BS EN 13445-2:2009+A2:2012

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BSI Standards Publication

Unfired pressure vessels

Part 2: Materials

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National foreword

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The UK participation in its preparation was entrusted to Technical Committee PVE/1, Pressure Vessels.

A list of organizations represented on this committee can be obtained on request to its secretary.

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31 August 2012	Corrected version issued by CEN, see EN forword for details of amendments A1:2012 and A2:2012
30 September 2013	Corrected pages issued by CEN, see EN foreword for details

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EUROPÄISCHE NORM

EN 13445-2+A2

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Récipients sous pression non soumis à la flamme - Partie 2 : matériaux

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Foreword

This document (EN 13445-2:2009) has been prepared by Technical Committee CEN/TC 54 “Unfired pressure vessels”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by *December 2009*, and conflicting national standards shall be withdrawn at the latest by *December 2009*.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

For relationship with EU Directive(s), see informative annex ZA, which is an integral part of this document.

This European Standard consists of the following Parts:

— Part 1: *General*.

— Part 2: *Materials*.

— Part 3: *Design*.

— Part 4: *Fabrication*.

— Part 5: *Inspection and testing*.

— Part 6: *Requirements for the design and fabrication of pressure vessels and pressure parts constructed from spheroidal graphite cast iron*.

— CR 13445-7, *Unfired pressure vessels — Part 7: Guidance on the use of conformity assessment procedures*.

— Part 8: *Additional requirements for pressure vessels of aluminium and aluminium alloys.*

— CEN/TR 13445-9, *Unfired pressure vessels — Part 9: Conformance of EN 13445 series to ISO 16528*

This document supersedes EN 13445-2:2002. This new edition incorporates the Amendments which have been approved previously by CEN members, and the corrected pages up to Issue 36 without any further technical change. Annex Y to EN 13445-1:2009 and Annex Y to this Part provides details of significant technical changes between this European Standard and the previous edition.

Amendments to this new edition may be issued from time to time and then used immediately as alternatives to rules contained herein. It is intended to deliver a new Issue of EN 13445:2009 each year, consolidating these Amendments and including other identified corrections. Issue 5 (2013-07) includes the corrected pages listed in Annex Y.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

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1 Scope

This Part of this European Standard specifies the requirements for materials (including clad materials) for unfired pressure vessels and supports which are covered by EN 13445-1:2009 and manufactured from metallic materials; it is currently limited to steels with sufficient ductility but it is, for components operating in the creep range, also limited to sufficiently creep ductile materials .

It specifies the requirements for the selection, inspection, testing and marking of metallic materials for the fabrication of unfired pressure vessels.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 764-1:2004, *Pressure equipment — Terminology — Part 1: Pressure, temperature, volume, nominal size.*

EN 764-2:2002, *Pressure equipment — Part 2: Quantities, symbols and units.*

EN 764-3:2002, *Pressure equipment — Part 3: Definition of parties involved.*

EN 1092-1:2007, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 1: Steel flanges*

EN 10002-1:2001, *Metallic materials - Tensile testing - Part 1: Method of test at ambient temperature*

EN 10028-2:2003, *Flat products made of steels for pressure purposes — Part 2: Non-alloy and alloy steels with specified elevated temperature properties.*

EN 10028-3:2003, *Flat products made of steels for pressure purposes — Part 3: Weldable fine grain steels, normalized.*

EN 10028-4:2003, *Flat products made of steels for pressure purposes — Part 4: Nickel alloy steels with specified low temperature properties.*

EN 10028-5:2003, *Flat products made of steels for pressure purposes — Part 5: Weldable fine grain steels, thermomechanically rolled.*

EN 10028-6:2003, *Flat products made of steels for pressure purposes — Part 6: Weldable fine grain steels, quenched and tempered.*

EN 10028-7:2007, *Flat products made of steels for pressure purposes — Part 7: Stainless steels.*

EN 10045-1:1990, *Metallic materials — Charpy impact test — Part 1: Test method.*

EN 10164:2004, *Steel products with improved deformation properties perpendicular to the surface of the product — Technical delivery conditions.*

EN 10204:2004, *Metallic products — Types of inspection documents.*

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EN 10216-3:2002, EN 10216-3:2002/A1:2004, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 3: Alloy fine grain steel tubes*

EN 10216-4:2002, EN 10216-4:2002/A1:2004, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 4: Non-alloy and alloy steel tubes with specified low temperature properties.*

EN 10217-3:2002, EN 10217-3:2002/A1:2005, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 3: Alloy fine grain steel tubes.*

EN 10217-4:2002, EN 10217-4:2002/A1:2005, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 4: Electric welded non-alloy steel tubes with specified low temperature properties.*

EN 10217-6:2002, EN 10217-6:2002/A1:2005, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 6: Submerged arc welded non-alloy steel tubes with specified low temperature properties.*

EN 10222-3:1998, *Steel forgings for pressure purposes — Part 3: Nickel steels with specified low temperature properties.*

EN 10222-4:1998, EN 10222-4:1998/A1:2001, *Steel forgings for pressures purposes — Part 4: Weldable fine grain steels with high proof strength.*

EN 10269:1999, EN 10269:1999/A1:2006, *Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties.*

EN 10273:2007, *Hot rolled weldable steel bars for pressure purposes with specified elevated temperature properties.*

EN 10291:2000, *Metallic materials — Uniaxial creep testing in tension – Method of test*.

