Safety Standards

of the
Nuclear Safety Standards Commission (KTA)

KTA 3204 (2017-11)

Reactor Pressure Vessel Internals
(Reaktordruckbehälter-Einbauten)

Previous versions of this Safety Standard
were issued 1984-03, 1998-06 and 2015-11

Editor:

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KTA SAFETY STANDARD

November 2017	Reactor Pressure Vessel Internals	KTA 3204

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Comments by the editor:

Taking into account the meaning and usage of auxiliary verbs in the German language, in this translation the following agreements are effective:

shall	indicates a mandatory requirement,
shall basically	is used in the case of mandatory requirements to which specific exceptions (and only those!) are permitted. It is a requirement of the KTA that these exceptions - other than those in the case of **shall normally** - are specified in the text of the safety standard,
shall normally	indicates a requirement to which exceptions are allowed. However, the exceptions used, shall be substantiated during the licensing procedure,
should	indicates a recommendation or an example of good practice,
may	indicates an acceptable or permissible method within the scope of this safety standard.

Fundamentals

(1) The safety standards of the Nuclear Safety Standards Commission (KTA) have the objective to specify safety-related requirements, compliance of which provides the necessary precautions in accordance with the state of the art in science and technology against damage arising from the construction and operation of the facility (Sec. 7 para. 2 subpara. 3 Atomic Energy Act - AtG) in order to achieve the fundamental safety functions specified in the Atomic Energy Act and the Radiological Protection Ordinance (StrlSchV) and further detailed in the Safety Requirements for Nuclear Power Plants as well as in the Interpretations on the Safety Requirements for Nuclear Power Plants.

(2) No. 3.1 of the Safety Requirements for Nuclear Power Plants, among other things, sets high requirements for the quality assurance and reliability of fabrication, the use of qualified materials, the safeguarding and maintenance of quality features during fabrication as well as the execution of regular in-service inspections to an extent that is necessary from a safety-related point of view. Requirement no. 5 requires to provide evidence regarding the safety of the plant. No. 6 (4) requires, among other things, the preparation and use of specifications regarding materials, construction, erection, testing and inspection as well as the documentation of quality assurance. Safety standard KTA 3204 is intended to specify detailed measures which shall be taken to meet these requirements within the scope of its application. For this purpose, a large number of standards from conventional engineering, in particular DIN standards, are also used; these are specified in each particular case.

(3) The safety requirements for reactor pressure vessel internals result from the requirements regarding

a) the capability for safe shutdown of the facility,
b) sufficient heat removal,
c) reliable closing of the isolating valves (BWR).

(4) Where the requirements regarding the

a) quality classes,
b) design approval,
c) documentation,
d) design and stress analysis,
e) materials and material testing,
f) manufacture and
g) operational monitoring and inspection

are met, it will be ensured that the safety requirements for reactor pressure vessel internals are satisfied during the service life of the facility.

(5) Principal quality assurance measures to be taken during the fabrication of the reactor pressure vessel internals are laid down in KTA Safety Standard 1401.

1 Scope

(1) This safety standard shall apply to

a) the reactor pressure vessel internals (RPV internals) of light water reactors as well as to the tools and equipment used for the installation, removal and laying down of components and subassemblies of RPV internals,
b) for welds between RPV internals and butterings or claddings on RPV internals,
c) load attachment points on RPV internals,
d) attachment welds of the RPV internals for direct attachment to the RPV, which are outside the distance limit to (3) (**Figure 1-1a**) and do not represent a pressure-retaining wall of the reactor coolant pressure boundary.

