



BSI Standards Publication

Metal bellows expansion joints for pressure applications

National foreword

This British Standard is the UK implementation of EN 14917:2021. It supersedes BS EN 14917:2009+A1:2012, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GSE/42, Gas fittings and connections including metal hose and hose assemblies.

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© The British Standards Institution 2021
Published by BSI Standards Limited 2021

ISBN 978 0 539 06281 6

ICS 23.040.99

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This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 August 2021.

Amendments/corrigenda issued since publication

Date

Text affected

English Version

Metal bellows expansion joints for pressure applications

Compensateurs de dilatation à soufflets métalliques
pour appareils à pression

Kompensatoren mit metallischen Bälgen für
Druckanwendungen

This European Standard was approved by CEN on 21 June 2021.

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European foreword

This document (EN 14917:2021) has been prepared by Technical Committee CEN/TC 342 “Metal hoses, hose assemblies, bellows and expansion joints”, the secretariat of which is held by SNV.

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of an identical text or by endorsement, at the latest by January 2022, and conflicting national standards shall be withdrawn at the latest by January 2022.

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

This document supersedes EN 14917:2009+A1:2012.

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

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

Modifications to EN 14917:2009+A1:2012:

- adaptation to Directive 2014/68/EU;
- general revision and correction;
- complete revision and restructuring of Clause 6, i.e.;
 - addition of design in the creep range;
 - modification of stress calculation for internal pressure capability;
 - reformulation of column instability calculation;
 - modification of in-plane instability calculation;
 - harmonisation of fatigue calculation for all bellows types and introduction of 4 fatigue curves for different material classes;
 - extension of material characteristics for calculating forces and moments on pressurised expansion joints;
- addition of Annex K for stress calculation of hardware;
- revision of Testing, inspection and documentation;
- revision of material properties in Annex B and Annex J;
- correction of Coefficient C_p .

Any feedback and questions on this document should be directed to the users' national standards body. A complete listing of these bodies can be found on the CEN website.

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

Introduction

Metal bellows expansion joints are used as parts in pressure vessels or piping components.

If an expansion joint is designed and manufactured covered by EU-Directive 2014/68/EU a risk assessment has to be done. The possible risks of an expansion joint and how they have been dealt in this document are described in Annex I.

1 Scope

This document specifies the requirements for design, manufacture and installation of metal bellows expansion joints with circular cross section for pressure applications with maximum allowable pressure greater than 0,5 bar.

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.

EN 764-4:2014, *Pressure equipment — Part 4: Establishment of technical delivery conditions for metallic materials*

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

EN 1092-1:2018, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, PN designated — Part 1: Steel flanges*

EN 1591-1:2013, *Flanges and their joints — Design rules for gasketed circular flange connections — Part 1: Calculation*

EN 1759-1:2004, *Flanges and their joints — Circular flanges for pipes, valves, fittings and accessories, Class designated — Part 1: Steel flanges, NPS 1/2 to 24*

EN 10028-1:2017, *Flat products made of steels for pressure purposes — Part 1: General requirements*

EN 10028-2:2017, *Flat products made of steels for pressure purposes — Part 2: Non-alloy and alloy steels with specified elevated temperature properties*

EN 10028-3:2017, *Flat products made of steels for pressure purposes — Part 3: Weldable fine grain steels, normalized*

EN 10028-4:2017, *Flat products made of steels for pressure purposes — Part 4: Nickel alloy steels with specified low temperature properties*

EN 10028-7:2016, *Flat products made of steels for pressure purposes — Part 7: Stainless steels*

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

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

EN 10216-2:2013+A1:2019, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 2: Non-alloy and alloy steel tubes with specified elevated temperature properties*

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

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

EN 10216-5:2013, *Seamless steel tubes for pressure purposes — Technical delivery conditions — Part 5: Stainless steel tubes*

EN 10217-1:2019, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 1: Electric welded and submerged arc welded non-alloy steel tubes with specified room temperature properties*

EN 10217-2:2019, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 2: Electric welded non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10217-3:2019, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 3: Electric welded and submerged arc welded alloy fine grain steel tubes with specified room, elevated and low temperature properties*

EN 10217-4:2019, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 4: Electric welded non-alloy steel tubes with specified low temperature properties*

EN 10217-5:2019, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 5: Submerged arc welded non-alloy and alloy steel tubes with specified elevated temperature properties*

EN 10217-6:2019, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 6: Submerged arc welded non-alloy steel tubes with specified low temperature properties*

EN 10217-7:2014, *Welded steel tubes for pressure purposes — Technical delivery conditions — Part 7: Stainless steel tubes*

EN 10222-2:2017, *Steel forgings for pressure purposes — Part 2: Ferritic and martensitic steels with specified elevated temperatures properties*

EN 10222-3:2017, *Steel forgings for pressure purposes — Part 3: Nickel steels with specified low temperature properties*

EN 10222-4:2017, *Steel forgings for pressure purposes — Part 4: Weldable fine grain steels with high proof strength*

EN 10222-5:2017, *Steel forgings for pressure purposes — Part 5: Martensitic, austenitic and austenitic-ferritic stainless steels*

EN 10253-2:2007, *Butt-welding pipe fittings — Part 2: Non alloy and ferritic alloy steels with specific inspection requirements*

EN 10253-3:2008, *Butt-welding pipe fittings — Part 3: Wrought austenitic and austenitic-ferritic (duplex) stainless steels without specific inspection requirements*

EN 10253-4:2008, *Butt-welding pipe fittings — Part 4: Wrought austenitic and austenitic-ferritic (duplex) stainless steels with specific inspection requirements*

EN 10269:2013, *Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties*

EN 10272:2016, *Stainless steel bars for pressure purposes*

EN 10273:2016, *Hot rolled weldable steel bars for pressure purposes with specified elevated temperature properties*

EN 13184:2001, *Non-destructive testing — Leak testing — Pressure change method*

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

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

EN 13480-2:2017, *Metallic industrial piping — Part 2: Materials*

EN 13480-2:2017/A1:2018, *Metallic industrial piping — Part 2: Materials*

EN 13480-2:2017/A2:2018, *Metallic industrial piping — Part 2: Materials*

EN 13480-2:2017/A3:2018, *Metallic industrial piping — Part 2: Materials*

EN 13480-3:2017, *Metallic industrial piping — Part 3: Design and calculation*

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

EN ISO 643:2020, *Steels — Micrographic determination of the apparent grain size (ISO 643:2019, Corrected version 2020-03)*

EN ISO 3651-2:1998, *Determination of resistance to intergranular corrosion of stainless steels — Part 2: Ferritic, austenitic and ferritic-austenitic (duplex) stainless steels — Corrosion test in media containing sulfuric acid (ISO 3651-2:1998)*

EN ISO 5817:2014, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections (ISO 5817:2014)*

EN ISO 6506-1:2014, *Metallic materials — Brinell hardness test — Part 1: Test method (ISO 6506-1:2014)*

EN ISO 6892-1:2019, *Metallic materials — Tensile testing — Part 1: Method of test at room temperature (ISO 6892-1:2019)*

EN ISO 6892-2:2018, *Metallic materials — Tensile testing — Part 2: Method of test at elevated temperature (ISO 6892-2:2018)*

EN ISO 9445-1:2010, *Continuously cold-rolled stainless steel — Tolerances on dimensions and form — Part 1: Narrow strip and cut lengths (ISO 9445-1:2009)*

EN ISO 9445-2:2010, *Continuously cold-rolled stainless steel — Tolerances on dimensions and form — Part 2: Wide strip and plate/sheet (ISO 9445-2:2009)*

EN ISO 9606-1:2017, *Qualification testing of welders — Fusion welding — Part 1: Steels (ISO 9606-1:2012 including Cor 1:2012 and Cor 2:2013)*

EN ISO 9606-4:1999, *Approval testing of welders — Fusion welding — Part 4: Nickel and nickel alloys (ISO 9606-4:1999)*

EN ISO 9712:2012, *Non-destructive testing — Qualification and Certification of NDT personnel (ISO 9712:2012)*

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

EN ISO 15609-1:2019, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 1: Arc welding (ISO 15609-1:2019)*

EN ISO 15609-2:2019, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 2: Gas welding (ISO 15609-2:2019)*

EN ISO 15609-3:2004, *Specification and qualification of welding procedures for metallic materials — Welding procedures specification — Part 3: Electron beam welding (ISO 15609-3:2004)*

EN ISO 15609-4:2009, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 4: Laser beam welding (ISO 15609-4:2009)*

EN ISO 15609-5:2011, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 5: Resistance welding (ISO 15609-5:2011, Corrected version 2011-12-01)*

EN ISO 15609-6:2013, *Specification and qualification of welding procedures for metallic materials — Welding procedure specification — Part 6: Laser-arc hybrid welding (ISO 15609-6:2013)*

EN ISO 15610:2003, *Specification and qualification of welding procedures for metallic materials — Qualification based on tested welding consumables (ISO 15610:2003)*

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

EN ISO 15614-1:2017,¹ *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 (ISO 15614-1:2017, Corrected version 2017-10-01)*

EN ISO 15614-2:2005, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 2: Arc welding of aluminium and its alloys (ISO 15614-2:2005)*

EN ISO 15614-3:2008, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 3: Fusion welding of non-alloyed and low-alloyed cast irons (ISO 15614-3:2008)*

EN ISO 15614-4:2005, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 4: Finishing welding of aluminium castings (ISO 15614-4:2005)*

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 15614-6:2006, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 6: Arc and gas welding of copper and its alloys (ISO 15614-6:2006)*

EN ISO 15614-7:2019; *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 7: Overlay welding (ISO 15614-7:2016)*

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)*

¹ As impacted by EN ISO 15614-1:2017/A1:2019.