EN 12074:2000, *Welding consumables — Quality requirements for manufacture, supply and distribution of consumables for welding and allied processes.*

EN 13445-1:2009, *Unfired pressure vessels — Part 1: General.*

EN 13445-3:2009, *Unfired pressure vessels — Part 3: Design.*

EN 13445-4:2009, *Unfired pressure vessels — Part 4: Fabrication.*

EN 13445-5:2009, *Unfired pressure vessels — Part 5: Inspection and testing.*

EN 13479:2004, *Welding consumables — General product standard for filler metals and fluxes for fusion welding of metallic materials.*

EN 20898-2:1993, *Mechanical properties of fasteners — Part 2: Nuts with specified proof load values — Coarse thread (ISO 898-2:1992)*

EN ISO 898-1:1999, *Mechanical properties of fasteners made of carbon steel and alloy steel — Part 1: Bolts, screws and studs (ISO 898-1:1999)*

EN ISO 2566-1:1999, *Steel — Conversion of elongation values — Part 1: Carbon and low alloy steels (ISO 2566-1:1984).*

EN ISO 2566-2:1999, *Steel — Conversion of elongation values — Part 2: Austenitic steels (ISO 2566-2:1984).*

EN ISO 3506-1:1997, *Mechanical properties of corrosion-resistant stainless-steel fasteners — Part 1: Bolts, screws and studs (ISO 3506- 1:1997)*

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EN ISO 3506-2:1997, *Mechanical properties of corrosion-resistant stainless-steel fasteners — Part 2: Nuts (ISO 3506-2:1997)*

CR ISO 15608:2000, *Welding — Guidelines for a metallic material grouping system (ISO/TR 15608:2000).*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this European Standard the terms and definitions given in EN 13445-1:2009, EN 764-1:2004, EN 764-3:2002 and the following terms and definitions shall apply.

3.1.1
minimum metal temperature T_M
the lowest temperature determined for any of the following conditions (also see 3.1.2, 3.1.3):

— normal operations;

— start up and shut down procedures;

— possible process upsets, such as flashings of fluid, which have an atmospheric boiling point below 0 °C;

— during pressure or leak testing.

3.1.2
temperature adjustment term T_S
relevant to the calculation of the design reference temperature T_R and is dependent on the calculated tensile membrane stress at the appropriate minimum metal temperature

NOTE 1 Values for T_S are given in Table B.2-12.

NOTE 2 For tensile membrane stress reference is made to EN 13445-3:2009, Annex C.

3.1.3
design reference temperature T_R
the temperature used for determining the impact energy requirements and is determined by adding the temperature adjustment T_S to the minimum metal temperature T_M:

$$T_R = T_M + T_S$$

3.1.4
impact test temperature T_{KV}
the temperature at which the required impact energy has to be achieved (see clause B.2).

3.1.5
impact energy KV
the energy absorbed by a sample of material when subjected to a Charpy-V-notch test in accordance with EN 10045-1:1990

3.1.6
reference thickness e_B
thickness of a component to be used to relate the design reference temperature T_R of the component with its required impact test temperature T_{KV} , (see Tables B.2-2 to B.2-7 and Figures B.2-1 to B.2-11). For unwelded parts the reference thickness e_B is equal to the nominal wall thickness (including corrosion allowance). For welded parts the reference thickness is defined in Table B.4-1.

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3.1.7
weld creep strength reduction factor (WCSRF)
factor to account for creep strength reduction at the weldment

3.2 Symbols and units

For the purpose of this part, the symbols and units of EN 764-2:2002 apply together with those given in Table 3.2-1 and Table 3.2-2.

Table 3.2-1 — Quantities for space and time

Quantity	Symbol	Unit
time	t	s, min, h, d, a
frequency	f	Hz
dimension	any Latin letter [a]	mm
length	l	mm
thickness	e	mm
corrosion allowance	c	mm
diameter	d, D	mm
radius	r, R	mm
area	A, S	mm^2
volume, capacity	V	mm^3 [b, c]
weight	W	N, kN
density	ρ	kg/mm^3 [d]
second moment of area	I	mm^4
section modulus	Z	mm^3
acceleration	γ	m/s^2
plane angle	any Greek letter [a]	rad, °

[a] Symbols may use any lower-case letter, except for those defined elsewhere in this table.
[b] Volume may also be given in m^3 or L.
[c] Litre "L" is a non-SI unit which may be used with SI units and their multiples.
[d] Density may also be given in kg/m^3.

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Table 3.2-2 — Mechanical quantities

Quantity [a]	Symbol [b]	Unit
force	F	N
moment	M	N·mm
pressure	p, P	bar [c], MPa
Temperature	T	°C
linear expansion coefficient	α	µm/m°C
normal stress	σ	MPa
shear stress	τ	MPa
nominal design stress	f	MPa
tensile strength	R_{m}	MPa
ultimate tensile strength at temperature T	$R_{m/T}$	MPa
yield strength	R_{e}	MPa
yield strength at temperature T	$R_{e/T}$	MPa
upper yield strength	R_{eH}	MPa
1 % proof strength	$R_{p1,0}$	MPa
0,2 % proof strength	$R_{p0,2}$	MPa
0,2 % proof strength at temperature T	$R_{p0,2/T}$	MPa
modulus of elasticity	E	MPa
shear modulus	G	MPa
Poisson's ratio	υ	–
strain	ε	%
elongation after fracture	A	%
impact energy	KV	J
hardness	HB, HV	–
Joint coefficient	z	–
safety factor	S	–
Mean 1 % creep strain limit at calculation temperature T and lifetime t	$R_{p1,0/T/t}$	MPa
Mean creep rupture strength at calculation temperature T and lifetime t	$R_{m/T/t}$	MPa
Weld creep strength reduction factor	z_{c}	-

[a] Quantities without a temperature index normally refer to room temperature.

