

BS EN 13445-4:2014



BSI Standards Publication

Unfired pressure vessels

Part 4: Fabrication

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National foreword

This British Standard is the UK implementation of EN 13445-4:2014. It supersedes BS EN 13445-4:2009+A1:2011 which is withdrawn.

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.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Compliance with a British Standard cannot confer immunity from legal obligations.

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Date	Text affected
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English Version

Unfired pressure vessels - Part 4: FabricationRécipients sous pression non soumis à la flamme - Partie 4:
Fabrication

Unbefeuerte Druckbehälter - Teil 4: Herstellung

This European Standard was approved by CEN on 19 August 2014.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the CEN-CENELEC Management Centre or to any CEN member.

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Foreword

This document (EN 13445-4:2014) 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of an identical text or by endorsement, at the latest by December 2014, and conflicting national standards shall be withdrawn at the latest by December 2014.

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.*

Although these Parts may be obtained separately, it should be recognised that the Parts are inter-dependant. As such the manufacture of unfired pressure vessels requires the application of all the relevant Parts in order for the requirements of the Standard to be satisfactorily fulfilled.

Corrections to the standard interpretations where several options seem possible are conducted through the Migration Help Desk (MHD). Information related to the Help Desk can be found at <http://www.unm.fr> (en13445@unm.fr). A form for submitting questions can be downloaded from the link to the MHD website. After subject experts have agreed an answer, the answer will be communicated to the questioner. Corrected pages will be given specific issue number and issued by CEN according to CEN Rules. Interpretation sheets will be posted on the website of the MHD.

This document supersedes EN 13445-4:2009. This new edition incorporates the Amendments which have been approved previously by CEN members, and the corrected pages up to Issue 5 without any further technical change. Annex Y 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 13445:2014 each year, starting with the present document as Issue 1, consolidating these Amendments and including other identified corrections.

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, Croatia, 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.

1 Scope

This document specifies requirements for the manufacture of unfired pressure vessels and their parts, made of steels, including their connections to non-pressure parts. It specifies requirements for material traceability, manufacturing tolerances, welding requirements, requirements for permanent joints other than welding, production tests, forming requirements, heat treatment, repairs and finishing operations.

2 Normative references

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

EN 287-1:2011¹⁾, *Qualification test of welders — Fusion welding — Part 1: Steels*

EN 10028-2:2009, *Flat products made of steels for pressure purposes — Part 2: Non-alloy and alloy steels with specified elevated temperature properties*

EN 10028-3:2009, *Flat products made of steels for pressure purposes — Part 3: Weldable fine grain steels, normalized*

EN 10028-4:2009, *Flat products made of steels for pressure purposes — Part 4: Nickel alloy steels with specified low temperature properties*

EN 10216-1:2013, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 1: Non-alloy steel tubes with specified room temperature properties*

EN 10216-2:2013, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 2: Non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10216-3:2013, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 3: Alloy fine grain steel tubes*

EN 10216-4:2013, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 4: Non-alloy and alloy steel tubes with specified low temperature properties*

EN 10217-1:2002, EN 10217-1:2002/A1:2005, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 1: Non-alloy steel tubes with specified room temperature properties*

EN 10217-2:2002, EN 10217-2:2002/A1:2005, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 2: Electric welded non-alloy and alloy steel tubes with specified elevated 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 and alloy steel tubes with specified low temperature properties*

1) EN ISO 9606-1 has been published in 2013 replaces EN 287-1. CEN has decided to have a transition period for EN 287-1. As a consequence, EN 287-1 is valid until October 2015.

EN 10217-5:2002, EN 10217-5:2002/A1:2005, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 5: Submerged arc welded non-alloy and alloy steel tubes with specified elevated 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 10222-2:1999, *Steel forgings for pressure purposes — Part 2: Ferritic and martensitic steels with specified elevated temperature properties*

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

EN 10222-4:1998+A1:2002, *Steel forgings for pressure purposes — Part 4: Weldable fine grain steels with high proof strength*

EN 13134:2000, *Brazing — Procedure approval*

EN 13445-1:2014, *Unfired pressure vessels — Part 1: General*

EN 13445-2:2014, *Unfired pressure vessels — Part 2: Materials*

EN 13445-3:2014, *Unfired pressure vessels — Part 3: Design*

EN 13445-5:2014, *Unfired pressure vessels — Part 5: Inspection and testing*

EN 14276-1:2006+A1:2011, *Pressure equipment for refrigerating systems and heat pumps — Part 1: Vessels — General requirements*

EN ISO 3834-2:2005, *Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements (ISO 3834-2:2005)*

EN ISO 3834-3:2005, *Quality requirements for fusion welding of metallic materials — Part 3: Standard quality requirements (ISO 3834-3:2005)*

EN ISO 4136:2012, *Destructive tests on welds in metallic materials — Transverse tensile test (ISO 4136:2012)*

EN ISO 5173:2010, *Destructive tests on welds in metallic materials — Bend tests (ISO 5173:2009)*

EN ISO 5178:2011, *Destructive tests on welds in metallic materials — Longitudinal tensile test on weld metal in fusion welded joints (ISO 5178:2001)*

EN ISO 9015-1:2011, *Destructive tests on welds in metallic materials — Hardness testing — Part 1: Hardness test on arc welded joints (ISO 9015-1:2001)*

EN ISO 9016:2012, *Destructive tests on welds in metallic materials — Impact tests — Test specimen location, notch orientation and examination (ISO 9016:2012)*

EN ISO 13585:2012, *Brazing — Qualification test of brazers and brazing operators (ISO 13585:2012)*

EN ISO 14732:2013, *Welding personnel — Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials (ISO 14732:2013)*

EN ISO 15609-1:2004, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding (ISO 15609-1:2004)*

EN ISO 15611:2003, *Specification and qualification of welding procedures for metallic materials — Qualification based on previous welding experience* (ISO 15611:2003)

EN ISO 15612:2004, *Specification and qualification of welding procedures for metallic materials — Qualification by adoption of a standard welding procedure* (ISO 15612:2004)

EN ISO 15613:2004, *Specification and qualification of welding procedures for metallic materials — Qualification based on pre-production welding test* (ISO 15613:2004)

EN ISO 15614-1:2004, EN ISO 15614-1:2004/A1:2008, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys* (ISO 15614-1:2004, ISO 15614-1:2004/A1:2008)

EN ISO 17639:2013, *Destructive tests on welds in metallic materials — Macroscopic and microscopic examination of welds* (ISO 17639:2003)

3 Requirements for manufacturing and subcontracting

3.1 Manufacturing

The general responsibilities of the pressure vessel manufacturer are stated in EN 13445-1:2014. Additionally to those requirements, the manufacturer shall ensure that:

- a) the organisation for the control of manufacturing operations which includes special processes such as welding, forming and heat treatment shall be clearly defined by the manufacturer;
- b) the manufacturing procedures such as welding, forming and heat treatment are adequate for the purpose and the pressure vessel meets the requirements of this standard. Where specific requirements are associated with materials these shall be taken into account, e.g. EAMs;
- c) the manufacturing equipment is adequate for fabrication;
- d) the staff is adequate for the assigned tasks;

NOTE As far as welding co-ordination is concerned, the qualifications, tasks and responsibilities can be defined by the manufacturer in accordance with EN ISO 14731:2007 [1] in the job assignment.

- e) the quality requirements for welding defined in EN ISO 3834-3:2005 are met as a minimum.

3.2 Subcontracting

The manufacturer may subcontract work, but shall ensure that the subcontractor carries out the work in accordance with the requirements of this European Standard. The manufacturer is responsible for the adequate definition of the subcontracted task and the need for any associated records.

On all occasions that the subcontractor work includes

- a) welding;
- b) forming including associated heat treatment;
- c) post weld heat treatment;
- d) non-destructive testing of welds (see EN 13445-5:2014),

the manufacturer shall obtain a subcontractor form (see Annex B).

Where welding operations are subcontracted, the manufacturer shall also either obtain copies of the welding procedure and welding operator qualification records or take other action to ensure that they comply with this standard.

In discharging his responsibility to ensure that the subcontractor carries out the work in accordance with this standard the manufacturer shall ensure that surveillance of the subcontracted work is performed.

Where a manufacturer is producing equipment that requires the intervention of a responsible authority, the manufacturer should inform the responsible authority of his intention to subcontract so that the responsible authority has the opportunity to take part in the subcontractor surveillance.

NOTE 1 See also EN 764-3:2002, 2.11 [2] and CR 13445-7.

NOTE 2 When the manufacturer is producing equipment based on quality assurance, the controls a manufacturer applies over subcontractors should be described in his approved quality system.

4 Materials

4.1 General

Materials for pressure vessels and the grouping of materials for pressure vessels shall be in accordance with EN 13445-2:2014.

The grouping applies regardless of product form, i.e. plate, forging, piping.

4.2 Material traceability

4.2.1 General

The vessel manufacturer shall have and maintain an identification system for materials used in fabrication, so that all material subject to stress due to pressure and those welded thereto in the completed work can be traced to its origin. This includes the use of welding consumables.

4.2.2 Identification system

4.2.2.1 The vessel manufacturer's identification system shall assure that all materials to be used in the vessel have been subjected to and satisfactorily passed the following:

- a) examination of material before fabrication for the purpose of detecting, as far as possible, imperfections which would affect the safety of the work;
- b) check of material to determine that it has the required thickness;
- c) check of the material to assure that the materials are permitted by this European Standard, fully traceable to the correct material certification and as specified in the design documentation;
- d) check of the welding consumables to assure the correct markings and that correct conditions are maintained to prevent deterioration.

4.2.2.2 Material traceability to the original identification markings shall be by one or more of the following methods:

- a) accurate transfer of the original identification markings to a location where the markings will be visible on the completed vessel;
- b) identification by a coded marking traceable to the original required marking;
- c) recording the identification markings using material lists or as built sketches which assure identification of each piece of material during fabrication and subsequent identification in the completed vessel;
- d) the batch numbers of welding consumables shall be recorded.

4.2.3 Visibility

Materials which cannot be stamped or which will not be visible after the vessel is completed or for small multiple parts or non pressure parts the manufacturer may operate a documented system which ensures material traceability for all materials in the completed vessel.

4.2.4 Review of material certification and material identification

All material certification shall be reviewed upon receipt. The review shall cover the completeness and adequacy of the reports against the following:

- a) mechanical and chemical properties required to be reported by the material specification;
- b) assuring that the reported results meet the requirements of the specification;
- c) all markings required by the material specification are satisfied and that there is traceability between the actual markings and those recorded on the material certification.

All materials certification shall be made readily available throughout manufacture.

4.2.5 Transfer of markings

In case the original identification markings are unavoidably cut out or the material is divided into two or more pieces the markings shall be accurately transferred by the manufacturer's nominated personnel prior to cutting.

The actual material marking shall be by methods which are not harmful to the material in subsequent use/operation.

The transfer of markings shall take place before partitioning of the product and after verification of the marks present with the corresponding certification.

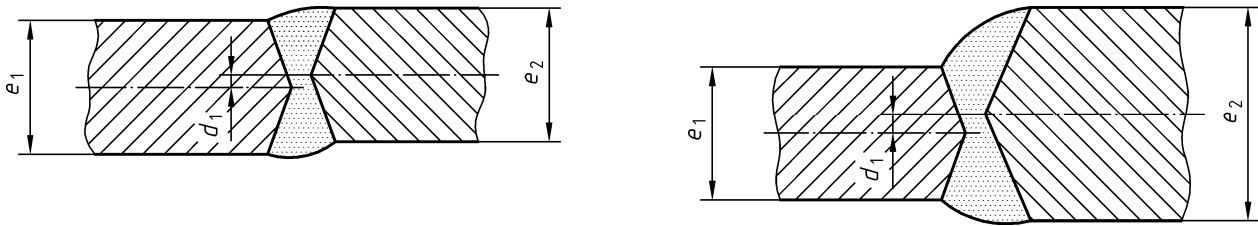
5 Manufacturing tolerances

5.1 Surface geometry of welds

The surface geometry of welded butt and fillet joints shall meet the requirements of EN 13445-5:2014 unless the drawing specifies more stringent requirements.

5.2 Middle line alignment

The misalignment tolerances of middle lines shall be as specified in Tables 5.2-1, 5.2-2, 5.2-3 and Figure 5.2-1.



a) Middle line alignment d_1 at equal thickness $e_1 = e_2$ b) Middle line alignment d_1 at different thickness $e_1 \leq e_2$

Figure 5.2-1 — Middle line alignment d_1

For longitudinal welds in cylinders, cones and rectangular/prismatic structures the middle lines of adjacent components (whether of equal or different thickness) shall be aligned within the tolerances specified in Table 5.2-1.

Table 5.2-1 — Offset of middle lines for longitudinal welds in cylinders, cones and rectangular/prismatic structures

Dimensions in millimetres

Thinner part thickness e_1	Maximum misalignment d_1
$e_1 \leq 2$	0,5
$2 < e_1 \leq 4$	$e_1/4$
$4 < e_1 \leq 10$	1
$10 < e_1 \leq 30$	$e_1/10$
$30 < e_1 \leq 60$	$e_1/30 + 2$
$60 < e_1$	4

For longitudinal welds in dished ends and welds in spherical components the middle lines of adjacent parts (whether of equal or different thickness) shall be aligned within the tolerances specified in Table 5.2-2.

Table 5.2-2 — Offset of middle lines for longitudinal welds in dished ends and in spherical components of adjacent parts

Dimensions in millimetres

Thinner part thickness e_1	Maximum misalignment d_1
$e_1 \leq 2$	0,5
$2 < e_1 \leq 4$	$e_1/4$
$4 < e_1 \leq 10$	1
$10 < e_1 \leq 30$	$e_1/10$
$30 < e_1 \leq 120$	$e_1/30 + 2$
$120 < e_1$	6

For circumferential welds the middle lines of adjacent parts (whether of equal or different thickness) shall be aligned within the tolerances specified in Table 5.2-3.

Table 5.2-3 — Offset of middle lines of circumferential welds of adjacent parts

Dimensions in millimetres

Thinner part thickness e_1	Maximum misalignment d_1
$e_1 \leq 30$	$e_1/10 + 1$
$30 < e_1 \leq 150$	$e_1/30 + 3$
$150 < e_1$	8

5.3 Surface alignment

5.3.1 Surface misalignment between parts

Where there is misalignment at the surface between parts of the same nominal thickness the transition across the weld shall be smooth and gradual with a slope of 1 in 4 over the width of the weld. If this taper cannot be accommodated within the weld width it is permissible to either:

- grind the higher plate surface, where this will not reduce the joint thickness at any point below the nominal specified plate thickness minus the plate thickness tolerance;
- build up the lower plate surface with added weld metal

5.3.2 Joining of parts of different thickness

Where different thickness are being joined a taper shall be produced in accordance with EN 13445-3:2014 by either:

- taper the thicker plate in accordance with the design drawing and then applying the requirements above for the same nominal thickness parts; or
- obtain the required slope across the width of the welds, or by a combination of weld build up on the lower surface with added weld metal and thereafter obtain the required slope across the weld width.

5.4 Tolerances for vessels subjected to internal pressure

5.4.1 External diameter

For cylindrical and spherical pressure vessels the mean external diameter derived from the circumference shall not deviate by more than 1,5 % from the specified external diameter.

For rectangular vessels and/or prismatic structures each external dimension shall not deviate by more than 1,5 % from the specified external dimension.

5.4.2 Out of roundness

Out of roundness (O) shall be calculated in accordance with the following Equation (5.4-1):

$$O [\%] = \frac{2 \cdot (D_{\max} - D_{\min})}{D_{\max} + D_{\min}} \cdot 100 \quad (5.4-1)$$

It shall not exceed the following values:

- 1,5 % for the ratio of $e/D < 0,01$;

- b) 1,0 % for the ratio of $e/D \geq 0,01$.

NOTE The determination of the out of roundness need not consider the elastic deformation due to the deadweight of the pressure vessel.

Irregularities in vessel profile (e.g. dents, buckling, flats on nozzle positions) shall be also within the tolerances in a) and b). A greater out of roundness may be acceptable provided they have been proven admissible by calculation or strain gauge measurements.

5.4.3 Deviation from the longitudinal axis

The deviation from the longitudinal axis over the length of the cylindrical portion of the pressure vessel shall not exceed 0,5 % of the length of the shell.

5.4.4 Irregularities in profile

- a) Local irregularities in vessel profile

Irregularities in profile (e.g. dents, buckling, flats on nozzle positions) shall be smooth and the depth shall be checked by a 20° gauge and shall not exceed the following values:

- 1) 2 % of the gauge length; or
- 2) 2,5 % of the gauge length provided that the length of the irregularities does not exceed one quarter of the length (with a maximum of 1 m) of the shell part between two circumferential joints.

Greater irregularities require proof by calculation or strain gauge measurement that the stresses are permissible.

