INTERNATIONAL STANDARD

ISO 21028-2

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Cryogenic vessels — Toughness requirements for materials at cryogenic temperature —

Part 2: **Temperatures between − 80 °C and − 20 °C**

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

Partie 2: Températures comprises entre − 80 °C et − 20 °C

Reference number
ISO 21028-2:2004(E)

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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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.

ISO 21028-2 was prepared by Technical Committee ISO/TC 220, *Cryogenic vessels*.

ISO 21028 consists of the following parts, under the general title *Cryogenic vessels — Toughness requirements for materials at cryogenic temperature*:

— *Part 1: Temperatures below − 80 °C*

— *Part 2: Temperatures between − 80 °C and − 20 °C*

Introduction

The use of materials at low temperatures entails special problems which have to be addressed. Consideration has to 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.

This part of ISO 21028 is based on European Standard EN 1252-2:2001.

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Cryogenic vessels — Toughness requirements for materials at cryogenic temperature —

Part 2:
Temperatures between – 80 °C and – 20 °C

1 Scope

This part of ISO 21028 specifies the toughness requirements of metallic materials for use at temperatures between – 20 °C and – 80 °C to ensure their suitability for cryogenic vessels. It is applicable to fine-grain and low-alloyed steels with specified yield strength ⩽ 460 N/mm², aluminium and aluminium alloys, copper and copper alloys and austenitic stainless steels.

2 Normative references

The following referenced documents are indispensable for the application 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 15614-1, *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*[1)]

3 Terms and definitions

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

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, and

— ambient conditions

NOTE See also 3.2 and 3.3.

1) To be published.

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 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 See Clause 5.

3.5
impact energy
KV
energy determined from Charpy V-notch tests performed in accordance with ISO 148.

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)

See Figures 1 to 5.

NOTE The reference thickness is based on the nominal thickness (including corrosion allowance) and shall 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

4 Requirements for steels with specified yield strength $\leqslant$ 460 N/mm^2

4.1 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 specified minimum yield strength $\leqslant$ 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 HAZ 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 4.2.

For materials with a specified minimum yield strength $>$ 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 minimum yield strength 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, ⩽ 360	40	1	2
	27	3	4
> 360	40	1	2
	27	3	5

4.2 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 % ; ⩽ 100 %	⩽ 75 %	⩽ 50 %	⩽ 50 N/mm^2
Non-welded, 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.

4.3 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_S 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

5 General test requirements

5.1 General

Where impact tests are required they shall be Charpy V-notched tests in accordance with ISO 148. 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 15614-1. 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 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 $\leqslant$ 460 N/mm^2. For other materials refer to the product standard.

5.2 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 — Impact requirements for sub-sized Charpy V-notched specimen if base material < 10 mm thick

Specimen geometry mm × mm		
10 × 10	10 × 7,5	10 × 5
27 J	22 J	19 J
40 J	32 J	28 J

5.3 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 procedure and 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	$T_{KV} - 15$

6 Welds

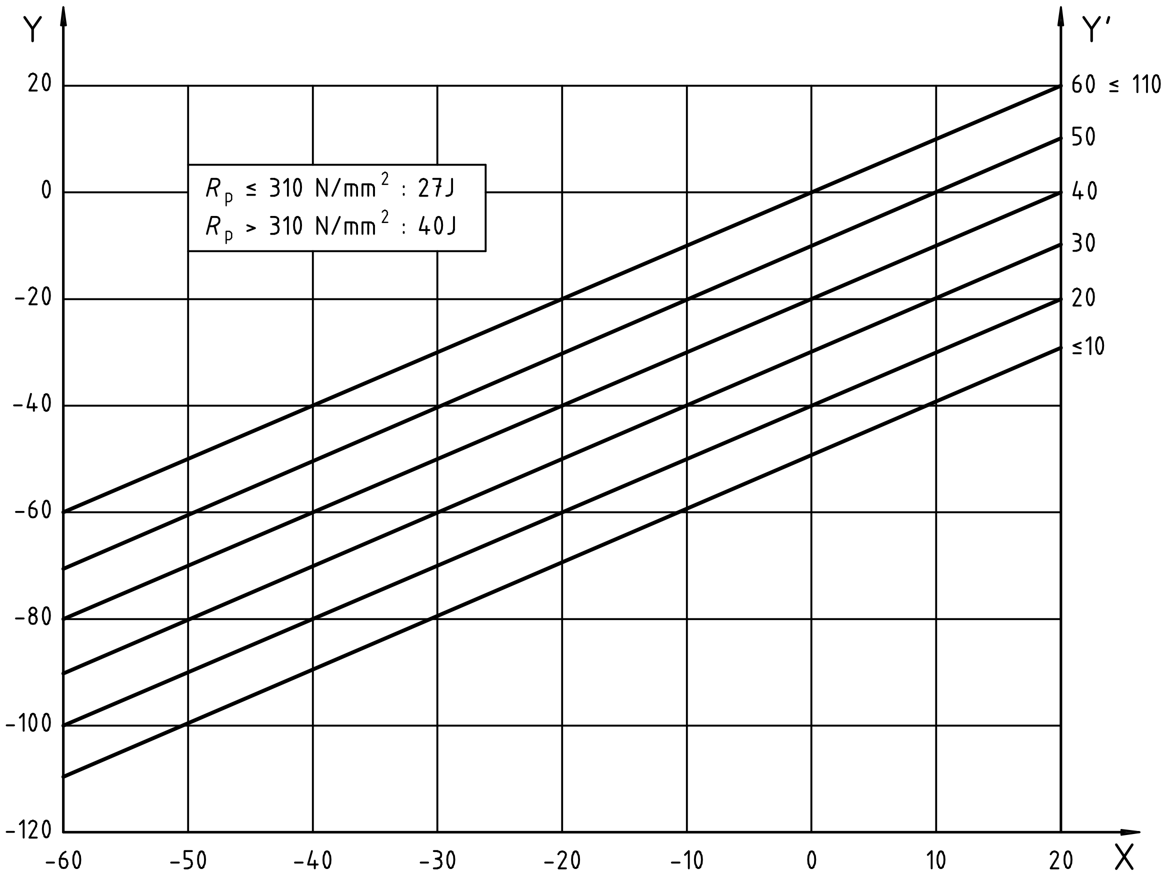
When materials are to be joined by welding, the choice of consumables and procedures (see ISO 15614-1) shall ensure that the required impact energy properties are achieved in weld regions and heat-affected zones, when tested in accordance with Clause 5.

