INTERNATIONAL STANDARD

ISO 21028-2

Second edition
2018-03

Cryogenic vessels — Toughness requirements for materials at cryogenic temperature —

Part 2: Temperatures between -80 degrees C and -20 degrees C

Récipients cryogéniques — Exigences de ténacité pour les matériaux à température cryogénique —

Partie 2: Températures comprises entre -80 degrés C et -20 degrés C

Reference number
ISO 21028-2:2018(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

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

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

This document was prepared by Technical Committee ISO/TC 220, *Cryogenic vessels.*

This second edition cancels and replaces the first edition (ISO 21028-2:2004), which has been technically revised.

The main changes compared to the previous edition are as follows:

— tables and figures on impact test temperatures and design reference have been modified;

— Annex B has been added to present an example of calculation of the lowest temperature authorized during operation.

A list of all parts in the ISO 21028 series can be found on the ISO website.

Introduction

The use of materials at low temperatures entails special problems which should be addressed. Consideration should be given, in particular, to changes in mechanical characteristics, expansion and contraction phenomena and the thermal conduction of the various materials. The most important property to be considered is the material toughness at low temperature.

Cryogenic vessels — Toughness requirements for materials at cryogenic temperature —

Part 2: Temperatures between -80 degrees C and -20 degrees C

1 Scope

This document specifies the toughness requirements of metallic materials for use at temperatures between −20 °C and −80 °C to ensure their suitability for cryogenic vessels. This document is applicable to fine-grain and low-alloyed steels with specified yield strength ≤460 N/mm^2, aluminium and aluminium alloys, copper and copper alloys and austenitic stainless steels.

NOTE For steel materials listed in EN 13445-2 or EN 13480-2 or for steel materials and weldings complying with the same fundamental safety requirements, the requirements for prevention of brittle fracture at low temperatures according to EN 13445-2:2014, Annex B, method 2, or EN 13480-2:2012, Annex B, method 2 can be applied.

2 Normative references

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

ISO 148 (all parts), *Metallic materials — Charpy pendulum impact test*

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

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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 https://www.iso.org/obp

3.1
minimum metal temperature
T_M
lowest temperature defined for each of the conditions:

— temperature during normal operation;

— temperature during start-up and shut down procedures;

— temperature which may occur during possible process upsets;

— temperature which may occur during pressure or leak testing;

— ambient conditions.

Note 1 to entry: See also *temperature adjustment term* (3.2) and *design reference temperature* (3.3).

3.2
temperature adjustment term
T_S
term relevant to the calculation of the *design reference temperature*, T_R (3.3) and dependent on the pressure-induced principal membrane stress at the appropriate minimum metal temperature

3.3
design reference temperature
T_R
temperature used for determining the impact energy requirements themselves, determined by adding the *temperature adjustment term*, T_S (3.2) to the *minimum metal temperature*, T_M (3.1):

$$T_R = T_M + T_S$$

Note 1 to entry: All applicable combinations of the temperatures T_M and T_S are to be considered and the lowest possible T_R value used for the determination of the required material *impact test temperature* (3.4).

3.4
impact test temperature
T_{KV}
temperature at which the required impact energy has to be achieved

Note 1 to entry: See Clause 5.

3.5
impact energy
KV
energy determined from Charpy V-notch tests

Note 1 to entry: These tests are performed in accordance with ISO 148 (all parts).

3.6
reference thickness
e_B
thickness of a component used to relate the *design reference temperature*, T_R (3.3) of the component with its required *impact test temperature*, T_{KV} (3.4)

Note 1 to entry: The reference thickness is based on the nominal thickness (including corrosion allowance) and can be as defined in Table 6. For butt-welded components, it is the nominal wall thickness of the component at the edge of the weld preparation.

Note 2 to entry: See Figures 1 to 5.

4 Symbols

Symbol	Definition	Unit
A-W	as-welded	
a	depth of the defect	mm
e	wall thickness	mm
e_B	reference thickness	mm
KV	impact energy	J

K_C	stress intensity factor	J
K_{IC}	critical stress intensity	J
K_0	constant 25 MPa√m	
PWHT	post-welded heat-treatment	
R_{el}	yield point	N/mm^2 or J
R_p	proof stress	N/mm^2 or J
SMYS	specified minimum yield strength	N/mm^2
t	component thickness	mm
T_{KV}	impact test temperature	°C
T_M	minimum metal temperature	°C
T_R	design reference temperature	°C
T_S	temperature adjustment term	°C
β	constant 1/60	
σ	stress coefficient	
π	coefficient	
ΔT_e	correction term	°C

5 Requirements for steels with specified yield strength ≤460 N/mm^2

5.1 General

This method, based on fracture mechanics, may be used to determine the requirements to avoid brittle fracture in C, CMn, fine-grain and low-alloy steels with a SMYS ≤460 N/mm^2.

In this procedure, the impact test temperature, T_{KV}, is not equal to the design reference temperature, T_R.

Parent material, welds and heat-affected zones shall meet the impact energy (KV) and impact test temperature, T_{KV}, requirements given in Table 1 for design reference temperatures, T_R, and reference thicknesses. Values of T_R shall be calculated from T_M using the values of T_S given in 5.2.

For materials with SMYS ≤310 N/mm^2, the impact energy at T_{KV} given in Figure 1 and Figure 2 shall be 27 J.

For materials with a SMYS >310 N/mm^2, the impact energy at T_{KV} given in Figure 1 and Figure 2 shall be 40 J.

Where 27 J is specified in the product standard, Figure 3 for the post-weld heat-treated condition applies.

For the as-welded case with SMYS in the range >310 N/mm^2 and ≤360 N/mm^2, Figure 4 applies.

For minimum yield strength >360 N/mm^2, Figure 5 applies.

