of the fastener to be tested.

Examples of appropriate material for the reference parts and clamped pieces are given in Table 18.

The shape, dimensions and preparation of the bolted joint models shall be in accordance with EN 10319-2, except for the reference nut: a reference threaded piece shall be used instead of the reference nut, with the following dimensions:

— tapped hole with a minimum threaded length of 2*d*, and

— minimum external diameter or width across flats of 2*d.*

For bolt, screw and stud testing, the engaged length into the grip shall be at least 1*d* of full threads. For nut testing, the incomplete threads at the end of the reference bolt/screw or test mandrel shall protrude outside the nut.

10.3.3 Test apparatus and measuring devices

The test apparatus and measuring devices shall be in accordance with EN 10319-2.

10.3.4 Test procedure

At least the following shall be agreed between the supplier and the purchaser before testing:

— the test load, corresponding to a specific percentage of the stress at 0,2 % non-proportional elongation R_{pf} for externally threaded fasteners (see Table 9 or 11), or to a specific percentage of the proof load for nuts (see Table 13 or 14),

— the accuracy of the test load determined by pre-test, and the pre-test conditions themselves,

— the clamped length (distance between the tested bolt, screw or nut bearing surface and the grip),

— the grip length,

— the specified test temperature, in relation to the expected service temperature,

— the heating rate,

— the specified test duration.

All length measurement accuracy shall be in accordance with EN 10319-2.

a) Pre-tests shall be performed in order to be able to reach the specified preload with an acceptable accuracy; e.g. torque/clamp force testing can be carried out in accordance with ISO 16047, with the mating reference fasteners specified in Table 18 and on fasteners from the same manufacturing lot.

b) For bolt, screw and stud testing and before assembly, the total length L_{ref} (including the head) shall be measured at ambient temperature.

c) The smallest possible amount of grease or lubricating paste for high temperature shall be applied on the thread of the fastener to be tested and on the bearing surface of the tightened component, in order to avoid galling during tightening and untightening.

d) For bolt, screw and stud testing, the assembly shall be made by rotating the reference tapped piece. For nut testing, the assembly shall be made by rotating the tested nut.

e) The fastener to be tested (or the reference bolt) shall be slowly tensioned at room temperature up to the specified load and torsional stress shall be avoided by using an appropriate device in accordance with EN 10319-2. The initial tightening torque shall be recorded.

f) This loading shall be repeated 3 more times, i.e. tightening the fastener shall be performed 4 times before heating the assembly. The last tightening torque shall be recorded.

g) After assembly, the total length L_{t1} of the bolt, screw or stud to be tested shall be measured at ambient temperature.

h) Heating the assembly, holding at temperature and cooling naturally back to the ambient temperature shall be performed in accordance with EN 10319-2. The heat duration shall be counted from the time at which the specified temperature is reached. For nuts, the machine method in accordance with NASM 1312-17 should be applied, i.e. the length shall be maintained automatically constant and the drop of the load shall be recorded during the test.

i) After the assembly is naturally left cooled back and maintained at ambient temperature, the total length L_{t2} of the tested bolt, screw or stud shall be measured.

j) Last, the assembly shall be untightened, and the total length L_{t3} of the tested bolt, screw or stud shall be measured.

k) The curve load against time (in hours) shall be plotted (see Figure 11).