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

7 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 for the weld consumable shows that it has a ferrite content exceeding 10 %.



Key

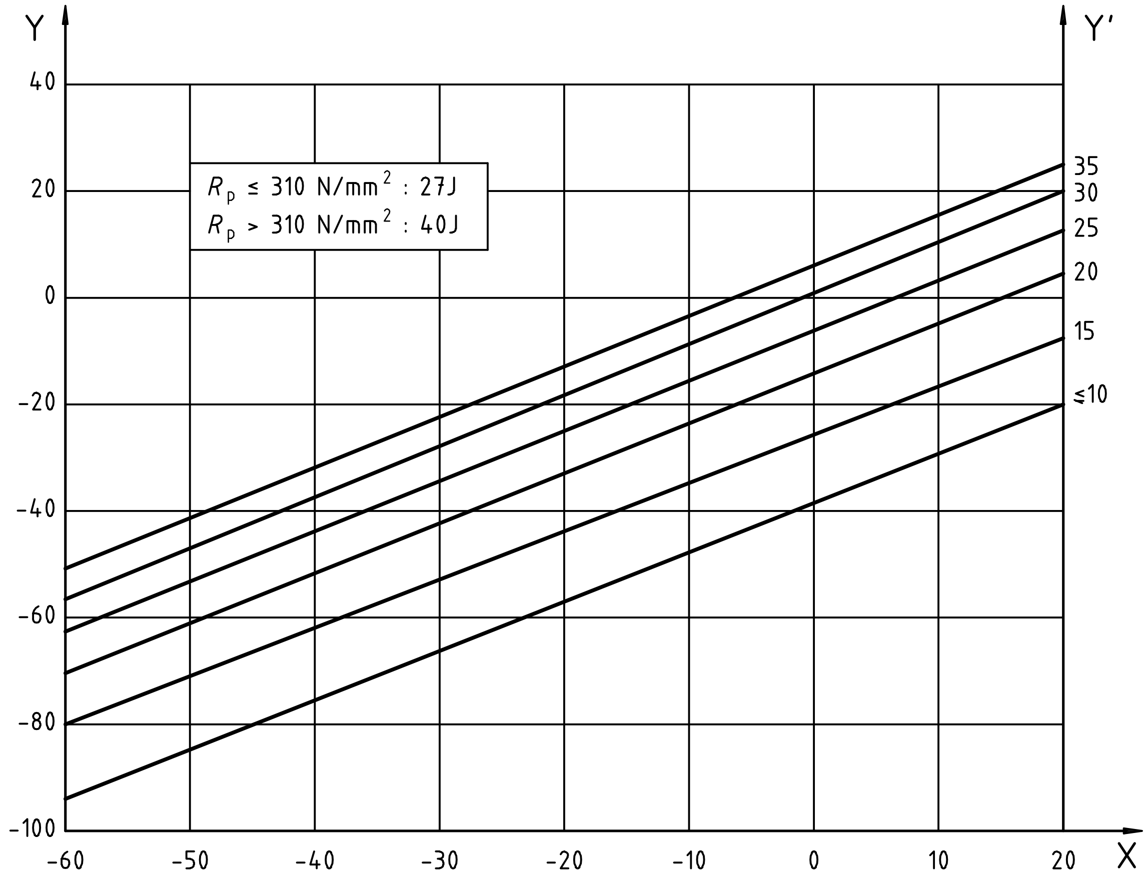
Y T_R design reference temperature, °C

X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress

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



Key

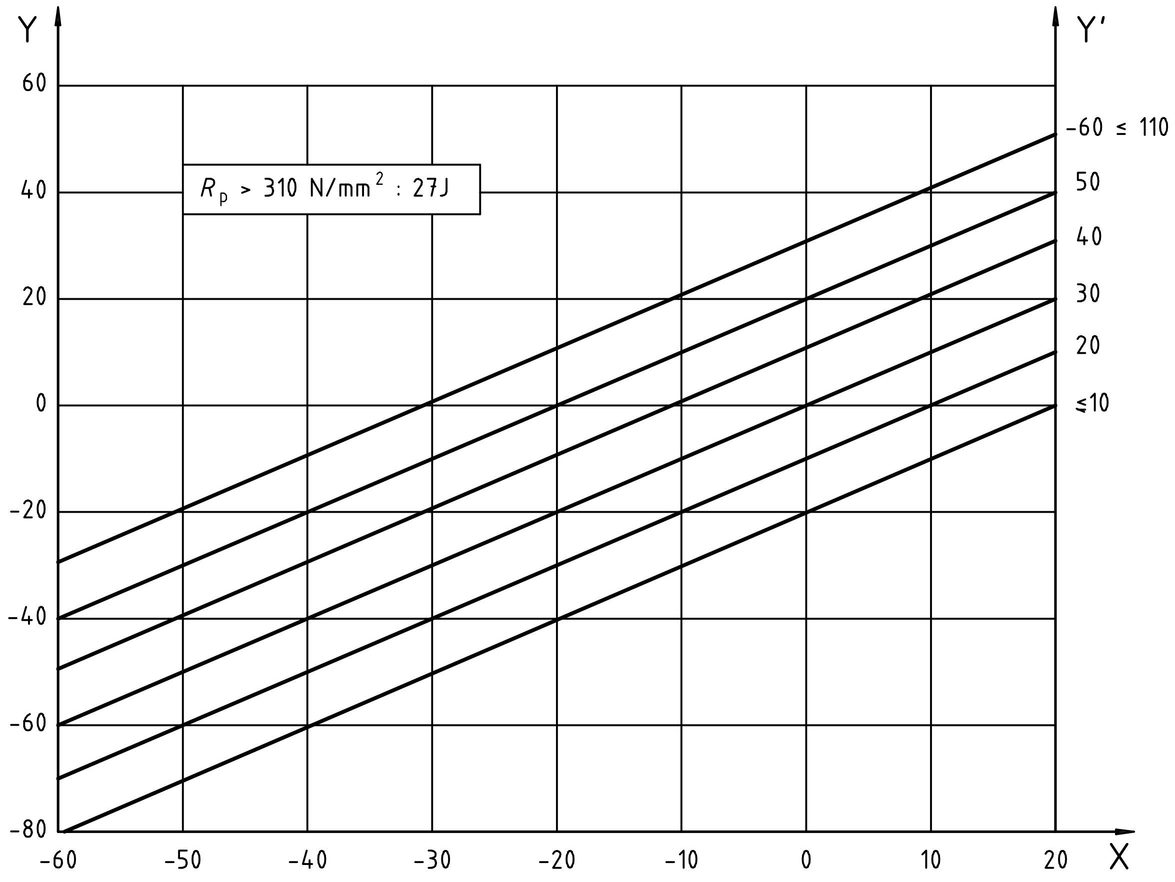
Y T_R design reference temperature, °C

X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress

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



Key

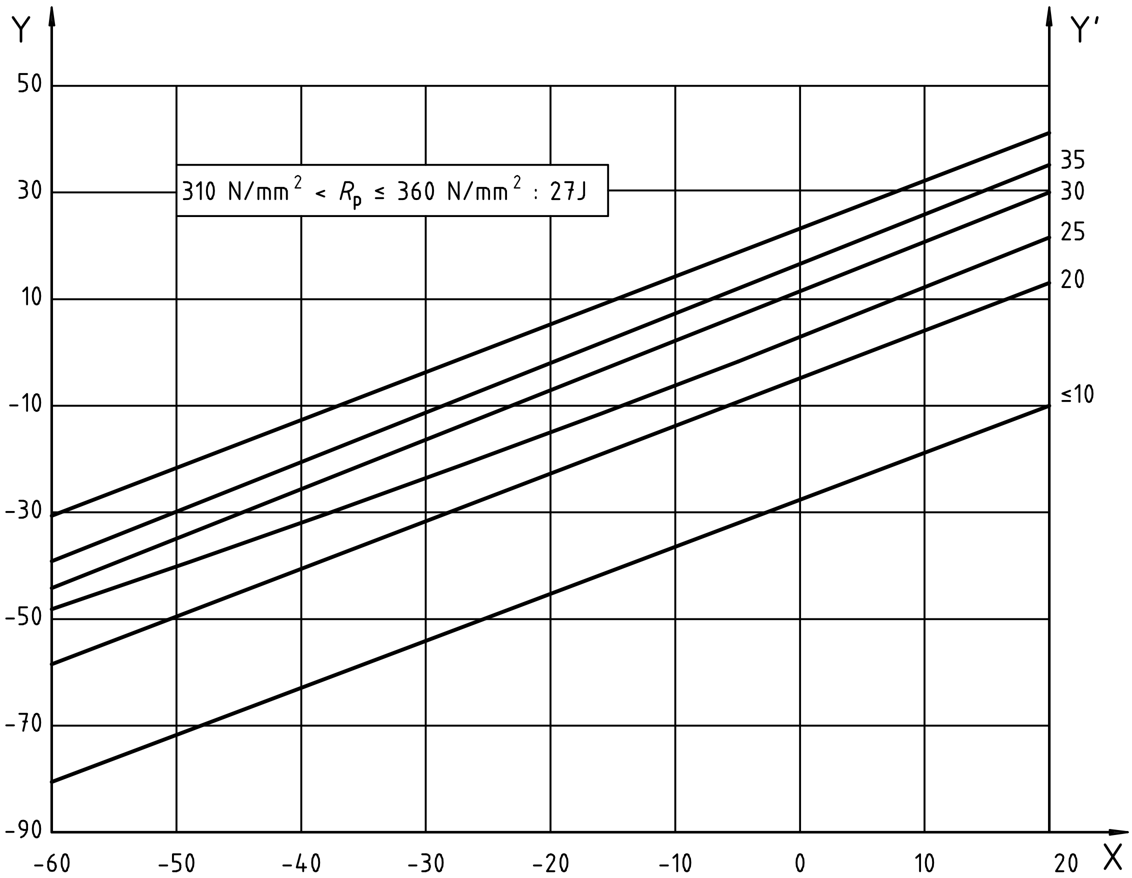
Y T_R design reference temperature, °C

X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress

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



Key

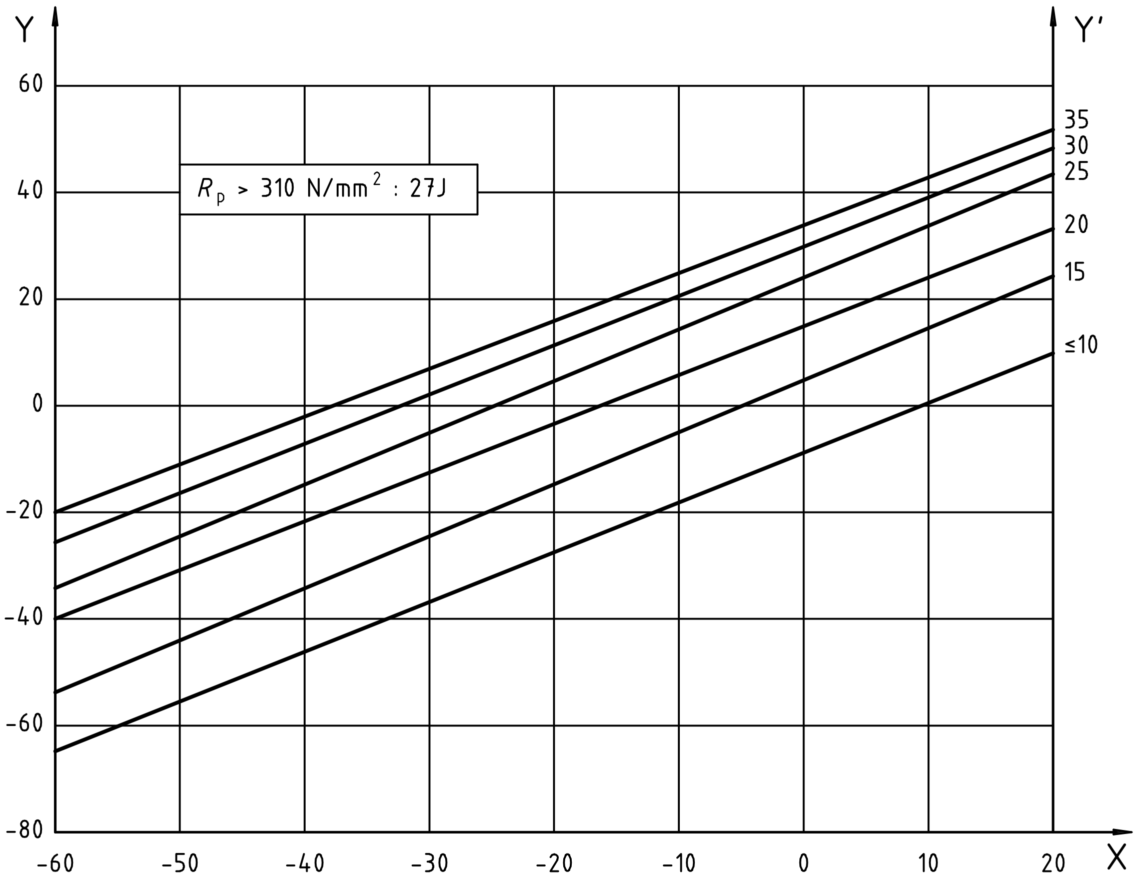
Y T_R design reference temperature, °C

X T_{KV} impact test temperature, °C

Y′ e_B reference thickness, mm

R_p proof stress

Figure 4 — 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

Figure 5 — Design reference and impact test temperature — As-welded condition