- b) Peaking on longitudinal butt welds

When irregularity in the profile occurs at the welded joint and is associated with "flats" adjacent to the weld, the irregularity in profile or (peaking) shall not exceed the values given in Tables 5.4-1 and 5.4-2.

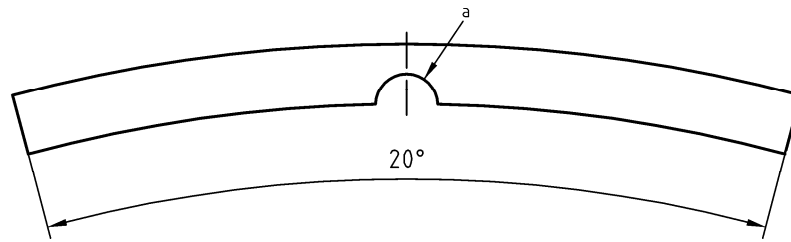
Measurement for peaking shall be made by means of a 20° profile gauge (or template), see Figure 5.4-1, or other types of gauge such as a bridge gauges or needle gauges.

For outwards peaking two readings shall be taken, P_1 and P_2 on each side of the joint, at any particular location, the maximum peaking is determined using Equation (5.4-2)

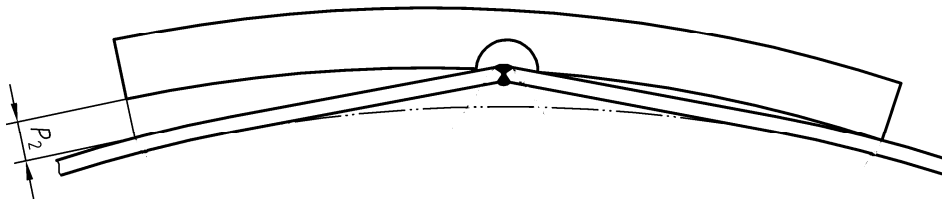
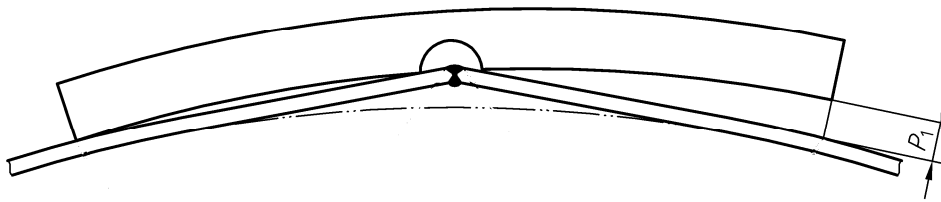
$$P = 0,25.(P_1 + P_2) \quad (5.4-2)$$

The inwards peaking P shall be measured.

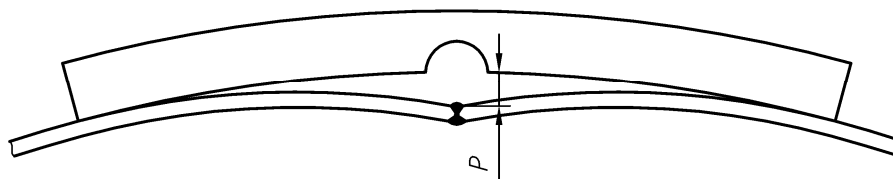
The inside radius of the gauge shall be equal to the nominal outside radius of the vessel.



a) sufficient cut-out to adequately keep clear off the weld reinforcement



b) For outwards peaking two readings P_1 and P_2 shall be taken



c) For inwards peaking P shall be measured

Figure 5.4-1 — Gauge details, measurement of peaking

Measurements shall be taken at approximately 250 mm intervals on longitudinal seams to determine the location with the maximum peaking value. The maximum peaking value for dynamic and cyclic loads shall be in accordance with Table 5.4-1 and for static loads in accordance with Table 5.4-2.

Table 5.4-1 — Maximum permitted peaking P in longitudinal welds for dynamic and cyclic loads

Dimensions in millimetres

Vessel wall thickness e	Maximum permitted peaking P
$e \leq 3$	1,5
$3 \leq e < 6$	2,5
$6 \leq e < 9$	3,0
$9 \leq e$	the lesser of $e/3$, or 10 mm

For cyclic loaded pressure vessels see also EN 13445-3:2014 and EN 13445-5:2014, Annex G in respect of peaking requirements. Peaking values in excess of the above are only permitted when supported by special analysis but in any case must not exceed the values in Table 5.4-2.

Table 5.4-2 — Maximum permitted peaking P at longitudinal welds for vessels subject to predominantly non cyclic loads

Dimensions in millimetres

Vessel ratio wall thickness e to diameter D	Maximum permitted peaking P
$e/D \leq 0,025$	5
$e/D > 0,025$	10

See also EN 13445-5:2014 for testing group 4 vessels for additional limits on peaking.

5.4.5 Local thinning

5.4.5.1 Local areas of thickness below the values $(e+c)$ where e is the required thickness and c is the corrosion allowance shall be permissible without further calculation provided all of the following conditions are fulfilled:

- the wall thickness difference does not exceed the smaller of the two values $0,05 e$ or 5 mm;
- the area of the thickness below the minimum design thickness shall be inscribed by a circle the diameter of which shall not exceed the smaller of the two values e or 60 mm;
- the distance between two areas from edge to edge of wall thickness below the minimum design thickness shall be at least the width

$$\sqrt{D \cdot e}$$

where

D is equal to the external diameter of the pressure part;

e is the required thickness of the plate;

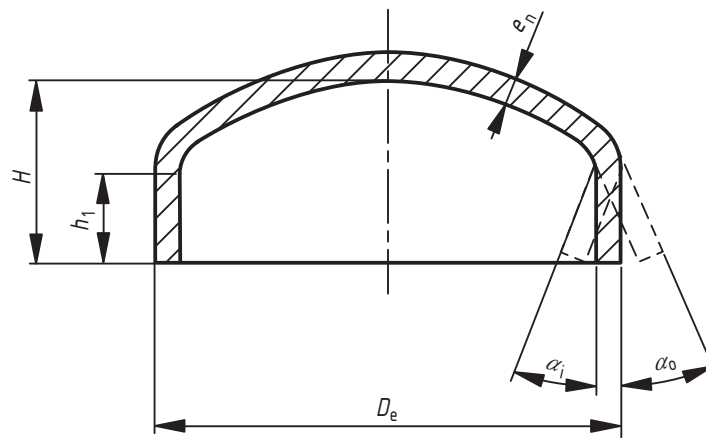
- the total area of thickness below the minimum design thickness shall not exceed 2 % of the total surface;
- the area is not in the knuckle region of a dished end.

5.4.5.2 Furthermore, local areas of wall thickness smaller than the minimum design wall thickness shall be permissible provided:

- the diameter of a circumscribed circle of the area with a wall thickness below the minimum design wall thickness has no larger dimension than that of a calculated permissible unreinforced opening according to EN 13445-3:2014 with a maximum of 200 mm;
- the residual wall thickness is greater than the thickness of a flat end of the same diameter and calculated with a *C*-factor of 0,35;
- the areas of reduced wall thickness are recorded.

5.4.6 Dished ends

Dished ends (see Figure 5.4-2) shall be aligned with the tolerances specified in Table 5.4-3 except that the crown radius shall not be greater than that specified in the design and the knuckle radius shall not be less than the values specified in the design.



Symbol	Quantity	Unit
D_e	Outside diameter	mm
H	Inner high	mm
h_1	Straight flange	mm
e_n^a	Nominal wall thickness	mm
α_i	Deviation of straight flange from cylindrical shape inner side angle	degree
α_o	Deviation of straight flange from cylindrical shape outer side angle	degree
C	Circumference	mm
O	Out of roundness $O = \frac{2 \cdot (D_{\max} - D_{\min})}{D_{\max} + D_{\min}} \cdot 100$	%

^a In place of the nominal wall thickness e_n , dished ends can be ordered with minimum wall thickness: $e_{\min} = e_n - \delta_e$. For e_n and δ_e refer to EN 13445-3:2014, 5.2.3

Figure 5.4-2 — Tolerances for dished ends

Table 5.4-3 — Dished end tolerances

Symbol	Range of application	Limit deviations	Notes	
<i>C</i>	$D_e \leq 300$ mm	± 4 mm		
	Ferritic materials:			
	$300 \text{ mm} < D_e \leq 1\,000$ mm	$\pm 0,4$ %		
	$1\,000 \text{ mm} < D_e$	$\pm 0,3$ %		
	Austenitic materials:			
	$D_e > 300$ mm	+ 0,5 % / - 0,7 %		
	Clad materials:			
	$D_e > 300$ mm	± 1 %		
<i>O</i>	all	≤ 1 %		
<i>H</i>	all	the greater of + 0,015 · D_e or + 10 mm		
e_n	$e_n \leq 10$ mm	- 0,3 mm	If minimum wall thickness e_{\min} for the dished end is specified no negative tolerance (δ_e) in thickness is permissible.	
	$10 \text{ mm} < e_n \leq 30$ mm	- 0,5 mm		
	$30 \text{ mm} < e_n \leq 50$ mm	- 0,8 mm		
	$e_n > 50$ mm	- 1,0 mm		
α_i α_o	all	$\leq 2^\circ$	In case of dished ends where the outer side angle is influenced by an upsetting due to the forming process the deviation of the straight flange from the cylindrical shape shall be measured only on the inside of the dished end.	
		$\leq 5^\circ$		
If not otherwise specified in the drawing the length of the straight flange h_1 shall be as following:				
h_1	all	$h_1 = 3 \cdot e_n$ or $h_1 = 3 \cdot e_{\min}$	The length of the straight flange need, however, not be more than:	
			Wall thickness e_n or e_{\min} mm	Length of the straight flange mm
			$50 < e_n \leq 80$	120
			$80 < e_n \leq 100$	100
			$100 < e_n \leq 120$	75
			$120 < e_n$	50

5.5 Tolerances for vessels subjected to external pressure

Tolerances shall be in accordance with EN 13445-3:2014, but in no case shall they exceed the tolerances specified in 5.4.

5.6 Structural tolerances

Structural tolerances, other than those specified in 5.4 and 5.5 should not exceed the values recommended in Annex A.

6 Weld details

6.1 General

The manufacturer in selecting an appropriate weld detail should give consideration to:

- a) the method of manufacture;
- b) the service conditions (e.g. corrosion);
- c) the ability to carry out the necessary non-destructive testing required in accordance with EN 13445-5:2014;
- d) the design requirements given in 5.7 and in Annex A of EN 13445-3:2014 for welds.

Other weld details may be used.

NOTE 1 Annex A of EN 13345-3:2014 gives figures of the joints in finished condition, design requirements mainly on geometry, a list of applicable testing groups, recommendations for prevention of lamellar tearing and corrosion.

NOTE 2 Basic weld details are given in EN 1708-1 [5]. These details show sound and commonly accepted practice. It is not intended that these are considered mandatory or should restrict development of welding technology any way and as a result other suitable weld details may be used.

6.2 Vessels or parts made of more than one course

Where a vessel or vessel part is made of two or more courses the longitudinal weld joints of adjacent courses shall be staggered by $4 \cdot e$ with 10 mm minimum, or 30 mm minimum when the vessel or vessel part is either working in the creep range or designed by Design by Analysis – Direct Route (Annex B of EN 13445-3:2014) or designed using 6.3 of EN 13445-3:2014.

6.3 Lapped joints, joggle joints, permanent backing strips

Design and weld details shall be in accordance with EN 13445-3:2014.

7 Welding

7.1 General

Welding of the component parts of a pressure vessel shall only be undertaken if the following conditions are satisfied:

- a) a welding procedure specification is held by the manufacturer;

- b) the welding procedures selected by the manufacturer are qualified for the field of application;
- c) the welders and welding operators are qualified for the work allocated to them and their approval is valid.

7.2 Welding procedure specification (WPS)

The manufacturer shall compile welding procedure specifications, in accordance with EN ISO 15609-1:2004 for all welds.

7.3 Welding procedure qualification record (WPQR)

Welding procedure specifications to be used in production shall be qualified by reference to an appropriate WPQR.

For the pressure retaining welds of a pressure vessel this shall be achieved by performing welding procedure approval tests in accordance with EN ISO 15614-1:2004 or by preproduction tests in accordance with EN ISO 15613:2004.

In addition to the requirements of EN ISO 15614-1:2004 the following tests shall apply:

- a) For test plates on butt joints equal to or over 20 mm thickness a longitudinal weld tensile test having a minimum diameter equal to or over 6 mm shall be performed in accordance with EN ISO 5178:2011 and R_{eT} , R_m and A_5 shall satisfy the specified minimum requirements of the base material or for weld consumables requirements in EN 13445-2:2014, 4.3.5 or other relevant values specifically taken into account in the design (e.g. austenitic filler metal in combination with 9 % Nickel steel).

Where the design temperature is higher than 300 °C then the test shall be done at the design temperature.

NOTE 1 It is important that special consideration is given where the mechanical properties of the weld are below the base materials by design, e.g. 9 % Ni steels welded with austenitic filler metal."

- b) a micro examination shall be performed for material groups 8.2 and 10 in accordance with EN 13445-2:2014, Table A-1.

— requirements on welds, material group 8.2: the micro examination shall show adequate microstructure

NOTE 2 Occasional isolated micro fissures with a length of $\leq 1,5$ mm may be acceptable, but should be reported.

— requirements on welds, material group 10: the micro examination shall show adequate microstructure

— the ferrite content in the heat affected zone (HAZ) shall be between min. 30 % and max. 70 %. In the high temperature HAZ, a distance of about two times the grain size from the fusion line, the ferrite content shall be equal to or less than 85 %. Where the welding consumable used are of an austenitic-ferritic matching type the ferrite content in the weld metal shall also be between 30 % and 70 %. The ferrite content shall be measured by metallographic methods. If the welding consumables are of non-matching type (i.e. austenitic) the requirement for ferrite content in the weld metal does not apply.

NOTE 3 The limit deviation on metallographic measurements frequently are of the order of $\pm 5\%$.

- c) Impact test: The testing and the acceptance criteria shall conform to EN ISO 15614-1:2004; in addition, the impact test requirements in accordance with EN 13445-2:2014, Annex B shall apply.

For austenitic steels see also 8.2 a) 2) of this part of the standard.

For welds other than pressure retaining welds directly attached to the pressure vessels e.g. tray rings, support feet, etc. welding procedure specifications may be acceptable by holding welding procedure approval records carried out in accordance with EN ISO 15611:2003 and EN ISO 15612:2004.

If required, the welding procedure approval records shall be approved by a competent third party, who shall perform examination and tests (or have them carried out) as specified in EN ISO 15614-1:2004 and this clause.

NOTE 4 For all test coupons it is permissible for a manufacturer to subcontract preparation of test pieces and their testing but not the welding of the test pieces.

7.4 Qualification of welders and welding operators

Welders and welding operators shall be approved to EN 287-1:2011 or EN ISO 14732:2013 respectively.

NOTE 1 The training, supervision and control of welders and welding operators is the responsibility of the manufacturer.

An up-to-date list of welders and welding operators together with records of their approval test shall be maintained by the manufacturer.

The prolongation (every 6 months) and re-approval (every 2 years) shall be carried out in accordance with EN 287-1:2011.

The evidence in support of the prolongation and re-approval shall be maintained for at least 2 years.

NOTE 2 Any welders not in the employ of the manufacturer may be used provided they are under the full technical control of the manufacturer and work to the manufacturer's requirements.

7.5 Filler metals and auxiliary materials

The technical delivery conditions for welding consumables shall be in accordance with EN 13445-2:2014. The filler metals and auxiliary materials shall be documented, and shall be suitable for use with the parent metals, the welding processes and the fabricating conditions.

All welding consumables shall be stored and handled with care and used in accordance with the conditions specified by the welding consumable manufacturer.

NOTE This is particularly important where baking and drying are specified.

Electrodes, filler wires and rods and fluxes that show signs of damage or deterioration, such as cracked or flaked coating, rusting or dirty electrode wire, shall not be used.

7.6 Joint preparation

Material shall be cut to size and shape by any mechanical or thermal cutting process or by combination of both.

NOTE 1 This may be carried out before or after forming operations.

Where thermal cutting is employed precautions shall be taken to ensure that the edges are not adversely influenced by hardening.

NOTE 2 For some materials this will involve preheating prior to cutting.

The cut edges of ferritic steel which are cut by the thermal process, shall be dressed back by grinding or machining if required by the WPS.

The surface to be welded shall be thoroughly cleaned of oxide, scale, oil grease or other foreign substance and shall be free of defects such as inclusions, cracks and laminations to avoid any detrimental effect on weld quality.

The edges to be welded shall be kept in position, either by mechanical means, temporary attachments or by tack welds or by a combination. The tack welds shall be removed or fused again in the weld bead (see Note 3). In both cases, the manufacturer shall take all precautions so that the tack welding or temporary attachment or a combination of these does not generate metallurgical or homogeneity defects.