(2) This safety standard does not apply to

a) components of the reactor core, core instrumentation, control elements and their drive mechanisms,
b) load suspension device,
c) the quenched and tempered steel attachments welded to the RPV,
d) attachment welds of the RPV internals for direct attachment to the RPV, which are within the distance limit to (3) (**Figure 1-1a**) or represent a pressure-retaining wall of the reactor coolant pressure boundary,

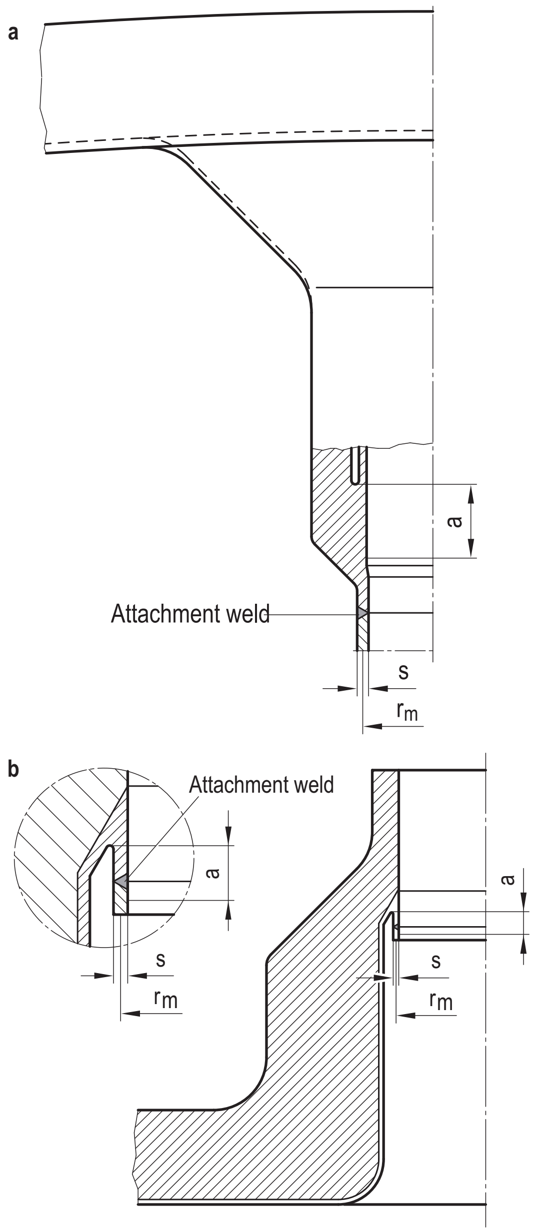


Figure 1-1: Direct attachment welds of RPV internals to the RPV (examples)

e) welds between the lay-down equipment and the storage pool.

Note:
The welds directly connecting the RPV internals and the RPV, which are within the distance limit to (3) or represent a pressure-retaining wall of the reactor coolant pressure boundary, and the quenched and tempered steel attachments welded to the RPV are covered by KTA 3201.3 and KTA 3201.4, the welds between the lay-down equipment and the storage pool by KTA 2502, and the load attachment riggings by KTA 3902 and KTA 3903.

(3) The distance limit as evaluation criterion for the assignment of the respective attachment weld to (1) or (2) above shall be determined by means of the following formula:

$$a = 0.5 \cdot \sqrt{r_m \cdot s}\ , \qquad (1\text{-}1)$$

where

r_m : average radius of curvature of the components welded together

s : thickness of the components welded together.

2 Definitions

Note:
The definitions regarding stress analysis are specified in Section 6.2.1.

(1) Plant vendor for nuclear facilities (A)

A plant vendor for nuclear facilities is the person who received an order by a plant user or the future user of this facility for the planning and delivery of a nuclear facility or its components.

(2) Sub-unit

A sub-unit is part of a component and consists of at least two parts.

(3) Part

A part is the smallest item of a sub-unit manufactured from product forms.

(4) Threaded fasteners

Threaded fasteners are fasteners which generally need not transfer residual gasket loads (e.g. screws, bolts, nuts).

(5) Specified operation

Specified operation means operating conditions or changes in operating conditions consisting of normal or anomalous operational load cases.

(6) Plant user

The plant user is the person responsible for the operation of a nuclear facility.

(7) Anomalous operational load cases

Anomalous operational load cases are operating conditions arising from malfunctions of components or systems (disturbed condition) unless there are no objections as to the safe continuation of operation.

