Unfired pressure vessels

Part 11: Additional requirements for pressure vessels of titanium and titanium alloys

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National foreword

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

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

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Contents

European foreword

This document (EN 13445-11:2024) 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of an identical text or by endorsement, at the latest by March 2025, and conflicting national standards shall be withdrawn at the latest by March 2025.

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For the relationship with EU Legislation, see informative Annex ZA, which is an integral part of this document.

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1 Scope

This document specifies requirements for unfired pressure vessels and their parts made of titanium and titanium alloys in addition to the general requirements for unfired pressure vessels under EN 13445-1:2021 to EN 13445-5:2021.

NOTE 1 Cast materials, HIP and additive manufacturing are not included in this version. Details regarding such materials will be subject to an amendment to or a revision of this European Standard.

NOTE 2 Materials in Groups 51.4 and 54 are not included in this version.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 764-5:2014, *Pressure equipment - Part 5: Inspection documentation of metallic materials and compliance with the material specification*

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

EN 13445-1:2021, *Unfired pressure vessels - Part 1: General*

EN 13445-2:2021+A1:2023, *Unfired pressure vessels - Part 2: Materials*

EN 13445-3:2021, *Unfired pressure vessels - Part 3: Design*

EN 13445-4:2021+A1:2023, *Unfired pressure vessels - Part 4: Fabrication*

EN 13445-5:2021, *Unfired pressure vessels - Part 5: Inspection and testing*

EN ISO 148-1:2016, *Metallic materials - Charpy pendulum impact test - Part 1: Test method (ISO 148-1:2016)*

EN ISO 9606-5:2000, *Approval testing of welders - Fusion welding - Part 5: Titanium and titanium alloys, zirconium and zirconium alloys (ISO 9606-5:2000)*

EN ISO 15614-5:2004, *Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 5: Arc welding of titanium, zirconium and their alloys (ISO 15614-5:2004)*

EN ISO 15614-8:2016, *Specification and qualification of welding procedures for metallic materials - Welding procedure test - Part 8: Welding of tubes to tube-plate joints (ISO 15614-8:2016)*

CEN ISO/TR 15608:2017, *Welding — Guidelines for a metallic materials grouping system (ISO/TR 15608:2017)*

3 Terms, definitions, symbols and units

For the purposes of this document, the terms, definitions, symbols and units given in EN 13445-1:2021 to EN 13445-5:2021 apply.

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

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

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

4 General requirements

The general requirements of EN 13445-1:2021 shall apply.

5 Materials

5.1 General

The general requirements of EN 13445-2:2021+A1:2023 shall apply with the following additions/exclusions in 5.2 to 5.5.

There are presently no European Standards or European Approval of Materials (EAMs) specifically for titanium and titanium alloys for pressure purposes. This document is therefore limited to the use of Particular Materials Appraisal (PMA).

5.2 Material specification

The material specification shall specify the composition limits for all constituents, heat treatment and the appropriate mechanical properties for acceptance and other purposes.

Only material having a minimum elongation after fracture of not less than 10 %, in its final fabricated state, shall be used for construction of pressure vessels. The specified minimum elongation after fracture shall be measured on a gauge length as defined in EN 13445-2:2021+A1:2023, 4.1.4.

NOTE To achieve this it can be necessary to start with a higher elongation after fracture, e.g. 14 %, prior to cold forming.

5.3 Material grouping system

EN 13445-2:2021+A1:2023, Annex A, is not applicable to pressure vessels of titanium and titanium alloys and is replaced by Annex A of this document.

The grouping system for titanium and titanium alloys shown in Table A.1 of this document is based on CEN ISO/TR 15608:2017. However, only the grades included in Annex B of document are considered suitable for welded pressure vessel construction.

5.4 Material documentation

Materials for pressure bearing parts compliant with the requirements of this document shall be accompanied by inspection documentation in accordance with EN 10204:2004.

The type of inspection document shall be in accordance with EN 764-5:2014 and include an affirmation of compliance to the material specification.

5.5 Prevention of brittle fracture

There are no general requirements for titanium and titanium alloys at temperatures down to

— −100 °C for group 51.1 and 51.2, and

— −60 °C for all other Groups.

Below these temperatures adequate toughness shall be demonstrated by impact testing of a Charpy-V-notch test specimen (according to EN ISO 148-1:2016) at a temperature not higher than the minimum metal temperature T_M achieving a mean impact energy KV of 27 J in the base material, welds, and heat affected zones. The impact tests shall be carried out in accordance with the requirements of EN 13445-2:2021+A1:2023, B.3.

NOTE For practical reasons, a test temperature of −196 °C is commonly used for all impact testing of titanium and titanium alloys for any minimum metal temperature below −100 °C.

Alternatively, a fracture mechanics approach in line with EN 13445-2:2021+A1:2023, Annex B method 3 may be employed.

6 Design

6.1 General

All the requirements included in EN 13445-3:2021 shall apply, with the following amendments, given in 6.2 to 6.7.

Physical properties of titanium and titanium alloys are given in Annex D of this document.

6.2 Corrosion, erosion and protection

Unalloyed titanium and titanium alloys have outstanding resistance to a wide range of reducing, neutral and oxidizing corrosive media. As a general rule no allowance is required for pitting or general corrosion.

Caution is required in the design of joints and the selection of gasket materials where crevice corrosion could occur.

6.3 Joint coefficient

For normal operating load cases the value of joint coefficient z is given in Table 6.3-1. It is related to the testing group of the governing welded joints.

Testing groups are specified in 8.2 of this document.

Table 6.3–1 — Joint coefficient and corresponding testing group

z	1	0,8
Testing group	1	3

Testing groups 2 and 4 are not permitted for pressure vessels made of titanium and titanium alloys.

6.4 Time-independent nominal design stress

The design stress for titanium and titanium alloy materials entering service in the annealed condition following removal of test coupons at the material manufacturer's works, shall be derived in accordance with Table 6.4-1.

Table 6.4–1 — Maximum allowed values of the nominal design stress for titanium and titanium alloy materials for pressure parts

Grade/group	Design stress for normal operating load cases	Design stress for testing and rare exceptional load cases
51.1 and 51.2	$f_d = \min\left(\frac{R_{p1,0/T}}{1,5}; \frac{R_{m/T}}{3}\right)$	$f_{test} = \left(\frac{R_{p1,0/T_{test}}}{1,05}\right)$
All others	$f_d = \min\left(\frac{R_{p0,2/T}}{1,5}; \frac{R_{m/T}}{3}\right)$	$f_{test} = \left(\frac{R_{p0,2/T_{test}}}{1,05}\right)$

For design temperatures not exceeding 50 °C, the value of the design stress derived at 20 °C may be used.

NOTE In case values of $R_{p\,1.0/T}$ are not available, $R_{p\,0,2/T}$ values can be used.