Table 1 — Impact energy requirements

Specified min. yield strength of base material N/mm^2	Required impact energy KV (on 10 mm × 10 mm test pieces) J	Figure defining required T_{KV}	
		Non-welded/ Post-weld heat-treated (PWHT)	As-welded (A-W)
≤310	27	1	2
>310 to ≤360	40	1	2
	27	3	4
>360	40	1	2
	27	3	5

5.2 Temperature adjustments

T_S is a temperature adjustment which may be used if the pressure-induced principal membrane stress does not exceed the percentage of the maximum allowable design stress or 50 N/mm^2 given in Table 2.

Table 2 — Temperature adjustments

Condition	Percentage of maximum allowable design stress			Membrane stress[b]
	>75 % to ≤100 %	>50 % to ≤75 %	≤50 %	≤50 N/mm^2
Non-welded, final post-weld heat treated[a]	0 °C	+10 °C	+25 °C	+50 °C
As-welded and reference thickness <30 mm	0 °C	0 °C	0 °C	+40 °C

[a] Also applicable for equipment where all nozzles and non-temporary welded attachments are first welded to vessel components and these sub-assemblies are post-weld heat-treated before being assembled into the equipment by butt-welding, but the main seams are not subsequently post-weld heat-treated.

[b] In this case, the membrane stress should take account of internal and external pressure and dead weight.

Annex A provides a case proposal for the technical justification for temperature adjustment term.

5.3 Procedure for base material <10 mm thick

Minimum T_R values are given in Table 3 which shall be used when the base material is less than 10 mm thick and the testing temperature ,T_{KV}, is 20 °C. The impact energy requirements are as specified in the relevant materials standards.

If these materials are to be used below the T_R values given in Table 3, the testing shall be performed in accordance with the relevant curve for 10 mm in Figure 1 to Figure 5. The required energies for the sub-sized specimens are given in Table 4.

Table 3 — Minimum T_R values for base material <10 mm thick and T_{KV} = 20 °C

Thickness mm	As-welded (A-W)	Post-weld heat-treated (PWHT)
	°C	
8	−20	−35
6	−25	−40
4	−40	−55
2	−55	−70

An example of calculation of the lowest temperature authorized during operation is given in Annex B.

6 General test requirements

6.1 General

Where impact tests are required, they shall be Charpy V-notched tests in accordance with ISO 148 (all parts). The impact energy requirements shall be met in the base material, heat-affected zone and weld metal. The specimen position shall be in accordance with ISO 9016. From each sample, three specimens shall be tested for each of the required positions and test temperatures. The mean value of the three specimens shall be at least equal to the impact energy requirement. Only one specimen may show a lower value, but this value shall not be less than 70 % of this requirement.

The required values for base material refer to the transverse direction. If transverse properties are not obtainable, the minimum impact energy requirements in longitudinal directions specified for transverse test pieces shall be multiplied by a factor of 1,5 for C, CMn, fine-grained and low-alloyed steels with a minimum specified yield strength ≤460 N/mm^2. For other materials, refer to the product standard.

6.2 Sub-sized specimens

If the base material is less than 10 mm thick, the energy requirements shall be as given in Table 4.

Alternatively, where proportional reduced energy requirements are preferred, Table 5 shall be applied.

Table 4 — Corresponding impact requirements for sub-sized Charpy V-notched specimen if base material <10 mm thick

Impact requirement for full size as required by Table 1 J	Corresponding impact requirement for sub-sized specimen J	
10 mm × 10 mm	10 mm × 7,5 mm	10 mm × 5 mm
27	20	14
40	30	20

6.3 Sub-sized specimens for components from which it is impossible to extract specimens of section size equal to reference thickness

There are cases of unusually shaped components and/or weld procedures and manufactured production plates where the Charpy V-notched specimen extracted is either <10 mm or not representative of the section thickness.

In these cases, sub-sized specimens shall be tested at lower impact test temperatures, in order to model the behaviour of a full thickness specimen, using temperature shifts in accordance with Table 5.

Impact tests should be performed on the maximum thickness which can be extracted from the component under consideration.

Table 5 — Equivalent impact energy requirements when sub-sized specimens extracted from thicker sections

Required impact energy KV J	Specimen geometry mm	Sub-sized specimen requirement		
		KV J	Specimen geometry mm × mm	Shift of impact test temperature °C
27	10 × 10	20	7,5 × 10	$T_{KV} - 5$
		14	5,0 × 10	$T_{KV} - 20$
40	10 × 10	30	7,5 × 10	$T_{KV} - 5$
		20	5,0 × 10	$T_{KV} - 20$
20	7,5 × 10	14	5,0 × 10	$T_{KV} - 15$
30	7,5 × 10	20	5,0 × 10	$T_{KV} - 15$