Table 6 — Reference thicknesses

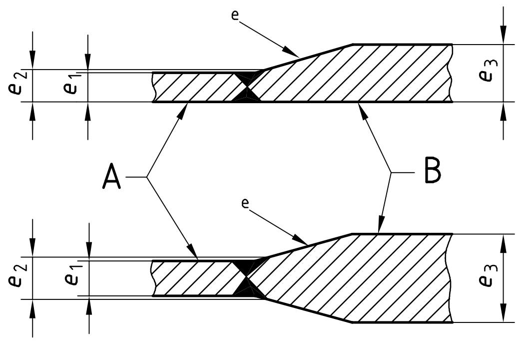
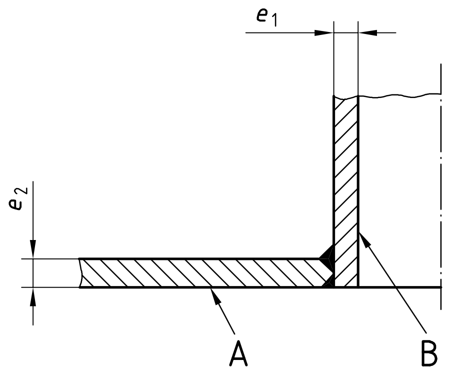
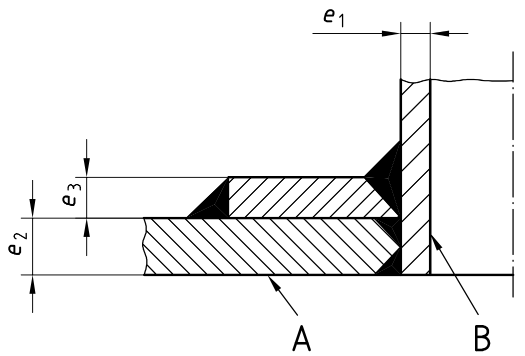
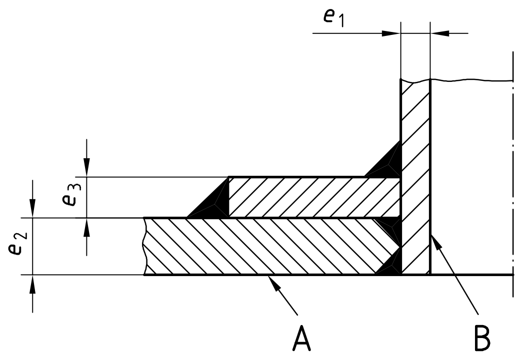
Construction detail	As-welded or Post-weld heat-treated	Reference thickness e_B (where $e_B = e_1, e_2, e_3$ or e_f)		
		Part A	**Weld**	**Part B**
Butt-welded components of unequal thickness 	A-W	e_1	e_2	e_2 check e_3 in Figure 1 or Figure 3 [a]
	PWHT	e_1	e_2	e_3
Branches and nozzles 	A-W	e_2	e_2	e_1
	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*)