(8) Normal operational load cases

Normal operational load cases are operating conditions for which the plant is designed and suited, with the systems being functionally fit (undisturbed condition).

(9) Refuelling

Refuelling is the entirety of tasks and work necessary for the shifting or replacement of spent or defective fuel elements to be removed from the core.

(10) Product form

A product form is the form in its raw condition into which materials are processed, e.g. plates and sheets, forgings and castings.

(11) Manufacturing

Manufacturing comprises all tasks required for the construction of a component.

(12) Verification of strength

The verification of strength is intended to prove, by using the generally accepted engineering rules, that the component is able to withstand the loadings occurring during its service life.

(13) Functional capability

Functional capability is the ability of a system or of one of its component parts (e.g., component, subsystem, train) including the necessary auxiliary, supply and power systems to perform the prescribed tasks.

(14) Manufacturer (H)

The manufacturer is the person who, by specific order, will fabricate and test the equipment ordered, e.g. product form, component part, subassembly or component under his responsibility.

(15) Verification of structural integrity

The verification of structural integrity means a verification by analysis or experiments that the safety requirements (e.g. with respect to strength, resistance to failure, leak tightness)) for the component are satisfied.

(16) Component

A component is that part of a system defined in terms of structural or functional criteria, which still performs independent part functions.

(17) Load attachment point (LAP)

The load attachment point is the connecting element between load suspension device and load and is either

a) an integral part of the load or
b) bolted on or
c) welded on.

(18) Progressive surface examination

Progressive surface examination is a liquid penetrant examination performed progressively with a weld seam being built up.

Note:
See also 8.9.1 (4).

(19) Room temperature

The temperature range for the room temperature is (23 ± 5) °C for the mechanical tests laid down in this safety standard.

(20) Representative locations, components or component parts

Such locations, components or component parts are considered to be representative where the in-service inspection will lead to at least comparable safety related results for other locations, components or component parts, taking into consideration the material composition, design and manufacturing quality as well as the type, level and frequency of loading.

(21) Authorized inspector (S)

For the purpose of this standard, this is the inspector charged by the licensing or supervising authority to perform inspections in accordance with § 20 of the Atomic Energy Act.

(22) Welding process

A welding process is a particular method of welding involving the application of certain metallurgical, electrical, physical, chemical or mechanical principles.

(23) Welding procedure

A welding procedure is a specified course of action to be followed in making the weld, including the welding process(es), reference to materials, welding consumables, preparation, preheating (if necessary), method and control of welding and post-weld heat treatment (if relevant), and necessary equipment to be used.

(24) Incidents

Incidents are deviations from specified operation in the event of which the operation of the plant cannot be continued for safety reasons:

A Emergencies (NF)

Emergencies are incidents having very little probability of occurrence

B Accidents (SF)

Accidents are incidents having an extremely little probability of occurrence, or are postulated load cases.

(25) Subcontractor

Subcontractor is the person who, by specific order of a manufacturer, will fabricate and test the equipment ordered, e.g. product form, machine element, component part, subassembly or component under his or the manufacturer's responsibility.

(26) Design approval

The design approval is the safety-related assessment of the design and construction, the verification of strength of the materials used, the manufacturing processes, the test and inspection schedule, the circuitry, the possibility of performing in-service inspections, the accessibility for maintenance and repair, and the equipment used for operational monitoring, by means of the plans, written instructions, drawings and calculations established for manufacture with reference to the requirements contained in the licence, in KTA safety standards and other technical rules.

(27) Acceptance criteria for non-destructive testing

Non-destructive testing acceptance criteria refer to the sum of all stipulations used to determine whether an indication can be evaluated to be acceptable without taking further measures (requirements of test instruction have been met) or whether further measures need be taken. The acceptance criteria contain both quantitative stipulations in form of acceptance limits (e.g. amplitude height, extension of indication, frequency, and distance between indications) and descriptive stipulations (e.g. linear or rounded indication, indication on surface or across volume, accumulation of indications).