7 Welds

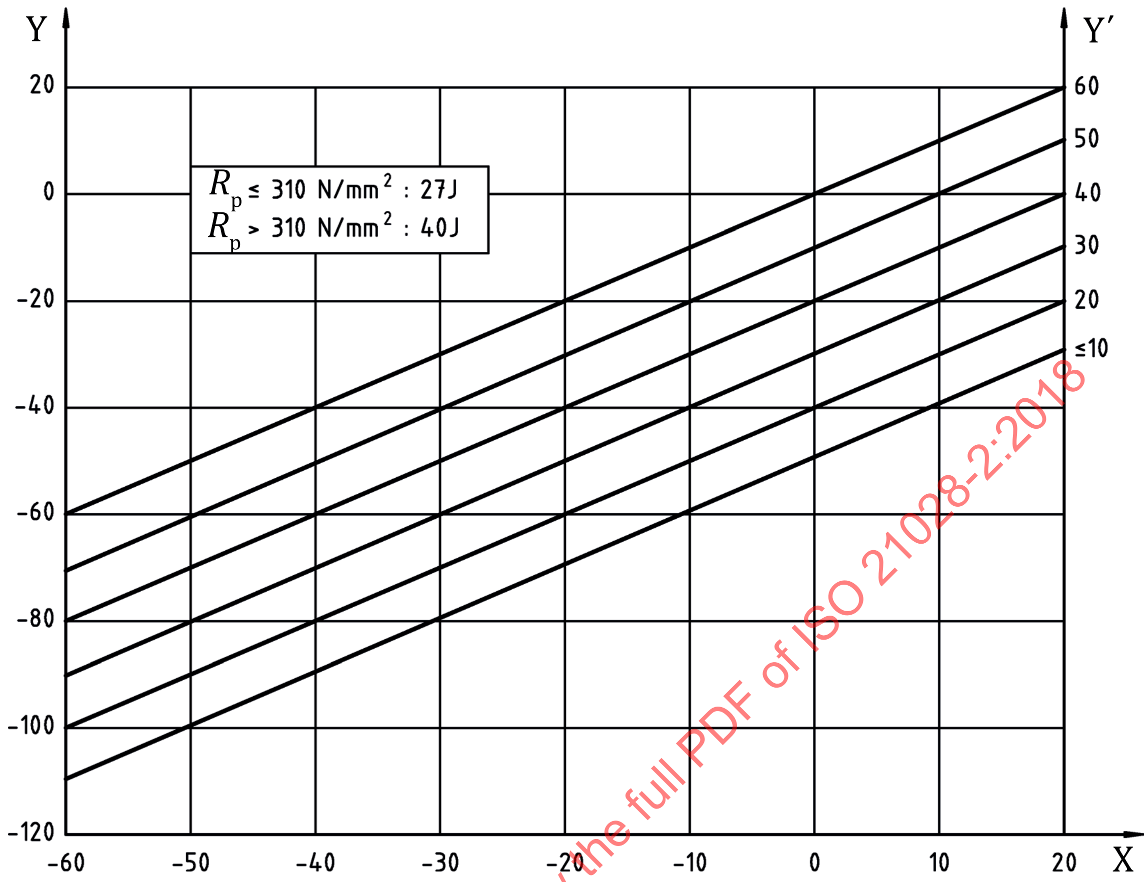
When materials are to be joined by welding, the choice of consumables and procedures (see ISO 9016) shall ensure that the required impact energy properties are achieved in weld regions and heat-affected zones, when tested in accordance with Clause 5.

The required impact energy shall be at least equal to the specified impact energy for the base metal.

8 Requirements for aluminium and aluminium alloys, copper and copper alloys and austenitic stainless steels

Toughness of aluminium and aluminium alloys, copper and copper alloys and austenitic stainless steels is inherently high enough at low temperature to render impact tests unnecessary.

Welds of austenitic stainless steels shall be impact tested if the material of the weld consumable/filler metal has a ferrite content exceeding 10 %.



Key

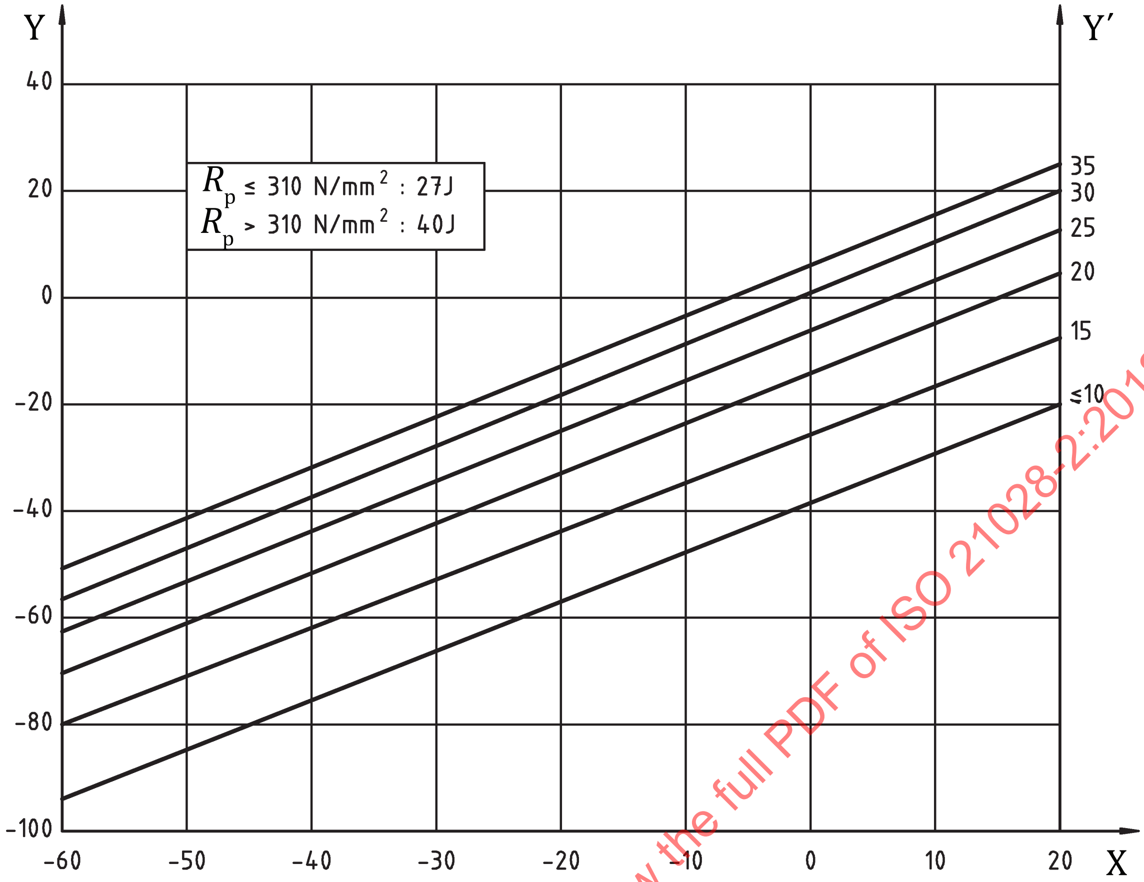
Y T_R design reference temperature, °C

X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress, N/mm^2

Figure 1 — Design reference and impact test temperatures — Non-welded/Post-weld heat-treated condition