[b] Some of these symbols, such as R, f, are not part of ISO 31.

[c] "bar" is a non-SI unit which may be used with SI units and their multiples. The unit bar shall be used on nameplates, certificates, drawings, pressure gauges and instrumentation and is always used as a gauge pressure. This is in line with the requirements of the Pressure Equipment Directive 97/23/EC.

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4 Requirements for materials to be used for pressure-bearing parts

4.1 General

4.1.1 Materials to be used for pressure-bearing parts shall meet the general requirements of 4.1 and the special provisions of 4.2, if applicable. Materials for pressure bearing parts shall be ordered complying with the technical delivery conditions in 4.3.

Marking of materials for pressure-bearing parts shall be performed in accordance with 4.4.

Materials shall be selected to be compatible with anticipated fabrication steps and to be suitable for the internal fluid and external environment. Both normal operating conditions and transient conditions occurring during fabrication transport, testing and operation shall be taken into account when specifying the materials.

NOTE 1 The requirements of 4.1 and 4.2 should also be fulfilled when technical delivery conditions are developed for European material standards, European approval of materials or particular material appraisals.

NOTE 2 When technical delivery conditions for pressure-bearing parts are developed, the structure and requirements of EN 764-4:2002 should be met. Exceptions should be technically justified.

The materials shall be grouped in accordance with CR ISO 15608:2000 to relate manufacturing and inspection requirements to generic material types.

NOTE 3 Materials have been allocated into these groups in accordance with their chemical composition and properties in view of manufacture and heat treatment after welding.

4.1.2 Materials for pressure-bearing parts compliant with the requirements of this European Standard shall be accompanied by inspection documents in accordance with EN 10204:2004. Certificate of specific control (3.1 or 3.2 certificate) shall be required for all steels if Design by Analysis – Direct Route according to Annex B of EN 13445-3:2009 is used.

NOTE The type of inspection document should be in accordance with EN 764-5:2002 and include a declaration of compliance to the material specification.

4.1.3 The materials shall be free from surface and internal defects which can impair their intended usability.

4.1.4 Steels shall have a specified minimum elongation after fracture measured on a gauge length

$$L_o = 5{,}65\sqrt{S_o} \qquad (4.1\text{-}1)$$

where

S_o is the original cross sectional area within the gauge length.

The minimum elongation after fracture in any direction shall be ≥ 14 %;

However, lower elongation values may also be applied (e.g. for fasteners or castings), provided that appropriate measures are taken to compensate for these lower values and the specific requirements are verifiable.

NOTE Examples for compensation:

— application of higher safety factors in design;

— performance of burst tests to demonstrate ductile material behaviour.

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4.1.5 When measured on a gauge length other than that stated in 4.1.4, the minimum elongation after fracture shall be determined by converting the elongation given in 4.1.4 in accordance with

— EN ISO 2566-1:1999 for carbon and low alloy steels;

— EN ISO 2566-2:1999 for austenitic steels.

4.1.6 Steels shall have a specified minimum impact energy measured on a Charpy-V-notch impact test specimen (EN 10045-1:1990) as follows:

— ≥ 27 J for ferritic and 1,5 % to 5 % Ni alloy steels;

— ≥ 40 J for steels of material group 8, 9.3 and 10

at a test temperature in accordance with Annex B, but not higher than 20 °C. The other requirements of Annex B shall also apply.

4.1.7 The chemical composition of steels intended for welding or forming shall not exceed the values in Table 4.1-1. Line 2 of the table refers to vessels or parts designed using Design by Analysis – Direct Route according to Annex B of EN 13445-3:2009. Exceptions shall be technically justified.

Table 4.1-1 — Maximum carbon-, phosphorus- and sulphur contents for steels intended for welding or forming

Steel group (according to Table A-1)	Maximum content of cast analysis		
	% C	% P	% S
Steels (1 to 6 and 9)	0,23[a]	0,035	0,025
Steels (1 to 6 and 9) when DBA – Direct Route is used [c]	0,20	0,025	0,015
Ferritic stainless steels (7.1)	0,08	0,040	0,015
Martensitic stainless steels (7.2)	0,06	0,040	0,015
Austenitic stainless steels (8.1)	0,08	0,045	0,015[b]
Austenitic stainless steels (8.2)	0,10	0,035	0,015
Austenitic-ferritic stainless steels (10)	0,030	0,035	0,015

[a] Maximum content of product analysis 0,25 %.
[b] For products to be machined a controlled sulphur content of 0,015 % to 0,030 % is permitted by agreement provided the resistance to corrosion is satisfied for the intended purpose.
[c] In addition the ratio on thickness reduction (ratio of initial thickness of slab/ingot to the thickness of the final plate) shall be equal or greater than:
— 4 for NL2 steels and steels of material group 9;
— 3 for other materials.

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4.2 Special provisions

4.2.1 Special properties

4.2.1.1 General

Where the behaviour of a material can be affected by manufacturing processes or operating conditions, to an extent that would adversely affect the safety or service life of the pressure vessel, this shall be taken into consideration when specifying material.