EN ISO 15614-10:2005, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 10: Hyperbaric dry welding (ISO 15614-10:2005)*

EN ISO 15614-11:2002, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 11: Electron and laser beam welding (ISO 15614-11:2002)*

EN ISO 15614-12:2014, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 12: Spot, seam and projection welding (ISO 15614-12:2014)*

EN ISO 15614-13:2012, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 13: Upset (resistance butt) and flash welding (ISO 15614-13:2012)*

EN ISO 15614-14:2013, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 14: Laser-arc hybrid welding of steels, nickel and nickel alloys (ISO 15614-14:2013)*

EN ISO 17635:2016, *Non-destructive testing of welds — General rules for metallic materials (ISO 17635:2016)*

EN ISO 20485:2018, *Non-destructive testing — Leak testing — Tracer gas method (ISO 20485:2017)*

3 Terms and definitions

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

3.1 expansion joint

metal equipment consisting of one or more bellows used to absorb movements such as caused by thermal or mechanical effects in piping or pressure vessels

Note 1 to entry: See also Clause 4 Classification.

3.2 bellows

flexible element consisting of one or more corrugations and the end tangents

3.3 corrugation convolution

flexible unit of a bellows with a leakproof wall consisting of one or more plies

3.4 ply

element of the bellows' wall usually made from sheet or strip material

3.5 end tangent

straight un-corrugated portion at the ends of a bellows

3.6 reinforcing collar

reinforcing sleeve or ring attached to the end tangent for reinforcement

3.7**assisting collar**

ring placed around the end tangents to facilitate welding

3.8**reinforcing and equalizing ring****reinforcing member**

device fitting snugly in the roots of the corrugations in order to reinforce the bellows against internal pressure and/or to limit the equivalent axial compression

3.9**internal sleeve**

circular element fixed to the inside of the expansion joint which allows a satisfactory flow of medium and protects the bellows from erosion and flow-induced vibrations

Note 1 to entry: It is designed so that it does not restrict the movement of the expansion joint.

3.10**hardware**

restraining parts of expansion joints being able to withstand the relevant forces and moments due to the effect of pressure thrust and additional loadings

Note 1 to entry: See also Clause 4 Classification.

3.11**shipping bar**

device that secures the expansion joint in a determined position during the period of shipment, handling and installation

3.12**classification**

classifying expansion joints according to the type of movement they are capable of absorbing or classifying their parts according to their pressure bearing capacity

3.13**maximum allowable pressure****PS**

maximum pressure for which the equipment is designed, as specified by the equipment manufacturer

3.14**maximum/minimum allowable temperature****TS**

maximum and minimum temperature for which the equipment is designed, as specified by the equipment manufacturer

3.15**nominal pressure****PN**

designation commonly used for reference purposes for piping components and stock parts, and which represents in this document the maximum allowable pressure at 20 °C

Note 1 to entry: Normally defined as a dimensionless alphanumeric number; see EN 1333:2006.

3.16

pressure thrust

F_p

axial force due to the effect of pressure on the expansion joint

3.17

neutral position

bellows length in a “stress-free” state

3.18

spring rate

reaction force or moment induced by a unit movement

3.19

cycle

full movement, from an initial point to the given working positions and back to the beginning

3.20

squirm

column or in-plane instability of the bellows under the effect of internal pressure and/or axial force

3.21

category

classification of pressure equipment according to ascending level of hazard

Note 1 to entry: See Annex A.

3.22

equipment manufacturer

natural or legal person responsible for the values of the parameters PS and TS

Note 1 to entry: This may be the manufacturer or planner of the piping or the pressure vessel for which the expansion joint is designed or the expansion joint manufacturer if free to set these values.

3.23

expansion joint manufacturer

natural or legal person responsible for the design and the manufacturing of the expansion joint

3.24

creep

time-dependent deformation at elevated temperature under load

3.25

creep range

operating range where creep is expected due to the design temperature and the specified life time of the equipment

4 Classification

4.1 Classification of expansion joints

4.1.1 General

There are four types of expansion joints which are designed according to the type of movements which can be absorbed. Where pressure balanced or provided with restraining parts, the expansion joints can in addition absorb the pressure thrust. Common examples are shown in Table 1.

4.1.2 Axial

Unrestrained expansion joint which absorbs mainly axial displacement. It does normally not restrain pressure thrust - only when pressure balanced (see 4.1.6).

4.1.3 Angular

Restrained expansion joint which absorbs angular rotation and restrains the pressure thrust. It allows rotation in a single plane when fitted with hinges and multi-plane rotations when fitted with gimbal rings.

4.1.4 Lateral

Restrained expansion joint which absorbs lateral deflection and restrains the pressure thrust. It allows lateral deflection in a single plane when fitted with hinges and multi-plane deflection when fitted with double hinges or double gimbals. Multi-plane deflection is also permissible when tie rods with spherical bearings are used; this design allows also angular rotation perpendicular to the plane containing the tie bars.

4.1.5 Universal

Unrestrained expansion joint which absorbs all types of movements. It does normally not restrain pressure thrust – only when pressure balanced (see 4.1.6).

4.1.6 Pressure balanced designs (axial or universal)

A pressure balanced expansion joint accommodates the movements and counteracts the bellows pressure thrust. An additional bellows is incorporated into the unit and is subject to the line pressure to generate a force equal and opposite to that on the main bellows. Tying these bellows together neutralises the pressure load on the unit.

Table 1 — Types of expansion joints

Type	Design	Pressure thrust restraint	Movement			
			Axial	Angular		Lateral
				Single plane	Multi-plane	Single plane
Axial	Non-pressure balanced internally pressurized	No	X	(X)	(X)	(X)
	Non-pressure balanced externally pressurized	No	X	(X)	(X)	(X)
	In-line pressure balanced	Yes	X			
Angular	Hinge	Yes		X		
	Gimbal	Yes		X	X	
Lateral	Two tie bars spherical	Yes		X		X

Type	Design	Pressure thrust restraint	Movement			
			Axial	Angular	Lateral	
				Single plane	Multi-plane	Multi-plane
	Two tie bars Pinned (plane)	Yes			X	
	Three or more tie bars	Yes			X	X
	Double hinge	Yes		X	X	
	Double gimbal	Yes		X	X	X
Universal	Unrestrained One or two bellows	No	X	X	X	X
	Pressure balanced	Yes	X	X With two tie bars only	X	X
NOTE 1 X — Applicable. NOTE 2 (X) — Limited use.						

4.2 Classification of the parts of expansion joints

4.2.1 Main pressure-bearing parts (A)

Parts and assemblies that envelope the medium under pressure and which according to their design and their stress level are essential for the pressure-bearing integrity of the equipment, i.e. its failure can result in a sudden discharge of pressure energy, see Figure 1.