Tensile and other strength values at room temperature may be used at temperatures below 20 °C.

6.5 Creep design

Where guaranteed creep rupture data are available for the intended life of the vessel from the material specification or the material manufacturer, design stresses for normal operating load cases shall be obtained from Table 6.5-1.

Table 6.5–1 — Maximum allowed values of the nominal design stress for titanium and titanium alloy materials for pressure parts for creep design when guaranteed creep rupture data are available

Grade/group	Design stress for normal operating load cases
All	$f_d = \min\left(\frac{R_{p0,2/T}}{1,5}; \frac{R_{m/T/t}}{1,5}\right)$
$R_{m/T/t}$ is the mean creep rupture strength at calculation temperature T and lifetime t (EN 13445-3:2021, 19.3)	

Where creep data are not available, a safe design for a life of up to 100,000 h can be achieved by using the design stresses obtained from Table 6.4-1 but taking $R_{p0,2/T}$ in place of $R_{p\,1,0/T}$.

Unalloyed titanium and titanium alloys can exhibit time dependent deformation when loads are sustained for long periods near the proof stress value. Informative Annex E of this document gives typical properties.

NOTE Time-dependent deformation is particularly relevant where the design conditions result in $R_{m/T/t}/3$ exceeding 70 % of $R_{p0,2/T}$. In such circumstances, in order for the designer to consider the effect of those properties which influence time dependent deformation, it may be appropriate to take specialist metallurgical advice.

6.6 Shells under external pressure

The requirements in EN 13445-3:2021, Clause 8, shall apply with the following modifications as shown in Table 6.6-1:

Table 6.6–1 — Nominal elastic limit

Grade/group	Elastic limit for shells	Elastic limit for stiffeners
51.1 and 51.2	$\sigma_e = \left(\frac{R_{p1,0/T}}{1,25} \right)$	$\sigma_{es} = \left(\frac{R_{p1,0/T,s}}{1,25} \right)$
All others	$\sigma_e = \left(\frac{R_{p0,2/T}}{1,25} \right)$	$\sigma_{es} = \left(\frac{R_{p0,2/T,s}}{1,25} \right)$

NOTE In case values of $R_{p1,0/T}$ are not available, $R_{p\,0,2/T}$ values can be used.

Values of the modulus of elasticity E as a function of the temperature can be found in Annex D of this document.

6.7 Flanges

The requirements of EN 13445-3:2021, Clause 11 or Annex G, shall apply with the following modifications:

Gaskets made from or containing polymers which could release fluoride on thermal or acid decomposition shall not be used.

NOTE 1 Due to the high elastic deformations of titanium and titanium alloys, to ensure leak tightness of flanges made of such materials the use of EN 13445-3:2021, Annex G, is preferred to EN 13445-3:2021, Clause 11.

NOTE 2 Current European Standards for pipework flanges do not contain rating tables for titanium and titanium alloys and therefore the use of standard flanges without calculation is not possible.

6.8 Fatigue design

For loads up to 500 equivalent full pressure cycles no fatigue analysis is required. Above 500 cycles the requirements of EN 13445-3:2021, Clause 17, shall apply with the following modifications:

The application of Clause 17 (see EN 13445-3:2021, 17.4.4) to titanium and titanium alloys shall be limited to temperatures not exceeding 150 °C.

The correction factor to account for the influence of temperature on fatigue resistance (see EN 13445-3:2021, 17.6.2.2) is:

For $T^* \geq 100$ °C:

$$C_T = 0,518 - 9,41 \times 10^{-5} T^* - 8,46 \times 10^{-7} (T^*)^2 \qquad (6.7\text{-}1)$$

For $T^* < 100$ °C, $C_T = 0,5$.

The requirements of EN 13445-3:2021, Clause 18, shall apply with the following modifications:

The application of Clause 18 (see EN 13445-3:2021, 18.4.3) to titanium and titanium alloys shall be limited to temperatures not exceeding 150 °C.

The correction factor to account for the influence of temperature on fatigue resistance, f_{T^*} (see EN 13445-3:2021, 18.10.6.2) is given by:

For $T^* \geq 100$ °C:

$$f_{T^*} = 0{,}518 - 9{,}41 \times 10^{-5} T^* - 8{,}46 \times 10^{-7} (T^*)^2 \quad (6.7\text{-}2)$$

For $T^* < 100$ °C, $f_{T^*} = 0{,}5$.

7 Manufacture

7.1 General

EN 13445-4:2021+A1:2023 shall apply, with the following amendments, given in 7.2 to 7.19.

NOTE Not all welding processes are suitable for all titanium alloys.

7.2 Filler metals

In all cases where the filler metals do not match parent metal combinations the filler metal used shall be suitable for the service conditions.

NOTE Welding consumables can be selected from EN ISO 24034:2020.

7.3 Attachment of dissimilar metals

Dissimilar metal attachments are generally incompatible by fusion welding with most commercially available titanium alloy materials.

7.4 Backing strips, joggle joints and partial penetration welds

Permanent backing strips, and joggle joints shall not be used. Partial penetration welds shall not be used on longitudinal and circumferential welds in the pressure containing parts.

7.5 Qualification of welding procedure specifications (WPQR)

The requirements of EN 13445-4:2021+A1:2023, 8.3, shall apply with the following modifications:

Approval testing of fusion welding procedures shall be conducted, recorded and reported in accordance with EN ISO 15614-5:2004 or EN ISO 15614-8:2016 as appropriate.

Impact testing is not normally required for pressure vessels of titanium and titanium alloys at temperatures down to −100 °C for group 51.1 and 51.2 and −60 °C for all other Groups. Below these temperatures adequate toughness shall be demonstrated by impact testing as specified in 5.5.

7.6 Qualification of welders and welding operators

The requirements of EN 13445-4:2021+A1:2023, 8.4, shall apply with the following modifications:

Replace reference to EN ISO 9606-1 with EN ISO 9606-5:2000.

7.7 Joint preparation

In addition to the requirements of EN 13445-4:2021+A1:2023, 8.6, the following shall apply for pressure vessels of titanium and titanium alloys:

All material shall be cut to size and shape preferably by non-thermal processes like machining, or water jet cutting.

Surfaces cut by shear cutting or by thermal processes like flame cutting, plasma arc cutting and laser cutting shall be mechanically dressed.

Edges to be welded shall be dressed back for a distance of 1,5 mm for edges that have been cut by laser cutting or shear cutting and 5 mm for edges that have been cut by any other process, unless the manufacturer can demonstrate that the material has not been adversely affected by the cutting process.

NOTE It is important that fire safety procedures are applied for the handling and control of titanium fines and turnings.

All surfaces to be welded shall be thoroughly cleaned, on both sides of the joint, for a distance of 50 mm from each welding edge. Cleaning shall be by degreasing using a suitable solvent such as acetone on a lint-free cloth, before and after wire brushing. Brushes shall be of either stainless steel or titanium, and shall only be used on titanium and titanium alloys. Surfaces shall be dry before welding commences.