Adverse effects may arise from:

— manufacturing processes: e.g. degree of cold forming and heat treatment;

— operating conditions: e.g. hydrogen embrittlement, corrosion, scaling and ageing behaviour of the material after cold forming.

4.2.1.2 Lamellar tearing

Where lamellar tearing due to the joint design and loading needs to be addressed, steels shall be used which have improved deformation properties perpendicular to the surface and verified in accordance with EN 10164:2004.

NOTE For guidance see EN 1011-2.

4.2.2 Design temperature above 20 °C

4.2.2.1 A material shall only be used for pressure parts within the range of temperatures for which the material properties required by EN 13445-3:2009 are defined in the technical specification for the material. If the technical delivery condition does not contain the specific material values required for the allowable temperature TS the values required in EN 13445-3:2009 for the design shall be determined by linear interpolation between the two adjacent values. Values shall not be rounded up.

For other than austenitic and austenitic-ferritic stainless steels, the specified value of R_{eH} ($R_{p0,2}$) at room temperature (RT) may be used for temperatures less than or equal to 50 °C. Interpolation between 50 °C and 100 °C shall be performed with the values of RT and 100 °C and using 20 °C as the starting point for interpolation. Above 100 °C linear interpolation shall be performed between the tabulated values given in the table.

4.2.2.2 As the impact properties may be affected by long or frequent holding of the material at elevated temperatures, it is presupposed that the temperatures and periods of exposure to elevated temperatures be recorded for review during in-service inspection. The influence of such exposure upon the lifetime expectancy shall be estimated and recorded.

For operations such as drying and cleaning of pressure vessels, steels with specified low temperature properties but without elevated temperature 0,2 % proof strength values may however be used at elevated temperatures for drying and cleaning processes provided that the values of 0,2 % proof strength used in design calculations for elevated temperatures shall be obtained by multiplying the specified minimum yield strength values at 20 °C by the factor given in Table 4.2-1.

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Table 4.2-1 — Yield strength reduction factors for low temperature steels

Steel	Temperature T			
	100 °C	200 °C	250 °C	300 °C
Quenched and tempered	0,75	0,68	0,64	0,60
Normalised or thermomechanically treated	0,70	0,58	0,53	0,48

Interpolation shall be carried out as in 4.2.2.1.

4.2.3 Prevention of brittle fracture

The requirements in Annex B shall apply.

4.2.4 Design properties in the creep range

4.2.4.1 Creep properties of base material

For interpolation and extrapolation of creep properties given in the materials standard, see EN 13445-3:2009, Clause 19.

When creep properties are not available from a materials standard, they shall be determined using EN 10291:2000.

4.2.4.2 Creep properties of weldments

Creep properties of weld joints subjected to stresses normal to the weld can differ significantly from those of the base material.

For the design of vessels in the creep range, this is taken into account in EN 13445-3:2009 by making use of a weld creep strength reduction factor z_c obtained from tests on weldments. If no data are available, a default value of z_c is used.

An acceptable method to determine z_c by cross-weld tests is given in Annex C (see also [17]).

4.2.5 Specific requirements for steels for fasteners

Fasteners include bolts, studs and nuts.

Free cutting steel shall not be used. Bolting made of carbon steel or Ni alloy ferritic steel with > 3,5 % nickel shall not be used above 300 °C.

The specified minimum tensile strength of bar material of ferritic and martensitic steel for bolts shall not exceed 1 000 MPa. The minimum elongation of bar material after fracture shall be at least A_5 = 14 %.

Impact requirements for ferritic and martensitic steels are specified in B.2.2.4.

Bolt material with a design temperature below – 160 °C shall be impact tested at – 196 °C.

Hydrogen embrittlement, fatigue or relaxation properties shall be taken into account where appropriate.

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NOTE 1 Detailed requirements on the surface condition and internal soundness of the bar can be necessary for some applications.

NOTE 2 Materials for fasteners compliant with the requirements of this standard should be certified on the basis of EN 10204:2004.

4.3 Technical delivery conditions

4.3.1 European Standards

The European Standards for plates, strips, bars, tubes, forgings and castings for pressure purposes shall be used.

NOTE 1 Table E.2-1 provides an overview on materials for pressure purposes specified in harmonised standards.

NOTE 2 Table E.1-1 contains an informative summary of European Materials Standards referred to and of European Standards covering components of pressure-bearing parts.

Special provisions due to fabrication and operation shall be taken into account, if appropriate.

4.3.2 European Approval for Materials

A material specified in an EMDS for pressure vessels shall only be used within its range of application and if 4.1 and 4.2 have been taken into consideration.

4.3.3 Particular material appraisals

Materials other than those specified in 4.3.1 and 4.3.2 may also be used provided that they have been undergone a particular material appraisal and if 4.1 and 4.2 have been taken into consideration.

4.3.4 Clad products

Technical delivery conditions for clad products for pressure parts shall be in accordance with the requirements of Annex D.

NOTE 1 European Standards specifying technical delivery conditions for clad products for pressure purposes are not currently available.

NOTE 2 Examples of national documents covering technical delivery condition for clad steels are given in [2] to [4].

4.3.5 Welding consumables

Technical delivery conditions for welding consumables used of pressure parts and attachments to pressure parts shall be in accordance with EN 13479:2004 and EN 12074:2000.