3 Quality classes

(1) All components, sub-units or parts of Reactor Pressure Vessel internals are assigned to quality classes with respect to their different tasks and functions (**Table 3-1**).

(2) Components, sub-units and parts of quality class "AS-RE 1" are structures which, according to their tasks and functions, shall ensure a safe possibility of shutdown and residual heat removal. The structural integrity and functional capability of these components, sub-units and parts shall be proven for normal operation and anticipated operational occurrences (levels A and B) and for incidents (levels C and D).

(3) Components, sub-units and parts of quality class "AS-RE 2" are structures which, according to their tasks and functions, do not directly ensure the safe possibility of shutdown and residual heat removal. The structural integrity and functional capability of these components, sub-units and parts shall be proven for normal operation and anticipated operational occurrences (levels A and B), however, failure of these components, sub-units and parts shall not impair the safe shutdown and residual heat removal.

(4) Components, sub-units and parts of quality class "AS-RE 3" are structures with subordinate tasks and functions and accessories. With regard to the requirements, they are classified as follows:

a) For components, sub-units and parts of quality class "AS-RE 3 within the RPV" the same requirements shall apply as for components, sub-units and parts of quality class "AS-RE 2", cf. (3).

b) For components, sub-units and parts of quality class "AS-RE 3 outside the RPV" the general standards and rules of engineering practice apply.

Quality class	Task and function	Components, sub-units and parts of Pressurized Water Reactor (PWR) [1] (see **Figure 3-1**)	Components, sub-units and parts of Boiling Water Reactor (BWR) [1] (see **Figure 3-2**)
AS-RE 1	support of the core centering of RPV internals guiding the control rod assemblies coolant water supply (BWR)	core support and upper core support lower and upper support plate control rod guide tubes and support support structure shroud control rod guide assembly and pins lower and upper tie plate core barrel (KB) bypass assembly centering and fixation details on the RPV	core shroud downcomer space cover upper core grid core plate control rod guide tubes thermal sleeves
AS-RE 2	guiding and distributing the coolant water supporting and protecting the instrumentation separating the components of steam-water mixture (BWR) fixation and protection of RPV internals and fuel assemblies absorption of component loadings	top and flow distribution plate guide assembly and support plate for in-core instrumentation flow distribution system core shroud (KU) vertical support RPV internals hold-down elements fuel assembly centering pins load attaching points	steam separator instrumentation tubes (core flux measurement tube) feed water sparger core flooding system steam dryer load attaching points
AS-RE 3	holding material specimens in position travel limitation of RPV internals installing, removing and laying down RPV internals guidance of RPV internals	specimen containers lay-down equipment installation and removal equipment auxiliary equipment guiding, centering and travel limiting elements	head spray cooling device alignment tracks specimen containers lay-down equipment installation and removal equipment auxiliary equipment

[1] When connecting two parts of different quality classes the following regulation for quality classes shall be observed:

a) In the case of welded joints the higher quality class of the two parts shall apply.
b) In the case of fasteners the quality class of the part to be connected shall apply.

Note:
Where components of the RPV internals are attached to the RPV, see Section 1, sub-clause 2.

Table 3-1: Assignment of tasks and functions of components, sub-units and parts to Reactor Pressure Vessel internals quality classes (AS-RE)