Methyl alcohol or sulphur-containing cleaning fluids shall not be used.

7.8 Execution of welded joints

In addition to the requirements of EN 13445-4:2021+A1:2023, 8.7, the following shall apply for pressure vessels of titanium and titanium alloys:

Each run of weld metal shall be thoroughly cleaned before the next run is deposited. Brushes shall be of either stainless steel or titanium, and shall only be used on titanium and titanium alloys.

Where the welding procedure requires removal of the root, before welding the second side of double sided joints the metal at the bottom of the first side shall be cut back to sound metal by machining or filing.

Where arc strikes show a rejectable oxide discolouration (see Table 8.6-1) the offending area shall be removed and, where necessary, repaired to an approved welding procedure.

To avoid contamination of heated surfaces by oxygen, hydrogen or nitrogen, welding shall be carried out either:

a) in a suitable chamber containing argon; or

b) by using trailing and purging argon gas shields.

The weld bead and surrounding area shall be protected until it has cooled below 250 °C.

Filler wire shall be thoroughly degreased prior to welding. When the filler wire is removed from the gas shield during or after welding, the first 20 mm of wire shall be discarded before welding re-commences.

After welding has been stopped for any reason, care shall be taken on re-starting to ensure satisfactory gas coverage of the welding zone together with satisfactory fusion and penetration with the parent material.

7.9 Preheat

Preheating of titanium and titanium alloys is not required for metallurgical reasons and is therefore not mandatory. Preheating may be applied by the manufacturer for practical reasons, e.g. a heating at about 50 °C may facilitate the elimination of traces of water.

7.10 Permanent joints other than welding

The requirements of EN 13445-4:2021+A1:2023, 8.10.3, are not applicable to titanium and titanium alloys.

7.11 Production test, reference criteria

The requirements of EN 13445-4:2021+A1:2023, 9.2, shall apply with the following modifications:

For temperatures not lower than −100 °C for group 51.1 and 51.2 and −60 °C for all other Groups, the requirements for impact testing of production control test plates are not applicable to titanium and titanium alloys; 9.2 a) of EN 13445-4:2021+A1:2023 is not applicable.

Below these temperatures impact tests shall be carried out on production test plates in accordance with the requirements of EN 13445-2:2021+A1:2023, B.3 at a temperature not higher than the minimum metal temperature T_M achieving a mean impact energy KV of 27 J in the base material, weld, and heat affected zone.

NOTE For practical reasons, a test temperature of −196 °C is commonly used for all impact testing of titanium and titanium alloys for any minimum metal temperature below −100 °C.

Production control test plates for titanium and titanium alloys vessels in Group 51 shall be carried out in accordance with EN 13445-4:2021+A1:2023, 9.2 d). In the case of longitudinal welds with joint coefficient 0,8 the requirements given in EN 13445-4:2021+A1:2023, 9.2 d) 2) and 5) for longitudinal welds with a joint coefficient 0,85 shall be applied.

Production control test plates for titanium and titanium alloys vessels in Groups 52 and 53 shall be carried out in accordance with EN 13445-4:2021+A1:2023, 9.2 e). In the case of longitudinal welds with joint coefficient 0,8 the requirements given in EN 13445-4:2021+A1:2023, 9.2 e) 2) and 5), for longitudinal welds with a joint coefficient 0,85 shall be applied.

7.12 Extent of testing

The requirements of EN 13445-4:2021+A1:2023, 9.3, shall apply with the following modifications:

Table 9.3-1 shall be replaced by Table 7.12-1 below:

Table 7.12–1 – Testing of production test plates

Material Group	**Thickness of test plate e [a] mm**	**Test specimens [b]**
All	$e \leq 12$	1 FB, 1 RB, 1 TT, 1 Ma
	$12 < e$	2 SB [c], 1 TT, 1Ma

[a] Thinner plate thickness.

[b] The symbols for Table 7.12–1 are given in Table 9.3–2 of EN 13445-4:2021+A1:2023.

[c] SB = side bends.

7.13 Performance of test and acceptance criteria

The requirements of EN 13445-4:2021+A1:2023, 9.4.1, 9.4.2, 9.4.5, 9.4.6, 9.4.9 and 9.4.10 shall apply, except that references to EN ISO 15614-1:2017 shall be replaced by EN ISO 15614-5:2004.

7.14 Forming procedures

7.14.1 Cold forming

The requirements of EN 13445-4:2021+A1:2023, 10.3.1, are not applicable for pressure vessels made of titanium and titanium alloys.

Cold forming of titanium and titanium alloy materials shall be carried out at temperatures below 200 °C.

Cleanliness of tooling and selection of correct lubrication are of particular importance. Suitable interface material shall be used between the forming equipment and the workpiece.

All cold forming methods may be used.

7.14.2 Hot forming

The requirements of EN 13445-4:2021+A1:2023, 10.3.2, are not applicable for pressure vessels made of titanium and titanium alloys.

Hot forming of titanium and titanium alloy materials shall be carried out in accordance with the material manufacturer's recommendations. The procedures shall include information such as material preparation for heating, heating times and temperatures, inspection and quality controls and any subsequent heat treatment and cleaning procedures.

The material shall be heated uniformly in a furnace to a maximum temperature of 600 °C, using a slightly oxidizing or inert atmosphere. Soaking times shall not exceed one hour per 50 mm of section thickness, and shall be kept to a minimum.

The material shall be heated uniformly without flame impingement.

NOTE Most fuels may be used provided that detrimental impurities, such as sulphur, are kept at low levels.

Titanium and titanium alloys shall be cleaned before heating.

Care shall be taken to avoid contact with any foreign substances, such as marking materials, die lubricants, pickling liquids, and any waste products encountered during the manufacturing process, which may be taken into the surface of the material at elevated temperatures.

7.15 Heat treatment after forming

7.15.1 General

Heat treatment after hot or cold forming shall be carried out in accordance with the requirements of 7.15.2, 7.15.3 or 7.15.4.

NOTE When using titanium and titanium alloys attention is drawn to the effect of heat treatment on the materials and in particular the formation of the brittle alpha case when an oxidizing atmosphere is used. A stress relieving post-weld heat treatment is not normally required for unalloyed titanium.

7.15.2 Heat treatment of flat products after cold forming

The requirements of EN 13445-4:2021+A1:2023, 10.4.2, are not applicable for pressure vessels made of titanium and titanium alloys.

Heat treatment of flat products after cold forming shall be carried out in accordance with 7.15.5, when required by Table 7.15-1. The ratio of deformation F is defined in EN 13445-4:2021+A1:2023, 10.2.