Key

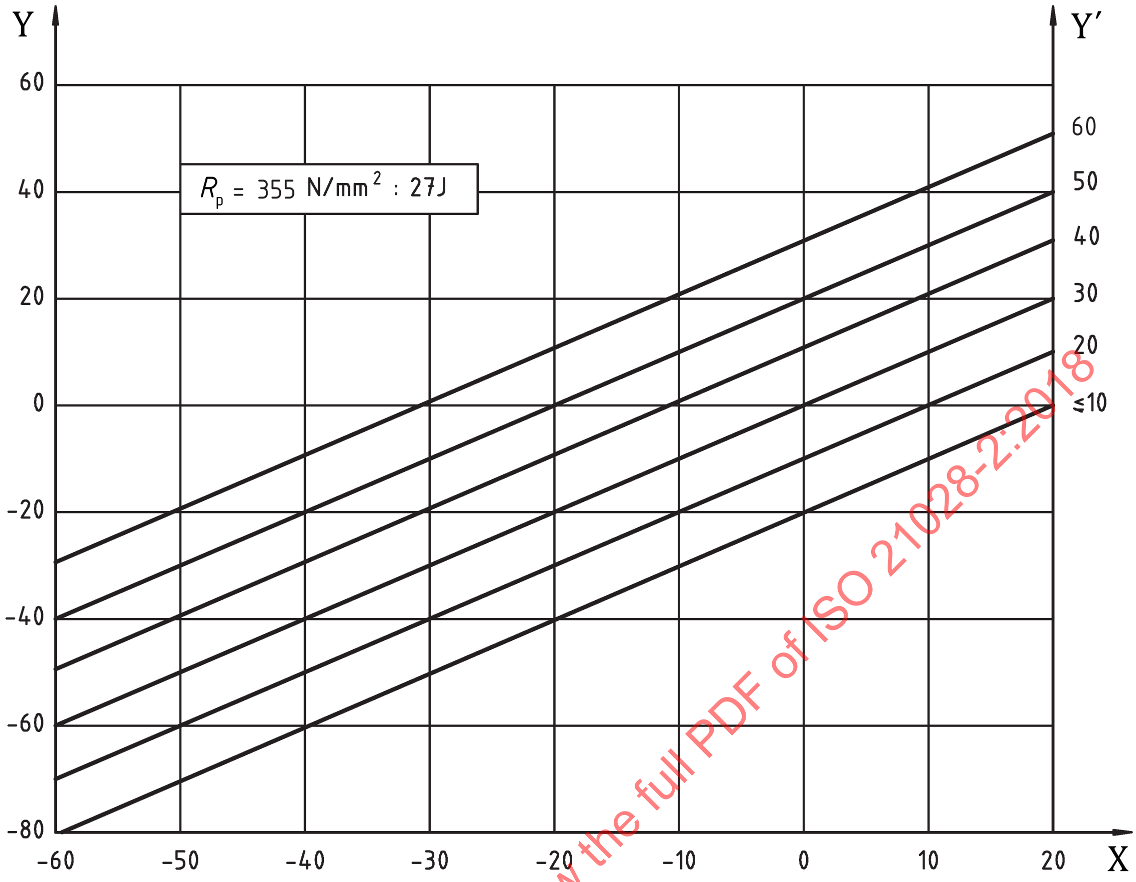
Y T_R design reference temperature, °C

X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress, N/mm^2

Figure 2 — Design reference and impact test temperatures — As-welded condition



Key

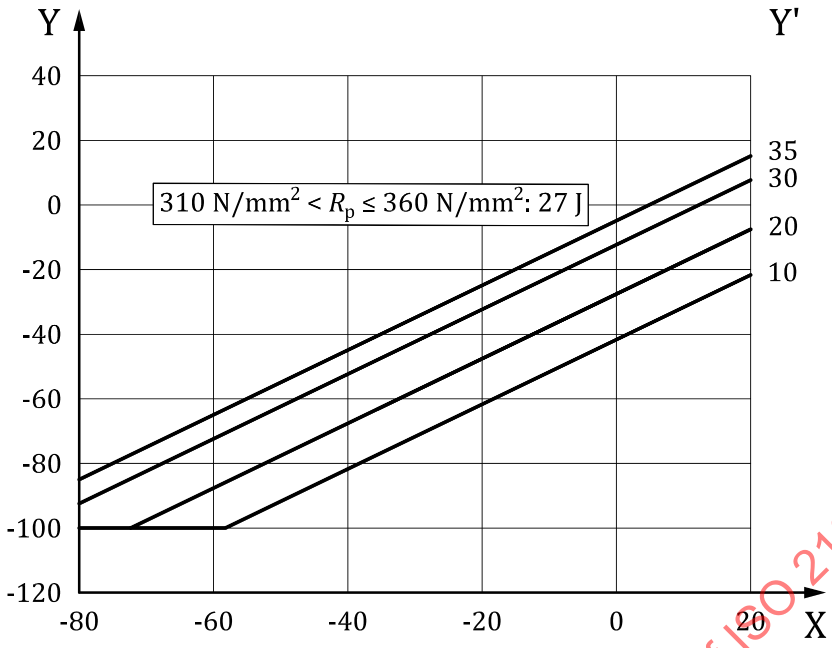
Y T_R design reference temperature, °C

X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress, N/mm²

Figure 3 — Design reference and impact test temperatures — Non-welded/Post-weld heat-treated condition