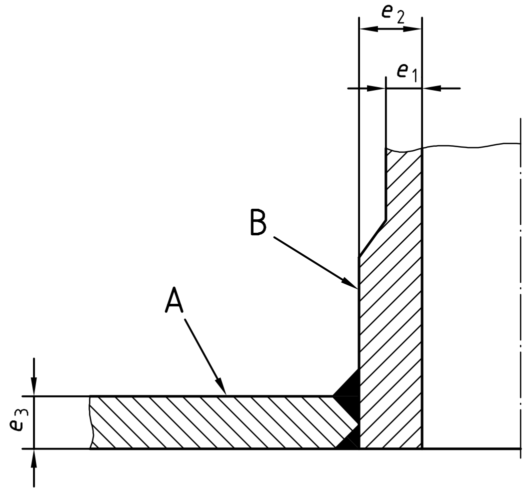
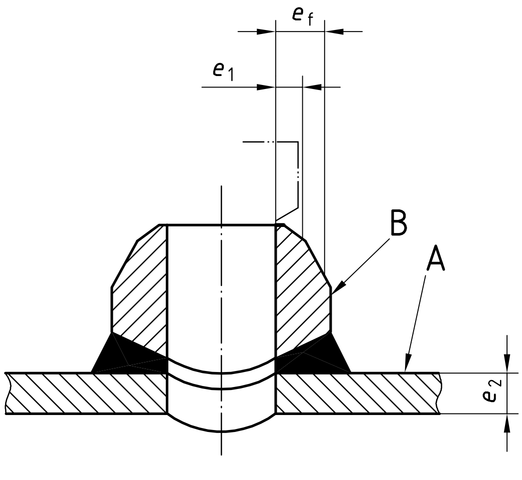
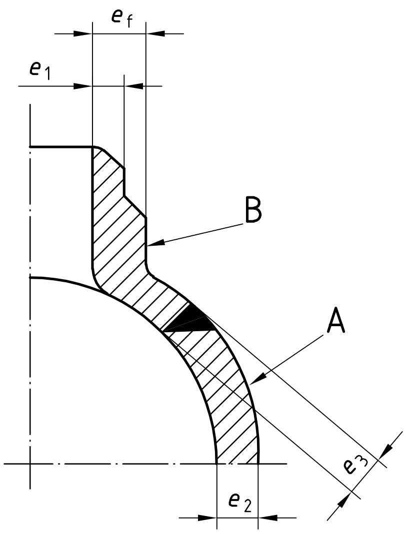
Construction detail	As-welded or Post-weld heat-treated	Reference thickness e_B (where e_B = e_1, e_2, e_3 or e_f)		
		Part A	**Weld**	**Part B**
	A-W	e_3	e_2 or e_3 if thicker	e_2
	PWHT	e_3	e_2 or e_3 if thicker	e_2
	A-W	e_2	e_2	e_1 or e e_f /4 if thicker
	PWHT	e_2	e_2	e_1 [b] or e_f/4 if thicker if necessary, check e_1 in Figure 2 or 4
	A-W	e_2	e_3	e_3 or e e_f /4 if thicker
	PWHT	e_2	e_3	e_3 [c] or e e_f /4 if thicker if necessary, check e_1 in Figure 2 or 4

Table 6 (*continued*)

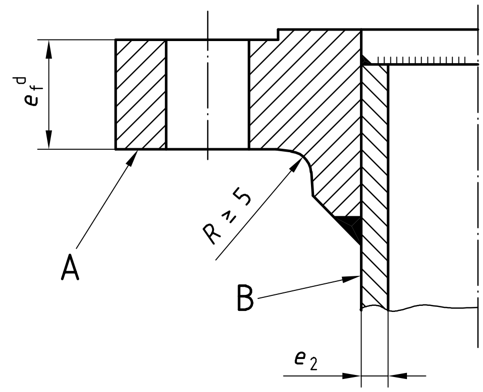
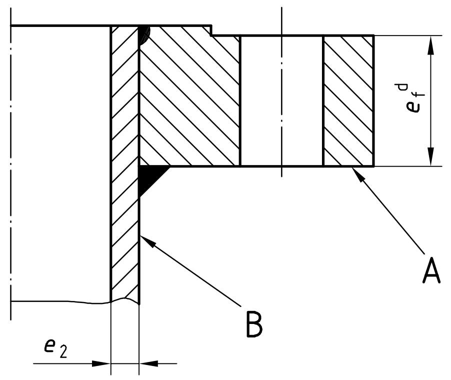
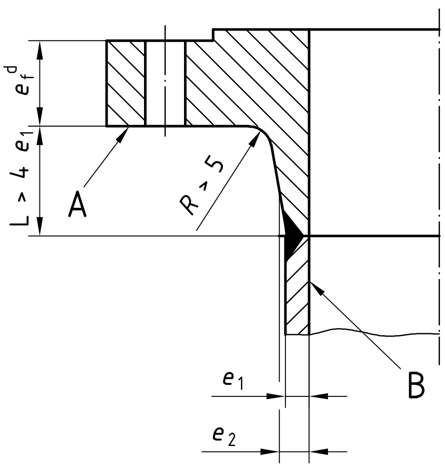
Construction detail	As-welded or Post-weld heat-treated	Reference thickness e_B (where $e_B = e_1, e_2, e_3$ or e_f) Part A	Weld	Part B
Slip-on and plate flanges  	A-W	e_f /4	e_2	e_2
	PWHT	e_f /4	e_2	e_2
 	A-W	e_f /4	e_2	e_2
	PWHT	e_f /4	e_2	e_2
Forged or cast welding neck flanges  	A-W	e_2 [c] check e_f /4 in Figure 1 or 3	e_2	e_1
	PWHT	e_2 or e_f /4 if thicker	e_2	e_1