4.2.2 Pressure parts other than main pressure-bearing parts (B)

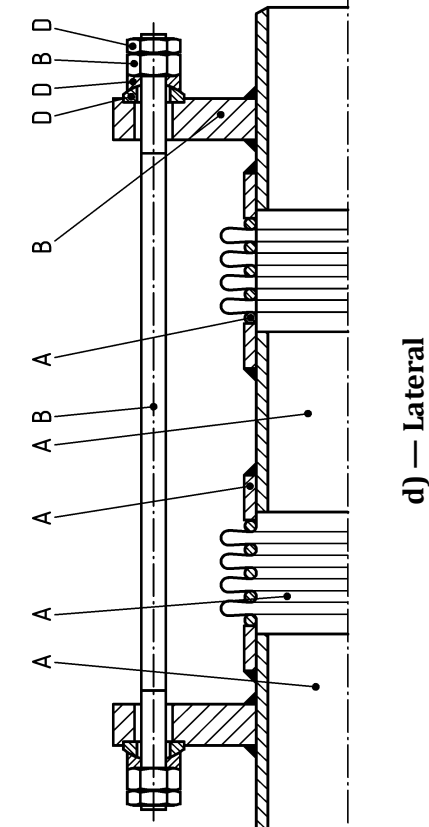
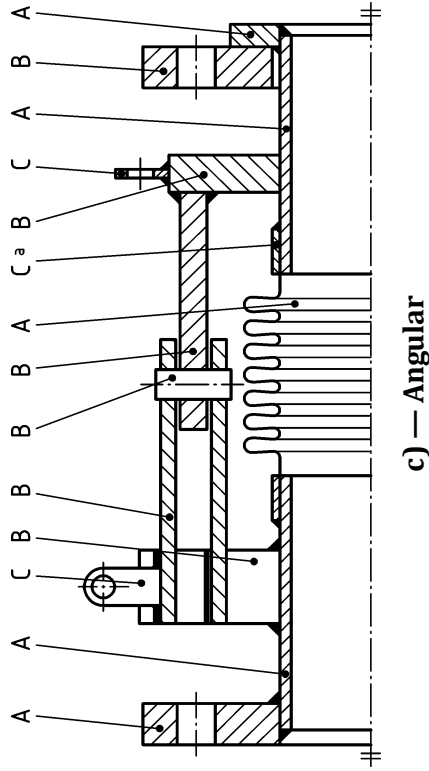
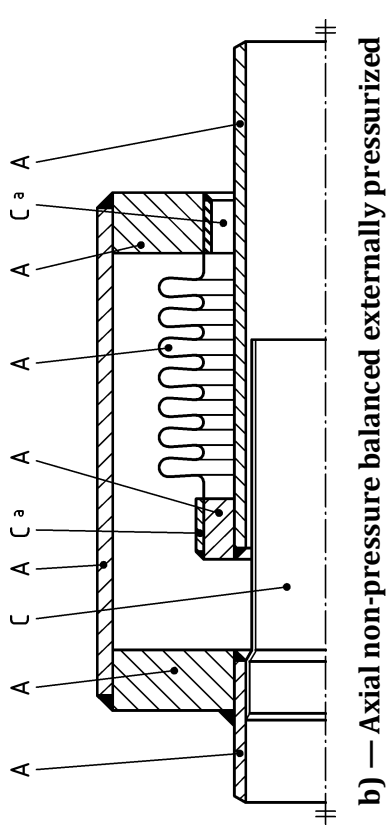
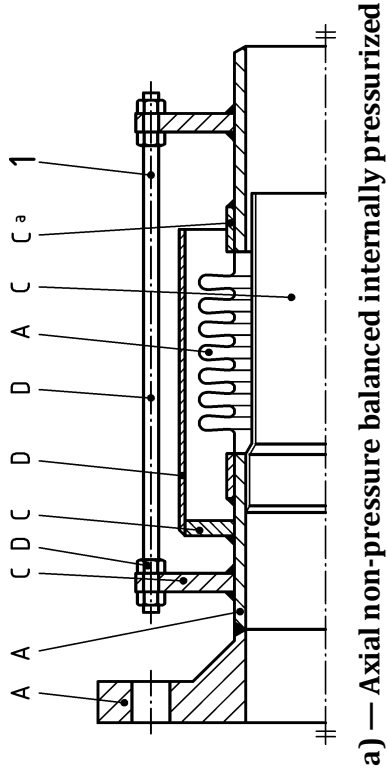
Parts that are charged by the pressure indirectly and have no direct contact to the medium and parts that are in contact with the medium but according to their design are not essential for the pressure-bearing integrity of the equipment, see Figure 1.

4.2.3 Attachments to main pressure-bearing parts and to pressure parts (C)

Parts that are directly welded to A or B parts.

4.2.4 Other parts (D)

Parts that are not A, B or C parts.



Key

- 1 pretension or shipping bars
 - a collars, if reinforcing are A parts (see Table 7)
- NOTE These sketches are diagrammatic only.

Figure 1 — Classification of the parts of expansions joint

5 Materials

5.1 General

5.1.1 Materials for pressure-bearing parts

Materials used for pressure-bearing parts as defined in 4.2.1 and 4.2.2 and shown in Figure 1 shall be free from surface and internal defects, which impair their suitability. These materials shall be selected to be compatible with anticipated fabrication techniques and to be suitable for the specified conditions.

5.1.2 Materials for parts attached to pressure-bearing parts

For parts that are attached to pressure-bearing parts as defined in 4.2.3 and shown in Figure 1, the materials used shall not limit the operating conditions of the pressure-bearing parts to which they are attached, especially when attached by welding.

5.1.3 Materials for non-pressure parts

All materials used for the manufacture of expansion joints shall be suitable for such application during the scheduled lifetime unless replacement is foreseen.

5.2 Pressure-bearing parts

5.2.1 Bellows

5.2.1.1 Allowable materials

Only materials shall be used that fulfil the general requirements of 5.1 and that are suitable for the special forming and welding procedures used for bellows according to the demands of 7.3 and 7.4.

Preferable materials are given in Table 2. The table also gives the minimum and maximum operative temperature limits for the various materials.

Annex J (informative) gives additional properties for some high temperature materials - like creep rupture stresses - and physical properties at low temperatures.

Other materials not listed in Table 2 may be used, provided they fulfil the general requirements of 5.1 and are also suitable for the special forming and welding procedures according to 7.3 and 7.4 and provided they conform to a harmonized standard or comply with an European Approval for Material (EAM) or have a Particular Material Appraisal (PMA) as defined in EN 764-4:2014.

5.2.1.2 Corrosion

The material selected for the bellows element shall have adequate resistance to all the corrosive agents likely to be encountered during the lifetime of the system.

Topics of special consideration include pitting corrosion, intergranular corrosion, crevice corrosion and stress corrosion cracking.

Bellows generally have a wall thickness substantially less than that of the rest of the system with which they are used. Hence the bellows shall be manufactured from a material having the same or a higher corrosion resistance than that used in the associated plant.

5.2.2 Other pressure-bearing parts

Allowable materials for other pressure-bearing parts shall be selected from Table 2 or from the standards given in Table 3 dependent on the application. Materials and temperature limitations of flanges which are designed according to 6.1 are defined in the appropriate flange standard.

The lowest allowable working temperature is depending on the degree of load G_{σ} which is defined by the maximum quotient of the stress levels resulting from the calculation of pressure resistance and the allowable stresses related to the regarded stress components:

$$G_{\sigma} = \max \left[P_{\theta} / f; P_m / f; (P_m + P_b) / (1,5 \cdot f) \right] \quad (1)$$

The use of low temperatures related to degrees of load less than 1,0 given in Table 3 is allowed if the following additional demands are fulfilled to achieve similar safety against brittle fracture:

- a) The expansion joint manufacturer shall ensure that:
 - stress raisers are avoided with regard to design and manufacture;
 - no cracks are to be expected under working conditions.
- b) The expansion joint manufacturer shall in addition carry out suitable heat treatment after forming or welding on parts of ferritic materials.
- c) Stress relieving after welding is dispensable for ferritic materials belonging to the material groups 1.1 or 1.2 according to CEN ISO/TR 15608:2013 [31] and having a wall thickness not greater than 10 mm.

Other materials may be used provided they fulfil the general requirements of 5.1 and conform to a harmonized standard or comply with a European Approval for Materials (EAM) or have a Particular Material Appraisal (PMA) as defined in EN 764-4:2014.

For pressure-bearing parts other than bellows an adequate allowance, protection against corrosion or other chemical attack shall be incorporated or material having the same or a higher corrosion resistance than that used in the associated plant have to be used, taking due account of the intended and reasonably foreseeable use.

5.2.3 Ductility

All materials shall be sufficiently ductile in the delivery state.

Materials used for main pressure-bearing parts (4.2.1) and other pressure-bearing parts (4.2.2) shall at least have:

- an elongation after rupture of $A = 14 \%$ and
- an impact energy of $KV = 27 \text{ J}$, measured on an ISO-V test-piece according to EN ISO 148-1:2016 at a temperature not greater than $20 \text{ }^{\circ}\text{C}$ but, not higher than the lowest scheduled design temperature or at $-196 \text{ }^{\circ}\text{C}$ if the design temperature is less.

Bellows materials after forming shall in addition conform to the requirements given in 7.4.

5.2.4 Brittle fracture

Consideration shall be given to the prevention of brittle fracture, especially for expansion joints that are subjected to temperatures below $-10 \text{ }^{\circ}\text{C}$:

- a) Bellows shall be manufactured from the allowable materials according to 5.2.1.1. If bellows are manufactured from materials according to Table 2 they shall not be used at temperatures lower than that given in the column "Minimum" in this table, except the nickel alloys 2.4816 and 2.4856.

To enable the use of these nickel alloys at lower temperatures impact energy values shall be specified and verification procedures shall be agreed to between the material manufacturer and the purchaser at the time of ordering.

- b) Other pressure-bearing parts shall be manufactured from the allowable materials according to 5.2.2 and shall not be used at temperatures below that given in Table 2 and Table 3, except the nickel alloys 2.4816 and 2.4856, see a).

Parts with more than 5 mm thickness from ferritic steel (Group 1) or more than 20 mm thickness from austenitic stainless steel (Group 8) and from nickel alloys shall pass a Charpy impact test (see 5.2.3) if the impact energy is not already covered by the related material standard.

The measured impact energy shall be:

- $KV \geq 27J$ for ferritic steels (Group 1);
- $KV \geq 40J$ for austenitic stainless steel (Group 8) and for nickel alloys or that given in the relating standard whatever is greater.