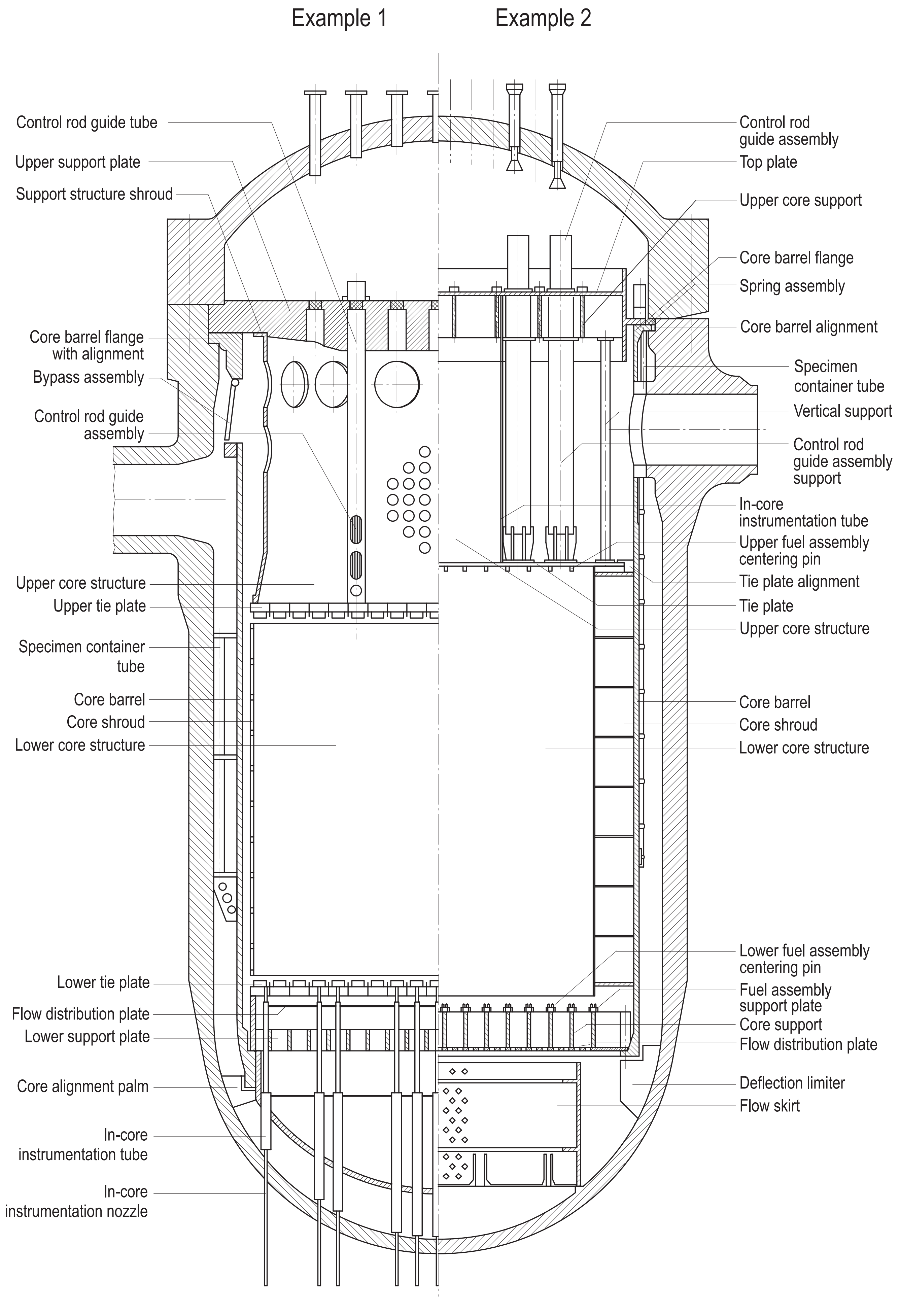


Figure 3-1: Typical internals of a Reactor Pressure Vessel (PWR)