Key

Y T_R design reference temperature, °C

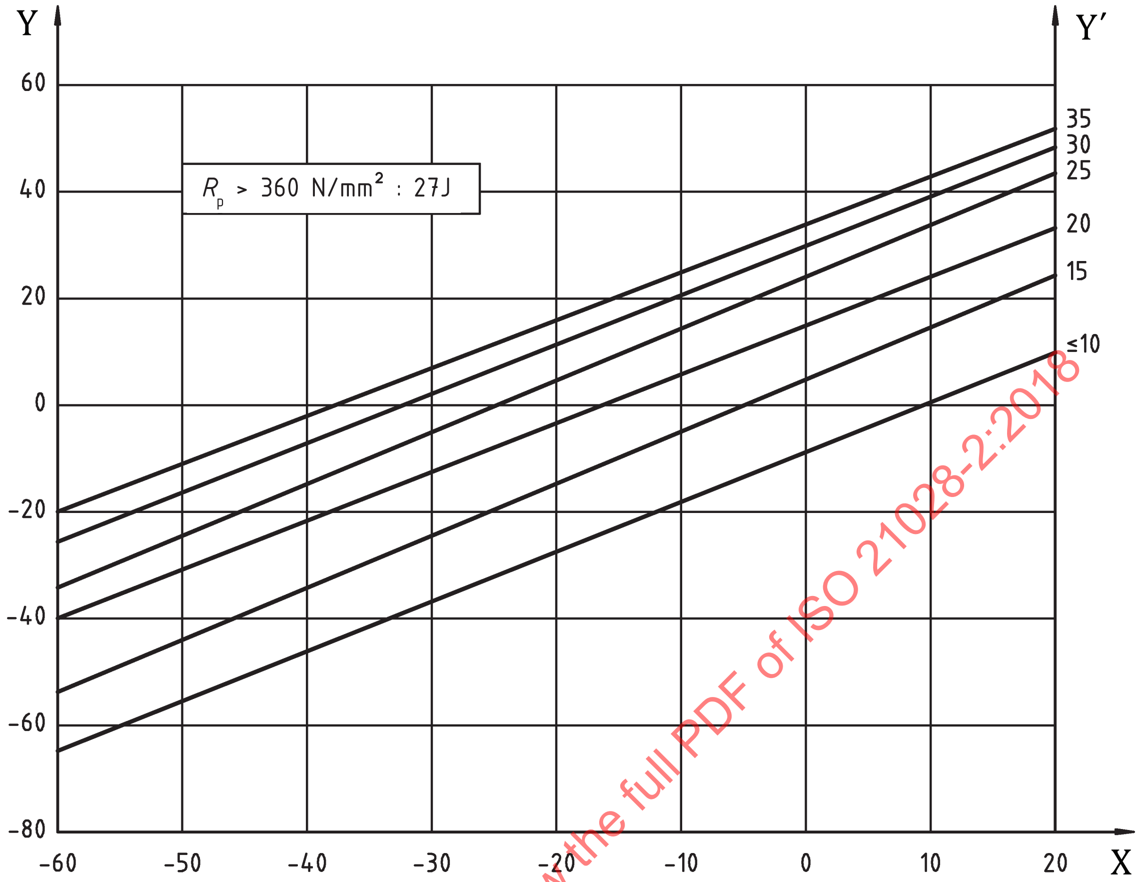
X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress, N/mm²

Figure 4 — Design reference and impact test temperatures — As-welded condition (with SMYS in the range > 310 N/mm² and ≤ 360 N/mm²)

NOTE Figure 4 is applicable to European materials covered by EN 13445-2/EN 13480-2. Verifications of suitability need to be made if applied to non-European materials; for this verification, see the principle of EN 13445-2/EN 13480-2.



Key

Y T_R design reference temperature, °C

X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress, N/mm^2

Figure 5 — Design reference and impact test temperature — As-welded condition (minimum yield strength > 360 N/mm^2)

Table 6 — Reference thicknesses

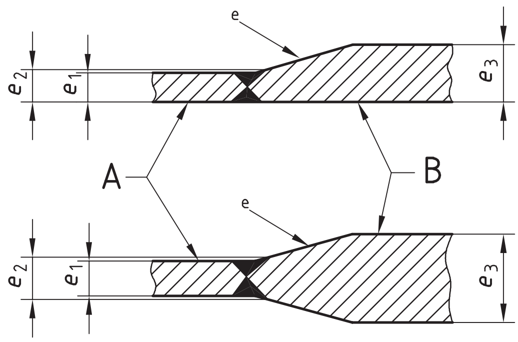
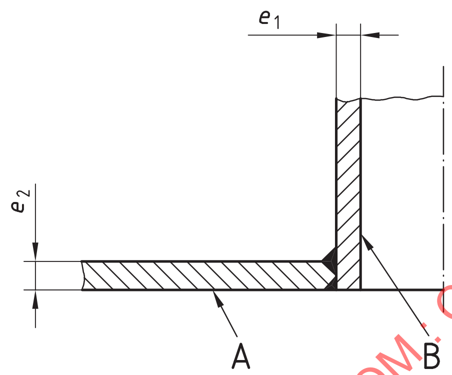
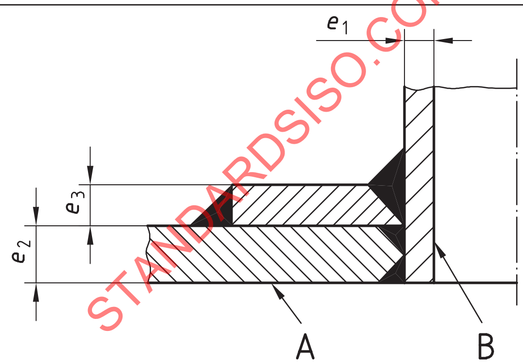
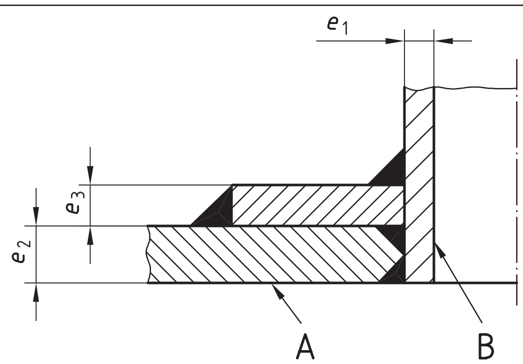
Construction detail	As-welded or post-weld heat-treated	Reference thickness e_B (where $e_B = e_1, e_2, e_3$ or e_f)		
		Part A	Weld	Part B
Butt-welded components of unequal thickness	A-W	e_1	e_2	e_2 check e_3 in Figure 2 or Figure 4[a]
	PWHT	e_1	e_2	e_3
Branches and nozzles	A-W	e_2	e_2	e_1
	PWHT	e_2	e_2	e_1
	A-W	e_2	e_2 or e_3 if thicker	e_1
	PWHT	e_2	e_2 or e_3 if thicker	e_1
	A-W	e_2	e_2 or e_3 if thicker	e_1
	PWHT	e_2	e_2 or e_3 if thicker	e_1