NOTE 3 It is permissible to use tack welds and incorporate them into the final weld provided they have been made to an approved welding procedure by approved welders.

Where single sided welds are being used, the manufacturer shall ensure that the alignment and the gap of the edges to be welded will be adequate to assure the required penetration at the weld root.

During the whole welding operation, the edges to be welded shall be held so that the alignment tolerances defined in 5.2 are satisfied.

7.7 Execution of welded joints

The welder shall have available the applicable WPS or detailed work instructions based on the approved WPS and defining all essential variables under direct control by the welder.

Depending on the weld process, after each weld run, the slag shall be removed and the weld cleaned and the surface defects removed to obtain the proper quality of weld metal.

Unless the welding process used provides effective and sound penetration, the second side of a welded joint shall be removed back to sound metal using a mechanical or thermal process or by grinding.

Arc strikes on pressure vessel parts outside the weld preparation shall be avoided. Where arc strikes occurs accidentally the affected area (including the heat affected area) shall be repaired in accordance with 11.1.

A record shall be maintained of which welder or welding operator has carried out each weld.

NOTE This may be by marking each weld with a welder identification mark or alternatively by means of records which assure traceability of the welder to his work throughout the construction of the pressure vessel.

7.8 Attachments, supports and stiffeners

Attachments, whether temporary or not, supports and stiffeners shall be welded to a part subject to pressure by qualified welders using a qualified procedure.

Temporary attachments shall be removed using a technique which does not affect the properties of the metal of the pressure part to which they are welded. Care shall to be taken that the area of the removed attachment is free of surface cracks. Repair shall be carried out in a accordance with 11.2.

Cold formed dished ends of ferritic steels without subsequent heat treatment shall not be welded or heated up locally to temperatures between 550 °C and 750 °C in the knuckle area.

7.9 Preheat

The manufacturer shall include in the WPS the preheating temperatures and, where relevant, the inter-pass temperatures required for the welding. The preheating temperature shall be determined by taking into consideration the composition, and thickness of the metal being welded, the welding process being used and the arc parameters.

NOTE Recommendations for preheating for ferritic steels are given in EN 1011-2 [4], recommendations for preheat control are given in EN ISO 13916 [6].

The preheating temperature specified in the WPS shall be adhered to when tack welding and during the entire welding operation. Adherence to the preheating temperature shall be continuously monitored with suitable measuring instruments or temperature indicating crayons.

No welding shall be carried out when the temperature of the parent metal near the joint is less than +5 °C.

7.10 Permanent joints other than welding

7.10.1 General

Where non-welded joints are made between metallic materials and/or non-metallic materials, procedures shall be qualified, for all joints, in a manner similar to that used in qualifying welding procedures. Similarly, operators shall be qualified for carrying out such procedures.

7.10.2 Mechanical roller expansion

Mechanical roller expansion procedures and expansion operator approvals shall be conducted in accordance with Annex C of this standard. Other expanding processes, e.g. hydro-expanding and explosive expanding, are not dealt with in Annex C (for such processes see 7.10.1). Where mechanical roller expansion and welding are used in combination, Annex C applies if the mechanical strength of the joint is only assured by the roller expansion process.

7.10.3 Brazing

For hand brazing and manual mechanical brazing, brazing procedures and brazer approvals shall be conducted in accordance with EN 13134:2000 and EN ISO 13585:2012. The rules for fully automated furnace brazing shall be in accordance with EN 14276-1:2006+A1:2011. Old approvals valid under the Directive 97/23/EC already before publication of this standard retain their validity.

8 Manufacture and testing of welds — Production test

8.1 General

In order to control the continuing quality of the manufacture and the compliance of the mechanical properties of the welds with the specification, production test plates shall be welded and tested in accordance with 8.2 and 8.3.

Production test plates apply only to governing shell-longitudinal and –circumferential welds (see EN 13445-3:2014).

Specific requirements apply to vessels and vessel parts made of thermo-mechanically rolled steels (group 2.1) and quenched and tempered steels (group 3.1). See 8.2 f).

NOTE When a vessel includes one or more longitudinal welds the test plates should wherever practicable be attached to the shell plate on one end of the weld so that the edges to be welded in the test plate are a continuation and duplication of the corresponding edges of the longitudinal welds. The weld metal should be deposited in the test plates continuously with the welding of the corresponding longitudinal weld so that the welding process, procedure and technique are the same. When it is necessary to weld the test plates separately, the procedure used should duplicate that used in the construction of the vessel.

Where difficulties are encountered with electro slag welds in transferring from welds with different curvatures (e.g. from a cylinder to a flat coupon plate) the test plate may be welded separately either immediately before or immediately after the welds of the vessel, using the same welding parameters.

When the test plates are required for circumferential welds they shall be welded separately from the vessel providing the technique used in their preparation duplicates as far as possible the procedure used in the welding of the appropriate welds of the vessel.

8.2 Reference criteria

The criteria for the determination the number of production test plates is given below. This is dependent upon the material, the length of welded joints, the thickness, post weld heat treatment (PWHT) and the joint coefficient for each qualified weld procedure. Special provisions are given for testing group 4. The actual testing of production test plates is dependent on the material and the thickness. Additional specific impact testing requirements are also addressed below.

a) In addition to the requirements in c) to f) below impact tests (in accordance with EN 13445-2:2014, B 3.) shall be carried out on a production test plate in the following situations.

1) For ferritic and austenitic-ferritic steels:

- When the material thickness is greater than 12 mm and the required impact temperature T_{KV} is below $-10\text{ }^{\circ}\text{C}$ and the impact test temperature of the welding procedure qualification test qualifying the weld to achieve the required impact energy is not more than $15\text{ }^{\circ}\text{C}$ below the T_{KV} .
- When the material thickness is greater than 6 mm, but less than or equal to 12 mm, and the required impact temperature T_{KV} is below $-30\text{ }^{\circ}\text{C}$ and the impact test temperature of the welding procedure qualification test qualifying the weld to achieve the required impact energy is not more than $15\text{ }^{\circ}\text{C}$ below T_{KV} . These requirements are summarised in Table 8.2.

Where a test plate is required by c) to f) below then the impact specimens may be cut from the test plate along with the other required test specimens. Where a test plate is not required by c) to e) then a short test plate sufficient in length only to obtain the required impact tests plus any allowance for retests shall be produced at a frequency of one test plate per vessel welded to the same procedure as the longitudinal welds. Where a number of similar vessels are welded at the same time, to the same welding procedure using the same batch of welding consumables, they may be represented by one production test for impact tests up to a maximum of 25 m of longitudinal weld by agreement of the responsible parties, as appropriate.

Table 8.2 — Required production control test plate for impact tests

Thickness of weld seam	$T_{KV} \geq -10\text{ °C}$	$T_{KV} < -10\text{ °C} \geq -30\text{ °C}$		$T_{KV} < -30\text{ °C}$	
		$T_{PQR} \leq$	$T_{PQR} >$	$T_{PQR} \leq$	$T_{PQR} >$
		$T_{KV} -15\text{ °C}$	$T_{KV} -15\text{ °C}$	$T_{KV} -15\text{ °C}$	$T_{KV} -15\text{ °C}$
$\leq 6\text{ mm}$	no	no	no	no	no
$> 6 \leq 12\text{ mm}$	no	no	no	no	yes
$> 12\text{ mm}$	no	no	yes	no	yes

T_{PQR} = the impact test temperature used on the relevant Welding Procedure Qualification test to achieve the required impact energy.

T_{KV} = the required impact test temperature taken from EN 13445-2:2014, Annex B.

NOTE 1 For carbon steels in groups 1.1 and 1.2: When PQR data is at a different test temperature from the required impact test temperature, it may be converted to a common temperature base on the basis of 1,5 J per °C. Such conversion shall be permitted only in the range of 18 J to 55 J of Charpy V impact energy. Values in excess of 55 J shall be taken as 55 J. The 1,5 J per °C relationship may also be utilised to determine the temperature adjustment when seeking to compare data at common impact energy levels, however, this may not exceed 15 °C reduction.

EXAMPLE 1 Conversion of 33 J at a T_{PQR} of -20 °C towards 40 J:

33 J at -20 °C may be regarded as equivalent to 40 J at -15 °C .

EXAMPLE 2 Conversion of 100 J at a T_{PQR} of -20 °C towards 40 J (restriction to max. 55 J):

100 J at -20 °C may be regarded as equivalent to 40 J at -30 °C .

EXAMPLE 3 Conversion of 100 J at a T_{PQR} of -20 °C towards 27 J (restriction to max. 55 J and reduction of max. 15 °C)

With 100 J at -20 °C one can use an equivalent of 27 J at a temperature not lower than -35 °C .

2) For austenitic steels:

When the minimum design temperature T_M of the vessel is less than -105 °C the weld and heat-affected zones shall meet a minimum of 40 J when tested at -196 °C .

NOTE 2 For practical reasons, the test temperature of -196 °C is standardised for all austenitic steel testing of any design temperature below -105 °C .

For filler metals of type 19 9 L, 19 9 Nb, 19 12 3 L, 19 12 3 L Si, 19 13 4 N L, 25 20 L, 25 22 2 N L, 27 31 4 Cu L and nickel based filler metals this may be demonstrated on procedure qualification tests, and further production test plates are not required.

For other weld metal composition and where the weld metal ferrite content exceeds 12 FN, each batch of weld metal shall demonstrate the required impact properties, or a production test plate for impact properties shall be carried out per vessel at -196 °C .

NOTE 3 For filler metal designation see EN ISO 14343.

b) For the welds in vessels in testing group 4 (see EN 13445-5:2014) no production test plates shall be required.

- c) There is a strict relationship between the WPS and the mechanical properties obtained in the procedure approval test for material group 1.1. Because of the tolerance of material group 1.1 to weld procedural variables, production tests are not required if all the following conditions are met:
- 1) the quality requirements for welding according to EN ISO 3834-2:2005 or EN ISO 3834-3:2005 are fulfilled;
 - 2) the welding process is fully mechanised (see ISO 857-1 [3]) ensuring that the welding procedure is applied consistently
 - 3) there is no requirement in the WPS for preheating or post weld heat treatment (PWHT);
 - 4) the wall thickness $e_n \leq 30$ mm.

d) For vessels made of materials in material groups 1.1, 1.2 and 8.1, the following shall apply:

- 1) for longitudinal welds, one test plate per vessel in the case of joint coefficient 1,0;
- 2) one test plate per 200 m of longitudinal welds in the case of joint coefficient 0,85 or of welds in heads except of hemispherical heads in the case of joint coefficient 1,0;
- 3) one test plate per year, where the circumferential welds are welded to a procedure involving joggle joints or permanent backing strips (see 6.3).

After 10 consecutive test plates have successfully passed the tests, testing may be reduced to the following:

- 4) one test plate per 200 m of longitudinal welds in the case joint coefficient of 1,0;
- 5) one test plate per 1 500 m of longitudinal welds in the case of joint coefficient 0,85 or of welds in heads except of hemispherical heads in the case of joint coefficient 1,0;
- 6) one test plate per year, where the circumferential welds are welded to a procedure involving joggle joints or permanent backing strips (see 6.3).

e) For vessels made of material in material groups other than those covered in d) the following shall apply:

- 1) for longitudinal welds, one test plate per vessel in the case of joint coefficient 1,0;
- 2) one test plate per 100 m of longitudinal welds in the case of joint coefficient 0,85 or of welds in heads except of hemispherical heads in the case of joint coefficient 1,0;
- 3) where the circumferential welds are welded to a procedure different to the longitudinal joints, two test plates per year or one test plate per vessel which ever is less.

After 50 consecutive test plates have successfully past the tests, testing may be reduced to the following:

- 4) one test plate per 50 m of longitudinal welds in the case of joint coefficient 1,0;
- 5) one test plate per 500 m of longitudinal welds in the case of joint coefficient 0,85 or of welds in heads except of hemispherical heads in the case of joint coefficient 1,0;
- 6) where the circumferential welds are welded to a procedure different to the longitudinal joints, two test plates per year or one test plate per vessel which ever is less.

- f) For vessels made of thermo-mechanically rolled steels (group 2.1) and quenched and tempered steels (group 3.1), independent of the joint coefficient, the following shall apply:
- 1) for vessels not subjected to post-weld heat treatment, d) shall apply;
 - 2) for longitudinal welds, made by an automatic welding process, one test plate per vessel, WPS, cast and post-weld heat treatment furnace load;
 - 3) for circumferential welds, made by an automatic welding process, if welded using the same WPS as for longitudinal welds, no further test plates are required. If welded by a different WPS to that used for longitudinal welds, one test plate per vessel, WPS, cast and post-weld heat treatment furnace load;
 - 4) for welds made by manual welding process, one test plate per vessel, WPS, welding position, cast and post-weld heat treatment furnace load;

After 10 consecutive test plates have successfully passed the tests, testing may be reduced to the following:

- 5) for automatic welded longitudinal welds, one test plate per vessel;
- 6) for manual welds, one test plate per vessel in the most difficult welding position.

The testing of the production test plate shall consider the parameters for the post-weld heat treatment(s) of the pressure vessel, taking in particular into account 10.5.1.

8.3 Extent of testing

The type and number of specimens to be taken from the test plate after final heat treatment shall be in accordance with Table 8.3-1 for the particular material and thickness applicable.

NOTE The number and type of test specimens to be taken from the test plate are dependent on material group and thickness.

The test plate shall be of sufficient size to allow for the required specimens including an allowance for retests.

Prior to cutting the test pieces, the test plate shall be non-destructively tested in order to ensure that the test specimens are taken from sound areas.

Table 8.3-1 — Testing of production test plates

Material group	Thickness of test plates e^a mm	Test specimens ^{b, c, d}
1.1 1.2	$e \leq 12$	1 FB, 1 RB, 1Ma
	$12 < e \leq 35$	3 IW, 1 Ma
	$35 < e$	3 IW, 1 TT, 1 LT, 1 Ma
1.3 2.1	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma, HT
	$12 < e$	3 IW, 3 IH, 1 TT, 1 LT, 1 Ma, HT
3.1	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma, HT
	$12 < e$	3 IW, 3 IH, 1 TT, 1 LT, 1 Ma, HT
4	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma, HT
	$12 < e$	3 IW, 3 IH, 1 TT, 1 LT, 1 Ma, HT
5	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma, HT
	$12 < e \leq 30$	3 IW, 3 IH (> 3 % Cr), 1 TT, 1 LT, 1 Ma, HT
	$30 < e$	3 IW, 3 IH, 1 TT, 1 LT, 1 Ma, HT
6	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma, HT
	$12 < e$	3 IW, 3 IH, 1 TT, 1 LT, 1 Ma, HT
7.1 7.2	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma, HT
	$12 < e$	3 IW, 3 IH, 1 TT, 1 Ma, HT
8.1	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma
	$12 < e$	3 IW, 1 TT, 1 Ma
8.2	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Mi
	$12 < e$	3 IW, 1 TT, 1 Mi
9	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma, HT
	$12 < e$	3 IW, 3 IH, 1 TT, 1 LT, 1 Ma, HT
10	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Mi, HT
	$12 < e$	3 IW, 3 IH, 1 TT, 1 LT, 1 Mi, HT

^a Thinner plate thickness.

^b When impact test requirements in accordance with EN 13445-2:2014, Annex B apply:
— for impact test temperature $T_{kv} \geq -30$ °C impact tests IW and IH are required for $e > 12$ mm;
— for impact test temperature $T_{kv} < -30$ °C impact tests IW and IH are required for $e > 6$ mm.

^c For LT see 8.4.3 for thickness limitation.

^d The symbols for Table 8.3-1 are given in Table 8.3-2.

Table 8.3-2 — Test specimens

Designation	Abbreviation
Face bend test to EN ISO 5173:2010+A1:2011	FB
Root bend test to EN ISO 5173:2010+A1:2011	RB
Transverse tensile test to EN ISO 4136:2012	TT
Longitudinal weld tensile test to EN ISO 5178:2011	LT
Impact test; weld deposit to EN ISO 9016:2012	IW
Impact test, HAZ to EN ISO 9016:2012	IH
Macro examination to EN ISO 17639:2013	Ma
Micro examination to EN ISO 17639:2013	Mi
Hardness test to EN ISO 9015-1:2011	HT

8.4 Performance of tests and acceptance criteria

8.4.1 General

The individual test pieces shall be manufactured, tested and shall meet the acceptance criteria defined.

8.4.2 Transverse tensile test

The testing and the acceptance criteria shall conform to EN ISO 15614-1:2004.

NOTE Special consideration should be given where the mechanical properties of the weld are below the base materials by design, e.g. 9 % Ni steels welded with austenitic filler metal.