Table 2 — Preferable materials for bellows elements and other pressure bearing parts and their temperature limits (see also Table 3)

Material			Temperature °C		Document
Type	Number	Steel name	Minimum	Maximum	
stainless austenitic steels	1.4301	X5CrNi18-10	- 196 ^a	550	EN 10028-7:2016
	1.4306	X2CrNi19-11	- 273 ^a	550	
	1.4401	X5CrNiMo17-12-2	- 196 ^a	550	
	1.4404	X2CrNiMo17-12-2	- 273 ^a	550	
	1.4435	X2CrNiMo18-14-3	- 273 ^a	550	
	1.4539	X1CrNiMoCuN25-20-5	- 196 ^a	550	
	1.4541	X6CrNiTi18-10	- 273 ^a	550	
	1.4550	X6CrNiNb18-10	- 196 ^a	550	
	1.4571	X6CrNiMoTi17-12-2	- 273 ^a	550	
heat resistant austenitic steels	1.4828	X15CrNiSi20-12	- 196	900 ^b	Annex B (1), Annex J
	1.4876	X10NiCrAlTi32-21 X10NiCrAlTi32-21 (H)	- 196	600 900 ^b	Annex B (2.1), Annex J Annex B (2.2), Annex J

Material			Temperature °C		Document
Type	Number	Steel name	Minimum	Maximum	
Nickel alloys	2.4360	NiCu30Fe	– 196	425	Annex B (3)
	2.4610	NiMo16Cr16Ti	– 196	400	Annex J
	2.4816	NiCr15Fe NiCr15Fe (H) ^c	– 10	450	Annex J
	2.4819	NiMo16Cr15W	– 196	400	Annex J
	2.4856	NiCr22Mo9Nb	– 196	450	Annex J
	2.4858	NiCr21Mo	– 273	540	Annex B (4)
ferritic steels	1.0345	P235GH	– 20	400	EN 10028-2:2017 (heat resistant steels)
	1.0425	P265GH	– 20	400	
	1.5415	16Mo3	– 20 ^d	500	
	1.7335	13CrMo4–5	– 20 ^d	500	
	1.0565	P355NH	– 20	400	EN 10028-3:2017
	1.8935	P460NH	– 20	400	(fine grain steels)
^a Minimum temperature in accordance with EN 13445-2:2014, Annex B and EN 13480-2:2017, EN 13480-2:2017/A1:2018, EN 13480-2:2017/A2:2018, EN 13480-2:2017/A3:2018, Annex B. ^b Special care should be exercised due to the risk of embrittlement when using the materials at elevated temperatures above 550 °C. ^c Heat resistant type (informative). ^d Minimum temperature is possible when the specified minimum impact energy of 27 J can be proved.					

Table 3 — Material standards for other pressure-bearing parts

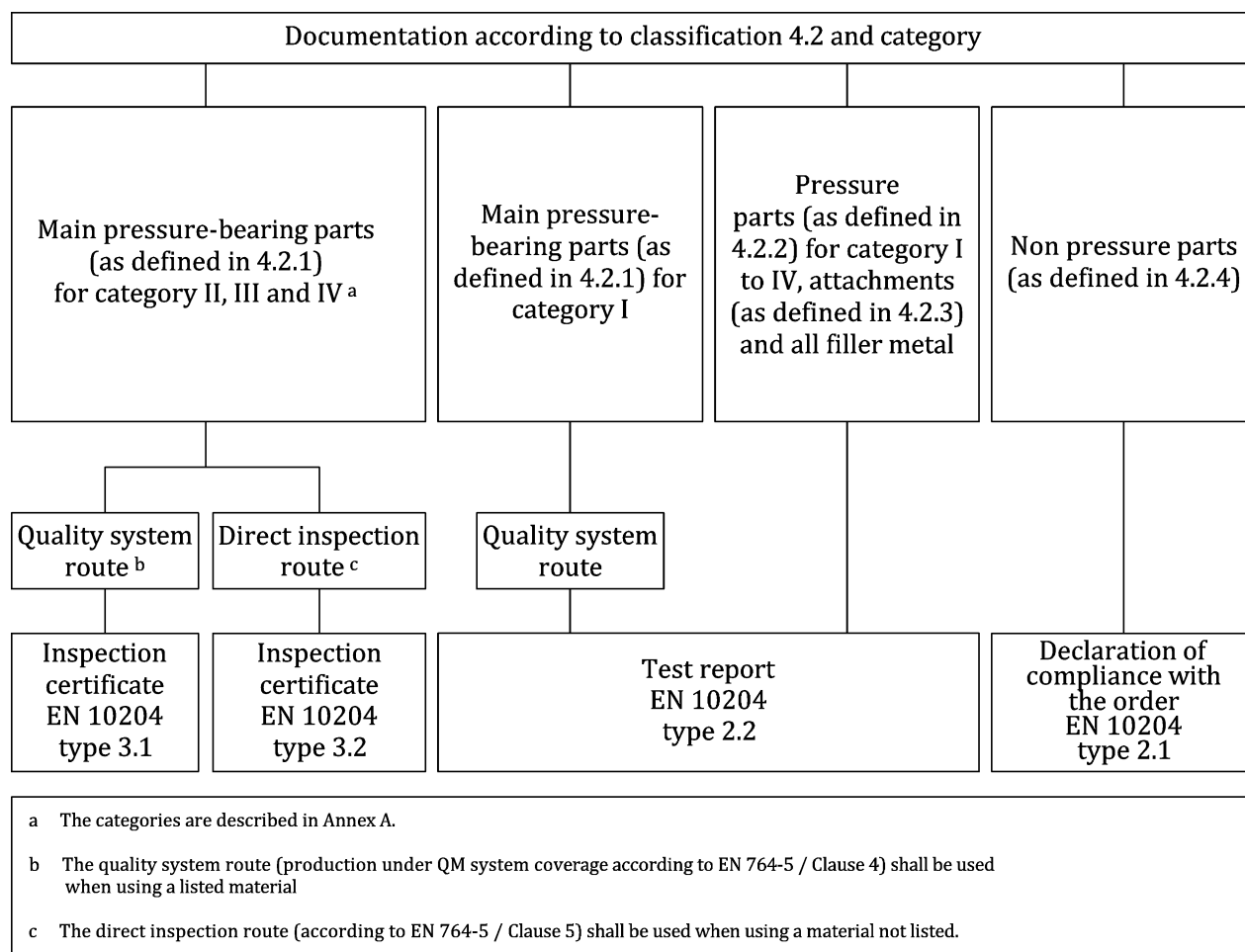
Running no	Description	European Standard	Lowest allowable working temperature in °C		
			Degree of load G_{σ}		
			1,0	0,75 ^a	0,25 ^a
1	Non-alloy steel tubes with specified room temperature properties: — seamless pipes — welded pipes	EN 10216-1:2013 EN 10217-1:2019	$t_{\min}^b$	$t_{\min} - 50$	$t_{\min} - 80$
2	Non-alloy and alloy steels with specified properties at elevated temperatures: — flat products — seamless pipes — welded pipes (E-welded) — welded pipes (SA-welded) — steel forgings — bars — fasteners	EN 10028-2:2017 EN 10216-2:2013+A1:2019 EN 10217-2:2019 EN 10217-5:2019 EN 10222-2:2017 EN 10272:2016, EN 10273:2016 EN 10269:2013	$t_{\min}^b$	$t_{\min} - 50$	$t_{\min} - 80$
3	Weldable fine grain mild steels, normalized: — flat products — seamless pipes — welded pipes — steel forgings	EN 10028-3:2017 (P...NH) EN 10216-3:2013 EN 10217-3:2019 EN 10222-4:2017	$t_{\min}^b$	$t_{\min} - 50$	$t_{\min} - 80$
4	Flat and long products from weldable fine grain mild steels, normalized / normalized rolled with specified low temperature properties	EN 10028-3:2017 (P...NL1, NL2)	$t_{\min}^b$	$t_{\min} - 50$	$t_{\min} - 80$
5	Flat products for pressure purpose from Nickel alloy steels with specified low temperature properties	EN 10028-4:2017	$t_{\min}^b$	$t_{\min} - 50$	$t_{\min} - 80$

Running no	Description	European Standard	Lowest allowable working temperature in °C		
			Degree of load G_σ		
			1,0	0,75 ^a	0,25 ^a
6	Pipes for pressure purpose, from non-alloy steels with specified low temperature properties: — seamless pipes — welded pipes (E-welded) — welded pipes (SA-welded)	EN 10216-4:2013 EN 10217-4:2019 EN 10217-6:2019	$t_{\min}^b$	$t_{\min} - 50$	$t_{\min} - 80$
7	Forgings for pressure purpose, Nickel steels with specified low temperature properties	EN 10222-3:2017	$t_{\min}^b$	$t_{\min} - 50$	$t_{\min} - 80$
8	Fittings for welding, with specified low temperature properties	EN 10253-2:2007	$t_{\min}^b$	$t_{\min} - 50$	$t_{\min} - 80$
9	Austenitic stainless steels according to Table 2 with minimum allowable temperature – 196 °C	EN 10028-7:2016 EN 10216-5:2013 EN 10217-7:2019 EN 10222-4:2017 EN 10253-3:2008 EN 10253-4:2008	– 196	– 255	– 270
^a Additional requirements for degrees of load smaller than 1,0, see 5.2.2. ^b Lowest temperature of the regarded material according to the mentioned standards.					

5.3 Material documentation

Materials used for expansion joints shall be delivered with documentation as defined in EN 764-5:2014.

A simplified diagram of the routes for inspection, documentation and compliance with the material specification is given in Figure 2.

**Figure 2 — Required material documentation**

6 Design

6.1 General

6.1.1 Symbols

The following symbols listed in Table 4 apply.