Table 7.15–1 — Heat treatment of flat products after cold forming

Material groups	Ratio of deformation *F*	Heat treatment
51.1 and 51.2	$F \leq 12{,}5$ %	No
51.1 and 51.2	$F > 12{,}5$ %	Yes, annealing
All others	$F \leq 10$ %	No
All others	$F > 10$ %	Yes, annealing
Heat treatment after forming of dished ends is not required when the minimum elongation after fracture from the material test certificate is not less than 25 %.		

7.15.3 Heat treatment of tubular products after cold forming

The requirements of EN 13445-4:2021+A1:2023, 10.4.3, are not applicable for pressure vessels made of titanium and titanium alloys.

Heat treatment of tubular products after cold forming shall be carried out in accordance with 7.15.5, when required by Table 7.15-2. The bending radius for the tube *R* is defined in EN 13445-4:2021+A1:2023, 10.2.4.

Table 7.15–2 — Heat treatment of tubular products after cold forming

Material groups	Bending radius for the tube *R*	Heat treatment
51.1 and 51.2	$R \geq 3{,}0\ D_e$	No
51.1 and 51.2	$R < 3{,}0\ D_e$	Yes, annealing
All others	$R \geq 4{,}0\ D_e$	No
All others	$R < 4{,}0\ D_e$	Yes, annealing

7.15.4 Heat treatment after hot forming

The requirements of EN 13445-4:2021+A1:2023, 10.4.5 and 10.4.6, are not applicable to pressure vessels made of titanium and titanium alloys.

Heat treatment of titanium and titanium alloys in groups 51.1, 51.2 and 52 is not required after hot forming. For materials in groups 51.3 and 53 heat treatment is recommended after hot forming and shall be carried out in accordance with 7.15.5.

7.15.5 Annealing

Following any hot forming operation, or when specified after cold forming, the material shall be given an annealing treatment in accordance with Table 7.15-3. The annealing hold time shall be determined by the manufacturer and is dependent on the material thickness, the amount of forming and the manufacturer's processing route.

Precautions shall be taken to avoid contamination and embrittlement. After annealing the surfaces might require a descaling treatment.

Table 7.15–3 — Heat treatment temperatures for unalloyed titanium and titanium alloys

Group	Anneal	
	Temperature °C	Time hr
51	650 – 730	1/2 – 4
52 and 53	700 – 780	1/2 – 4

When heat treatment in an oxidizing atmosphere is used sandblasting and/or pickling and passivation after heat treatment is required. Heat treatment should preferably be carried out in argon or helium, or in a vacuum.

NOTE Heat treatment in a reducing atmosphere results in hydrogen absorption and causes embrittlement.

7.16 Sampling of formed products

7.16.1 Cold formed products without heat treatment

The requirements of EN 13445-4:2021+A1:2023, 10.5.1, are not applicable to pressure vessels made of titanium and titanium alloys.

If heat treatment is not required by Tables 7.15-1 or 7.15-2 after cold forming, mechanical testing is not required.

7.16.2 Hot formed or cold formed products with heat treatment

The requirements of EN 13445-4:2021+A1:2023, 10.5.2, are not applicable to pressure vessels made of titanium and titanium alloys.

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;

— separately formed test coupons simulated heat treated.

The following number of test coupons shall be taken from each cast of material:

a) one test coupon from a batch of up to 10 parts;

b) two test coupons from a batch of up to 25 parts;

c) three test coupons from a batch of up to 100 parts;

d) one test coupon for every further 100 parts.

These requirements are also applicable when formed products are supplied in accordance with a fitting specification or standard.

7.17 Tests

7.17.1 Base material

The requirements of EN 13445-4:2021+A1:2023, 10.6.1, are not applicable to pressure vessels made of titanium and titanium alloys.

For pressure vessels of titanium and titanium alloys one tensile test shall be taken from each test coupon required in 7.16.2. The test specimens shall be taken transverse to the rolling direction with a deviation not greater than 20°.

7.17.2 Butt welds

The requirements of EN 13445-4:2021+A1:2023, 10.6.2, are not applicable to pressure vessels made of titanium and titanium alloys.

NOTE This does not decrease the need to have a PQR test in the heat treated condition as required by 7.5.

7.18 Post weld heat treatment (PWHT)

The requirements of EN 13445-4:2021+A1:2023, Clause 11, are not applicable to pressure vessels made of titanium and titanium alloys.

The following shall apply:

Post weld heat treatment is not normally necessary for welded titanium or titanium alloy pressure vessels.

If post weld heat treatment is required it shall be carried out in accordance with the material manufacturer's recommendations.

7.19 Repairs

The requirements of EN 13445-4:2021+A1:2023, 12.1 shall apply except that surface examination shall be by PT, where required.

The requirements of EN 13445-4:2021+A1:2023, 12.2 do not apply and shall be replaced by:

Weld defects shall be removed by machining or milling. In case the defects are removed by grinding, the welding surfaces need to be dressed for 1,5 mm by milling unless the manufacturer can demonstrate that the material has not been adversely affected by the grinding process.

Repair welding shall be performed using a qualified PQR and using qualified welders. Repaired welds shall be examined using the same techniques as the original weld.

8 Inspection and testing

8.1 General

The requirements of EN 13445-5:2021 shall apply with the following modifications:

8.2 Non-destructive testing of welded joints

8.2.1 General

The non-destructive testing of welded joints shall depend upon the testing group in Table 8.2-1.

All testing groups shall require 100 % visual inspection. Testing groups 2 and 4 are not permitted for pressure vessels made of titanium and titanium alloys.

Table 8.2–1 — Testing groups for pressure vessels of titanium and titanium alloys

Requirements	**Testing group**	
	1	**3**
Permitted materials [a]	All	All
Extent of NDT for governing welded joints [b] [c]	100 %	25 % – 10 % [d]
NDT of other welds	Defined for each type of weld in Table 8.3–1 of this document	
Joint coefficient	1	0,80 [e]
Minimum thickness for which specific materials are permitted	Unlimited [f]	3 mm
Maximum thickness for which specific materials are permitted	Unlimited [f]	Unlimited [f]
Welding process	Unlimited [f]	Unlimited [f]
Service temperature range for group 51.1	−150 °C to 250 °C	−150 °C to 250 °C
Service temperature range for groups 51.2, 52 and 53	−150 °C to 300 °C	−150 °C to 300 °C

[a] See Clause 5 of this document for permitted materials.

[b] Testing details are given in Table 8.3–1 of this document.

[c] The percentage relates to the percentage of welds of each individual vessel.

[d] First figure: initially, second figure: after satisfactory experience. For definition of "satisfactory experience" see 8.2.2.

[e] The joint coefficient has been decreased from 0,85 to 0,80 to allow for the difficulties in welding titanium.

[f] "Unlimited" means no additional restriction due to testing. The limitations mentioned in this table are limitations imposed by testing. Other limitations given in the various clauses of the standard (such as design, or material limitations, etc.) shall be taken into account.