8.4.3 Longitudinal weld tensile test

For test plates on butt joints equal to and over 20 mm thickness a longitudinal weld tensile test having a minimum diameter equal to and over 6 mm shall be performed in accordance with EN ISO 5178:2011 and R_{eT} , R_m and A_5 shall satisfy specified requirements of the base material or other relevant values specifically taken into account in the design (e.g. austenitic filler metal in 9 % Nickel steel). Where the design temperature is higher than 300 °C then the test shall be done at the design temperature.

NOTE Special consideration should be given where the mechanical properties of the weld are below the base materials by design, e.g. 9 % Ni steels welded with austenitic filler metal.

8.4.4 Impact test

The testing and the acceptance criteria shall conform to EN ISO 15614-1:2004; in addition, if applicable, the impact test requirements according to EN 13445-2:2014, Annex B shall apply.

8.4.5 Bend test

The testing and the acceptance criteria shall conform to EN ISO 15614-1:2004.

8.4.6 Macro examination

The testing and the acceptance criteria shall conform to EN ISO15614-1:2004.

The macro examination shall show sound build-up of beads and sound penetration.

8.4.7 Micro examination

— requirements on welds, material group 8.2: the micro examination shall show adequate microstructure

NOTE Occasional isolated micro fissures with a length of $\leq 1,5$ mm may be acceptable, but should be reported.

— requirements on welds, material group 10: the micro examination shall show adequate microstructure

The ferrite content in the heat affected zone (HAZ) shall be between min. 30 % and max. 70 %. In the high temperature HAZ, a distance of about two grain size from the fusion line, a ferrite content shall be equal or less than 85 %. Where the welding consumable used are of an austenitic-ferritic matching type the ferrite content in the weld metal shall also be between 30 % and 70 %. If the welding consumables are of non-matching type (i.e. austenitic) the requirement for ferrite content in the weld metal does not apply.

NOTE The limit deviations on metallographic measurements frequently are of the order of ± 5 %.

8.4.8 Hardness test

The testing and the acceptance criteria shall conform to EN ISO 15614-1:2004.

8.4.9 Retests

Where individual tests do not conform to the requirements specified in this standard and the reasons shall be investigated. Where the unsatisfactory test result is due to poor testing technique or to a locally limited imperfection the following retests shall be made:

- a) tensile test: the test shall be repeated on two tensile test specimens taken from the same test plate, both results shall meet the requirements;
- b) bend test: the test shall be repeated on two bend test specimens taken from the same test plate; both results shall meet the requirements;
- c) impact test: the test shall be repeated on three Charpy-V-notch specimens taken from the same test plate;
 - 1) the mean value obtained from all six individual specimens shall be equal to or greater than the specified minimum value;
 - 2) not more than two of the six individual values shall be less than the specified minimum value;
 - 3) not more than one of the six individual values shall be less than 70 % of the specified minimum value.

Should any of the retests fail to comply with the requirements then the joints/vessels represented by the test plate shall be deemed not in compliance with this Part of this European Standard.

NOTE Production factors may result in a scatter of mechanical test results which may occasionally fall below the agreed specification level.

8.4.10 Test report

A test report shall be prepared indicating compliance of the test results and the as found values meeting the specified requirements.

9 Forming of pressure parts

9.1 General

Manufacturers of formed pressure parts shall maintain records of the forming procedure and the subsequent heat treatment.

NOTE Formed pressure parts can be cold or hot formed. Formed pressure parts can comprise dished ends, segments, cylinders and other formed parts. Formed pressure parts may consist of individual parts which are welded together and formed subsequently.

9.2 Ratio of deformation

9.2.1 Dished circular products

The following Equation (9.2-1) shall be used for the calculation of deformation F for all dished circular products (e.g. elliptical or torispherical heads, spherical caps) and shall be used for all types of forming processes (see also Figure 9.2-1):

$$F = 100 \ln \frac{D_{b(x)}}{D_e - 2e} [\%] \quad (9.2-1)$$

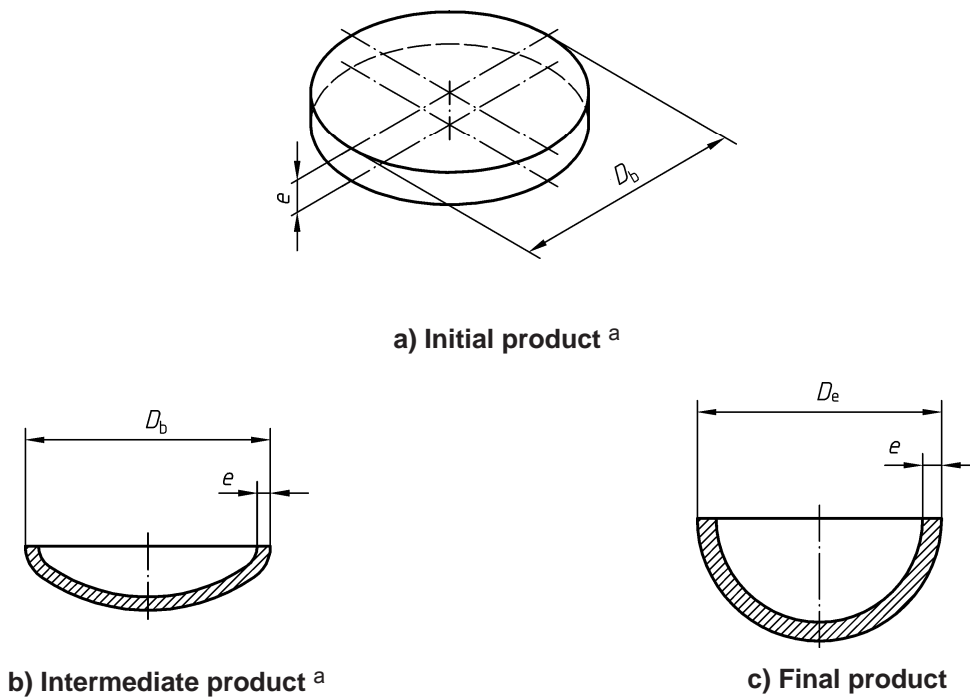
where

e is the thickness of the initial or intermediate product;

$D_{b(x)}$ is the diameter of the blank or diameter of intermediate product;

D_e is the external diameter of the finished product;

\ln is the natural logarithm.



^a In case of different forming steps without intermediate heat treatment (see 9.4.2), the deformation is the total amount of deformation of the individual forming steps. In case of intermediate heat treatment, the deformation is that deformation achieved after the last previous heat treatment.

Figure 9.2-1 — Forming of dished circular products

9.2.2 Cylinders and cones made by rolling

The following Equation (9.2-2) shall be used for the calculation of deformation F for cylinders and cones made by rolling (see also Figure 9.2-2).

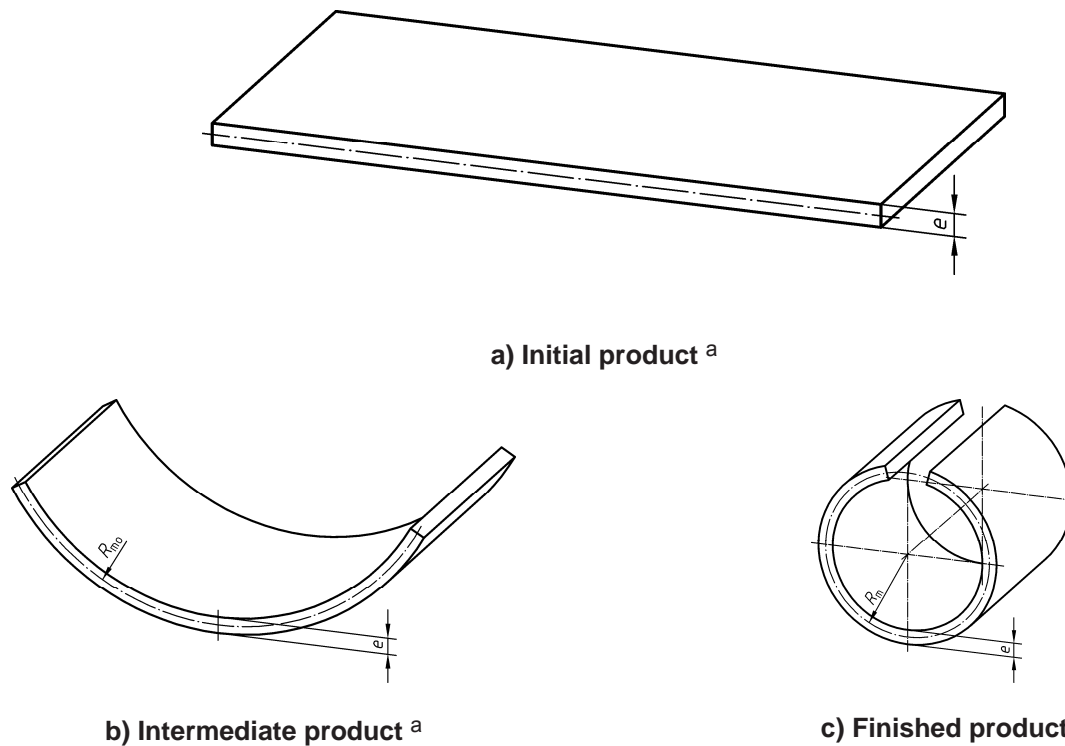
$$F = \frac{50e}{R_m} \cdot \left(1 - \frac{R_m}{R_{mo}} \right) [\%] \tag{9.2-2}$$

where

e is the thickness of the initial or intermediate product;

R_{mo} is the mean radius of the intermediate product (in case of a unformed initial product is $R_{mo} = \infty$);

R_m is the mean radius of the finished product (for cones, the mean radius of the smaller diameter shall be used).



^a In case of different forming steps without intermediate heat treatment (see 9.4.2), the ratio of deformation is the total amount of the ratio of deformation of the individual forming steps. In case of intermediate heat treatment, the deformation is that deformation achieved after the last previous heat treatment.

Figure 9.2-2 — Forming of cylinders and cones

9.2.3 Other product types

The Equation (9.2-3) shall be used for the calculation of deformation (F) of all other types of formed products (see also Figure 9.2-3):

$$F = \frac{200}{\sqrt{3}} \sqrt{F_1^2 + F_2^2 + F_1 F_2} \quad [\%] \quad (9.2-3)$$

where

$$F_1 = \ln \frac{l_1}{l_0}, \quad F_2 = \ln \frac{l_2}{l_0}$$

\ln is the natural logarithm;

l_0 is the diameter of a circle marked on the plate prior to forming in the area which shall be deformed with a maximum deformation. After forming, the circle of diameter l_0 is transformed into an ellipse with a large axis l_1 and a small axis l_2 .

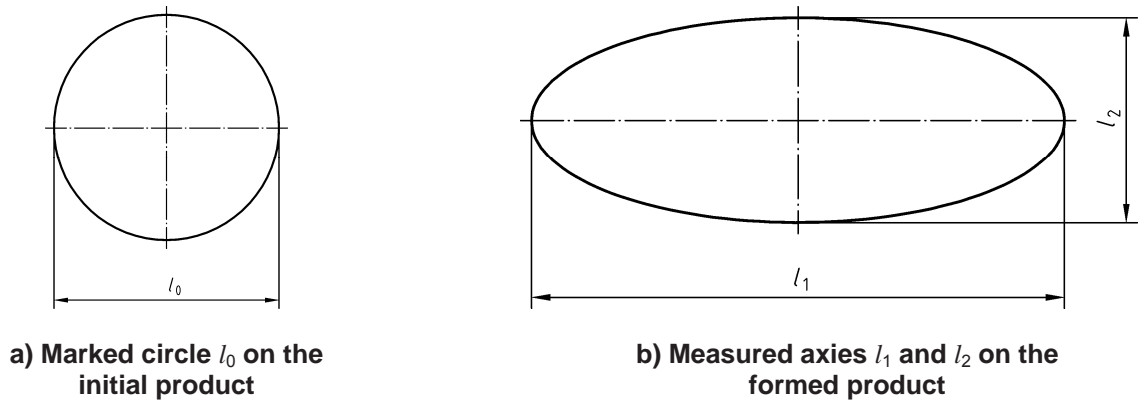


Figure 9.2-3 — Forming of products others than cylinders, cones and dished circular products

9.2.4 Tube bends

The Equation (9.2-4) shall be used for the calculation of deformation F of tube bends (see also Figure 9.2-4):

$$F = 100 \frac{D_e}{2R} [\%] \quad (9.2-4)$$

where

R is the radius of curvature for tube

D_e is the external diameter of the tube

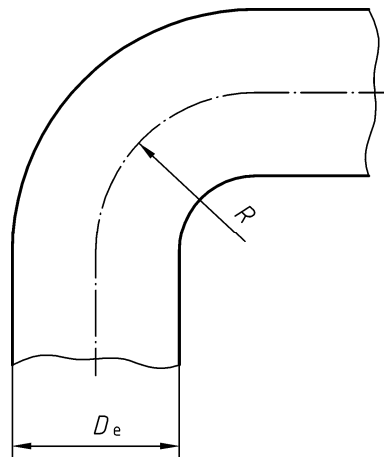


Figure 9.2-4 — Tube bending

9.2.5 Forming of Segments

The Equation (9.2-5) shall be used for the calculation of deformation F of segments e.g. of multi-sectional torispherical heads or spheres (see also Figure 9.2-5):

$$F = \frac{100e}{R} [\%] \quad (9.2-5)$$

where

- e is the thickness of the initial product;
- R is the smallest mean radius of the segment (mean radius of spherical segment, mean knuckle radius of knuckle segment of a torispherical head).

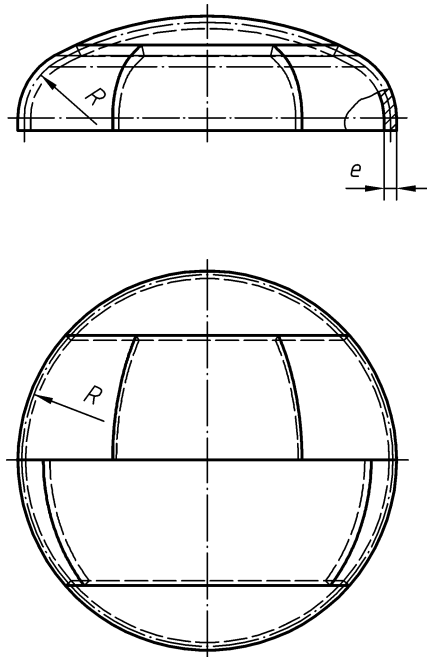


Figure 9.2-5 — Forming of Segments

9.3 Forming procedures

9.3.1 Cold forming

Cold forming of material group 1.1, 1.2, 1.3, 2.1, 3.1, 4, 5, 6 and 9 shall be carried out at temperatures at least 30 °C below the maximum permissible temperature for stress relieving, see Table 10.1-1.

In the case of TMCP steels, the maximum permissible temperature shall be 580 °C.

NOTE Ductile problems may however be encountered at intermediate temperatures in the range 200 °C to 350 °C due to dynamic strain ageing in this temperature range.

Cold forming of material group 8.1, 8.2 and 10 shall be carried out at temperatures below 300 °C.

For other types of materials the cold forming temperatures shall be taken from appropriate European Standards, data sheets or other specifications.

9.3.2 Hot forming

9.3.2.1 General

Hot forming of material group 1.1, 1.2, 1.3, 3.1, 4, 5, 6 and 9 shall be carried out at temperatures above the maximum permissible temperature for stress relieving, usually in the temperature range of normalising, in accordance with the material specifications.

Hot forming of thermo-mechanically treated steel grades is not permitted.

Hot forming of material group 8.1, 8.2 and 10 shall be carried out at a temperature of 300 °C or above usually in the temperature range according to Table 9.3-1.

For other types of materials the hot forming temperatures shall be in accordance with appropriate European Standards, data sheets or other specifications.

The forming procedure shall define the rate of heating, the holding temperature and the holding time given to the formed part.

NOTE 1 Hot forming is a process which is performed at temperatures above the stress relief temperature and will usually be carried out in the austenite region.

In view of danger of excessive grain growth, the product shall be austenitised above Ac3, but not higher than 1 050 °C.

NOTE 2 After reaching the temperature in the product it should be kept at temperature not longer than 10 min. For the same reason, the heating rate should be defined.

After the hot forming the product shall be cooled in still air, unless otherwise specified in Table 9.3-1.

As every heat treatment above the normalising temperature leads to a grain growth which adversely affects the impact values, the hot forming for normalised steels shall be divided into two groups as per 9.3.2.2 and 9.3.2.3.

9.3.2.2 Normalised steels with specified impact values at temperatures above and including –20 °C

For normalised steels which are hot formed only in a single operation the maximum temperature of the product shall not be above 980 °C.

For hot forming operations in more than a single operation the maximum temperature of the product shall not be above 1 050 °C. Before the last operation the product shall be cooled down below 500 °C. For the last operation the maximum temperature of the product shall be below 980 °C for steels with a minimum yield strength ≤ 360 MPa, or 940 °C for steels with a minimum yield strength > 360 MPa.