Table 4 — Symbols

Symbol	Description	Unit
A	elongation at rupture according to EN ISO 6892-1	%
A_c	cross sectional metal area of one corrugation; see Formula (4)	mm ²
A_e	bellows effective area; see Formula (5)	mm ²
A_r	cross sectional metal area of one bellows reinforcing member; see Figure 14	mm ²
a	factor for calculation of the effective spring rate; see Table 14	—
b	factor for calculation of the effective spring rate; see Table 14	—

Symbol	Description	Unit
b_n	nominal width of material (strip, sheet, plate); see Table 20	
C_1, C_2	factors used to determine the shell coefficients C_p, C_f, C_d ; see Formulae (6), (7)	—
C_p, C_f, C_d	shell coefficients for U-shaped corrugations; see Figures 5, 6 and 7	—
$c_{c(d)}$	factor correcting $\sigma_{m,b}(\Delta q)$ for multi-ply bellows; see Formula (22)	—
$c_{n(P)}$	factor correcting $\sigma_{m,b}(P)$ for multi-ply bellows; see Formula (21)	—
c_{dyn}	dynamic factor for column instability; see Formula (46)	—
$\hat{c}_p$	increasing factor for curved bellows under pressure; see 6.2.8.4	—
C_r	correction factor for reinforced bellows; see Formula (23)	—
c_w	stress increasing factor due to circumferential welds; see Formula (133)	—
c_σ	stress correction factor; see Formula (211)	—
D_c	mean diameter of end tangent reinforcing collar; see Formula (8)	mm
D_i	inside diameter of bellows corrugations; see e.g. Figure 8	mm
$D_{i,pp}$	inside diameter of pipe end; see e.g. Figure 8	
$D_{i,t}$	inside diameter of bellows end tangents; see e.g. Figure 8	
D_m	mean diameter of bellows corrugation; see Formula (9)	mm
D_o	outside diameter of bellows corrugation (u-shaped or toroidal); see e.g. Figure 8	mm
D_n	inside neutral diameter of original tube or ring-plate before forming; see Formulae (59) and (60) and Figure 4	mm
d_p	pin diameter; see Table 18	mm
d_H	bearing diameter of the hinges, pin or sphere; see 6.2.9.3	mm
E_B	modulus of elasticity of bellows material, temperature depending	N/mm ² (MPa)
E_c	modulus of elasticity of collar material, temperature depending	N/mm ² (MPa)
E_r	modulus of elasticity of reinforcing member material, temperature depending	N/mm ² (MPa)
e	bellows nominal thickness; see Formula (10)	mm
e_c	end tangent reinforcing collar thickness; see Figures 9, 14 and 16	mm
e_p	nominal thickness of one ply	mm
$e_{p,c}$	nominal thickness of one ply at crest	mm

Symbol	Description	Unit
$e_{p,r}$	nominal thickness of one ply at root	mm
e^*	equivalent bellows wall thickness (thinning during forming); see Formula (20)	mm
e_p^*	equivalent ply thickness (thinning during forming); see Formulae (17), (18) and (19)	mm
e_{pp}	wall thickness of the pipe end; see Figure 8	mm
F_p	force due to pressure effect (pressure thrust); see Formula (24)	N
F_w	working force of expansion joints; see Formulae (215), (223), (232) and (241)	N
f	allowable general membrane stress at design temperature; see Table 5	N/mm ² (MPa)
f_{20}	allowable general membrane stress at room temperature	N/mm ² (MPa)
f_T	allowable general membrane stress at test conditions; see Table 5	N/mm ² (MPa)
f_{cr}	allowable design stress in the creep range; see Formula (2)	N/mm ² (MPa)
G	shear modulus; see Formula (255)	
G_σ	degree of load; see Formula (1)	—
H	width of lug in the bored cross section; see Table 18	mm
K_B	axial spring rate of one bellows; see Formulae (35), (36) and (37)	N/mm
K_f	correction factor for allowable meridional stresses due to cold work; see Formulae (38), (39), (40) and (41)	—
K_{sr}	correction factor for the normalized equivalent axial displacement due to cold work; see Formulae (43) and (44)	—
K_F	friction factor to calculate the forces or moments due to friction in the bearings of the restraining parts; see Formulae (222), (231), (240) and (248)	mm ² or mm ³
$\tilde{K}$	effective spring rate of a bellows; see Formulae (212), (217), (226), (235) and (244)	N/mm or Nmm/radian
K_p	factor giving additional forces or moments of curved bellows due to the influence of pressure; see Formulae (220), (221), (229), (230), (238), (239) and (247)	mm or mm ² or mm ³ /radian
K_β	spring rate for the effect of side wall tilting on forces or moments; see Formulae (213), (218), (227), (236) and (245)	N/mm or Nmm/radian
K_μ	factor for the effect of friction between the plies on forces or moments; see Formulae (214), (219), (228), (237) and (246)	mm ² or mm ³
$K_{m,b}$, $K_{\theta,l}$	in-plane instability factors; see Formulae (110) and (111)	—

Symbol	Description	Unit
$k_{p,t}$	de-rating factor for the pressure at the temperature t ; see Formula (3)	—
k_s	stabilizing factor influencing column instability; see Formulae (93) and (94)	—
k_l	factor for occasional load; see 6.4.2.2.2	—
k_t	correction factor for bellows tangent; see Formula (31)	—
k_c	correction factor for reinforcing collar; see Formula (32)	—
L	distance of the pin centre to the end of the head of the lug; see Table 18	mm
L_c	bellows collar length; see Figures 8, 14 and 16	mm
L_t	end tangent length; see Figures 8, 14 and 16	mm
LT	lifetime in the creep range; see Table 6	h
l_B	initial corrugated length of a bellows; see Figure 20	mm
$\bar{l}_B$	equalised corrugated length of a bellows; see Formula (95)	mm
l^*	middle distance of the bellows of a double bellows type; see Figure 23	mm
M_t	torsional moment; see Formulae (256) and (257)	Nmm
$M_{wy}, M_{w\theta}$	working moment of bellows due to lateral deflexion or angular rotation; see Formulae (224), (233), (242) and (249)	Nmm
M_y, M_θ	elastic moment due to lateral deflection or angular rotation; see Formulae (175), (178), (181) and (184)	Nmm
N	number of corrugations of one bellows	—
N_{alw}	allowable number of fatigue cycles; see Formulae (169) and (170)	—
N_{spe}	specified number of fatigue cycles; see 6.2.6.1	—
n	yield exponent for effective spring rate calculation; see Table 14	—
n_p	number of plies	—
n_B	number of bellows in an expansion joint without intermediate pipe	—
p_a	calculation pressure	N/mm ² (MPa)
P_m	primary membrane stress	N/mm ² (MPa)
P_b	primary bending stress	N/mm ² (MPa)
P_θ	primary circumferential membrane stress	N/mm ² (MPa)
$p_s a$	maximum allowable pressure; see 3.13	N/mm ² (MPa)
P_{sc}	limiting internal design pressure based on column instability; see Formulae (93), (94) and (96)	N/mm ² (MPa)

Symbol	Description	Unit
P_{Si}	limiting design pressure based on in-plane instability; see Formulae (100) and (101)	N/mm ² (MPa)
PT	test pressure; see 8.6.2.2	bar
$P_{t, \max a}$	maximum allowable pressure at temperature t	bar
Q	shear stress; see Table 18	N/mm ² (MPa)
q	corrugation length; see Figures 8, 14 and 16	mm
R_e^*	temperature depending local yield strength of bellows material in the as-formed or annealed condition; see Formulae (27), (28) and (29)	N/mm ² (MPa)
$R_{eH, t}$	minimum specified value of upper yield strength at design temperature	N/mm ² (MPa)
$R_{m, t}$	minimum specified value of tensile strength at design temperature	N/mm ² (MPa)
$R_{m, 20}$	minimum specified value of tensile strength at room temperature	N/mm ² (MPa)
$R_{m/TL} / t$	mean creep rupture strength at lifetime $TL(h)$ and design temperature	N/mm ² (MPa)
R_{p0}	yield point at room temperature; see Table 14	N/mm ² (MPa)
$R_{p0,2}$	0,2 % proof strength at room temperature	N/mm ² (MPa)
$R_{p1,0}$	1 % proof strength at room temperature	N/mm ² (MPa)
$R_{p0, t}$	yield point at design temperature; see Table 14	N/mm ² (MPa)
$R_{p0,2, t}$	minimum specified value of 0,2 % proof strength at design temperature	N/mm ² (MPa)
$R_{p1,0, t}$	minimum specified value of 1 % proof strength at design temperature	N/mm ² (MPa)
$R_{p1,0/TL} / t$	mean creep strain limit (1 %) at lifetime $TL(h)$ and design temperature	N/mm ² (MPa)
r_i	internal radius of crest and root knuckle of U-shaped corrugations; see Formula (25) and Figures 8 and 14	mm
S_b	local secondary bending stress; see Table 18	N/mm ² (MPa)
S_L	thickness of the lug in the bored cross section; see Table 18	mm
SF_c	time-dependent safety factor; see Table 6	—
s_θ	circumferential true strain caused by deformation; see 6.2.2.5.2 and 7.4.1.2	—
s_b	bending component of true strain caused by deformation; see 6.2.2.5.2 and 7.4.1.2	—
s_d	equivalent true strain caused by deformation; see 6.2.2.5.2 and 7.4.1.2	—
s_r	true strain of rupture; see Formula (272)	—
TS	maximum / minimum allowable temperature; see 3.14	°C