8.2.2 Demonstration of satisfactory experience for testing group 3

The requirements of EN 13445-5:2021, 6.6.1.2.4, shall apply with the following modification:

— in the case of titanium and titanium alloys, the successful production is 25 consecutive pressure vessels or 50 consecutive metres of governing welded joints;

8.3 Determination of extent of non-destructive testing

The requirements of EN 13445-5:2021, 6.6.2, shall apply, with the following modification:

EN 13445-5:2021, Table 6.6.2-1 shall be replaced by Table 8.3-1 of this document.

The requirements of EN 13445-5:2021, 6.6.2.2 shall be replaced by:

Table 8.3-1 is designed for the following types of welded joints:

a) multilayer welds welded as single or double sided welds;

b) performed by Tungsten Inert Gas (TIG 141).

Special problems arising from elements such as those described below shall be considered especially for longitudinal joints:

1) other process, e.g. plasma 15, electron beam (EB) 76, friction welding 42;

2) single run weld, single run from one side or both sides;

3) automatic and mechanized welding processes.

Table 8.3–1 — Extent of non-destructive testing

Type of weld [a]			Testing [b]	Extent for testing group	
				1	3
Full penetration butt weld	1	Longitudinal joints	RT or UT PT	100 % 100 %	25 % – 10 % [c] 100 %
	2a	Circumferential joints on a shell [d]	RT or UT PT	100 % 100 %	5 % 100 %
	3a	Circumferential joints on a nozzle d_i > 150 mm or e > 16 mm	RT or UT PT	100 % 100 %	0 % 100 %
	4	Circumferential joints on a nozzle $d_i \leq 150$ mm and $e \leq 16$ mm	RT or UT PT	0 % 100 %	0 % 100 %
	5	All welds in spheres, heads and hemispherical heads to shells	RT or UT PT	100 % 100 %	25 % – 10 % [c] 100 %
	6	Assembly of a conical shell with a cylindrical shell without a knuckle (large end of the cone) [e f]	RT or UT PT	100 % 100 %	10 % 100 %
	7	Assembly of a conical shell with a cylindrical shell without a knuckle (small end of the cone)	RT or UT PT	100 % 100 %	10 % 100 %
Circumferential lapped joints [g]	8b	Bellows to shell $e \leq 8$ mm	RT or UT PT	0 % 100 %	0 % 100 %
Assembly of a flat head or a tubesheet, with a cylindrical shell Assembly of a flange or a collar with a shell	9	With full penetration	RT or UT PT	100 % 100 %	25 % – 10 % [c] 100 %
Assembly of a flange or a collar with a nozzle	12	With full penetration	RT or UT [h] PT	0 % 100 %	0 % 100 %
	14	With full or partial penetration $d_i \leq 150$ mm and $e \leq 16$ mm [i]	RT or UT PT	0 % 100 %	0 % 100 %

Type of weld [a]			Testing [b]	Extent for testing group	
				1	3
Nozzle or branch [j]	15	With full penetration d_i > 150 mm and e > 16 mm	RT or UT PT	100 % 100 %	25 % – 10 % [c] 100 %
	16	With full penetration d_i ≤ 150 mm or e ≤ 16 mm.	RT or UT PT	0 % 100 %	0 % 100 %
Tube ends into tubesheet	20		PT	[k]	[k]
Permanent attachments [l]	21	With full penetration or partial penetration	RT or UT PT	25 % 100 %	10 % 100 %
Pressure retaining areas after removal of temporary attachments	22		PT	100 %	100 %
Repairs	24		RT or UT PT	100 %	100 %

[a] Annex A of EN 13445-3:2021 gives design limitations on welds.

[b] RT = Radiographic testing, UT = Ultrasonic testing, PT = Penetrant testing.

[c] First figure: initially, second figure: after satisfactory experience. For definition of “satisfactory experience” see 8.2.2.

[d] The NDT requirements are valid only if the construction fulfils the requirements of EN 13445-4:2021+A1:2023 as modified by Clause 7 of this document.

[e] Unless the design is such that the thickness at the weld exceeds 1,4 e_j (see 7.6.6 of EN 13445-3:2021). In which case, use NDT of line 2a.

[f] For connections with a knuckle, case 2a applies.

[g] For limitations of application see 5.7.4 of EN 13445-3:2021.

[h] RT or UT not possible for geometrical reasons.

[i] In exceptional cases or where the design or load bearing on the joint is critical, it may be necessary to employ both techniques (i.e. RT and UT, and PT).

[j] Percentage in the table refers to the total weld length of all nozzle attachments in one group of nozzles (see 6.6.2.5 b) of EN 13445-5:2021).

[k] Type and extent of testing are to be determined under the responsibility of the manufacturer and customer.

[l] No RT or UT for weld throat thickness ≤ 16 mm.

8.4 Selection of non destructive testing methods for internal imperfections

The requirements of EN 13445-5:2021, 6.6.3.3, shall apply, with the following modification:

Allowance shall be made for the lower absorption of X-rays by titanium and titanium alloys, when compared with steel.

Titanium or an aluminium Image Quality Indicator shall be used to demonstrate radiographic sensitivity.

8.5 Selection of non destructive testing methods for surface imperfections

The requirements of EN 13445-5:2021, 6.6.3.4, shall apply, with the following modification:

Testing shall be carried out by penetrant testing (PT) only.

8.6 Assessment of defects

Visual examination of titanium and titanium alloy welds is used to assess the adequacy or otherwise of the gas shielding methods applied, making use of the interference colours generated by thin layers of surface oxide in the weld zone.

The acceptance criteria shall be in accordance with Table 8.6-1. The colour comparison shall be performed using colour coupons.

Table 8.6–1 — Colour comparison acceptance criteria

Colour	Acceptable	Actions	Cleaning
Silver	Yes	None required	None required
Light straw	Yes	Correct	Interpass/Post inspection
Dark straw	Yes for non impact/non fatigue designs [a]	Correct	Interpass/Post inspection
Red	No	Cut out	None – Cut out
Purple	No	Cut out	None – Cut out
Blue	No	Cut out	None – Cut out
Yellow	No	Cut out	None – Cut out
Gray	No	Cut out	None – Cut out
White	No	Cut out	None – Cut out
Brushed	No	Cut out	None – Cut out

[a] Not acceptable when impact testing is required or for vessels in fatigue service.

8.7 Standard hydrostatic test

For a vessel designed according to testing group 1 or 3 the test pressure shall be not less than that determined by EN 13445-5:2021, 10.2.3.3.

EN 13445-5:2021, 10.2.3.3.2 is not applicable.

9 Finishing operations

The requirements of EN 13445-4:2021+A1:2023, Clause 13 shall apply.

Annex A
(normative)

Grouping system for titanium and titanium alloys

Titanium and titanium alloys shall be grouped as shown in Table A.1.