Table 6 *(continued)*

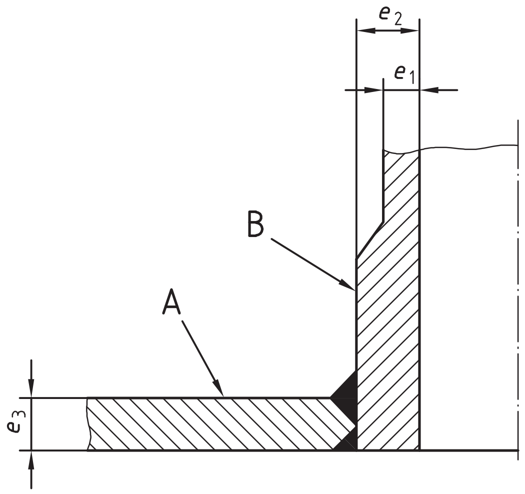
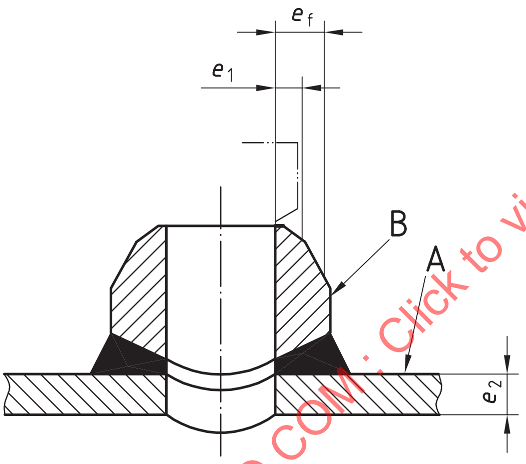
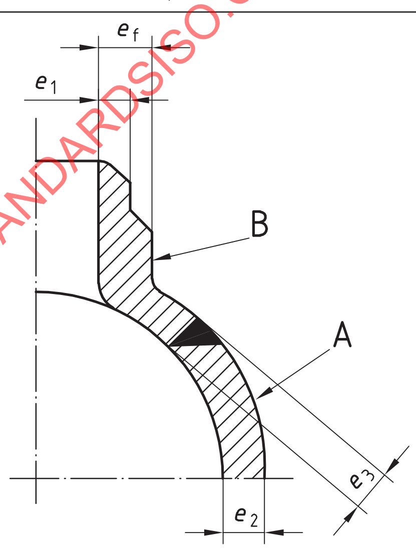
Construction detail	As-welded or post-weld heat-treated	Reference thickness e_B (where $e_B = e_1, e_2, e_3$ or e_f)		
		Part A	Weld	Part B
	A-W	e_3	e_2 or e_3 if thicker	e_2
	PWHT	e_3	e_2 or e_3 if thicker	e_2
	A-W	e_2	e_2	e_1 or e_f /4 if thicker
	PWHT	e_2	e_2	e_1[b] or e_f/4 if thicker if necessary, check e_1 in Figure 1 or 3
	A-W	e_2	e_3	e_3 or e_f /4 if thicker
	PWHT	e_2	e_3	e_3[c] or e_f /4 if thicker if necessary, check e_1 in Figure 1 or 3

Table 6 *(continued)*

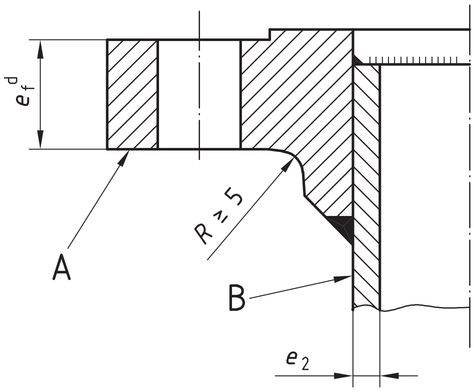
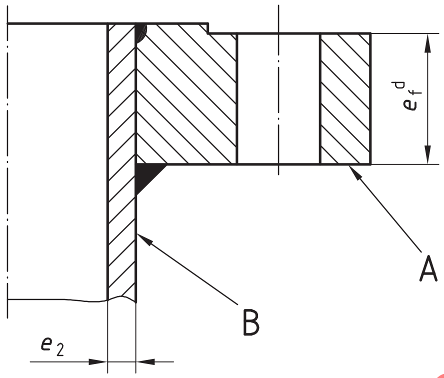
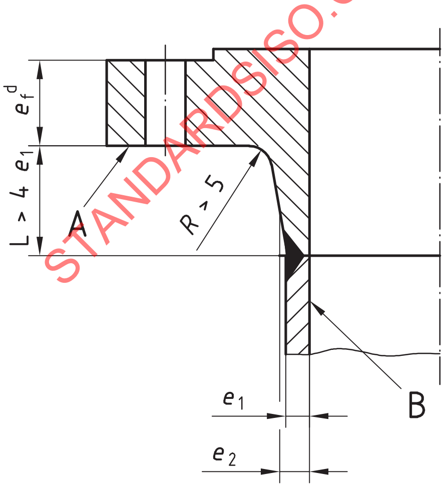
Construction detail	As-welded or post-weld heat-treated	Reference thickness e_B (where $e_B = e_1, e_2, e_3$ or e_f)		
		Part A	Weld	Part B
Slip-on and plate flanges	A-W	$e_f/4$	e_2	e_2
	PWHT	$e_f/4$	e_2	e_2
	A-W	$e_f/4$	e_2	e_2
	PWHT	$e_f/4$	e_2	e_2
Forged or cast welding neck flanges	A-W	e_2[c] check $e_f/4$ in Figure 2 or 4	e_2	e_1
	PWHT	e_2 or $e_f/4$ if thicker	e_2	e_1