Symbol	Description	Unit
t	design temperature	°C
t_n	nominal thickness of the material (strip, sheet, plate); see Table 20	mm
w	corrugation height, see e.g. Figures 8 and 14	mm
x	applied axial displacement from the neutral position; see 6.2.7	mm
$\bar{x}$	mean axial displacement; see Formula (97)	mm
y	applied lateral deflection; see Figures 22 and 23	mm
z	joint coefficient; see 8.4.4 and Tables 24, 25, 28	—
α	dimensional parameter for in-plane instability calculation; see Formula (109)	—
β_0	initial side wall angle of the corrugation; see Formula (84)	degree
$\beta_{e,alw}$	maximum allowable side wall angle of the corrugation in the extended position; see Formula (197)	degree
ΔL	cylindrical length of reinforcing member	mm
Δq	equivalent axial displacement range per corrugation; see Formula (207)	mm
Δq^*	normalized equivalent axial displacement; see Formula (45)	—
δ	stress capacity ratio for in-plane instability calculation; see Formula (109)	—
η	factor for the influence of the forming process; see Formula (30)	—
κ	calculation factor; see Formula (48)	1/mm
$\bar{\mu}$	effective friction factor regarding friction between the plies; see Formula (47)	—
μ_H	friction factor regarding friction of hinge bearings; see NOTE 2 in connection with Formula (222)	—
ν_B	Poisson's ratio of bellows material (for stainless steel $\nu = 0,3$)	—
$\sigma(\Delta q)$	stress due to equivalent axial displacement range Δq	N/mm ² (MPa)
$\sigma(P)$	stress due to pressure P	N/mm ² (MPa)
σ_{eq}	total equivalent stress range due to the cyclic axial displacement range Δq	N/mm ² (MPa)
θ	applied angular rotation; see Figure 24	radians

Symbol	Description		Unit
Subscripts:			
0 initial	b bending	r reinforced bellows	
B bellows	c collar, corrugation, compression	t end tangents, torsion, toroidal, design temperature	
E end	d deformation	Δ difference	
I intermediate	e extension	Θ circumferential	
H hinge	h hardware	Σ sum	
LT Lifetime in the creep range	i inside	μ friction	
P pin	m membrane or meridional		
T test conditions	o outside		
	p ply		
^a All pressures for calculation purposes are in N/mm ² (MPa) and $p_{t, \max}$ is in bar.			

6.1.2 Basic design criteria

6.1.2.1 General

Expansion joints shall be designed to withstand the specified pressure PS at the specified temperature TS. This combination of pressure and temperature shall as a minimum represent the most critical foreseeable working conditions.

The specified additional loadings according to 6.1.4 shall be taken into account as well.

NOTE Annex H gives the main design conditions and information and may be used as a guideline.

6.1.2.2 Bellows

Shall be designed according to 6.2.

6.1.2.3 Flanges

Standard flanges shall conform to EN 1092-1:2018 or EN 1759-1:2004. Alternatively the flanges shall be calculated according to the methods in EN 13445-3:2014, EN 13480-3:2017, EN 1591-1:2013 or Annex K in this standard for special hardware flanges.

6.1.2.4 Pipe sections

Shall be designed according to the appropriate standard EN 13445-3:2014 or EN 13480-3:2017.

6.1.2.5 Internal sleeves

Shall be designed according to 6.3.

6.1.2.6 Hardware

Shall be designed according to 6.4.

6.1.3 Allowable stresses

6.1.3.1 General

The design stress shall be the lower of the time-independent stress value defined in Table 5 and the time-dependent stress value defined in 6.1.3.3 and shall be determined for each design condition.

The values of the design stress shall be determined from the material properties as defined in the standards and specifications given in Table 2 and 3 or from relevant material standards.

These minimum values, specified for delivery conditions of the materials, shall be used for design purpose, unless fabrication and/or heat treatment is known to lead to lower values. In such cases, the values to be used shall be agreed by the parties involved.

For the design of main pressure-bearing parts and pressure parts other than bolts the maximum allowable stresses (general membrane stress for predominantly static loads) shall be determined as given below.

NOTE Where materials are used having higher proof stresses and sufficient strains to rupture certified by the material manufacturer in an Inspection certificate according to EN 10204:2004, type 3.1 or 3.2, the allowable stresses may be increased. The increase should not be more than 50 % of the difference between the specified values of the standards and the certified values in the certificate and maximum 15 % of the standard value divided by the relevant safety factor.

6.1.3.2 Design below the creep range (time-independent)

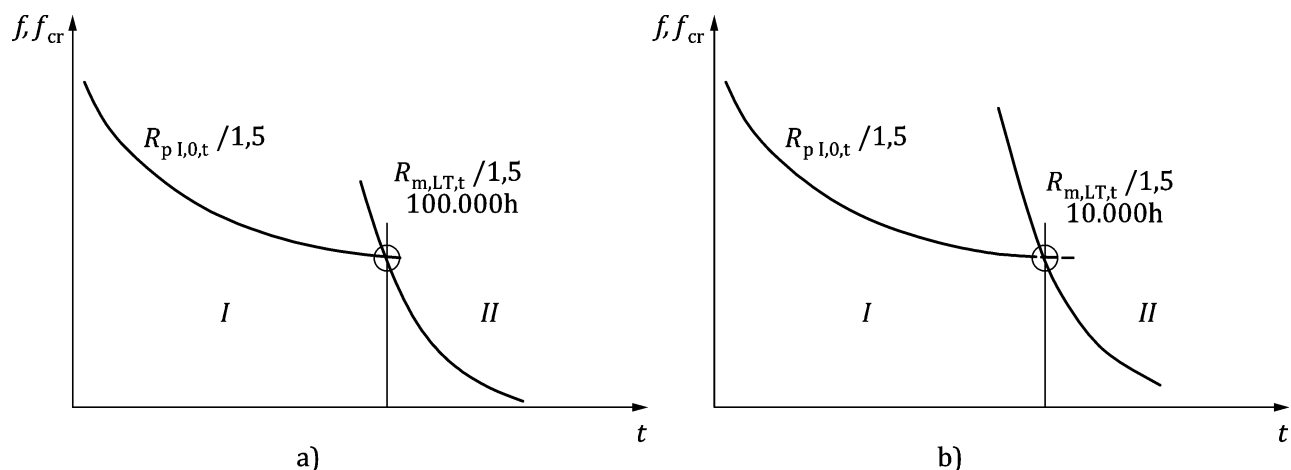
The allowable stresses are given in Table 5.

Table 5 — Allowable stresses

Material	Design conditions	Test conditions
Austenitic steel and Ni alloys — general (30 % < A ≤ 35 %) a b — alternatively ^c if A > 35 %	$f = \left(\frac{R_{p1,0,t}}{1,5} \right)$ $f = \min \left(\frac{R_{p1,0,t}}{1,2}; \frac{R_{m,t}}{3} \right)$	$f_T = \left(\frac{R_{p1,0,T}}{1,05} \right)$ $f_T = \max \left(\frac{R_{p1,0,T}}{1,05}; \frac{R_{m,T}}{2} \right)$
Ferritic steel ^d including normalized (normalized rolled) steel	$f = \min \left(\frac{R_{eH,t}}{1,5} \text{ or } \frac{R_{p0,2,t}}{1,5}; \frac{R_{m,20}}{2,4} \right)$	$f_T = \left(\frac{R_{p0,2,T}}{1,05} \right)$
^a Where A < 30 % use allowable stresses for “Ferritic steel”. ^b For Ni-alloys $R_{p0,2,t}$ shall be used instead of $R_{p1,0,t}$. ^c Shall not be used for the design of bellows. ^d Non-alloy or low-alloy cast steel are excluded.		

6.1.3.3 Design in the creep range (time-dependent)

Where pressure equipment is operated at elevated temperatures near the creep range available time-independent allowable stresses shall be used up to the temperature where the time-dependent allowable stresses are crossed (see Figure 3 a); i.e. “the lower stress value” according to 6.1.3.1.

**Key**

- I* below the creep range
II creep range

Figure 3 — Allowable stresses at high temperatures

Where the time-independent value for the highest temperature available in the harmonized material standards does not reach the time-dependent values the time-independent value for the highest temperature shall be extrapolated up to the temperature where the time-dependent values are crossed; see Figure 3 b). This extrapolated value is regarded as allowable time-independent stress.

The design stress in the creep range f_c to be used for design under static loadings shall be:

$$f_{cr} = \frac{R_{m,LT,t}}{SF_c} \quad (2)$$

where

$R_{m,LT,t}$ is the mean value of creep rupture strength, shall be taken from Table J.3 or from harmonized European standards;

SF_c is the safety factor which is depending on the design lifetime LT is given in Table 6.

For welds other than circumferential welds in welded pipes and fittings the creep strength values of the base material shall be reduced by 20 %, except where ensured creep strength values have been determined for these bellows, pipes and fittings.

This shall also be taken into consideration for bellows with longitudinal welds welded with filler material; this reduction is only valid for dimensioning.

If the design lifetime is not specified, the mean creep rupture strength at 100 000 h shall be used.

NOTE If the creep characteristics determine the thickness, additional creep tests (based on extrapolation using the Larson-Miller formula) for instance on the welding consumables and the complete weld should be performed.