Table A.1 — Grouping system for titanium alloys from CEN ISO/TR 15608:2017

Group	Sub-group	Type of titanium and titanium alloys
51		Unalloyed titanium
	51.1	Titanium with $O_2 < 0,20$ %
	51.2	Titanium with $0,20\ \% < O_2 \leq 0,25\ \%$
	51.3	Titanium with $0,25\ \% < O_2 \leq 0,35\ \%$
	51.4	Titanium with $0,35\ \% < O_2 \leq 0,40\ \%$
52		Alpha alloys: Ti-0,2Pd; Ti-2,5Cu; Ti-5Al-2,5Sn; Ti-8Al-1Mo-1V; Ti-6Al-2Sn-4Zr-2Mo; Ti-6Al-2Nb-1Ta-0,8Mo
53		Alpha-beta alloys: Ti-3Al-2,5V; Ti-6Al-4V; Ti-6Al-6V-2Sn; Ti-7Al-4Mo
54		Near beta and beta alloys: Ti-10V-2Fe-3Al; Ti-13V-11Cr-3Al; Ti-11,5Mo-6Zr-4,5Sn; Ti-3Al-8V-6Cr-4Zr-4Mo
NOTE Not all materials are suitable for pressure vessels. See Annex B of this document.		

Annex B
(informative)

Designation of some titanium and titanium alloy materials

Table B.1 contains information on European and international standards for titanium and titanium alloys for pressure purposes.

Table B.1 — Designation of some titanium and titanium alloy materials

ISO material group	EN no.	EN name	ISO no.	ISO designation	DIN name	Werkstoff no.	ASTM grade	UNS no.	Type of titanium and titanium alloy
51			1	CPTi240	Ti1	3.7025	1	R50250	CPTi
51			2	CPTi345	Ti2	3.7035	2/2H [a]	R50400	CPTi
51			3	CPTi450	Ti3	3.7055	3	R50550	CPTi
52			7	TiCR0,18Pd345	Ti2Pd	3.7235	7/7H [a]	R52400	Ti-Pd
52					Ti1Pd	3.7225	11	R52250	Ti-Pd
52			12	TiCR0,3Mo0,75Ni483	TiNi0,8Mo0,3	3.7105	12	R53400	Ti-0,3Mo-0,8Mo
52			16	TiCR0,06Pd345			16/16H [a]	R52402	Ti-Pd
52							17	R52252	Ti-Pd
52			26	TiCR0,11Ru345			26/26H [a]	R52404	Ti-Ru
52							27	R52254	Ti-Ru
53			9	TiA3Al2,5V	TiAl3V2,5	3.7195	9	R56320	Ti-3Al-2,5V
53							28	R56323	Ti-3Al-2,5V-Ru

[a] Material is identical to the corresponding numeric grade (that is, Grade 2H = Grade 2) except for the higher guaranteed minimum UTS, and may always be certified as meeting the requirements of its corresponding numeric grade. In general over 99 % of materials in these grades will meet the 400 MPa minimum UTS value.

Annex C
(informative)

Materials

C.1 General

The materials listed in this annex are suitable for and may be employed in the manufacture of pressure vessels made of titanium and titanium alloys, provided that they comply with the requirements specified below together with the requirements given in the main body of this document, and provided that they have been undergone a particular material appraisal (PMA).

C.2 ISO material specifications

ISO 18762:2016 - Tubes of titanium and titanium alloys - Welded tubes for condensers and heat exchangers - Technical delivery conditions.

From ISO 18762 the following alloys in Table C.1 may be selected:

Table C.1 — ISO 18762 alloys

Grade	Designation
1	CPTi240
2	CPTi345
3	CPTi450
7	TiCR0,18Pd345
9	TiA3Al2,5V
12	TiCR0,3Mo0,75Ni483
16	TiCR0,06Pd345
26	TiCR0,11Ru345

C.3 ASME and ASTM material specifications

Table C.2 — ASME and ASTM specifications

Specification	Product form
ASME SB-265 / ASTM B265	Plate
ASME SB-338 / ASTM B338	Condenser and heat exchanger tubes
ASME SB-348 / ASTM B348	Bars
ASME SB-363 / ASTM B363	Fittings
ASME SB-381 / ASTM B381	Forgings
ASME SB-861 / ASTM B861	Seamless pipe
ASME SB-862 / ASTM B862	Welded pipe

From the standards in Table C.2 the following alloys in Table C.3 may be selected:

Table C.3 — ASME and ASTM alloys

ASME/ASTM Grade	UNS Number
1	R50250
2/2H	R50400
3	R50550
7/7H	R52400
9	R56320
11	R52250
12	R53400
16/16H	R52402
17	R52252
26/26H	R52404
27	R52254
28	R56323

C.4 DIN material specifications

Table C.4 — DIN specifications

Specification	Product form
DIN 17860	Plate
DIN 17861	Seamless tubes
DIN 17862	Bars
DIN 17864	Forgings

From the standards in Table C.4 the following alloys may be selected:

Table C.5 — DIN alloys

Name	Werkstoff no.
Ti1	3.7025
Ti2	3.7035
Ti3	3.7055
Ti2Pd	3.7265
TiAl3V2,5	3.7195
Ti1Pd	3.7225
TiNi0,8Mo0,3	3.7105

Annex D
(informative)

Physical properties of titanium and titanium alloys

D.1 Definitions

D.1.1 Density

The density ρ_{20} of titanium and titanium alloys at 20 °C may be taken as 4510 kg/m³ for material groups 51 and 52, and 4480 kg/m³ for material group 53. The density at temperature T may be calculated from the equation given in EN 13445-3:2021, O.3.1. The linear coefficient of thermal expansion $\beta_{20,T}$ is obtained from D.2 of this annex.

D.1.2 Poisson's ratio

The value of Poisson's ratio ν for all titanium alloys, independent of temperature, may be taken as

$\nu = 0{,}32$

D.2 Physical properties of titanium and titanium alloys

D.2.1 General

The physical properties may be calculated by polynomials using Formula (O.4-1) in EN 13445-3:2021, Annex O, or may be read from Figures D.1 and D.2 of this document.

For the purpose of evaluating the physical properties the temperature T should not exceed the following limits:

Material groups 51 and 52 $\quad 0\ °C \leq T < 400\ °C$

Material group 53 $\quad 0\ °C \leq T < 300\ °C$

D.2.2 Polynomial coefficients

The polynomial coefficients for evaluating the modulus of elasticity and coefficient of linear thermal expansion are given in Tables D.1 and D.2.