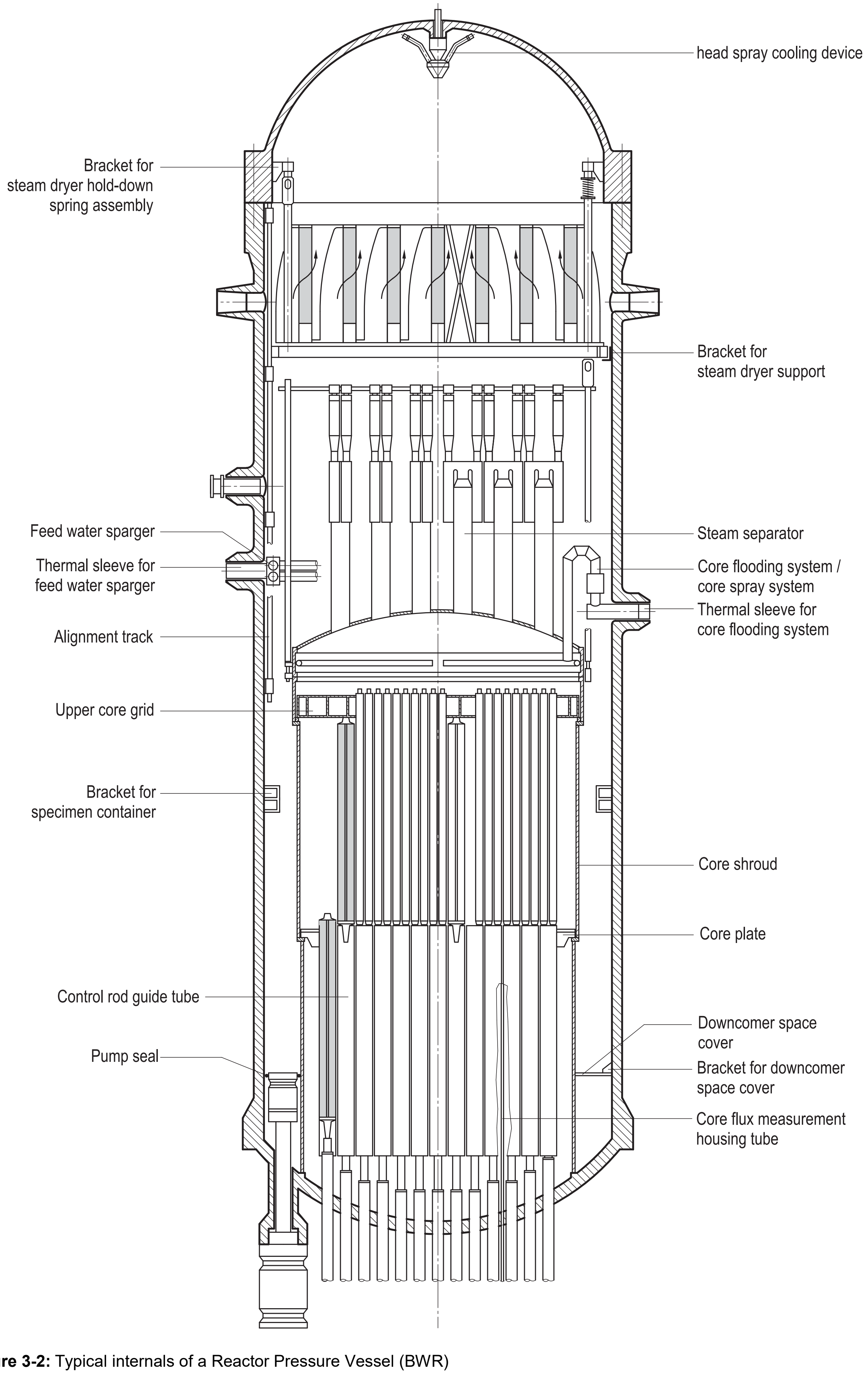


Figure 3-2: Typical internals of a Reactor Pressure Vessel (BWR)

4 Design approval

The design approval documents for Reactor Pressure Vessel internals shall be submitted with the mark of approval in due time prior to the beginning of the individual manufacturing step according to **Table 4-1**.