Table 6 — Safety factor related to lifetime

Design life time	LT	100 000 h		200 000 h	
Mean creep rupture strength	$R_{m,LT,t}$	$R_{m,100\,000,t}$		$R_{m,100\,000,t}$	$R_{m,200\,000,t}$
Safety factor	SF_c	1,25 a	1,5 b	1,5 a	1,25 a
a With lifetime monitoring system.					
b without lifetime monitoring system.					

Different approaches are possible when agreed between the involved parties.

6.1.3.4 Test conditions

The designer shall ensure that the stress under proof test conditions, given in 8.6.2.2, shall not exceed the allowable stresses for test condition according to Table 5. This is also valid for the test pressure in the creep range where f_T shall only be based on the time-independent yield strength values at design temperature or - if not available - at the highest temperature for which time-independent values are available in the harmonized European material standards.

NOTE Pressure resistance can only be demonstrated by the proof test with respect to time-independent failure risks because of the short test duration. Proof test cannot give information about long term pressure resistance especially not regarding material damage resulting from design temperatures in the creep range.

6.1.3.5 Design on PN basis

Expansion joints designed on PN basis may be designated for temperatures higher than 20 °C but, not more than the maximum allowable temperature below the creep range where only time-independent stresses are allowed to be used (see also 6.1.3.2). In these cases the manufacturers de-rating factor for pressure, $k_{p,t}$, which shall be based on the respective material standards, shall be applied according to the following Formula (3):

$$p_{t,max} = PN \cdot k_{p,t} \quad (3)$$

6.1.4 Additional loadings

Additional loadings that may influence the design of expansion joints, but are not the loads normally regarded for the design of bellows (see 6.2.2.2), shall also be taken into consideration.

a) Additional loadings present within the expansion joint:

- dead weight of expansion joint components (i.e. intermediate pipe, inner sleeve, restraint hardware, refractory linings etc.);
- dead weight of flow medium within expansion joint;
- dynamic loading due to flow of medium.

These loadings (normal or occasional) shall be defined by the expansion joint manufacturer.

b) External additional loadings due to adjacent piping or equipment:

- unsupported weight of adjacent piping/equipment;
- pipe pre-stressing;
- thermal movement;
- environmental (i.e. snow, wind etc.);
- vibration from adjacent equipment (i.e. pumps, compressors, machines, etc.);
- shock loading (i.e. earth quake, explosion loading, etc.);
- dynamic loading due to flow of medium.

External loadings (normal or occasional) shall be provided by the piping or pressure vessel manufacturer. These lists are not exhaustive.

6.2 Bellows design

6.2.1 Purpose

This subclause provides rules for design and calculation of bellows subject to internal and external pressure and cyclic displacement.

They are applicable to the following three types of bellows (single or multiple corrugations):

- a) unreinforced nominal U-shaped bellows as shown in Figure 8;
- b) reinforced nominal U-shaped bellows as shown in Figure 14;
- c) toroidal bellows as shown in Figure 16.

These bellows are part of expansion joints as defined in Clause 4.

NOTE Attention is drawn to the fact that the design of bellows is complex because strength and flexibility requirements are generally conflicting. Annex E gives detailed information on this issue.

6.2.2 Conditions of applicability

6.2.2.1 Geometry

- A bellows comprises one or more identical axisymmetric corrugations.
- Each corrugation may have one or more plies of the same thickness and of same material.

Deviant characteristics; e.g. different height of corrugations or different ply-materials, are allowed provided they are treated analogously to the given calculation method and all eventual additional effects like stiffness (spring rates) and stability are taken into consideration.

6.2.2.2 Loadings

Loadings mainly regarded for the design of bellows dealt with in 6.2 are static or variable internal pressure, and cyclic axial, lateral or angular movements.

Specific regard shall be given to cover external pressure (see 6.2.3.4) and bellows torsion (see 6.2.10).

Additional loadings according to 6.1.4 shall be given special consideration.

6.2.2.3 Temperature

The requirements are valid for materials at temperatures below the creep range and in the creep range, as stated in 5.2.1.1 or in the relevant European material standards.

6.2.2.4 Welding seams

6.2.2.4.1 General

Typical welding joints of bellows besides other weld seams in an expansion joint are shown in Figures 31 and 32.

6.2.2.4.2 Longitudinal butt welds W1 and W2

Bellows may include one or several longitudinal butt welds.

- a) Bellows without circumferential welds: For longitudinal butt welds W1 no weld joint coefficient z is applied ($z = 1$);
- b) Bellows with circumferential welds (see 6.2.3.6): the concept of weld joint coefficient z shall be applied to longitudinal butt welds W2; see 8.4.3.1.

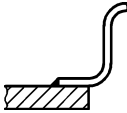
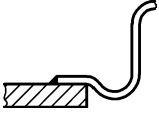
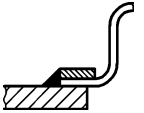
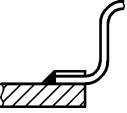
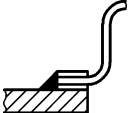
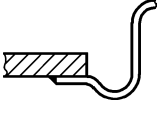
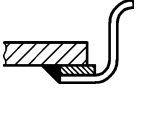
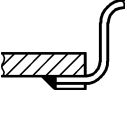
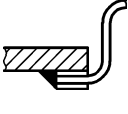
6.2.2.4.3 Circumferential butt welds W3

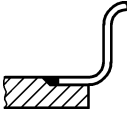
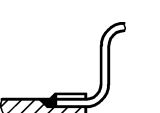
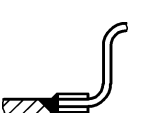
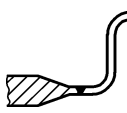
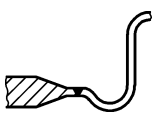
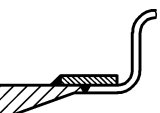
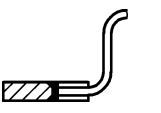
For bellows with circumferential welds (see 6.2.3.6) and for butt weld bellows attachment as shown in Table 7 No 3.0, the concept of weld joint coefficient z does not apply to such butt welds.

6.2.2.4.4 Bellows attachment welds

The circumferential attachment welds of single and multi-ply bellows shall be designed according to the sketches given in Table 7. For butt weld bellows attachment as shown in Table 7, No 3.0, the provision of 6.2.2.4.3 applies.

Table 7 — Bellows attachment welds

Weld type		Variants (Combinations of A to D are permitted)			
No	General design	A increased neck	B reinforcing collar	C Assisting collar single	D double
1.1	a  outside lap joint/filled weld		b 		
1.2	a  inside lap joints/fillet weld				

Weld type		Variants (Combinations of A to D are permitted)			
No	General design	A increased neck	B reinforcing collar	C Assisting collar single	D double
2.1	 outs. lap joint/groove weld				
2.2	 inside lap joint/groove weld				
3.0	c  butt weld	c 			
4.1	d  radial edge weld (inside or outside)				
4.2	 axial edge weld (inside or outside)				
General: Fittings and reinforcing collars opposite to the pressure bearing side of the bellows shall have a radius or a bevel at the edge in contact with the bellows and tangent. a In the case of fillet welds, the weld thickness "a" shall fulfil following formula: $a \geq 0,7 \cdot e$. b The reinforcing collar shall be fixed axially by welding or mechanical devices. c In the case of butt welds, special tools are necessary for welding of multi-ply bellows. d The diameter of the weld should not exceed the mean diameter of bellows D_m by more than 20 % of the corrugations height w.					

6.2.2.5 General factors and coefficients

6.2.2.5.1 General intermediate factors

The following general factors apply in 6.2 Bellows.

Cross sectional metal area of one corrugation:

$$A_c = \begin{cases} 2 \cdot \left[w + r_m \cdot (\pi - 2) \right] \cdot e^*, & \text{for U - shaped bellows} \\ \left[(2 \cdot r_m \cdot \pi - G_p) \cdot e^* + (2 \cdot L_{t,eff} + D_m - D_i - 2 \cdot r_m) \cdot e \right], & \text{for toroidal bellows} \end{cases} \quad (4)$$

Bellows effective area:

$$A_e = \frac{\pi}{4} \times \begin{cases} D_m^2, & \text{for U - shaped unreinforced and toroidal bellows} \\ (D_m + r_i)^2, & \text{for U - shaped reinforced bellows} \end{cases} \quad (5)$$

Factors used to determine the shell coefficients C_p , C_f , C_d ; see 6.2.2.5.3.

$$C_1 = \frac{2 \cdot r_m}{w} \quad (6)$$

$$C_2 = \frac{2 \cdot r_m}{1,1 \sqrt{D_m \cdot e_p^*}} \quad (7)$$

Mean diameter of end tangent reinforcing collar:

$$D_c = D_{i,t} + 2 \cdot e + e_c \quad (8)$$

Mean diameter of bellows corrugations:

$$D_m = \begin{cases} D_i + e + w, & \text{for U - shaped bellows} \\ D_o - e - 2 \cdot r_m, & \text{for toroidal bellows} \end{cases} \quad (9)$$

Bellows nominal wall thickness:

$$e = n_p \cdot e_p \quad (10)$$

Minimum ply thickness for:

— U-shaped bellows made from cylinders:

$$e_{p,o} = e_p \cdot \left(\frac{D_i + 2 \cdot w}{D_i + 2 \cdot \eta \cdot w} \right)^{-0,75} \quad (11)$$

$$e_{p,i} = e_p \cdot \left(\frac{D_i}{D_i + 2 \cdot \eta \cdot w} \right) \quad (12)$$