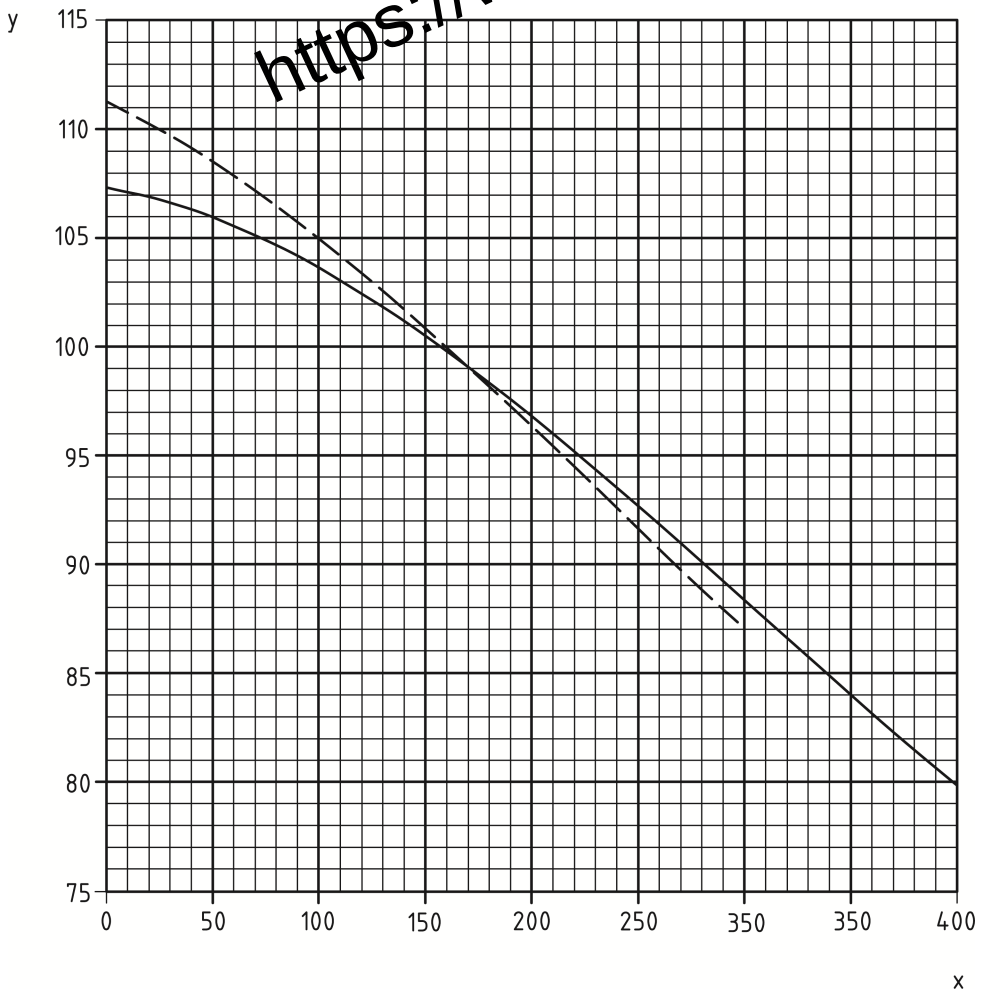
Table D.1 — Polynomial coefficients for modulus of elasticity

Modulus of elasticity E_T 10^3 MPa	**Coefficients for polynomials for temperature T in °C**			
Material group	c_0	c_1	c_2	c_3
51 and 52	107,3	$-1{,}6 \times 10^{-2}$	$-2{,}338 \times 10^{-4}$	$2{,}55 \times 10^{-7}$
53	111,3	$-4{,}61 \times 10^{-2}$	$-1{,}98 \times 10^{-4}$	$2{,}737 \times 10^{-7}$

Table D.2 — Polynomial coefficients for linear thermal expansion

Linear thermal expansion $\beta_{20,T}$ µm/(m K) (= 10^{-6} K^{-1})	**Coefficients for polynomials for temperature T in °C**			
Material group	c_0	c_1	c_2	c_3
51 and 52	8,220	$4{,}46 \times 10^{-3}$	$1{,}614 \times 10^{-5}$	$2{,}54 \times 10^{-8}$
53	8,309	$5{,}024 \times 10^{-3}$	$-9{,}81 \times 10^{-6}$	$1{,}374 \times 10^{-8}$

D.2.3 Figures for physical properties of titanium and titanium alloys



Key

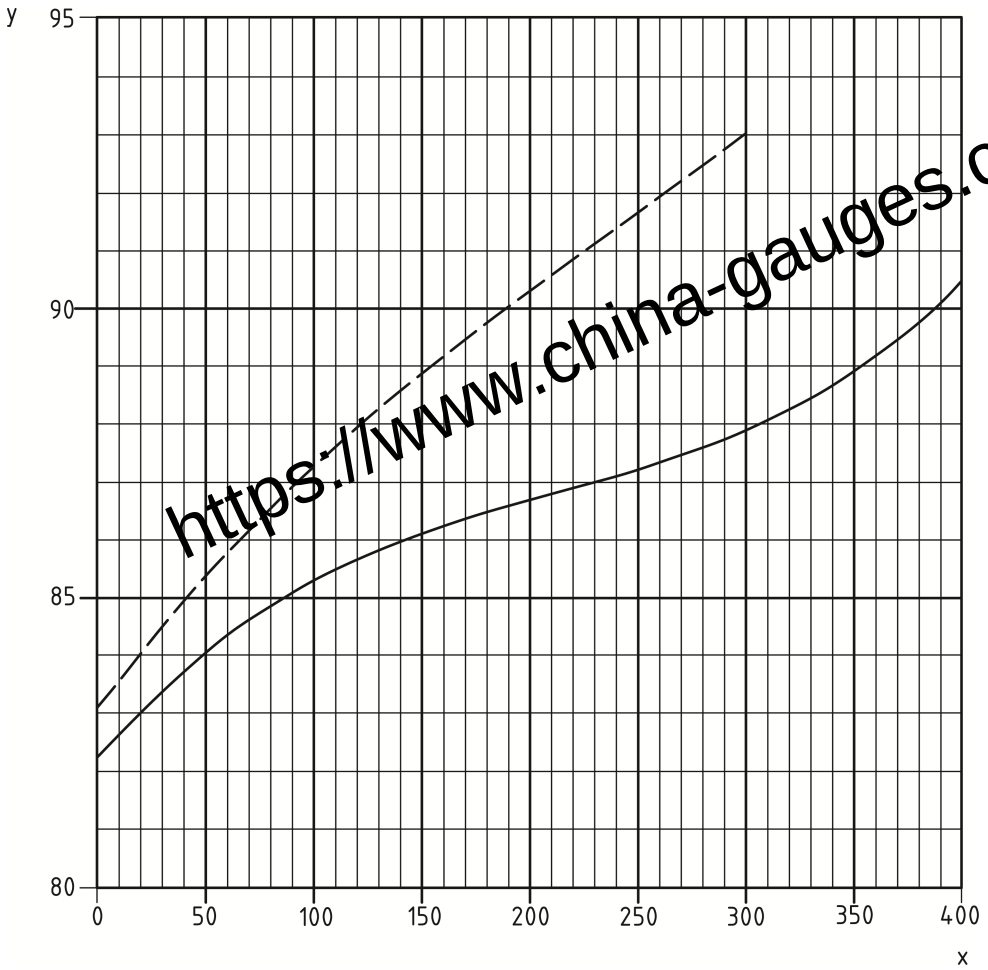
x temperature °C

y $E\ 10^3$ MPa

_____ groups 51 and 52

_ __ _ group 53

Figure D.1 — Modulus of elasticity of titanium and titanium alloys



Key

x	temperature °C
y	β µm/(m·K)
———	groups 51 and 52
— — —	group 53

Figure D.2 — Coefficient of linear thermal expansion of titanium and titanium alloys