A subsequent heat treatment may be waived, if the forming process of the last operation has been completed at a temperature above 750 °C or above 700 °C where the degree of deformation does not exceed 5 %.

If the conditions of 9.3.2.2, especially regarding the maximum and minimum temperatures in the last operation can not be achieved, normalising as specified by the steel manufacturer shall be carried out after the forming process.

NOTE For steels which have to be tempered after normalising, the prescribed tempering treatment may be performed when the hot forming has been carried out according to 9.3.2.2.

9.3.2.3 Normalised steels with specified impact values at temperatures below – 20 °C

For normalised steels which are hot formed only in a single operation the maximum temperature of the product shall not be above 940 °C when the steels with minimum yield strength ≤ 360 MPa, or 925 °C for steels with a minimum yield strength > 360 MPa.

For hot forming operations in more than a single operation the maximum temperature of the product shall not be above 1 050 °C. Between the different operations the product shall be cooled down below 500 °C. For the last operation the maximum temperature of the product shall be below 940 °C for steels with a minimum yield strength ≤ 360 MPa, or 925 °C for steels with a minimum yield strength > 360 MPa.

A subsequent heat treatment may be waived, if the forming process of the last operation has been completed at a temperature above 750 °C, or above 700 °C if the degree of deformation does not exceed 2 %.

If the conditions of 9.3.2.3, especially regarding the maximum and minimum temperatures in the last operation can not be achieved, normalising as specified by the steel manufacturer shall be carried out after the hot forming process.

NOTE For steels which have to be tempered after the normalising, the prescribed tempering treatment may be performed when the hot forming has been carried out according to 9.3.2.3.

9.3.2.4 Quenched and tempered steels

For quenched and tempered steels, it is absolutely necessary to perform a total new quenching plus tempering operation after hot forming. For the hot forming process itself, the conditions specified in 9.3.2.1 and 9.3.2.2 shall apply.

9.3.2.5 Austenitic and austenitic-ferritic steels

Austenitic and austenitic-ferritic steels, material groups 8.1, 8.2 and 10, shall be hot formed in accordance with Table 9.3-1.

Table 9.3-1 — Forming conditions of material groups 8.1, 8.2 and 10

Product type	Maximum temperature	Minimum temperature	Cooling Conditions ^b
Low carbon ^a	1 150 °C	850 °C	still air for $e \leq 25$ mm
Stabilised			water for $e > 25$ mm
Not stabilised			still air for $e \leq 6$ mm
			water for $e > 6$ mm
^a Content of C ≤ 0,03 %.			
^b Cooling conditions defined in the material specifications shall be govern.			

9.3.2.6 Clad steels

The temperature and procedure for hot forming of clad steels shall be based on the material of the backing steel, however consideration shall be given on the effect of this treatment on the clad material, particularly its corrosion resistance. Where this treatment will adversely affect the properties of the clad material, consideration shall be given to either using a different material for cladding or adding the cladding after the forming and heat treatment (e.g. weld overlay) or the adequacy of an alternative heat treatment shall be demonstrated by tests to comply with the requirements of the material specification or the design.

9.4 Heat treatment after forming

9.4.1 General

Heat treatments after cold or hot forming, shall be carried out in accordance with the appropriate standards or data sheets or other specifications and shall include normalising, normalising plus tempering, quenching plus tempering, annealing, solution annealing.

NOTE 1 These treatments are recognised as removing the effects of the forming processes.

NOTE 2 The parameters given by the base materials manufacturer in the inspection documents should be taken as an indication or recommendation for heat treatments. Other parameters may be applied if the procedure is defined and the product or a formed test piece representing the product is tested after forming and heat treatment to comply with the requirements of the material specifications or the design.

NOTE 3 In the case of cold-formed TMCP steels, the parameters defined should be suitable for a post-forming heat treatment.

9.4.2 Heat treatment of flat products after cold forming

Postforming heat treatments of flat products after cold forming of flat products shall be carried out in accordance with 9.4.1 and Table 9.4-1.

Table 9.4-1 gives the rules for the necessary heat treatment as a function of the deformation under the assumption that the plates fulfil the requirements of EN 13445-2:2014, Annex B.

Table 9.4-1 — Heat treatment of flat product after cold forming

Material groups	Ratio of deformation F	Heat treatment
1.1 ^c , 1.2 ^a , 1.3 2.1 ^{a, b} 3.1 4	$F \leq 5\%$	no
5 6 9 10	$F > 5\%$	yes
8.1, 8.2	d	d

^a Thermo mechanically treated steel shall not be heat treated after forming, consequently the deformation (F) shall be limited to $\leq 5\%$.

^b For material group 2.1 tests shall be performed when the deformation is between 2% and 5% to verify the adequacy of the formed material with the design.

^c 1) Torispherical dished ends (flange radius $\geq 0,1 D_e$ and crown radius $\leq D_e$) do not require heat treatment if the following conditions are fulfilled:

- material group is 1.1;
- thickness $e \leq 8$ mm;
- $h_1 \leq 40$ mm (see Figure 5.4-2);
- the design temperature is between -10 °C and $+120$ °C.

2) Jackets on vessels used only for heating or cooling of pressure vessels, see EN 13445-3:2014, do not require heat treatment if the following conditions are fulfilled:

- material group is 1.1, and steel shall be fully killed;
- the material test certificate shows elongation after fracture $A_5 \geq 31\%$;
- thickness $e \leq 8$ mm;
- used for cylinders and cones when the maximum deformation F is such that mean radius $R_m \geq 3e$ nominal thickness;
- the design temperature is between -10 °C and $+150$ °C;
- fluid shall be water and/or steam.

^d Austenitic steel in a heat treatment condition solution annealed and quenched or stabilised do not require heat treatment after cold forming in any of the following cases 1), 2), 3), and 4), provided the risk for stress corrosion related is neglectable:

- 1) Austenitic steel with required minimum values for elongation after fracture $A_5 \geq 30\%$ or if the material test certificate shows an elongation after fracture $A_5 \geq 30\%$ the deformation shall be $F \leq 15\%$. Or if evidence is supplied that there is a minimum elongation after fracture $A_5 \geq 15\%$ after cold forming.
- 2) For deformation $F > 15\%$, proof can be furnished in individual cases that there is a minimum elongation after fracture $A_5 \geq 15\%$ after cold forming.
- 3) For dished ends, the material test certificate for the base material shows the following values for elongation at elongation after fracture A_5 :
 - $A_5 \geq 40\%$ in the case of wall thickness $e \leq 15$ mm at design temperatures down to -196 °C;
 - $A_5 \geq 45\%$ in the case of wall thickness $e > 15$ mm at design temperatures down to -196 °C;
 - $A_5 \geq 50\%$ if design temperature is below -196 °C.
- 4) Deformation does not exceed 10% in case of pressure vessel parts (excluding ends) if the design temperature is below -196 °C.

NOTE For material groups 1.3, 2 and 3 a drop of ductility/shift of transition temperature of 5 °C per % deformation may occur and should be considered.

9.4.3 Heat treatment of tubular products after cold forming

Postforming heat treatments of tubular products after cold forming of tubular products shall be carried out in accordance with 9.4.1 and Table 9.4-2.

The Table 9.4-2 gives the rules for heat treatment necessity as a function of the deformation under the assumption that the tubes fulfil the requirements of EN 13445-2:2014, Annex B.

Table 9.4-2 — Heat treatment of tubular products after cold forming

Material groups	Radius of curvature for the tube R	External diameter of the tube D_e	Heat treatment
1.1, 1.2, 1.3	$\leq 1,3 D_e$	all diameters	yes
3.1 4 5 6	$> 1,3 D_e$	≤ 142 mm	no
8.1, 8.2		> 142 mm	yes ^a
9 10	$\geq 2,5 D_e$	all diameters	no

^a For material groups 8.1 and 8.2 at design temperature above -196 °C heat treatment is not required.

9.4.4 Heat treatment of clad steels after cold forming

Postforming heat treatments of clad steels after cold forming shall be carried out in accordance with 9.4.1 and Table 9.4-1. For calculation of the ratio of deformation the total thickness of the clad material shall be considered. The influence of this heat treatment to the cladding shall be considered, particularly regarding the corrosion resistance.

9.4.5 Heat treatment after hot forming

Heat treatment after hot forming shall be carried out in accordance with 9.4.1 and Table 9.4-3.

Table 9.4-3 — Heat treatments after hot forming

Material groups	Hot forming conditions	Heat treatment
1.1, 1.2, 1.3, 9.1	see 9.3.2	no
3.1 4 5 6 7.1 9.2, 9.3	all	quenching and tempering or normalising and tempering or double normalising and tempering ^a
8.1, 8.2	according to Table 9.3-1	no
	other conditions than those stated in Table 9.3-1	solution annealing and quenching
10	all	solution annealing and quenching
^a Other heat treatments are available if their validity has been demonstrated by tests to comply with the requirements of the material specifications or the design.		

9.4.6 Heat treatment of clad steels after hot forming

The conditions for heat treatment of clad steels after hot forming shall be carried out in accordance with Table 9.4-3 based on the material backing steel. The influence of this heat treatment on the cladding shall be considered, particularly regarding the corrosion resistance.

9.5 Sampling of formed test coupons

9.5.1 Cold formed products without heat treatment

If heat treatment is not required by Tables 9.4-1 and 9.4-2 after cold forming of plates or tubes, then no mechanical tests are required in respect of forming.

9.5.2 Hot formed or cold formed products with heat treatment

Compliance with the material specifications shall be verified by means of test coupons taken from excess of length of the formed product. Where this is not possible separate test coupons shall be taken from the original material, formed and heat treated if appropriate in the same way as the formed product and tested.

Where the formed products consist of individual parts of different casts, one test coupon per cast and of the welded joint shall be taken.

Formed products shall be individually tested until the manufacturer has successfully passed 30 test coupons of formed products within the appropriate material group. Thereafter the tests are performed per batch. A batch is defined by products of the same cast and the same final heat treatment.

The batch testing shall be performed as follows:

a) Material groups 1.1, 1.2, 8.1.

Where delivered formed products are in same heat treatment condition as the original material then compliance with material specification shall be covered by the original material test certificate. Where this is not the case one test coupon from each batch shall either be taken from the material to be formed or from the heat treated formed product. It shall be subjected to heat treatment together with the formed products or subjected to a simulated heat treatment separately.

Material groups 1.1 and 1.2 subject to specific impact energy values at temperatures below $-20\text{ }^{\circ}\text{C}$ shall be sampled according to b) below, this shall be for impact test only.

b) Material groups 1.3, 3.1, 4, 5, 6, 8.2, 9 and 10.

Compliance with material specifications shall be verified by means of one of the following:

- test coupons taken from excess length of formed part;
- alternatively separately formed test coupons heat treated together with the formed parts;
- if this is not possible separately formed test coupons simulated heat treated.

The following number of test coupons shall be taken:

- one test coupon from a batch of up to 10 parts;
- two test coupons from a batch of up to 25 parts;
- three test coupons from a batch up to 100 parts;
- one test coupon for every further 100 parts.

9.6 Tests

9.6.1 Base material

One tensile test and three impact test specimens shall be taken from each test coupon required in 9.5.2. The test specimens shall be taken transverse to the rolling direction with a deviation not greater than 20° .

NOTE For steels of material group 1.1 and 1.2 the impact test specimens may be taken longitudinal to the rolling direction.

In the case of pressure parts made of quenched and tempered steels with batch testing, 10 % of the formed parts, but not less than 3 formed parts, in addition shall be subjected to hardness testing by the manufacturer.

9.6.2 Butt welds

Where formed products are welded together from several individual parts before forming, the production test shall be performed in accordance with the frequency described in Clause 8.

9.6.3 Acceptance criteria for formed test coupons

For base material the test specimens required in 9.6.1 shall meet the requirements of base materials.

For butt welds the test specimens required in 9.6.2 shall meet the requirements of 8.4.

The hardness values shall have a variation of not more than 50 HV 10 within one formed part.

9.6.4 Retests of formed coupons

9.6.4.1 If the test results fail to comply with the requirements, the following shall apply:

- a) where the unsatisfactory test result is due to poor testing technique or to a locally limited defect of a single specimen, the test result may be neglected and the individual test shall be repeated;
- b) where the unsatisfactory test result is due to inadequate heat treatment, all parts of the batch and relevant test coupons shall be heat treated again and the full extent of testing shall be repeated.

9.6.4.2 Where the results obtained from test specimens which were correctly taken and tested do not comply with the requirements, the following retests shall be made:

- a) tensile test: the test shall be repeated on two tensile test specimens taken from the same test plate; both results shall meet the requirements;
- b) bend test: the test shall be repeated on two bend test specimens taken from the same test plate; both results shall meet the requirements;
- c) impact test: the test shall be repeated on three Charpy-V-notch specimens taken from the same test plate;
 - 1) the mean value obtained from all six individual specimens shall be equal to or greater than the specified minimum value;
 - 2) not more than two of the six individual values shall be less than the specified minimum value;
 - 3) not more than one of the six individual values shall be less than 70 % of the specified minimum value.

In case of batch testing where the test results failed to comply with the specification. The testing shall be repeated on two other formed parts of the same batch where the test results shall comply with the specification.

Should any of the retests fail to comply with the requirements then the joints/parts represented by the test plate shall be deemed not in compliance with this Part of this standard.

9.7 Visual inspection and control of dimension

Formed pressure parts shall be subject to visual examination and dimensional check in the delivery condition by the producer of the formed product. The results of the visual inspection and the dimensional check shall be documented.

9.8 Marking

Formed products which form part of a pressure vessel shall be marked according to the relevant material specification. In this case the mark of the base material manufacturer may be waived. Traceability to the base material shall be ensured. In addition, the mark of the producer of the formed product shall be added. In the case of batch testing the relationship to the batch shall be evident. Identification shall be maintained between the test coupon and the formed product from which they were taken.

For small formed products (less than 220 mm nominal size) marking according to 4.2.2.2 b) is permissible.

9.9 Documentation

Formed products which form part of a pressure vessel require the following documentation:

- a) a sub-contractor form (when forming is not carried out by pressure vessel manufacturer);
- b) the original material certification;
- c) type and record of heat treatment, if applicable;
- d) formed product test coupon results, if applicable;
- e) description of the formed part with main nominal dimensions and extent of deformation in the case of cold forming without heat treatment;
- f) markings.

10 Post weld heat treatment (PWHT)

10.1 General

PWHT shall be performed in accordance with a written procedure which describe the parameters critical for the heat treatment process.

Equipment used for the heat treatment shall be suitable for the heat treatment in question. It shall permit the temperature control in the pressure part with adequate accuracy and uniformity especially for materials having a small permissible temperature range for that heat treatment.

The heat treatment of pressure vessels or pressure parts shall be recorded and certified by the manufacturer indicating the holding temperature, the heating- and cooling-rate and the holding time.

NOTE 1 CR ISO 17663 [7] gives useful information concerning quality control of post weld heat treatment.

NOTE 2 Heat treatment as per Table 10.1-1 particularity in the upper range of holding temperature and/or holding time may unduly impair the physical properties (e.g. yield, tensile strength and toughness of the material) the additional effect of multiple heating cycles should be considered. This effect is explained and published as Hollomon-Jaffe Parameter P as given in Equation (10.1-1):

$$P = T_s (20 + \lg t) 10^{-3} \quad (10.1-1)$$

where

T_s is the holding temperature, in Kelvin;

t is the holding time, in hours.

$\lg = \log_{10}$

Without prior agreement between the manufacturer of the pressure vessel/part and the material manufacturer the actual tempering temperature of NT or QT material shall not be lower than the admissible temperature as per Table 10.1-1. A higher PWHT temperature than tempering temperature would impair the mechanical properties of the material. In Table 10.1-1 a P_{crit} -value is introduced. This parameter, a critical Hollomon-Jaffe value, shall not be exceeded without proving the mechanical properties according to the procedures described in 10.5.

10.2 Heat treatment conditions

10.2.1 Post weld heat treatment, with the exception of those materials covered in 10.6 and 10.7, shall be applied to steels in accordance with Table 10.1-1 on completion of welding.

NOTE PWHT may be carried out on steels of thickness lower than specified by Table 10.1-1. Such instances will include vessels intended for service with media liable to cause stress corrosion cracking or prevention of brittle fracture in accordance with EN 13445-2:2014, Annex B.

Where the cladding of the clad plate is decisive for the type and procedure of the PWHT then such data shall be documented and taken into consideration when assessing the base material properties.

10.2.2 Where the vessel contains welded joints connecting parts which differ in thickness, the thickness to be used in applying the requirements for post weld heat treatment shall be:

- a) the thinner of the two parts butt welded together;
- b) the thickness of the shell in connection to flanges, tube plates or similar connections;
- c) the weld throat thickness of the shell or end plate to nozzle weld in nozzle attachment welds;
- d) the base material thickness in material integrally clad with an austenitic or nickel base corrosion resistant material (clad plate);
- e) the base material thickness divided by 4 in material weld overlay clad with an austenitic or nickel based corrosion resistant material.