Table 6 (*continued*)

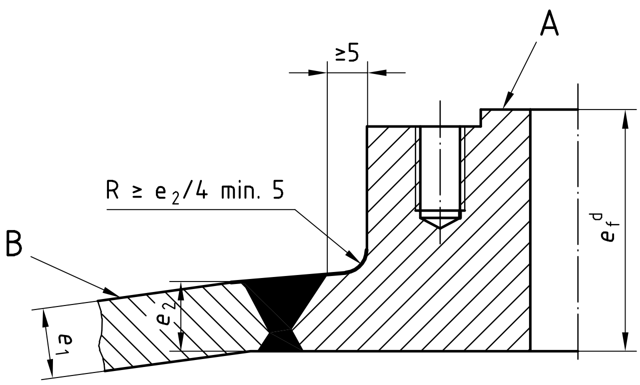
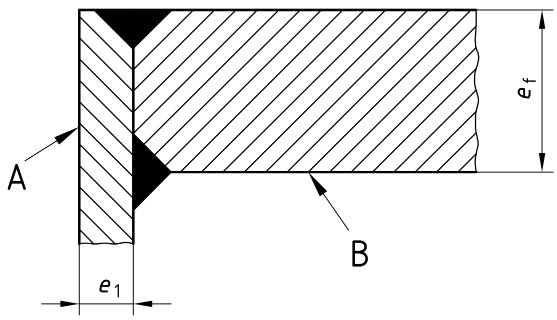
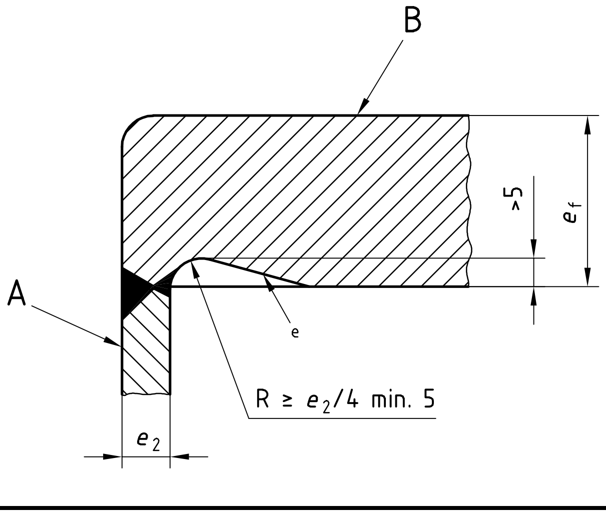
Construction detail	**As-welded or Post-weld heat-treated**	**Reference thickness** e_B (where $e_B = e_1, e_2, e_3$ or e_f) **Part A**	**Weld**	**Part B**
Pad-type flanges 	A-W	e_2 [c] check e_f /4 in Figure 1 or 3	e_2	e_1
	PWHT	e_2 or e_f /4 if thicker	e_2	e_1
Flat ends 	A-W	e_1	e_1	e_f /4 or e_1 if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

Table 6 (*continued*)

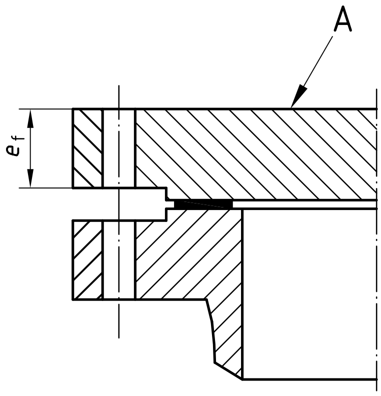
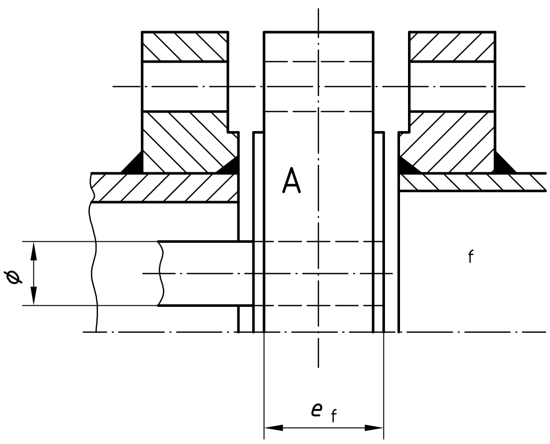
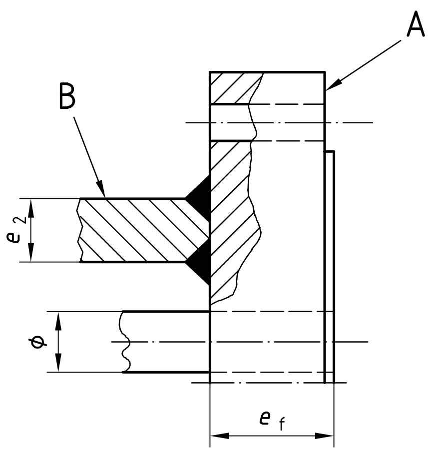
Construction detail	As-welded or Post-weld heat-treated	Reference thickness e_B (where $e_B = e_1$, e_2, e_3 or e_f)		
		Part A	**Weld**	**Part B**
Covers and blind flanges 	A-W	e_f /4	—	—
	PWHT	e_f /4	—	—
Tube plates 	A-W	N/A	N/A	N/A
	PWHT	e_f /4	N/A	N/A
	A-W	e_f /4 or e_2 if thicker	e_2	e_2
	PWHT	e_f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