Table 6 *(continued)*

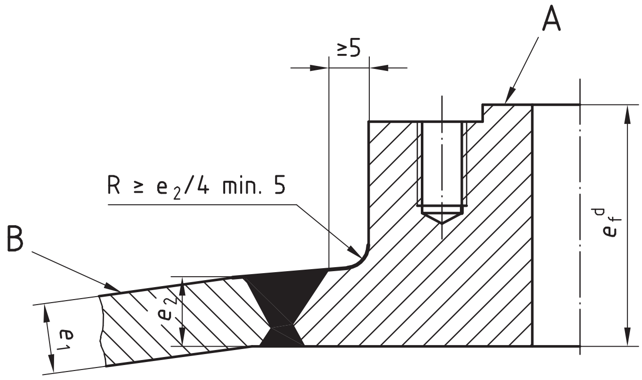
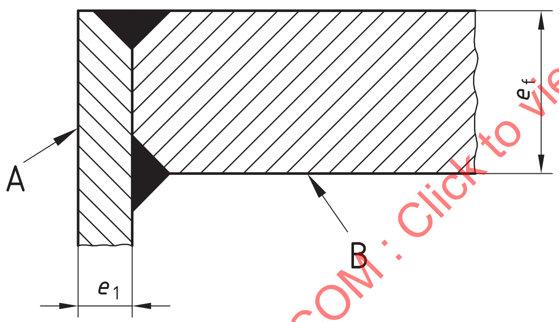
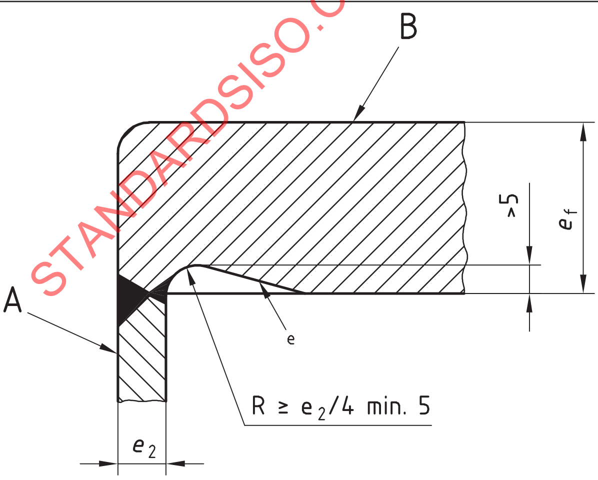
Construction detail	As-welded or post-weld heat-treated	Reference thickness e_B (where $e_B = e_1, e_2, e_3$ or e_f) Part A	Weld	Part B
Pad-type flanges	A-W	e_2[c] check $e_f/4$ in Figure 2 or 4	e_2	e_1
	PWHT	e_2 or $e_f/4$ if thicker	e_2	e_1
Flat ends	A-W	e_1	e_1	$e_f/4$ or e_1 if thicker
	PWHT	e_1	e_1	$e_f/4$ or e_1 if thicker
	A-W	e_2	e_2	e_2[c] check $e_f/4$ in Figure 2 or 4
	PWHT	e_2	e_2	$e_f/4$ or e_2 if thicker

Table 6 *(continued)*

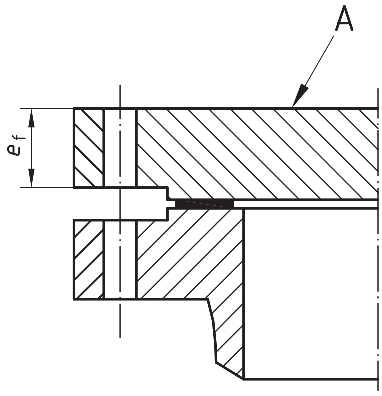
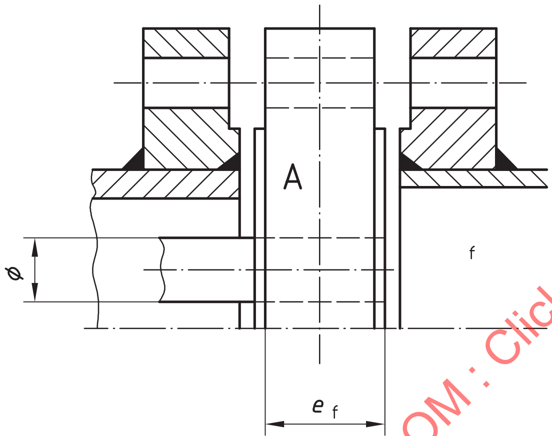
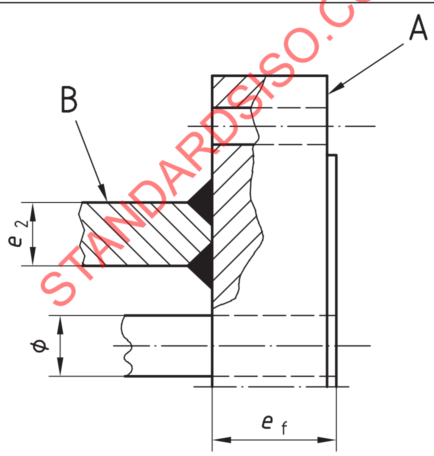
Construction detail	**As-welded or post-weld heat-treated**	**Reference thickness** e_B (where $e_B = e_1, e_2, e_3$ or e_f)		
		Part A	Weld	Part B
Covers and blind flanges	A-W	$e_f/4$	—	—
	PWHT	$e_f/4$	—	—
Tube plates	A-W	—	—	—
	PWHT	$e_f/4$	—	—
	A-W	$e_f/4$ or e_2 if thicker	e_2	e_2
	PWHT	$e_f/4$ or e_2 if thicker	e_2	e_2