10.2.3 When additional welds or welds repairs have been made to a vessel after post weld heat treatment, a further heat treatment shall be carried out in accordance with 10.3. The thickness to be used in defining the time required at temperature shall be the thickness of the weld applied after the PWHT.

Table 10.1-1 — Post weld heat treatment

Material Group	Material ¹⁾	Temperature (°C)	Nominal thickness (mm) ²⁾	Holding time (min)	P _{crit} (see Clause 10.1)
1.1	Unalloyed steel with R _{eH} ≤ 275 MPa	550-600	≤ 35 ³⁾ > 35 ≤ 90 > 90	30 e _n - 5 40+0,5*e _n	17,5
1.2	Unalloyed steel with R _{eH} > 275 ≤ 360 MPa				
	• delivery condition M	530-580			17,3
	• delivery condition QT	550-600 ⁴⁾			17,5
	• delivery condition N (except 16Mo3)	550-600	≤ 35 ³⁾ > 35 ≤ 90 > 90	30 e _n - 5 40 + 0,5 * e _n	17,5
	• 16Mo3, 18MnMo4-5, 18Mo5	550-620			17,5
1.3	Normalized fine grain steels with R _{eH} > 360 MPa	550-600			17,3
2.1	Thermo-mechanically treated fine grain steels with 360 MPa < R _{eH} ≤ 460 MPa	530-580			17,3
3.1	Quenched and tempered steels with R _{eH} > 360 ≤ 690 MPa				
	• 15NiCuMoNb5-6-4 NT and QT	580-620 ⁴⁾	≤ 15 > 15 ≤ 60 > 60	30 2 * e _n 120	17,5 17,5 -
	• 20MnMoNi4-5 ⁵⁾	550-620 ⁴⁾			
	• R _{eH} > 360 ≤ 500 MPa ³⁾	530-580 ⁴⁾			
	• R _{eH} > 500 ≤ 690 MPa				
4.1	Low vanadium alloyed Cr-Mo-(Ni) steels with Mo ≤ 0,7 % , V ≤ 0,1 % , Cr ≤ 0,3% and Ni ≤ 0,7 %				
	• 18MnMoNi5-5	580-640 ⁴⁾	≤ 15 ⁵⁾ > 15 ≤ 60 > 60	30 2 * e _n 120	-
	• 15MnCrMoNiV5-3				
5.1	Cr-Mo-steels with 0,75 % < Cr ≤ 1,5 % and Mo ≤ 0,7 % and free of V				
	• 25CrMo4, 26CrMo4-2				
	• 13CrMoSi5-5	620-680 ⁴⁾ ⁸⁾	≤ 15 > 15 ≤ 60 > 60	30 2 * e _n 60 + e _n	18,7 18,5
	• All others				
5.2	Cr-Mo-steels with 1,5 % < Cr ≤ 3,5 % and 0,7% < Mo ≤ 1,2 % and free of V				
	• 10CrMo9-10, 11CrMo9-10 ⁹⁾	660-720 ⁴⁾	≤ 15 > 15 ≤ 60 > 60	30 2 * e _n 60 + e _n	19,2
	• 12CrMo9-10	660-720 ⁴⁾ ¹⁰⁾	≤ 125 > 125	2,4 * e _n 225+0,6*e _n	19,3
5.3	Cr-Mo-steels with 3,5 % < Cr ≤ 7 % and 0,4 % < Mo ≤ 0,7 % and free of V				
	• X11CrMo5, X12CrMo5	680-750	≤ 15 > 15 ≤ 60 > 60	30 2 * e _n 60 + e _n	19,5 -
	• X16CrMo5-1	700-750			
5.4	Cr-Mo-steels with 7 % ≤ Cr ≤ 10 % and 0,7 % < Mo ≤ 1,2 % and free of V	740-780	≤ 12 > 12 ≤ 60 > 60	30 2,5 * e _n 90 + e _n	-

Table 10.1-1 (continued)

Material Group	Material ¹⁾	Temperature (°C)	Nominal thickness (mm) ²⁾	Holding time (min)	P _{crit} (see Clause 10.1)
6.1	High vanadium Cr-Mo-(Ni) with 0,3 % < Cr ≤ 0,75 % and Mo ≤ 0,7 % and V ≤ 0,35 %	680-730	all	90 + e _n (180 minimum)	-
6.2	High vanadium Cr-Mo-(Ni) with 0,75 % < Cr ≤ 3,5 % and 0,7 % < Mo ≤ 1,2 % and V ≤ 0,35 %	690-710 ⁴⁾	≤ 125	2,4 * e _n	19,4
	> 125		225 + 0,6 * e _n		
6.3	High vanadium Cr-Mo-(Ni) with 3,5 % < Cr ≤ 7,0 % and Mo ≤ 0,7 % and 0,45 % < V ≤ 0,55 %	⁶⁾			
6.4	High vanadium Cr-Mo-(Ni) with 7,0% < Cr ≤ 10 % and 0,7 % < Mo ≤ 1,2 %	730-780 ¹¹⁾	≤ 30	60	20,5
	<ul style="list-style-type: none"> • X10CrMoVNb9-1 		> 30 ≤ 60	120	
> 60			2 * e _n		
6.4	<ul style="list-style-type: none"> • X20CrMoV11-1 	730-770 ¹¹⁾	≤ 12	30	-
			> 12 ≤ 60	2,5 * e _n	
			> 60	90 + e _n	
8.1	Austenitic stainless steels with Cr ≤ 19 %	Generally not applicable ⁶⁾			
8.2	Austenitic stainless steels with Cr > 19 %				
9.1	Ni alloyed steels with Ni ≤ 3,0 %	530-580	≤ 35 ³⁾	30	-
9.2	Ni alloyed steels with 3,0 % < Ni ≤ 8,0 % ^{4) 12)}		> 35 ≤ 90	e _n - 5	
			> 90	40 + 0,5 * e _n	
9.3	Ni alloyed steels with 8,0 % < Ni ≤ 10 %	⁷⁾			
10.1	Austenitic ferritic stainless steels with Cr ≤ 24 %	Generally not applicable ⁶⁾			
10.2	Austenitic ferritic stainless steels with Cr > 24 %				

Table 10.1-1 (continued)

1)	Heat treatment conditions of base material: M = thermomechanically rolled; N = normalised; NT = normalised and tempered; QT = quenched and tempered
2)	Nominal thickness e_n is that required by 10.2.2.
3)	For thickness ≤ 35 mm post weld heat treatment is optional and normally only necessary in special cases (e.g. to reduce the danger of stress corrosion cracking or hydrogen-induced cracking (sour gas)).
4)	If higher temperatures are used, conditions given in clause 10.5.3 apply.
5)	For thickness ≤ 15 mm PWHT is optional.
6)	If PWHT is considered necessary, the PWHT time and temperature shall take into account recommendations from the material manufacturer as well as the welding consumable manufacturer to achieve the required material properties.
7)	Normally welded with austenitic filler metal; in view of possible carbon diffusion PWHT should be avoided.
8)	No post weld heat treatment is required if all the following conditions are fulfilled: – tubes with nominal diameter < 120 mm; – nominal wall thickness < 13 mm
9)	No post weld heat treatment required if all the following conditions are fulfilled: – tubes with nominal diameter < 120 mm – nominal wall thickness < 13 mm – design temperature > 480 °C
10)	In case of intermediate stress relieving (ISR): 630 °C – 650 °C
11)	Intermediate cooling of the weld below the M_f temperature (typically 90 °C – 100 °C) should take place before PWHT to ensure full transformation into martensite.
12)	After the welding of the 3,5 % Ni steels with a thickness over 35 mm, it is permitted to weld, without new heat treatment, components that are not subject to pressure provided the following conditions are met: – the weld dimensions (weld thickness or corner joint throat) are less or equal to 12 mm; – a preheat temperature of minimum 100 °C is applied during the welding operation.

10.3 Method of PWHT

10.3.1 Wherever possible, the vessel shall be heat treated by heating in a single operation in an enclosed furnace.

NOTE Where it is impracticable to heat treat the whole vessel in a furnace it is permissible to adopt the methods described in 10.3.2 to 10.3.6, but it should be noted that they may not ensure the same degree of immunity from susceptibility to stress corrosion cracking.

10.3.2 It is permissible to heat treat the completed vessel in sections in an enclosed furnace, in which case the overlap of the vessel being heated shall be at least 1 500 mm or $5\sqrt{Re_n}$, whichever is the greater. The additional temperature cycle in the overlapping area shall thereby be taken into account for determination of the mechanical properties.

NOTE R = internal radius, e_n = nominal thickness required by 10.2.2.

Where this method is used the portion outside the furnace shall be shielded by thermal insulation so that the longitudinal temperature gradient of the part to be heated is such that between a measuring point "0" on the component directly outside the furnace with temperature T_0 and a measuring point at a distance of $2,5\sqrt{Re_n}$ outside the furnace there is a temperature difference of $\Delta T \leq 0,5 T_0$.

The influence of attachments e.g. nozzles, partition walls etc. on the temperature gradient and temperature balance shall be considered.

10.3.3 It is permissible to heat treat circumferential welds in shells locally by heating a shielded band around the entire circumference, in which case the width of the heated band shall be not less than $5\sqrt{Re_n}$ with the weld in the centre.

Where the circumferential welds to be post weld heat treated is between a shell course and a dished or hemispherical head, the whole dished end shall be included in the heated band. The width of the heated band on the shell course side shall be $2,5\sqrt{Re_n}$.

Sufficient thermal insulation shall be fitted to ensure that the temperature of the weld and its heat affected zone is not less than that specified and that the temperature at the edge of the heated band is not less than half the peak temperature. In addition, the adjacent portion of the vessel outside the heated zone shall be thermally insulated such that the temperature gradient is not harmful. The influence of attachments e.g. nozzles, partition walls etc. on the temperature gradient and temperature balance shall be considered.

NOTE For thermal insulation a minimum insulated band width of $10\sqrt{Re_n}$ with the weld in the centre is recommended.

10.3.4 It is permissible to heat treat branches nozzles or other welded attachments or local repairs in shells locally by heating a shielded band in accordance with 10.3.3, the width of the heated band shall cover a minimum distance of $2,5\sqrt{Re_n}$ in each direction from the edge of the welds to be heat treated.

10.3.5 It is permissible to heat treat the vessel internally, for which purpose it shall be fully encased with thermal insulating material. During heat treatment care shall be taken that no internal pressure is building up which can impair the stress reduction.

10.3.6 Vessels of different thickness, which are subject to post weld heat treatment in the same furnace, shall be treated in accordance with the heat treatment requirements of the greater thickness of the vessels in the furnace.

When this results in a time at temperature greater than 3 h the requirements of 10.5 shall be satisfied for all the vessels in the furnace.

10.4 PWHT procedure

10.4.1 The PWHT temperatures and times shall be in accordance with Table 10.1-1.

Materials other than those listed in Table 10.1-1 shall be heat treated according to the specification of the material manufacturer.

10.4.2 During the heating and cooling periods, for temperatures up to 500 °C variation in temperature throughout the vessel or component shall not exceed 150 °C within 4 500 mm and the temperature gradient shall be gradual. Above 500 °C, this variation shall not exceed 100 °C.

During the heating and holding periods, the furnace atmosphere shall be controlled so as to avoid excessive oxidation of the surface of the vessel or component. There shall be no direct impingement of flame on the vessel or component.

When the vessel or component has attained a uniform holding temperature (see Table 10.1-1) this temperature shall be held for the period specified in Table 10.1-1.

10.4.3 In the case of furnace PWHT, the temperature of the furnace at the time when the vessel or component is placed in or taken out of the furnace shall not exceed:

- 400 °C for vessels or components of not complicated shape or $e_n < 60$ mm thickness;
- 300 °C for vessels or components of complicated shape or $e_n \geq 60$ mm thickness.

The rate for heating or cooling of the vessel or component shall not exceed the following:

- for thickness $e_n \leq 25$ mm: 220 °C/h;
- for thickness $e_n > 25$ mm and ≤ 100 mm: $(5\ 500/e_n)$ °C/h;
- for thickness $e_n > 100$: 55 °C/h;

where: e_n is the nominal thickness in mm, required by 10.2.2.

10.4.4 The temperature specified shall be the actual temperature of any part of the vessel or zone being heat treated and shall be determined by thermocouples in effective contact with the vessel.

10.4.5 A sufficient number of temperatures shall be recorded continuously and automatically. Several thermocouples shall be applied to ensure that the whole vessel or zone being heat treated is within the range specified and that undesirable thermal gradients do not occur.

The number and location of thermocouples shall be sufficient to demonstrate that the requirements of 10.3 and 10.4 have been satisfied.

10.5 Mechanical properties after heat treatment

10.5.1 The PWHT shall be considered with respect to its effect on the mechanical properties of the base material, plate, forgings, pipe etc. and any welds, including heat affected zones.

For materials in groups 1.1 and 1.2 (except for steels in delivery condition M) the beneficial effect of the PWHT is such that its negative effect on strength and fracture toughness of the base material shall be ignored when the Hollomon-Jaffe parameter P for the actual heat treatment applied is less than or equal to 17.5.

NOTE For many 1.1- and 1.2-materials the P_{crit} -value in Table 10.1-1 is different from the one given in EN 10028-2:2009.

10.5.2 Where the P value exceeds 17.5, but is ≤ 18.5 for material in groups 1.1 and 1.2, the effect of the PWHT on the mechanical properties shall be allowed for by either:

- a) verifying that the properties shown in the material certificate for that material are
 - i) at least 5 % above the specified minimum tensile strength value R_m and at least 8 % above the specified minimum 0.2 proof strength value $R_{p0.2}$, and the average Charpy impact value (where specified) is at least 23 Joules above the specified minimum value for P -values > 17.5 , but ≤ 18.0 ;
 - ii) at least 10 % above the specified minimum tensile strength value R_m and at least 12 % above the specified minimum 0.2 proof strength value $R_{p0.2}$, and the average Charpy impact value (where specified) is at least 30 Joules above the specified minimum value for P -values > 18.0 , but ≤ 18.5 .

or

- b) demonstrating that the material properties after welding and heat treatment verified as described below meet the minimum specification requirements. This can be done either:
 - on test materials heat treated with the vessels; or
 - on test coupons subjected to a simulated PWHT by the material supplier; or
 - on test coupons subjected to a simulated PWHT by the vessel manufacturer.

10.5.3 For all other materials except those covered in 10.5.2 generally the maximum actual PWHT temperature shall be at least 30 °C below the minimum actual tempering temperature, and the critical P -value (P_{crit}) given in Table 10.1-1 shall not be exceeded.

However, when the maximum actual PWHT temperature is not at least 30 °C below the minimum actual tempering temperature or if the P -value for the actual heat treatment exceeds P_{crit} , then the specified mechanical properties of the material shall be verified by one of the following ways:

- on test materials heat treated with the vessel(s) or
- on test coupons subjected to a simulated PWHT by the material supplier or
- on test coupons subjected to a simulated PWHT by the vessel manufacturer.

When simulating the effect of longer times at temperature, it is permissible to cover multiple heat treatment of the agreed time. Alternatively, slightly different temperature (± 40 °C) and times by reference to the Hollomon-Jaffe time/temperature parameter may be used.

10.6 Dissimilar ferritic joints

10.6.1 Where a vessel is manufactured from dissimilar ferritic steels special consideration with respect to the influence on the mechanical properties shall be given to the post weld heat treatment.

10.6.2 If the maximum temperature in Table 10.1-1 required of one material in the dissimilar combination is equal to or greater than the minimum of the second, e.g. 16Mo3 to 13CrMo4-5, then PWHT for the material with the highest temperature in Table 10.1-1 shall be carried out, but as close to the minimum temperature as practical. In this respect the time shall be measured when the lowest reading thermocouple reaches a temperature 10 °C below the minimum specified in Table 10.1-1 (without the need for requalification of the welding procedure). Consideration shall be given to the effect of this higher temperature and possibly longer time on the mechanical properties of the second material in accordance with the requirements of 10.5.2 and 10.5.3.

10.6.3 When the maximum temperature allowed in Table 10.1-1 of one material in the dissimilar combination is lower than the minimum temperature allowed for the second, e.g. 13CrMo4-5 to X11CrMo9-1 then one of the following routes shall be followed:

- a) PWHT the combination in accordance with the requirements for the material requiring the highest temperature according to Table 10.1-1 and carry out a simulated treatment on the other material to determine suitable mechanical properties for design. This shall include the effect of PWHT on impact values and microstructure in addition to strength;
- b) redesign the combination to include a transition material that overlaps the temperature range.

EXAMPLE First weld X11CrMo9-1 to 10CrMo9-10 and PWHT at (730 to 750) °C, then later weld 10CrMo9-10 to 13CrMo4-5 and PWHT at (670 to 690) °C.