Table 6 (*continued*)

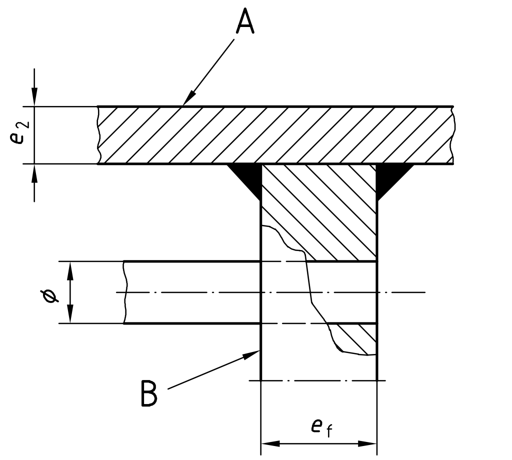
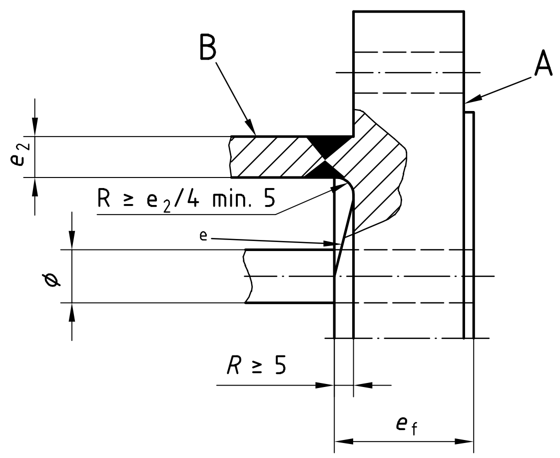
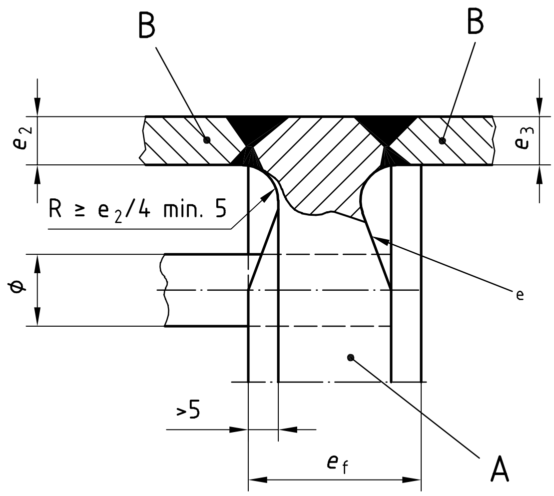
Construction detail	As-welded or Post-weld heat-treated	Reference thickness e_B (where $e_B = e_1, e_2, e_3$ or e_f)		
		Part A	**Weld**	**Part B**
Welded into shell/channel  Preferably not to be used	A-W	e_f /4 or e_2 if thicker	e_2	e_2
	PWHT	e_f /4 or e_2 if thicker	e_2	e_2
Forged tube plate with stubs  	A-W	e_2 [c] check e_f /4 in Figure 1 or 3	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 1 or 3</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>
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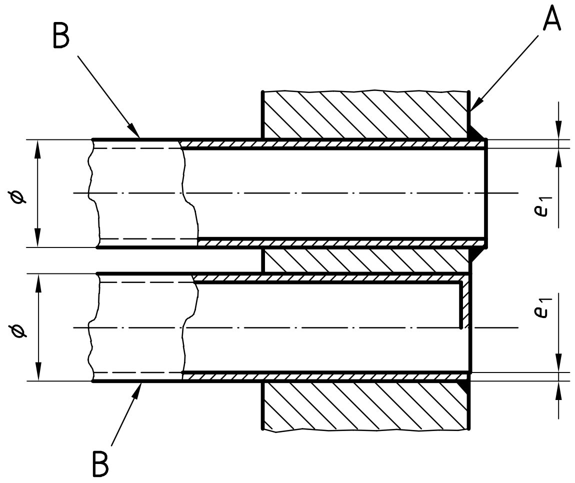
</td><td>A-W</td><td>N/A</td><td>e_1</td><td>e_1</td></tr>
<tr><td>PWHT</td><td>N/A</td><td>e_1</td><td>e_1</td></tr>
</table>

[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.

N/A Not applicable.

Annex A
(informative)

Case proposal — Technical justification for temperature adjustment term

A.1 General

The relevant regulations and standards of France, Sweden and Great Britain are based on fracture mechanics considerations: the basis of the French standard is the Sanz concept [1], that of the Swedish standard the work of Sandström [2] and the British standard is based on wide plate tests, the results of which were reassessed in 1998 on the basis of fracture mechanics considerations [3]. The fracture mechanics concepts take into account the influence of wall thickness, loading rate and that of the conditions *as-welded (A-W)*, *unwelded* and *post-weld heat-treated (PWHT)*.