NOTE Equivalent national/international specifications are accepted which fulfil the same criteria with respect to the requirements for the Quality Assurance System and the requirements for manufacture, supply, distribution, test methods and evaluation of consumables.

4.4 Marking

The marking of the products or delivery units shall ensure traceability between the product or delivery unit and the inspection documents.

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For European standardised materials the marking shall fulfil the requirements of the relevant product standard.

For materials not contained in a European Standard the marking shall at least contain:

— the material specification (reference, material designation);

— the manufacturers name or mark;

— the stamp of the inspection representative, if applicable.

For material supplied with specific inspection the marking shall include an identification which permits the correlation between the product or delivery unit and the relevant inspection document.

5 Requirements for materials to be used for non-pressure parts

For non-pressure parts, e.g. for supporting lugs, skirts, baffles and similar parts welded to pressure vessels, material shall be used which are supplied to material specifications covering at least requirements for the chemical composition and the tensile properties. These materials shall not limit the operating conditions of the material to which they are attached.

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Annex A
(normative)

Grouping system for steels for pressure equipment

Steels shall be grouped as shown in Table A-1. The figures given in group 1 are referring to the ladle analysis of the materials. The figures given in group 4 to 10 are based on the element content used in the designation of the alloys.

Table A-1 — Grouping system for steels (extract from CR ISO 15608:2000)

Group	Sub-group	Type of steel
1		Steels with a specified minimum yield strength $R_{eH} \leq 460$ MPa [a] and with analysis in %: C ≤ 0,25 Si ≤ 0,60 Mn ≤ 1,70 Mo ≤ 0,70[b] S ≤ 0,045 P ≤ 0,045 Cu ≤ 0,40[b] Ni ≤ 0,5[b] Cr ≤ 0,3 (0,4 for castings)[b] Nb ≤ 0,05 V ≤ 0,12[b] Ti ≤ 0,05
	1.1	Steels with a specified minimum yield strength $R_{eH} \leq 275$ MPa
	1.2	Steels with a specified minimum yield strength 275 MPa $< R_{eH} \leq 360$ MPa
	1.3	Normalised fine grain steels with a specified minimum yield strength $R_{eH} > 360$ MPa
	1.4	Steels with improved atmospheric corrosion resistance whose analysis may exceed the requirements for the single elements as indicated under 1
2		Thermomechanically treated fine grain steels and cast steels with a specified minimum yield strength $R_{eH} > 360$ MPa
	2.1	Thermomechanically treated fine grain steels and cast steels with a specified minimum yield strength 360 MPa $< R_{eH} \leq 460$ MPa
	2.2	Thermomechanically treated fine grain steels and cast steels with a specified minimum yield strength $R_{eH} > 460$ MPa
3		Quenched and tempered steels and precipitation hardened steels except stainless steels with a specified minimum yield strength $R_{eH} > 360$ MPa
	3.1	Quenched and tempered steels with a specified minimum yield strength 360 MPa $< R_{eH} \leq 690$ MPa
	3.2	Quenched and tempered steels with a specified minimum yield strength $R_{eH} > 690$ MPa
	3.3	Precipitation hardened steels except stainless steels

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Table A-1 (*concluded*)

Group	Sub-group	Type of steel
4		Low vanadium alloyed Cr-Mo-(Ni) steels with Mo ≤ 0,7 % and V ≤ 0,1 %
	4.1	Steels with Cr ≤ 0,3 % and Ni ≤ 0,7 %
	4.2	Steels with Cr ≤ 0,7 % and Ni ≤ 1,5 %
5		Cr-Mo steels free of vanadium with C ≤ 0,35 %[c]
	5.1	Steels with 0,75 % ≤ Cr ≤ 1,5 % and Mo ≤ 0,7 %
	5.2	Steels with 1,5 % < Cr ≤ 3,5 % and 0,7 < Mo ≤ 1,2 %
	5.3	Steels with 3,5 % < Cr ≤ 7,0 % and 0,4 < Mo ≤ 0,7 %
	5.4	Steels with 7,0 % < Cr ≤ 10 % and 0,7 < Mo ≤ 1,2 %
6		High vanadium alloyed Cr-Mo-(Ni) steels
	6.1	Steels with 0,3 % ≤ Cr ≤ 0,75 %, Mo ≤ 0,7 % and V ≤ 0,35 %
	6.2	Steels with 0,75 % < Cr ≤ 3,5 %, 0,7 % < Mo ≤ 1,2 % and V ≤ 0,35 %
	6.3	Steels with 3,5 % < Cr ≤ 7,0 %, Mo ≤ 0,7 % and 0,45 % ≤ V ≤ 0,55 %
	6.4	Steels with 7,0 % < Cr ≤ 12,5 %, 0,7 % < Mo ≤ 1,2 % and V ≤ 0,35 %
7		Ferritic, martensitic or precipitation hardened stainless steels with C ≤ 0,35 % and 10,5 % ≤ Cr ≤ 30 %
	7.1	Ferritic stainless steels
	7.2	Martensitic stainless steels
	7.3	Precipitation hardened stainless steels
8		Austenitic steels
	8.1	Austenitic stainless steels with Cr ≤ 19 %
	8.2	Austenitic stainless steels with Cr > 19 %
	8.3	Manganese austenitic stainless steels with 4 % < Mn ≤ 12 %
9		Nickel alloyed steels with Ni ≤ 10 %
	9.1	Nickel alloyed steels with Ni ≤ 3 %
	9.2	Nickel alloyed steels with 3 % < Ni ≤ 8 %
	9.3	Nickel alloyed steels with 8 % < Ni ≤ 10 %
10		Austenitic ferritic stainless steels (duplex)
	10.1	Austenitic ferritic stainless steels with Cr ≤ 24 %
	10.2	Austenitic ferritic stainless steels with Cr > 24 %

[a] In accordance with the specification of the steel product standards, R_{eH} may be replaced by $R_{p0,2}$ or $R_{t0.5}$.