- c) Weld overlay the joint preparations with stainless steel or high nickel weld metal;

PWHT each component separately after welding at the appropriate time and temperature for each material in the combination.

Weld the component/material combination of the weld overlaid joints using stainless/high nickel weld and do not carry out further PWHT.

10.6.4 Where a weld is between a structural part and a pressure part the PWHT should be as for the pressure part.

10.7 Special materials

For PWHT of vessels fabricated from metals in the material groups 5.1, 5.2, 5.3, 5.4, 6 and 9.3 using matching filler metal, but when the grade of material is not specifically listed in Table 10.1-1 then any temperature above 600 °C may be selected as long as it is fully documented and the mechanical properties after heat treatment shall be demonstrated by one of the alternatives in 10.5.3.

When a material has special properties that have been used in the design of the vessel and these properties can only be developed by a specific heat treatment, this shall be documented and applied to the vessel. The mechanical properties after heat treatment shall be demonstrated by one of the alternatives specified in 10.5.3.

10.8 Heat Treatment for reasons other than welding

When Table 10.1-1 does not mandate that Post Weld Heat Treatment to be carried out, it is permissible to carry out a heat treatment at a lower temperature than the temperatures listed in Table 10.1-1. This may for example be required by the vessel manufacturer in order to stabilise the structure for machining or to reduce the risk of environmentally-assisted inter-granular stress corrosion cracking.

When a treatment temperature and/or time are lower than that required by Table 10.1-1, the joint or vessel shall not be considered as been subject to PWHT. Thus, for example, when considering the low temperature suitability and the impact energy requirements such a vessel shall be treated as "As Welded (AW)" in terms of EN 13445-2:2014, Annex B.

11 Repairs

This clause covers the requirements in respect of surface and weld repairs.

11.1 Repairs of surface defects in the parent metal

If surface defects which are not very deep are involved, such as accidental arc strikes, tool marks, or oxyacetylene cutting marks, the defects shall be removed by grinding, and the ground area shall have a smooth transition with the adjoining surfaces. The grinding shall be followed by visual inspection for surface defects. Ground accidental arc strikes on parental materials other than from material groups 1.1 and 8.1 shall be tested by MT or PT as per EN 13445-5:2014.

The depth of the repair shall be checked to ensure that tolerance limits of the remaining material are fulfilled.

In case of build-up welds or if grinding reduces the thickness of the wall below the permissible value and repair by welding is necessary, the manufacturer shall carry out this repair in accordance with a qualified procedure and by qualified welders and operators. The affected area shall be inspected as per EN 13445-5:2014, Table 6.6.2-1 (line 24).

NOTE General cosmetic grinding or dressing (i.e. removal of excess weld metal) are not considered to be repairs.

11.2 Repair of weld defects

All unacceptable imperfections shall be removed, either by mechanical means (such as grinding or machining) or by thermal means (such as arc air gouging or thermal gouging) or by a combination of thermal and mechanical means. It is the responsibility of the manufacturer to decide how unacceptable imperfections shall be removed. This may be by local means or by removal of the weld from the joint followed by rewelding.

When thermal gouging/arc air gouging is used on austenitic steels, care shall be taken to remove any contamination of the remaining weld or material. Similarly when gouging with carbon electrodes is used on ferritic steels, the affected surface shall be removed by mechanical means to a minimum depth of 0,3 mm.

When unacceptable imperfections are removed and are not followed by welding, all the remaining thickness shall be greater than the minimum thickness necessary to satisfy the design unless the local area satisfies the conditions of 5.4.5. The area shall have a taper with the adjoining surfaces, and blend smoothly.

Repairs by welding shall be carried out in accordance with a WPS which has been qualified in accordance with 7.3.

NOTE This may be the same WPS as the one used for making the joint originally or a specific qualified repair procedure.

Repairs shall be carried out by qualified welders or operators in accordance with 7.4. Weld repaired areas shall be non destructively examined in accordance with EN 13445-5:2014.

When repair welding is carried out after post weld heat treatment or hydraulic test these operations shall be repeated. Any further post weld heat treatment carried out in accordance with 10.2.2, shall be considered in terms of its effect on material and weld properties.

12 Finishing operations

Finishing operations shall be carried out after the vessel has been pressure tested and before shipment/transport.

NOTE 1 Their aim is to protect the vessel from impacts and pollution during transportation, installation and its connection to its equipment.

If any thermal or mechanical operations are strictly necessary following the pressure and leak tests, then the treatment, the pressure and leak tests and the surface treatment shall be carried out again.

NOTE 2 However, this provision does not apply to components which do not contribute to the mechanical strength of the vessel.

The following finishing operations shall be carried out:

- a) complete examination of inner and outer surface;
- b) cleaning of inner surfaces and complete drying of the vessel;
- c) protection of all flanges and nozzles against impacts and oxidation;
- d) protection of inner surface against corrosion from the atmosphere and against any introduction of foreign matters.

NOTE 3 Further finishing operations (e.g. sand blasting, painting, picking, passivating) are generally agreed by the contracting parties.

Annex A (informative)

Structural tolerances

Structural tolerances others than specified in 5.4 and 5.5 should not exceed the values in Tables A.1 to A.4. These values are considered as reasonable values that the manufacturer may apply to his manufactured items.

Table A.1 — Tolerances on nozzles

Item no	Type of deviations and elements considered	Limit deviations						
1.1	Levelness of flat joint span expressed as a function of joint thickness	$0,2 e$						
1.2	Deviation between the surface of a flange and the tangential line (LT) of an end or the reference line (LR)	± 5 mm						
1.3	Deviation between axis of a nozzle and the reference line (LR)	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">Connection nozzle ≤ 100 mm</td> <td style="text-align: center;">± 5 mm</td> </tr> <tr> <td style="width: 50%;">Other nozzles and manholes</td> <td style="text-align: center;">± 10 mm</td> </tr> </table>	Connection nozzle ≤ 100 mm	± 5 mm	Other nozzles and manholes	± 10 mm		
Connection nozzle ≤ 100 mm	± 5 mm							
Other nozzles and manholes	± 10 mm							
1.4	Deviation between the axis of a nozzle with an axis parallel to that of the vessel	± 5 mm						
1.5	Deviation in relation to the theoretical orientation measured by the circumferential deviation between the reference generating lines and the nozzle	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">Connection nozzle</td> <td style="text-align: center;">± 5 mm</td> </tr> <tr> <td style="width: 50%;">Manhole</td> <td style="text-align: center;">± 10 mm</td> </tr> </table>	Connection nozzle	± 5 mm	Manhole	± 10 mm		
Connection nozzle	± 5 mm							
Manhole	± 10 mm							
1.6	Deviation between flange facing and vessel wall	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">Connection nozzle</td> <td style="text-align: center;">± 5 mm</td> </tr> <tr> <td style="width: 50%;">Manhole</td> <td style="text-align: center;">± 10 mm</td> </tr> </table>	Connection nozzle	± 5 mm	Manhole	± 10 mm		
Connection nozzle	± 5 mm							
Manhole	± 10 mm							
1.7	Slope of the flange facing in relation to theoretical plane	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 50%;">Connection nozzle</td> <td style="text-align: center;">$\pm 0,5^\circ$</td> </tr> <tr> <td style="width: 50%;">Manhole</td> <td style="text-align: center;">$\pm 1^\circ$</td> </tr> <tr> <td style="width: 50%;">For measurement apparatus</td> <td style="text-align: center;">$\pm 0,25^\circ$</td> </tr> </table>	Connection nozzle	$\pm 0,5^\circ$	Manhole	$\pm 1^\circ$	For measurement apparatus	$\pm 0,25^\circ$
Connection nozzle	$\pm 0,5^\circ$							
Manhole	$\pm 1^\circ$							
For measurement apparatus	$\pm 0,25^\circ$							
1.8	Deviation between nozzle axes for measurement apparatus	$\pm 1,5$ mm						
1.9	Difference in level between the two flange facing for measuring device	± 1 mm						

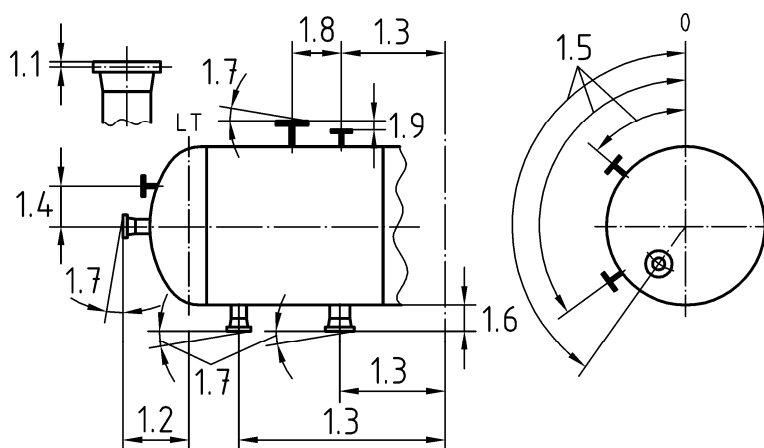
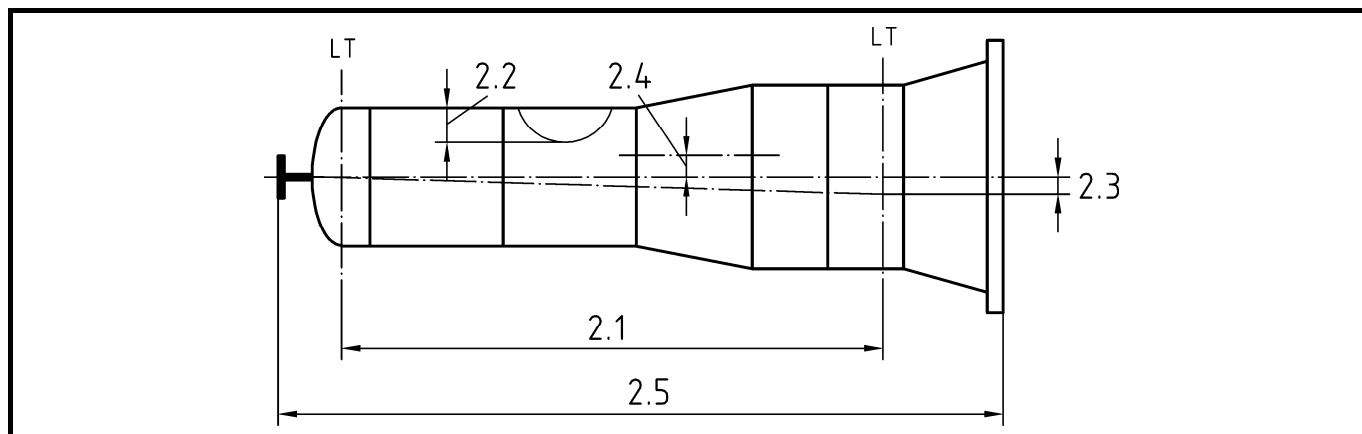
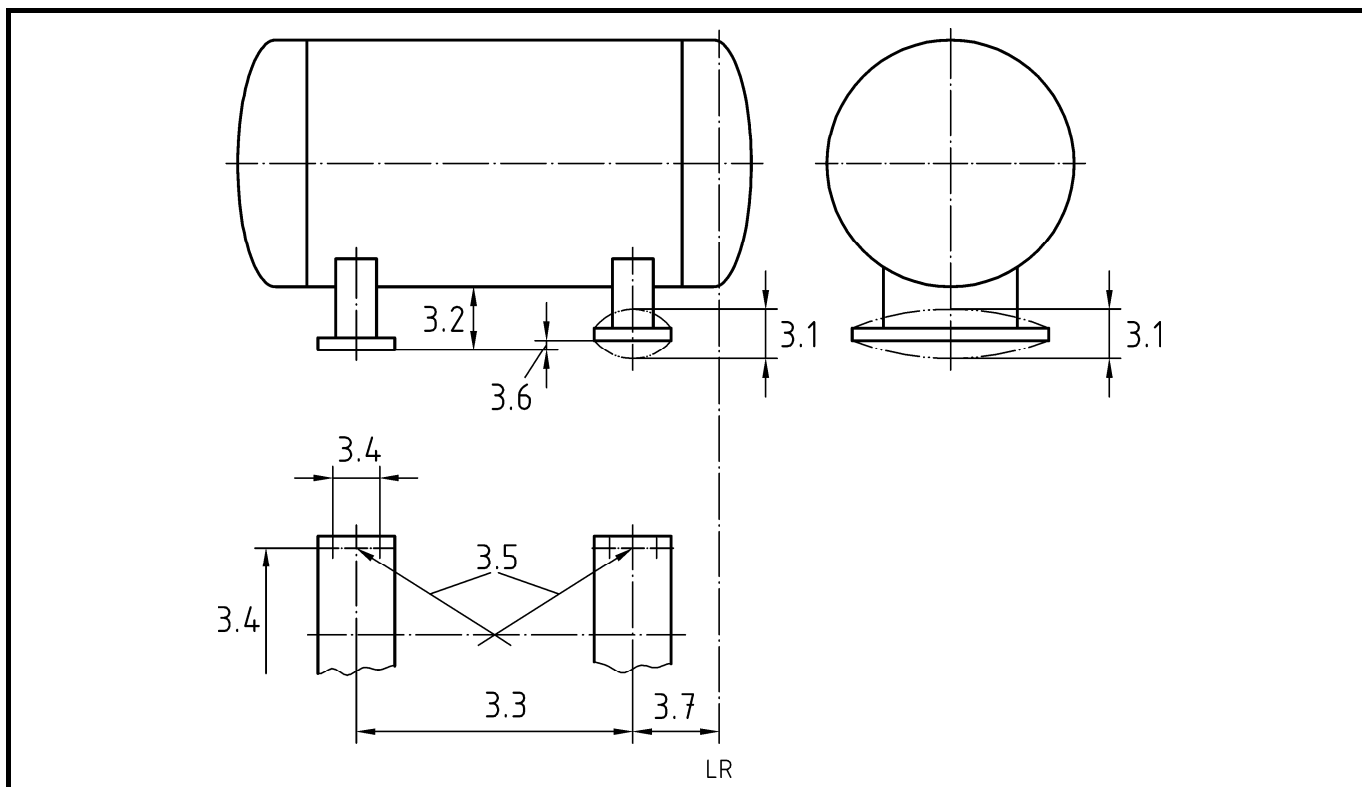


Table A.2 — Tolerances after erection of a vertical vessel



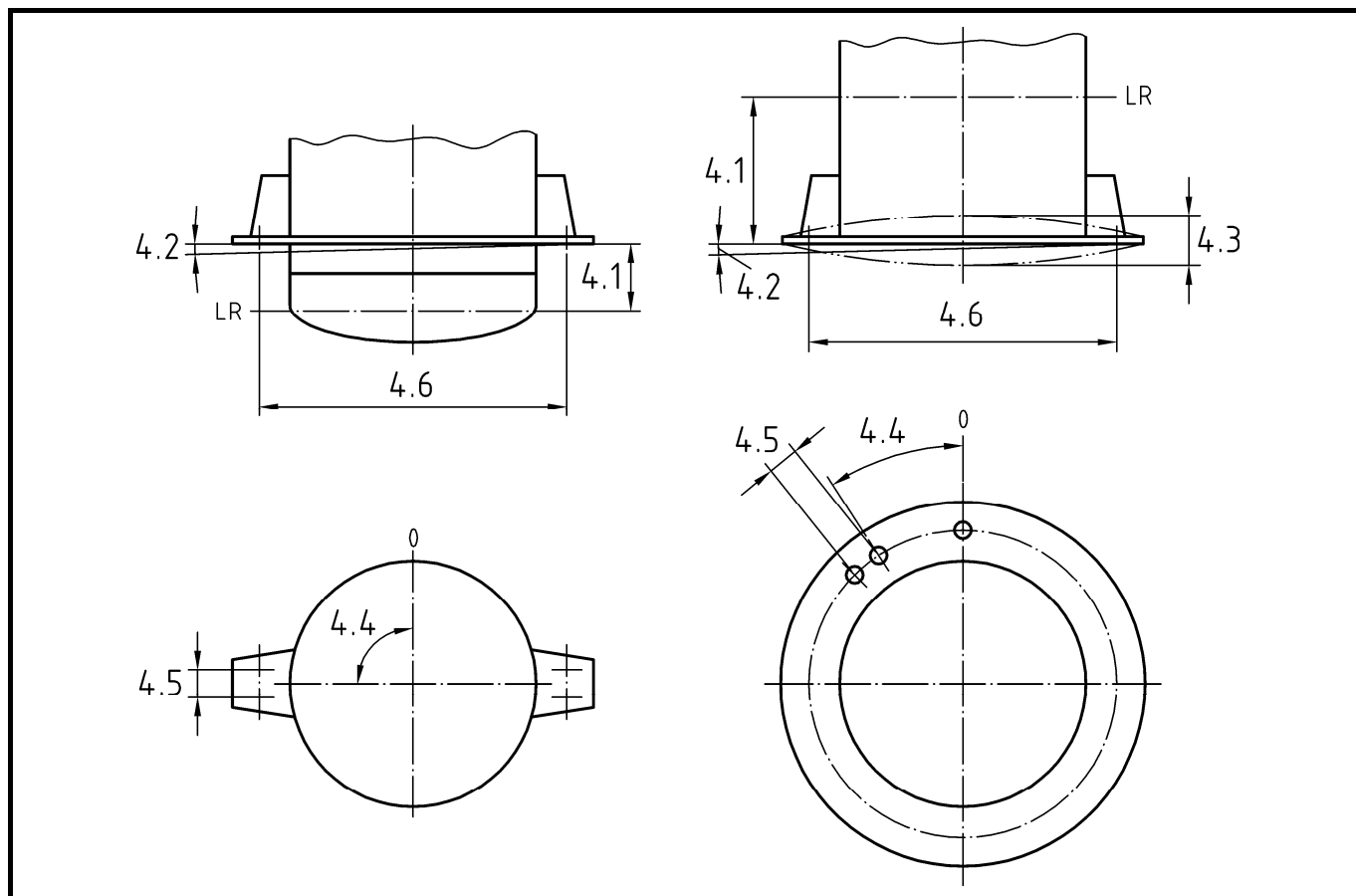
Item no	Type of deviations and elements considered	Limit deviations
2.1	Difference in length over distance L of extreme tangential lines (LT)	$L \leq 30\,000$ mm
		$L > 30\,000$ mm
2.2	Wall straightness deviation	Local defect measured on generating line ± 6 mm
2.3	Deviation between main axis of vessel and the vertical L (2.1) of vessel	$\pm \min. (0,001 L; 30 \text{ mm})$
2.4	Concentricity deviation of two sections with different diameters, expressed as a function of the greater diameter D	$\pm \min. (0,003 D; 20 \text{ mm})$
2.5	Deviation over total height or overall length of the vessel	cumulated tolerances