In the German regulations and standards, minimum values for impact energy are determined on the basis of extensive operational experience; brittle fracture reducing-influences by means of reduction of the wall thickness, loading rates and stress-relief are not taken into consideration additionally.

All concepts consider the influence of the load level on toughness (T_2). Agreement was reached in the sub-group “Low Temperature” on the use of the brittle fracture concept of Sandström in the Swedish standard and contained in Method 2, *Technical requirements*, previously entitled *Code of practice developed from fracture mechanics*. The agreement reached in favour of the Sandström concept was essentially due to two considerations: on the one hand the concept contains the formula by Sanz, which is used in the French standard, and on the other hand the type of classification into strength classes is similar to existing standards, for example, British and Dutch.

A.2 The brittle fracture concept

The fundamental requirement of the brittle fracture concept is that components with defects do not fail with a loading at the level of the yield point R_{el}. For this purpose a certain material toughness is required for the material used, with:

$$K_{\mathrm{IC}} > K_{\mathrm{CComponent}}$$

The correlation of the fracture toughness with the impact energy forms the basis of the Sandström concept. The equation of Barsom and Rolfe, which is based on a large number of steels, is used for the correlation. Later investigations have also confirmed the validity of the equations.

$$K_{\mathrm{IC}} = \delta E^{1/2} (KV)^{3/4}$$

In the correlation two yield point ranges are assumed. The fracture toughness values in the transfer from brittle to ductile behaviour are correlated with the impact energy values. The results are as follows.

— Materials with $R_{\mathrm{el}} \leqslant 310$ N/mm^2: requirements of 27 J

  (corresponds to $K_{\mathrm{IC}} = 78$ MPa $\sqrt{m}$);

— Materials with $R_{\mathrm{el}} > 310$ N/mm^2: requirements of 40 J

  (corresponds to $K_{\mathrm{IC}} = 105$ MPa $\sqrt{m}$).

A.3 Assumptions for the calculation of the minimum operating temperature

Defect size

For the defect size a semi-elliptical surface defect with a depth of 0,25 times the wall thickness was taken, which corresponds to the provisions of the ASME Code Section III.

Loads

The loads are assumed as 1,4 times the yield in the A-W condition. The loads consist of the permitted primary stress and remaining residual stresses.

In the PWHT state, loads are assumed to be equivalent to the yield point. On these assumptions the minimum operating temperatures are calculated.

The calculation of the minimum metal temperature is conducted according to Sandström with the equation:

$$T_{\mathrm{M}} + \ln\left(\frac{K_{\mathrm{c}} - K_0}{K_1 - K_0}\right) : \beta + T_{\mathrm{KV}} + \Delta T_e$$

where

T_{KV} impact test temperature $T_{27\mathrm{j}}$ or $T_{40\mathrm{J}}$ (K_{IC} = 78 or 105 MPa $\sqrt{m}$);

K_{c} stress intensity factor $K_{\mathrm{c}} = \sigma\sqrt{(\mathrm{a}\pi)}$

where

σ is the stress coefficient,

a is the depth of the defect,

π is a coefficient;

β constant 1/60;

K_0 constant 25 MPa $\sqrt{m}$;

ΔT_e correction term for the influence of the component thickness.

The correction term ΔT_e takes into consideration the influence of the wall thickness, e.

NOTE For the purposes of this annex, e is the symbol for wall thickness, while t is the symbol for component thickness.

The starting factor of the concept is a wall thickness greater than or equal to 110 mm. If the wall thickness becomes less, this influences the stress condition and has beneficial effects on the brittle fracture safety. The transition from the multi-dimensional strain condition to the level plain strain condition is taken into account by means of the correction term.

In the Sandström concept, the influence of the yield point on the size of the plastic zone is also taken into consideration, in addition to the influence of the wall thickness. This leads to a correction term, t_{ps}.

The correction term is proportional to $(K_{\mathrm{c}}/\sigma)^2$, where σ is the yield stress $(R_{\mathrm{el}}/R_{\mathrm{m}})/2$ of the material.

Definition of the temperature displacement ΔT_e by comparison of t_{ps} with the component thickness, t:

$e = t + 110 - t_{\mathrm{ps}}$, $t_{\mathrm{ps}} > 110$ mm

$e = t_{\mathrm{ps}}$, $t_{\mathrm{ps}} \geqslant 110$ mm =

ΔT_e = 0, $e > 110$

ΔT_e = 0,53e – 59, 110 $> e >$ 60

ΔT_e = 0,97e – 58, 60 $> e >$ 30

ΔT_e = 1,8e – 110, 30 $> e >$ 10

T_{M} is calculated as a function of the impact test temperature T_{KV} and the component thickness. The result of the calculations are Figures 1 to 5, which show the impact test temperatures as a function of wall thickness for the yield point ranges. Figure 1 shows the dependence for the condition unwelded and/or post-weld heat-treated. From a thickness of 60 mm the impact test temperature is equal to the minimum metal temperature. If the component thickness becomes less, the strain condition is shifted in the direction of plain strain condition. This is taken into consideration with a lower minimum metal temperature.

A.4 Temperature adjustment term

In the brittle fracture concept, loads at the level of the yield point and/or 1,4 times the yield point are assumed. If the actual loads are under the maximum permissible loads, this is taken into account with a temperature adjustment term T_{S}. The temperature T_{R} is determined from the minimum metal temperature and T_{S}. The temperature adjustment term has the effect that the material can be used at lower temperatures.

The Swedish standard, like AD-W 10 or BS 5 500, provides for a temperature adjustment term for loads below the permissible load.

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