Table 6 *(continued)*

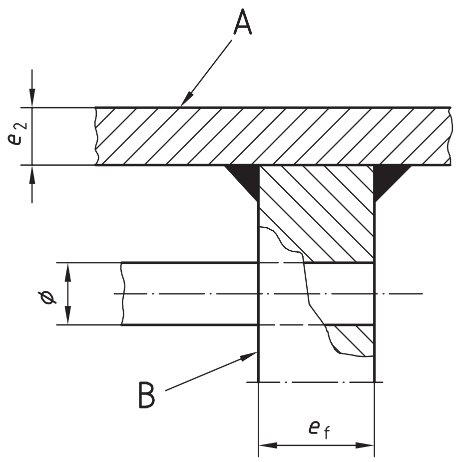
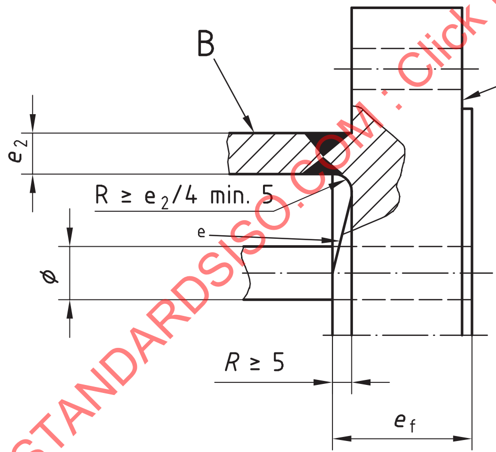
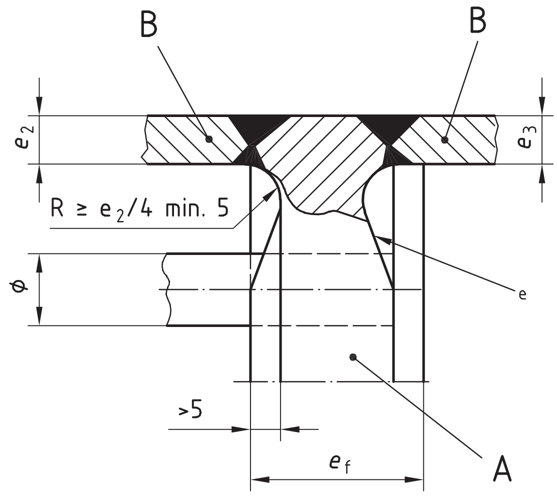
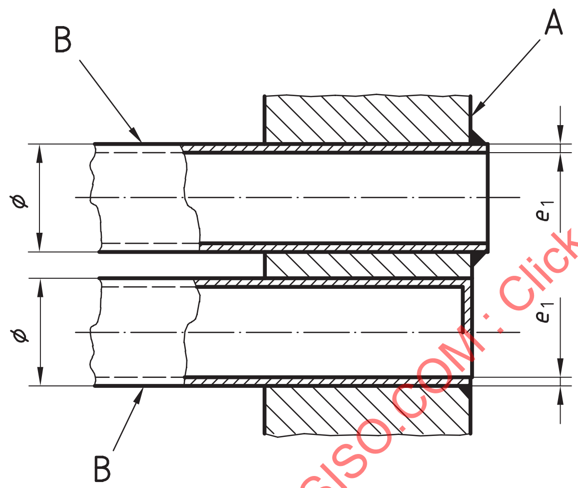
Construction detail	As-welded or post-weld heat-treated	Reference thickness e_B (where $e_B = e_1, e_2, e_3$ or e_f)		
		Part A	Weld	Part B
Welded into shell/channel  Preferably not to be used	A-W	$e_f/4$ or e_2 if thicker	e_2	e_2
	PWHT	$e_f/4$ or e_2 if thicker	e_2	e_2
Forged tube plate with stubs 	A-W	e_2[c] check $e_f/4$ in Figure 2 or 4	e_2	e_2
	PWHT	$e_f/4$ or e_2 if thicker	e_2	e_2

Table 6 *(continued)*

<table>
<tr><th rowspan="2">Construction detail</th><th rowspan="2">As-welded or post-weld heat-treated</th><th colspan="3">Reference thickness
e_B
(where $e_B = e_1, e_2, e_3$ or e_f)</th></tr>
<tr><th>Part A</th><th>Weld</th><th>Part B</th></tr>
<tr><td rowspan="2">
</td><td>A-W</td><td>e_2[a]
or e_3 if thicker
check $e_f/4$ in Figure 2 or 4</td><td>e_2
(e_3)</td><td>e_2
(e_3)</td></tr>
<tr><td>PWHT</td><td>$e_f/4$
or e_2
or e_3
if thicker</td><td>e_2
(e_3)</td><td>e_2
(e_3)</td></tr>
<tr><td rowspan="2">Tube-to-tube plate connection

</td><td>A-W</td><td>—</td><td>e_1</td><td>e_1</td></tr>
<tr><td>PWHT</td><td>—</td><td>e_1</td><td>e_1</td></tr>
</table>

[a] The minimum test temperature of the conditions: e_2 (A-W), e_3 (PWHT) shall be taken.

[b] The minimum test temperature of the conditions: e_1 (A-W), $e_f/4$ (PWHT) shall be taken.

[c] The minimum test temperature of the conditions: e_2 (A-W), $e_f/4$ (PWHT) shall be taken.

[d] e_f may be measured radially if advantageous.

[e] Slope 1:4.

[f] Not welded to shell or channel.

— Not applicable.