Table A.3 — Tolerances on saddles and supports



Item no	Type of deviations and elements considered	Limit deviations	
3.1	Flatness deviation of the bearing surface of a support	Transversal direction	± 2 mm
		Longitudinal direction	± 4 mm
3.2	Deviation between bearing sole plate and lower generation line of vessel	± 3 mm	
3.3	Deviation between axes of extreme supports	± 5 mm	
3.4	Deviation between axes of bolt holes	± 3 mm	
3.5	Deviation between diagonals of end saddles	± 6 mm	
3.6	Deviation between levels of end bearing sole plates	0/+ 5 mm	
3.7	Deviation between saddle axis and vessel tangential or reference line (LR)	± 5 mm	

Table A.4 — Tolerances on saddles and supports



Item no	Type of deviations and elements considered	Limit deviations	
4.1	Difference in the distance between the lower surface of supports or the base ring and the reference line (LR)	± 6 mm	
4.2	Perpendicularity defect of supports or base ring in relation to vessel axis or skirt	± 6 mm	
4.3	Flatness defect	± 4 mm	
4.4	Orientation deviation of axis of hole supports or skin reference	$D \leq 3\,000$ mm	± 4 mm
		$3\,000$ mm $< D \leq 6\,000$ mm	± 8 mm
		$D > 6\,000$ mm	± 12 mm
4.5	Deviation between two bolt holes	± 3 mm	
4.6	Anchoring diameter deviation, expressed as a function of theoretical diameter D	$\pm \min. (0,002 D, 10)$	

Annex B
(informative)

Example of a sub-contractors form

Declaration for sub-contracted works for pressure vessel parts or components						
GENERAL						
Sub-contractor:						
Name and address of sub-contractor						
Manufactured for:						
Name and address of manufacturer						
Drawing details:						
Drawing No, revision data						
In accordance with EN 13445-.... :						
Part No, Edition						
Design:						
Principal design conditions of the pressure vessel						
Design pressure bar	Design temperature °C	Testing group	Hazard category	Corrosion allowance	joint coefficient	Conformity assessment module
SUB-CONTRACTED WORKS						
Description of sub-contracted pressure part or component:						
.....						
General product name for part or component and quantity						
Sub-contracted works:						
<input type="checkbox"/> Design:						
<input type="checkbox"/> Forming:						
<input type="checkbox"/> Welding:						
<input type="checkbox"/> Heat treatment:						
<input type="checkbox"/> NDT:						
<input type="checkbox"/> Proof test:						
Name of responsible authority, if appropriate:						
The undersigned declares that the subcontracted works has been carried out according to the contract and the requirements above mentioned						
Date, Location				Sub-contractor		
.....						
				Position/Signature		

Annex C (normative)

Specification and approval of expansion procedures and operators

C.1 General

C.1.1 Introduction

This annex defines the requirements for the qualification and approval of mechanical roller expansion (RE) procedures and operators.

The approval of expansion procedures is obtained by expansion procedure tests and for operators by procedure test or production.

C.1.2 Responsibility

The manufacturer of pressure equipment shall be responsible for the mechanical roller expansion procedures he carries out, and shall conduct the tests required by this annex.

The manufacturer shall keep all mechanical roller expansion procedure qualification records and operator qualifications.

C.1.3 Specification of expansion procedures

The purpose of the Expansion Procedure Specification (EPS) is to determine that the expansion procedure proposed is capable of providing the required properties for its intended application.

The expansion test shall be adequately planned prior to production; the planning shall provide EPS's for all expansion joints. An EPS shall be classified as a pEPS until approved in accordance with the requirements of this annex.

The manufacturer may, in addition to the EPS, prepare detailed work instructions etc. to be used during the actual production. Work instructions are not mandatory and are the responsibility of the manufacturer.

If prepared, work instructions shall:

- be prepared on the basis of an EPS;
- define values for the expansion process to be used by the operators for all essential variables under control of the operator.

The EPS shall give details of how the expansion operation is to be performed and shall contain all relevant information of the expansion work.

C.1.4 Technical content of expansion procedure specification (EPS)

The EPS shall contain at least – and when applicable – the following information:

- a) identification of the manufacturer;
- b) identification of workshops or sites where the EPS is applicable;
- c) identification of the EPS;
- d) reference to the Expansion Procedure Approval Record (EPAR) or other documents as required;
- e) following material details:
 - 1) identification of material range of tube sheet and tube, preferably by reference to an appropriate standard or specification (see EN 13445-2:2014, Table A-1); an EPS may cover a group of materials;
 - 2) any additional material complying with this standard;
 - 3) the actual yield strength of the materials used (taken from material certificate)
- f) material dimension range
 - 1) thickness ranges of the tube sheet;
 - 2) outside diameter and thickness of the tubes;
- g) expansion process: by mechanical rolling (RE);
- h) joint design including a sketch of the joint design showing configuration, pitch and pattern of tube, hole geometry (grooves, etc.), surface finish;
- i) equipment, tool and process information:
 - 1) type, form and length of the roll;
 - 2) torque or other representative settings;
 - 3) length of rolling zone;
 - 4) cleaning of the surfaces between the items to be joined;
 - 5) lubrication of the tooling;
- j) expansion factor T

$$\text{with } T = 100 \times \left(\frac{d_{if} - d_{ii} - d + d_e}{d_e - d_{ii}} \right)$$

where

- d diameter of the hole inside the tube sheet;
- d_{if} internal diameter of the tube after expansion;
- d_e external diameter of the tube before expansion;
- d_{ii} internal diameter of the tube before expansion;

k) information whether PWHT is applied and its parameter range.

C.1.5 Expansion procedure qualification test (EPQT)

Variables are defined as:

- essential variables: variables in which a change may affect the mechanical properties of the expanded joint and may require a requalification according to C.3;
- non-essential variables: variables in which a change may be made without a requalification.

The essential variables are covered in C.3.

The shear test shall be performed on one or several tubes surrounded by peripheral tubes. For test qualification, it is necessary to have one central tube plus a crown of 6 tubes for triangular pitch or 8 tubes for square pitch. For the operator approval it is sufficient to have a single tube for each operator.

NOTE The test qualification also qualifies the operator. Therefore, the operator approval is usually made with the same test piece and the same number of tubes as the test qualification. In some cases, however (e.g. custom-built heat exchangers), it may be helpful for the operator qualification to use a single tube if a second operator or more operators have to be qualified and only little material is left for test pieces.

The test piece shall be representative of the intended production piece. It shall be of sufficient size to represent the constraint applied in production, and the number of test pieces shall be sufficient for all the examinations required by C.4 to be carried out.

The parameters recorded for the essential variables during the EPQT shall determine the range of approval.

C.2 Examination and testing

C.2.1 General

The tests used in the expansion procedure and performance qualifications are defined below.

C.2.2 Visual examination

Visual examination shall be carried out on all test joints to assess external appearance.

C.2.3 Dimensional verification

The following dimensions shall be measured:

- diameter of bore in tube sheet;
- hole pitch; type of pattern (square or triangle), possible grooves;
- external diameter of tube before expansion;
- internal diameter and/or thickness of tube before expansion;
- internal diameter of tube after expansion;
- length of expanded joint.

C.2.4 Testing

After the expansion, the expanded joints shall be submitted to a shear test the value of which must exceed the design value required in EN 13445-3:2014.

If post-weld heat treatment (PWHT) is to be carried out, this shall be before the shear test is carried out.

C.3 Range of approval

C.3.1 General

All of the conditions of validity stated below shall be met independently of each other.

A change outside of the ranges specified shall require a new expansion procedure test.

C.3.2 Manufacturer

An approved EPS is valid for use in all locations under the same technical and quality control of that manufacturer who carried out the expansion procedure qualification test.

C.3.3 Material

The approval is valid for the same material group as used during qualification test, with the range of actual yield strengths given in Table C.3.1.

Table C.3-1 — Material approval range

Actual yield strength used in the test	Minimum yield strength qualified	Maximum yield strength qualified
Y for tube sheet	0,75 Y	1,6 Y
Y for tubes	0,75 Y	1,25 Y, but it must not exceed 95 % of the tube sheet strength

C.3.4 Tube dimensions

The approval is valid with the same nominal tube diameter and the same thickness range with the use of the same type of expansion tool (brand or model including the same number of rollers).

C.3.5 Expansion factor

The approval is valid with the range of expansion factor as quoted in the EPS.

For an expansion factor T between 5 % and 10 %, the approval performed on a tube of outside diameter d_e and thickness $(d_e - d_{fi})/2$ is valid for a tube of the same outside diameter and larger thickness, and also for a tube of the same thickness and larger outside diameter.

An expansion with $T > 10$ % requires a separate qualification.

NOTE An expansion with $T < 5\%$ is not expected to give adequate strength in the joint.

C.3.6 Joint design

The approval is valid for a joint design type and for the joint clearances range specified in the EPS and

- lengths longer than the qualified expanded length;
- pitches greater than the qualified pitch;
- square pattern hole when the approval was performed on a triangular hole pattern;
- tube sheet with grooves when the approval was performed on a tube sheet without grooves.

C.3.7 Tool

The approval is only valid for the type of expansion tool used to carry out the EPQT.

A change in tool from a smaller number of rolls to a higher number is included in the EPQT if the EPQT has been carried out for the smaller number.

However, a change from a higher number of rolls to a smaller number requires a further EPQT if the original EPQT has been carried out for the higher number.

C.3.8 PWHT

If PWHT is required, the approval is valid for the same PWHT range as used during the qualification process.

Approval of an EPQT without PWHT does not qualify an EPS with PWHT, or vice versa.

C.4 Expansion Procedure Approval Record (EPAR)

The Expansion Procedure Approval Record (EPAR) is a statement of the results taken from an EPQT. As a minimum, the EPAR shall include all the essential variables described in C.3, together with any other details that are considered relevant to the acceptance of the EPAR. If there are no unacceptable test results, the EPAR is approved and shall be signed and dated by the appropriate persons.

When a test piece fails any of the tests required by C.2, the reason for the failure shall be investigated and the qualification test be repeated in its entirety.

C.5 Expansion operator approval

C.5.1 General

The operator approval ensures that when operators work in accordance with an approved EPS – with or without supplementary work instructions – they are capable of achieving the minimum requirements specified for an acceptable expansion joint.

C.5.2 Validity range of expansion operator qualification

An operator shall be qualified to carry out mechanical roller expansions on the type of equipment on which the approval test was carried out. The qualification covers all material thicknesses, all material groups and all expansion factors within the limits given in C.3.

C.5.3 Qualification tests

C.5.3.1 General

Each expansion operator who has successfully passed the expansion test is qualified for each expansion process to be used in the production expansion. The expansion operator who prepares the EPS qualification test piece is also qualified.

This qualification shall be based on the operator's experience, on his/her expansion ability and his/her capacity to follow and respect the procedure instructions.

A file shall be established for each operator, specifying the criteria that led to this choice (list of devices, characteristics, trainee...), with a list of qualified operators.

C.5.3.2 Test piece

The test piece shall be representative of the intended production piece. It shall be of sufficient size to represent the constraint applied in production, and the number of test pieces shall be sufficient for all the examinations required by C.2 to be carried out.

C.5.3.3 Assessment of the test piece

The test piece shall be expanded in accordance with the previously qualified EPS/pEPS being qualified. The operator shall assess the test piece components for parameters needed before starting the expansion operation.

C.5.4 Examination and testing

Each piece shall be tested by a visual and dimensional examination as defined in C.2.2 and C.2.3 and followed by a test as given in C.2.4.

C.5.5 Period of validity

C.5.5.1 Initial approval

The validity of an expansion operator approval begins at the date when all the required tests have been completed and have been approved. The period of validity is five years provided that all the following conditions are fulfilled:

- 1) the expansion operator is continuously employed on expansion duties and there has been no interruption of expansion work for a period longer than twelve months;
- 2) there is no specific reason to question the expansion operator's ability, skill or knowledge in the expansion field.

If any of these conditions are not fulfilled, the approval shall be cancelled.

C.5.5.2 Prolongation

An existing approval certificate may be prolonged for a further five-year period, provided that each of the following conditions is fulfilled:

- 1) the production expanded joints made by the expansion operator are continuously of required quality;
- 2) records of tests, e.g. documentation or reports about non-destructive tests or destructive tests or any comments, are maintained on file together with the approval certificate.

C.5.6 Certification

An operator approval certificate shall be issued by the manufacturer on the satisfactory completion of the prescribed test, and shall include as a minimum:

- name of the operator, including any identification number;
- name and address of the manufacturer;
- description of the type of expansion equipment;
- reference to Annex C of this part of the standard;
- date from which the certificate is valid;
- date on which the certificate expires;
- authorising signature of the manufacturer;
- verification signature of any independent second/third party, if relevant.

Annex Y (informative)

History of EN 13445-4

Y.1 Differences between EN 13445-4:2009 and EN 13445-4:2014

The 2014 edition of EN 13445-4 contains the 2009 edition of the standard and all amendments and corrections issued in the meantime.

Significant technical changes include:

- a revision of Clause 10.5 “Mechanical properties after heat treatment” according to the revised PWHT-table;
- the addition of a new Clause 10.8 on heat treatment for reasons other than welding;
- an update of the normative references;
- the introduction of a new Clause 7.10 “Permanent joints other than welding”;
- stipulating requirements for mechanical roller expansion and for brazing;
- the introduction of a new normative Annex C dealing with the specification and approval of expansion procedures and operators.

NOTE The changes referred include the significant technical changes but is not an exhaustive list of all modifications.

Annex ZA (informative)

Relationship between this European Standard and the Essential Requirements of the EU Pressure Equipment Directive 97/23/EC

This European Standard has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association to provide a means of conforming to Essential Requirements of the New Approach Pressure Equipment Directive 97/23/EC.

Once this standard is cited in the Official Journal of the European Union under that Directive and has been implemented as a national standard in at least one Member State, compliance with the clauses of this standard given in Table ZA.1 confers, within the limits of the scope of this standard, a presumption of conformity with the corresponding Essential Requirements of that Directive and associated EFTA regulations.

Table ZA.1 — Correspondence between this European Standard and Pressure Equipment Directive 97/23/EC

Clause(s)/subclause(s) of this EN	Essential Requirements (ERs) of Pressure Equipment Directive 97/23/EC	Qualifying remarks/Notes
3, 5	3.1	Appropriate techniques and procedure
9.2, 9.3	3.1.1	Manufacturing procedures, forming
7.6	3.1.1	Preparation of component parts
7.3, 8	3.1.2, 7.2	Properties of permanent joints
7.4, 7.10, Annex C	3.1.2	Qualified personnel to carry out permanent joints
7.3, 7.7, 7.8, 7.9, 7.10, 11, Annex C	3.1.2	Operating procedure to carry out permanent joints
9.4, 10	3.1.4	Heat treatment
4.2	3.1.5	Traceability
12	3.2.1	Final inspection

WARNING — Other requirements and other EU Directives may be applicable to the product(s) falling within the scope of this standard.

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