Annex E
(informative)

Creep data for unalloyed titanium

Table E.1 — Creep rupture strength of titanium (reference data from DIN 17869:1992

Name	Creep rupture strength $R_{m/T/t}$ MPa at a temperature (in °C) of													
	20	75	100	150	200	250	300	20	75	100	150	200	250	300
	Design lifetime 10 000 h							Design lifetime 100 000 h						
Ti1	220	175	160	150	130	110	–	200	160	145	130	120	90	–
Ti2	320	230	205	196	188	176	160	280	215	195	191	186	172	150
Ti3	368	279	255	233	230	214	185	340	257	242	232	230	211	178

Annex ZA
(informative)

Relationship between this European Standard and the Essential Requirements of Directive 2014/68/EU aimed to be covered

This European Standard has been prepared under a Commission's standardization request M/601 to provide one voluntary means of conforming to essential requirements of Directive 2014/68/EU on the harmonization of the laws of the Member States relating to the making available on the market of pressure equipment.

Once this standard is cited in the Official Journal of the European Union under that Directive, compliance with the normative 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 Annex I of Directive 2014/68/EU

Essential Requirements of Directive 2014/68/EU	Clause(s)/sub-clause(s) of this EN	Remarks/Notes
2.2.1, paragraph 6	6.8	Corrosion and erosion, fatigue, etc. Fatigue only
2.2.3 (a)	6.1, 6.6, 6.7, 6.8	Calculation method – Design by Formula (DBF)
2.2.3 (b), paragraph 6	6.3	Calculation method – Appropriate joint factors
3.1.1	7.7	Preparation of the component parts – Joint preparation
3.1.1	7.14	Preparation of the component parts – Forming
3.1.2, paragraph 2	7.5, 7.11, 7.12, 7.13	Properties of permanent joints. Permanent joints other than welding are not covered
3.1.4	7.15, 7.16, 7.17, 7.18	Heat treatment. Materials in groups 51.3 and 53, and annealing hold time are not covered
3.2.1	8.1	Final inspection – Internal and surface defect
3.2.2	8.7	Proof test
4.1 (a)	5.5, 7.5, 7.11	Prevention of brittle fracture. EN 13445-2:2021+A1:2023, Annex B method 1 and 2 only
4.3	5.4	Material documentation

Essential Requirements of Directive 2014/68/EU	**Clause(s)/sub-clause(s) of this EN**	**Remarks/Notes**
7.1	6.4	Specific quantitative requirements – Allowable stresses – Equivalent overall level of safety
7.2	6.3	Specific quantitative requirements – Joint coefficient – Equivalent overall level of safety
7.5	5.5	Specific quantitative requirements – Material characteristics – Ductility – Equivalent overall level of safety. EN 13445-2:2021+A1:2023, Annex B method 1 and 2 only

WARNING 1 — Presumption of conformity stays valid only as long as a reference to this European Standard is maintained in the list published in the Official Journal of the European Union. Users of this standard should consult frequently the latest list published in the Official Journal of the European Union.

WARNING 2 — Other Union legislation may be applicable to the product(s) falling within the scope of this standard.

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[1] EN ISO 15614-1:2017[1], *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Arc and gas welding of steels and arc welding of nickel and nickel alloys (ISO 15614-1:2017)*

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[3] ISO 18762:2016, *Tubes of titanium and titanium alloys — Welded tubes for condensers and heat exchangers — Technical delivery conditions*

[4] ASME II Part B, 2023 Edition, SB-265 / ASTM B265-20a, *Standard Specification for Titanium and Titanium Alloy Strip, Sheet, and Plate*

[5] ASME II Part B, 2023 Edition, SB-338 / ASTM B338-17, *Standard Specification for Seamless and Welded Titanium and Titanium Alloy Tubes for Condensers and Heat Exchangers*

[6] ASME II Part B, 2023 Edition, SB-348 / ASTM B348-21, *Standard Specification for Titanium and Titanium Alloy Bars and Billets*

[7] ASME II Part B, 2023 Edition, SB-363 / ASTM B363-23, *Standard Specification for Seamless and Welded Unalloyed Titanium and Titanium Alloy Welding Fittings*

[8] ASME II Part B, 2023 Edition, SB-381 / ASTM B381-21, *Standard Specification for Titanium and Titanium Alloy Forgings*

[9] ASME II Part B, 2023 Edition, SB-861 / ASTM B861-19, *Standard Specification for Titanium and Titanium Alloy Seamless Pipe*

[10] ASME II Part B, 2023 Edition, SB-862 / ASTM B862-19, *Standard Specification for Titanium and Titanium Alloy Welded Pipe*

[11] DIN 17850:1990, *Titan; Chemische Zusammensetzung (Titanium; chemical composition)*

[12] DIN 17851:1990, *Titanlegierungen; Chemische Zusammensetzung (Titanium alloys; chemical composition)*

[13] DIN 17860:2010, *Bänder und Bleche aus Titan und Titanlegierungen - Technische Lieferbedingungen (Titanium and titanium alloy strip, sheet and plate - Technical conditions of delivery)*

[14] DIN 17861:1990, *Nahtlose kreisförmige Rohre aus Titan und Titanlegierungen; Technische Lieferbedingungen (Seamless circular titanium and titanium alloy tubes; Technical delivery conditions)*

[15] DIN 17862:2012, *Stangen aus Titan und Titanlegierungen - Technische Lieferbedingungen (Titanium and titanium alloy bars - Technical delivery conditions)*

[1] Document impacted by +A1:2019.

[16] DIN 17864:2012, *Schmiedestücke aus Titan und Titan-Knetlegierungen (Freiform- und Gesenkschmiedeteile) - Technische Lieferbedingungen (Titanium and titanium wrought alloys forgings (hammer and drop forgings) - Technical specification)*

[17] DIN 17869:1992, *Werkstoffeigenschaften von Titan und Titanlegierungen; Zusätzliche Angaben (Material properties of titanium and titanium alloys; additional data)*

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