[b] A higher value is accepted provided that Cr + Mo + Ni + Cu + V ≤ 0,75 %.

[c] "Free of vanadium" means not deliberately added to the material.

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Annex B
(normative)

Requirements for prevention of brittle fracture at low temperatures

B.1 General

This annex distinguishes between pressure equipment that has design temperature for normal operation higher or lower than 50 °C.

For pressure equipment with normal operation temperatures higher than 50 °C B.5 applies. If B.5 is not applicable, the following rules for lower normal operation temperatures shall be used.

For pressure equipment with design temperature equal to or less than 50 °C this annex specifies three alternative methods for establishing criteria for the prevention of low temperature brittle fracture[1)] of steels in the form of plate, strip, tubes, fittings, forgings, castings, flanges, fasteners and weldments used in pressure parts. The criteria are based on impact energy requirements at specified temperatures for the base material, heat affected zone (including the fusion line) and weld metals.

The three methods are:

Method 1 Code of Practice:

a) Technical requirements based on the choice of $T_R = T_{27J}$ as specified in harmonised European Material Standards and on the assumption that it is possible to achieve these minimum properties after fabrication. Calculated from the principles of fracture mechanics used for method 2 for C and CMn steels with yield strength < 460 MPa and

b) based on operating experience for Ni-alloyed steels with Ni ≥ 3 % up to 9 %, for austenitic steels and for bolts and nuts.

Method 2 Method developed from the principles of fracture mechanics and from operating experiences:

A more flexible approach than method 1 for derivation of technical requirements applicable to C, CMn, fine grain steels, Ni-alloyed steels with not more than 1,5 % of Ni with a specified minimum yield strength ≤ 500 MPa and for austenitic-ferritic steels with a specified minimum yield strength ≤ 550 MPa. This method can be applied for these steels to a wider range of thicknesses and temperatures than method 1 because T_R must not be equal to T_{27J} (see Figures B.2–1 to B.2–11). In addition, for ferritic steels with max 355 MPa in PWHT condition operation experience was considered for higher thicknesses.

Method 3 The application of a fracture mechanics analysis. This general method is applicable to cases not covered by methods 1 or 2. This method may also be used to justify deviations from the requirements of method 1 or 2. Only general guidance is given on the use of this method which shall only be used in agreement with the parties concerned.

1) Including temperatures at pressure tests

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Each of the three methods may be used independently. It is only necessary to satisfy the requirement of any one method.

All applicable combinations of the temperatures T_M (minimum metal temperature) and T_S (temperature adjustment term) shall be considered and the lowest possible T_R-value (design reference temperature) shall be used for the determination of the required material impact test temperature.

NOTE For definitions of temperature terms see 3.1.1 to 3.1.4.

B.2 Material selection and impact energy requirements

B.2.1 Introduction

The methods specified in B.2.2 (method 1) or B.2.3 (method 2) shall be used to determine the impact energy required to avoid brittle fracture. Alternatively, B.2.4 (method 3) may be used to determine the required toughness. The method used shall be fully documented, in order to ensure that compliance can be verified.

Reference thickness for constructional details is defined in Table B.4-1.

B.2.2 Method 1

B.2.2.1 General

Method 1 allows the selection of materials taken from harmonised European material standards with regard to prevention of brittle fracture. Table B.2–1 gives an overview to the following tables by steel type and product form.

The weld metal, the heat affected zone and other parts affected by manufacturing processes shall satisfy the same impact energy requirements as the guaranteed minimum properties for the base material at T_R given in the tables.

The Table lists design reference temperatures for maximum thickness at given strength levels represented by steels from harmonised European material standards with guaranteed minimum strength and impact properties. Where it is not possible to achieve these minimum properties after fabrication, a tougher starting material shall be selected.

Table B.2–1 — Guide to material selection

Table	Material or product form	Steel group	Clause
B.2–2	Plates and strips	Ferritic steels	B.2.2.2
B.2–3	Seamless and welded pipes		
B.2–4	Bars		
B.2–5	Forgings		
B.2–6	Ni alloyed steels (1,5 < Ni ≤ 5 %)	Ferritic steels	B.2.2.3
B.2–7	Ni-alloyed steel (9 % Ni)		
B.2–8	Bolts and nuts	Ferritic steels Austenitic steels	B.2.2.4
B.2–9			
B.2–10			
B.2–11	Austenitic steel grades	Austenitic steels	B.2.2.5

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NOTE Requirements for austenitic-ferritic steels are only given in B.2.3 (method 2).

Where test pieces of at least 5 mm wide can not be obtained the material need not be subject to impact testing.

Values of the design reference temperature T_R shall be calculated from the metal temperature T_M using the values of the temperature adjustment T_S given in Table B.2–12.

B.2.2.2 Ferritic steels

Tables B.2–2 to B.2–5 list ferritic steels taken from harmonised European material standards with specified impact properties below –10 °C.

The tabulated value of T_R is based on the impact test temperature T_{KV} for KV = 27 J.