- U-shaped bellows made from half-corrugations:

$$e_{p,o} = e_p \cdot \left(\frac{D_o - e_p}{D_{n,o}} \right) \quad (13)$$

$$e_{p,i} = e_p \cdot \left(\frac{D_i + e_p}{D_{n,i}} \right)^{-0,75} \quad (14)$$

- Toroidal bellows:

$$e_{p,o} = e_p \cdot \left(\frac{D_i + 4 \cdot r_m}{D_i} \right)^{-0,75} \quad (15)$$

$$e_{p,i} = e_p \quad (16)$$

Equivalent ply thickness for:

- U-shaped bellows made from cylinders:

$$e_p^* = e_p \cdot \left[(1 - \eta) \cdot \left(1 + (1 - \eta) \cdot w / D_i \right)^{-0,5} + \eta \cdot \left(1 + \eta \cdot w / D_i \right)^{-0,667} \right] \quad (17)$$

- U-shaped bellows made from half-corrugations:

$$e_p^* = \frac{(e_{p,c} + e_{p,r}) \cdot r_m \cdot \frac{\pi}{4} + e_p \cdot \left[w - r_m \cdot \left(2 - \frac{\pi}{2} \right) \right]}{w + r_m \cdot (\pi - 2)} \quad (18)$$

- Toroidal bellows:

$$e_p^* = e_p \cdot \left[0,5 \cdot \left(1 + D_o / D_i \right) \right]^{-0,5} \quad (19)$$

Equivalent wall thickness:

$$e^* = n_p \cdot e_p^* \quad (20)$$

Correction factors for multi-ply bellows ($n_p > 1$):

- Correction for bending stress in the sidewall due to pressure:

$$c_{n(P)} = \text{MIN} \left\langle 1 - \left\{ \frac{e_p}{r_m} \cdot (n_p - 1) \cdot \left[\frac{r_m}{w \cdot \sqrt{C_p}} - \frac{1}{4} \left(\frac{1}{\sqrt{C_p}} - 1 \right) \right] - \frac{1}{2} \left(\frac{1}{\sqrt{C_p}} - 1 \right) \right\}; 1 \right\rangle \quad (21)$$

- Correction of corrugation height to reduce bending stress due to movement:

$$c_{c(d)} = \left[1 - \left(n_p - 1 \right) \cdot \frac{e_p}{w} \right] \quad (22)$$

Correction factor for reinforced bellows:

$$\begin{aligned} C_r &= 0,36 \cdot \ln \left(\frac{w}{\Delta q} \right); \text{ valid for } 16 \geq \frac{w}{\Delta q} \geq 2,5; \\ C_r &= 1,0 \text{ for } \left(w/\Delta q \right) > 16; C_r = 0,33 \text{ for } \left(w/\Delta q \right) < 2,5 \end{aligned} \quad (23)$$

NOTE $C_r = 1$ for $w/\Delta q = 16$; i.e. very small or no movement.

Axial pressure force (pressure thrust):

$$F_p = A_e \cdot P \quad (24)$$

Mean inner radius of crest and root knuckle of a u-shaped corrugation:

$$r_i = (r_{ic} + r_{ir}) / 2 \quad (25)$$

Mean radius of crest and root knuckle of a u-shaped corrugation:

$$r_m = r_i + e/2 \quad (26)$$

Local yield strength after forming and heat treatment:

$$R_e^* = R_{p1,0,t} \cdot c^* \cdot (s_d)^m \text{ for as formed bellows} \quad (27)$$

with the factors c^* and m acc. to Table 8 and s_d acc. to 6.2.2.5.2.

$$R_e^* = R_{p1,0,t} \text{ for bellows annealed acc. to Table 8 (without cold work)} \quad (28)$$

$$R_e^* = R_{p1,0,t} \cdot 0,9 \text{ for otherwise annealed bellows} \quad (29)$$

$R_{p1,0,t}$ shall be replaced by $R_{p0,2,t}$ if $R_{p1,0,t}$ is not available or allowed (e.g. Ni-alloys).

For ferritic materials R_e^* is equal to R_{eH} .

Table 8 — Material dependent parameters for cold work calculation

Material (Strip, sheet)		Condition	Material properties ^a (minimum values)				Stress-strain parameters ^{b c}	
Number	Alloy		$R_{p0,2}$	$R_{p1,0}$	R_m	A	c^*	m
Steel name	(informative)		N/mm ²	N/mm ²	N/mm ²	%	-	-
1.4301 X5CrNi18-10	304	cold rolled, solution annealed	230	260	540	40	2,96	0,27
1.4306 X2CrNi19-11	304L		220	250	520	45	2,84	0,27
1.4401 X5CrNiMo17-12-2	316		240	270	530	40	2,91	0,27
1.4404 X2CrNiMo17-12-2	316L		240	270	530	40	2,91	0,27
1.4435 X2CrNiMo18-14-3	316L		240	270	550	40	2,85	0,27
1.4539 X1CrNiMoCuN25-20-5	904L		240	270	530	35	2,96	0,27
1.4541 X6CrNiTi18-10	321	hot rolled, solution annealed	220	250	520	40	2,88	0,27
1.4550 X6CrNiNb18-10	347		200	240	520	40	3,00	0,27
1.4571 X6CrNiMoTi17-12-2	316Ti		240	270	540	40	2,81	0,27
1.4828 X15CrNiSi20-12	309	solution annealed	230	270	550	30	3,04	0,27
1.4876 X10NiCrAlTi32-21	800	soft annealed	210	240	500	30	3,15	0,27
1.4876 (H) X10NiCrAlTi32-21	800 H	solution annealed	170	200	450	30	3,53	0,3

Material (Strip, sheet)		Condition	Material properties ^a (minimum values)				Stress-strain parameters ^{b c}	
Number	Alloy		$R_{p0,2}$	$R_{p1,0}$	R_m	A	c^*	m
Steel name	(informative)		N/mm ²	N/mm ²	N/mm ²	%	-	-
2.4360 NiCu30Fe	400	soft annealed	175	200	450	30	3,60	0,3
2.4610 NiMo16Cr16Ti	C-4	solution annealed	305	340	700	40	2,68	0,24
2.4816 NiCr15Fe	600	soft annealed	200	230	550	30	2,96	0,3
2.4816 (H) NiCr15Fe	600 H	solution annealed	180	210	500	35	3,67	0,31
2.4819 NiMo16Cr15W	C-276	solution annealed	310	330	730	30	3,30	0,27
2.4856 NiCr22Mo9Nb	625, Grade 1	soft annealed	400	440	830	35	2,59	0,25
2.4858 NiCr21Mo	825	solution annealed	235	265	550	30	3,23	0,29
^a The parameters c^* and m are based on the given material properties. ^b c^* and m are based on test data. These parameters can be achieved by using minimum 5 experimental stress-strain curves from tensile tests, generating a mean value curve out of these 5 curves, normalizing this mean value test curve to $R_{p0,2}$, $R_{p1,0}$ and R_m from the appropriate EN material standard and fitting the curve to $\sigma = c^* \cdot \varepsilon^m$ with $c^* = \frac{C}{R_{p1,0}}$ and $C = a \cdot 100^m$ by defining the parameters a and m to get a curve close to the normalized mean value test curve. ^c For austenitic stainless steels not listed in this table $c^*=2,8$ and $m=0,27$ may be used if $R_{p0,2} \geq 200 \text{ N/mm}^2$, $R_{p1,0} \geq 240 \text{ N/mm}^2$ and $R_m \geq 520 \text{ N/mm}^2$.								

Forming factor depending on the forming process:

$$\eta = \left| \frac{D_n - D_i}{2 \cdot w} \right| \quad (30)$$

with the neutral diameter D_n as the original inner diameter of the cylinder or of the ring plate before forming starts. It is depending on the forming process, see Table 9 for information.

Table 9 — Typical values of forming factor η (informative)

Forming process for corrugations		Forming factor η	Remarks
1	From inside to outside with restraining tools starting from the inner diameter D_i by: — hydraulic or elastomer forming — expansion (punching) — roll-forming	0	Restraining tools holding back the roots of the corrugations on the diameter of the original cylinder
2	Partly to outside and to inside within two steps starting from a neutral diameter D_n by: — roll-forming — a combined process (hydraulic / elastomer or expansion and roll-forming)	0,4 to 0,6	Restraining tools holding back the neutral diameter D_n during the first step
3	Partly to outside and to inside within one step; roll-forming with counter-rotating rolls (free forming)	0,5 to 0,8	Crest and root diameter result from equilibrium of strains

Correction factors considering the stiffening effect of bellows attachments:

a) Unreinforced and reinforced bellows with nominally U-shaped corrugations:

— Correction factor for bellows tangent:

$$k_t = \min \left[\left(\frac{L_t}{1,5 \cdot \sqrt{(D_{i,t} + e) \cdot e_p}} \right); 1,0 \right] \quad (31)$$

— Correction factor for the reinforcing collar:

$$k_c = \min \left[\left(\frac{L_c}{1,5 \cdot \sqrt{D_c \cdot e_c}} \right); 1,0 \right], \text{ for collars fixed to the fitting} \quad (32)$$

For different types of attachments see also Table 10.