Table B.2–2 — General requirements for prevention of brittle fracture — Reference thicknesses for plates and strips

Plates and Strips								
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. reference thickness e_B mm AW	Max. reference thickness e_B mm PWHT	Design reference temperature T_R °C	Material group to CR ISO 15608:2000	Remarks
1	EN 10028-2:2003	P235GH	1.0345	35	200	– 20	1.1	
2		P265GH	1.0425	35	200			
3		P295GH	1.0481	35	110		1.2	
4		P355GH	1.0473	35	70			
29	EN 10028-3:2003	P275NH	1.0487	35	200	– 20	1.1	
30		P275NL1	1.0488	35	200	– 40		
31		P275NL2	1.1104	35	200	– 50		
32		P355N	1.0562	35	70	– 20	1.2	
33		P355NH	1.0565	35	70	– 20		
34		P355NL1	1.0566	35	70	– 40		
35		P355NL2	1.1106	35	70	– 50		
39	EN 10028-4:2003	11MnNi5-3	1.6212	35	80	– 60	9.1	
40		13MnNi6-3	1.6217	35	70	– 60		
41		15NiMn6	1.6228	35	70	– 80		
50	EN 10028-5:2003	P355M	1.8821	35	-	– 20	1.2	a)
51		P355ML1	1.8832	35	-	– 40		a)
52		P355ML2	1.8833	35	-	– 50		a)
53		P420M	1.8824	35	-	– 20	2.1	a)
54		P420ML1	1.8835	35	-	– 40		a)
55		P420ML2	1.8828	35	-	– 50		a)
59	EN 10028-6:2003	P355Q	1.8866	35	70	– 20	1.2	
60		P355QH	1.8867	35	70	– 20		
61		P355QL1	1.8868	35	70	– 40		
62		P355QL2	1.8869	35	70	– 60		

a) TMCP steels shall not be Post Weld Heat Treated

If the planned component thickness is greater than that given in table B.2-2 alternative Charpy toughness requirements are provided in chapter B.2.3.1.

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Table B.2–3 — General requirements for prevention of brittle fracture — Reference thicknesses for seamless and welded tubes

Seamless and welded tubes								
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. reference thickness e_B mm		Design reference temperature T_R °C	Material group to CR ISO 15608:2000	Remarks
				AW	PWHT			
231	EN 10216-3:2004	P275NL1	1.0488	35	100	– 40	1.1	a)
232		P275NL2	1.1104	35	100	– 50		a)
233		P355N	1.0562	35	70	– 20	1.2	
234		P355NH	1.0565	35	70	– 20		
235		P355NL1	1.0566	35	70	– 40		
236		P355NL2	1.1106	35	70	– 50		
248	EN 10216-4:2004	P215NL	1.0451	10	10	– 40	1.1	a)
249		P255QL	1.0452	35	40	– 40		a)
250		P265NL	1.0453	25	25	– 40		a)
251		26CrMo4-2	1.7219	15	40	– 60	5.1	a)
252		11MnNi5-3	1.6212	35	40	– 60	9.1	a)
253		13MnNi6-3	1.6217	35	40	– 60	9.1	a)
306	EN 10217-3:2004	P275NL1	1.0488	35	40	– 40	1.1	a)
307		P275NL2	1.1104	35	40	– 50		a)
308		P355N	1.0562	35	40	– 20	1.2	a)
309		P355NH	1.0565	35	40	– 20		a)
310		P355NL1	1.0566	35	40	– 40		a)
311		P355NL2	1.1106	35	40	– 50		a)
316	EN 10217-4:2004	P215NL	1.0451	10	10	– 40	1.1	a)
317		P265NL	1.0453	16	16	– 40	1.1	a)
321	EN 10217-6:2004	P215NL	1.0451	10	10	– 40	1.1	a)
322		P265NL	1.0453	25	25	– 40	1.1	a)

a) Thickness limitation results from wall thickness limitation in the European material standards and in the European component standards respectively.

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Table B.2–4 — General requirements for prevention of brittle fracture with reference thickness for bars

Bars								
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. reference thickness e_B AW	PWHT	Design reference temperature T_R (°C)	Material group to CR ISO 15608:2000	Remarks
147	EN 10273:2007	P275NH	1.0487	35	75	– 20	1.1	
148		P355NH	1.0565	35	55		1.2	
150		P355QH	1.8867	35	55		1.2	

Table B.2–5 — General requirements for prevention of brittle fracture with reference thickness for forgings

Forgings								
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. ref.. thickness e_B AW	PWHT	Design reference temperature T_R (°C)	Material group to CR ISO 15608:2000	Remarks
367	EN 10222-3:1998	13MnNi6-3	1.6217	35	70	– 60	9.1	
369		15NiMn6	1.6228	35	50	– 80	9.1	
378	EN 10222-4:1998	P285QH	1.0478	35	85	– 20	1.2	
380		P355QH	1.0571	35	60	– 20	1.2	
382		P420QH	1.8936	35	50	– 20	3.1	

B.2.2.3 Ni –alloyed steels (Ni > 1,5 %)

Table B.2-6 lists Ni alloyed steels up to and including 5 % Nickel taken from harmonised European material standards.

Table B.2-7 lists Ni alloyed steels with 9 % Nickel taken from harmonised European material standards.

The tabulated value of T_R is based on the impact test temperature T_{KV} for KV = 27 J.

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Table B.2–6 — General requirements for prevention of brittle fracture with reference thickness for Ni-alloyed steels with 1,5 % < Ni ≤ 5 %

Ni-alloyed steel, 1,5 % < Ni [a] ≤ 5 %								
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. reference thickness e_B AW	Max. reference thickness e_B PWHT	Design reference temperature T_R (°C)	Material group to CR ISO 15608:2000	Remarks
plates and strips								
42	10028-4:2003	12Ni14	1.5637	35	80	– 100	9.2	[b]
43		X12Ni5	1.5680	35	80	– 120		
seamless tubes								
254	EN 10216-4:2001	12Ni14	1.5637	25	—	– 100	9.2	[b]
255		12Ni14		35	40	– 90		[b]
256		X12Ni5	1.5680	25	—	– 120		
257		X12Ni5		35	40	– 110		
forgings								
370	EN 10222-3:1998	12Ni14	1.5637	35	—	– 100	9.2	[b]
371		12Ni14		35	50			[b]
372		12Ni14		35	70			[b]
373		X12Ni5	1.5680	35	—	– 120		
374		X12Ni5		35	50			

a) Nickel content is nominal.

b) If used at – 105 °C (e. g. ethylene application), then 27 J shall be guaranteed at this temperature.

NOTE Thickness limitation result from wall thickness limitation in European material standards.

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Table B.2–7 — General requirements for prevention of brittle fracture with reference thickness for Ni-alloyed steels with 9 % Ni

9 % - Ni [a] alloys							
No. as per Table E.2-1	European Standard	Grade	Material No.	Max. reference thickness e_B AW | PWHT	Design reference temperature T_R (°C)	Material group to CR ISO 15608:2000	Remarks
plates and strips							
44	10028-4:2003	X8Ni9	1.5662	— [b]	– 196	9.3	
48		X7Ni9	1.5663				
seamless tubes							
258	EN 10216-4:2001	X10Ni9	1.5682	— [b]	– 196	9.3	
forgings							
375	EN 10222-3:1998	X8Ni9	1.5662	— [b]	– 196	9.3	

a) Nickel content is nominal.

b) Materials can be used to maximum thickness permitted in harmonised European material standards.

B.2.2.4 Bolts and nuts

For other bolts and nuts than given in Table B.2-8 a specified impact energy of minimum 40 J is required at T_{KV} = RT for T_M = ≥ –10 °C (where RT means Room Temperature).

If T_M is lower than –10 °C, specified impact energy of minimum 40 J is required at $T_{KV} \leq T_M$.

Except bolting material made from austenitic stainless steels specified in Table B.2-9 and B.2-10, bolting material with a design temperature below –160 °C shall be impact tested at –196 °C.

Table B.2–8 — General requirements for prevention of brittle fracture with reference thickness for nuts and bolts for TM ≥ -10 °C

European Standard	Type of material [a]	Thickness limitation	Impact test *KV* for $T_M \geq$ -10 °C	Test temperature / value
EN 10269:1999	All steels	According to EN 10269:1999	According to EN 10269:1999, Table 4	According to EN 10269:1999, Table 4
EN ISO 898-1:1999	5.6	M ≤ 39	M ≥ 16	RT [b] / 40 J
	8.8	M ≤ 39	M ≥ 16	RT [b] / 52 J
EN 20898-2:1993	5	M ≤ 39	None	—
	8	M ≤ 39	None	—

a) Starting material shall comply with EN 10269:1999.

b) According to EN 10045-1:1990, the room temperature, RT, is equal to 23 °C ± 5° C

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Table B.2–9 — General requirements for prevention of brittle fracture with reference thickness for nuts and bolts, bolting material according to EN 10269:1999

Type of material	Thickness limitation	Impact test	T_M	Remark
1.4307, 1.4301, 1.4303, 1.4404, 1.4401, 1.4948, 1.4919, 1.4941, 1.4980 a)	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 4	– 196 °C	Verification required for diameter or thickness > 20mm
1.4429, 1.4910,	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 4	– 273 °C	Verification required for diameter or thickness > 20mm
1.5523, 1.1133 1.6563	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 7	– 20 °C	—
1.7218	$d \leq 60$ mm	According to EN 10269:1999, Table 7	– 60 °C	—
	60 < $d \leq 100$ mm		– 50 °C	
1.6582, 1.6580, 1.7225	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 7	– 40 °C	—
1.5680	$d \leq 45$ mm	According to EN 10269:1999, Table 7	– 120 °C	—
	45 < $d \leq 75$ mm		– 110 °C	
1.5662	According to EN 10269:1999, Table 7	According to EN 10269:1999, Table 7 at – 196°C	– 196 °C	—
a) When used at -273 °C, verification testing at -196 °C according to Table 7 of EN 10269:1999 is required.				

Table B.2–10 — General requirements for prevention of brittle fracture with reference thickness for nuts and bolts

Standard	Type of material [a)]		Thickness limitation	T_M	Impact test
EN ISO 3506-1:1997	A2, A3	50	M ≤ 39	– 196 °C	None
		70	M ≤ 24		
EN ISO 3506-1:1997	A4, A5	50	M ≤ 39	– 60 °C [b)]	None
		70	M ≤ 24		
EN ISO 3506-2:1997	A2, A3, A4, A5	50	M ≤ 39	– 196 °C	None
		70	M ≤ 24		

a) Starting material shall comply with EN 10269:1999.

b) – 196 °C for studs

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