no.	Design approval documents	Quality classes								
		AS-RE 1			AS-RE 2			AS-RE 3		
		design approval performed by								
		H	A	S	H	A	S	H	A	S
1	Manufacture of the product form in acc. with Section 7	no design approval required								
2	Manufacture of the part a) Assembly drawing, sub-unit drawings	—	X	X	—	X	X	—	X	X
	b) Test and inspection sequence plan with table of contents	X	X	X	X	X	—	—	—	—
	c) Materials list	X	X	X	X	X	—	X	X	—
	d) Welding procedure sheet (welding procedure specification) / brazing procedure sheet [1)]	X	X	X	X	X	X	X [2)]	X [2)]	—
	e) Heat treatment plan	X	X	X	X	X	—	—	—	—
	f) Weld location plan	X	—	—	X	—	—	—	—	—
	g) Test instructions for non-destructive testing	X	X	X	X	X	—	X	X	—
	h) Dimensional check plan acc. to Table 8-6 no. 4	X	X	X	X	X	—	—	—	—
	i) Final drawing / detail drawing	X	X	—	X	X	—	X	X	—
	j) Cleaning plan	X	X	—	X	X	—	—	—	—
	k) Demonstration of free movement of control rods, tolerance considerations	—	X	X	—	X	X	—	X	X
	l) Cleaning and coating instruction	—	—	—	—	—	—	X	X	—
3	Installation of the sub-unit/part a) Stress analysis	—	X	X	—	X	X	X	X	—
	b) Dimensional check plan acc. to Table 8-6 no. 4.3 and 4.4	X	X	X	X	X	X	X	X	X
	c) Test schedule for functional tests acc. to Table 8-6 no. 5	—	—	—	—	—	—	X	X	X
4	Commissioning of reactor coolant pressure boundary All documents required at this point of time according to Section 9 (operational monitoring and in-service inspection)	X	X	X	X	X	X	—	—	—
5	Nuclear commissioning of the plant The remaining documents regarding stress analysis according to Section 6 on the basis of loads measured during trial operation	X	X	X	X	X	X	—	—	—

[1)] For design approval purposes, the written statement of the authorized inspector on procedure qualifications to section 8.6 shall accompany the welding or brazing procedure qualification test report.

[2)] For welded joints in load path only.

A: Plant vendor H: Manufacturer S: Authorized inspector

Table 4-1: Requirements and documents regarding design approval

5 Documentation

5.1 General requirements

(1) All documents as per paragraph 5.2 shall be part of the documentation and shall be established step by step at the intervals mentioned.

(2) In the case of changes the documentation shall be updated.

(3) Changed documents subsequently design-approved anew in accordance with section 4 shall be identified with a revision mark. Repair plans shall be marked accordingly.

(4) In the case of deviations the reviewed application for tolerating the respective deviation and the document describing the deviation shall become part of the documentation with the same registration number.

(5) The interrelationship between the various technical documents of the documentation is shown schematically in **Figure 5-1**.

(6) Forms shall be used for each individual document, in which case the contents shall be considered to be binding, and the layout of the form is only a recommendation (see sample **forms 5-1** to **5-6**).

(7) Each collection of individual documents as shown in **Figure 5-1** shall be reviewed for completeness and latest state of documentation.

Note:
Details on the type and period of filing are laid down in KTA 1404.

5.2 Documents to be included in the documentation

5.2.1 Parts inside the reactor pressure vessel

For parts inside the reactor pressure vessel the documents of **Table 5-1** shall be included in the documentation.

5.2.2 Parts outside the Reactor Pressure Vessel

For parts outside the reactor pressure vessel the documents of **Table 5-2** shall be included in the documentation.

<table>
<tr><th>Type of technical document</th><th>Referenced in Section/Table</th><th>Comments regarding the technical document in question</th><th>Point in time at which the technical document shall be collected</th></tr>
<tr><td colspan="4">Regarding design (Section 6.1)</td></tr>
<tr><td>Assembly drawing</td><td rowspan="2">Table 4-1 no. 2 a)</td><td>including parts lists (with referencing to respective AS-RE); as-built condition of parts/sub-units shall be shown completely</td><td rowspan="4">prior to installation of the sub-unit/part</td></tr>
<tr><td>Sub-unit drawing</td><td>none</td></tr>
<tr><td>Materials list</td><td>Table 4-1 no. 2 c)</td><td>none</td></tr>
<tr><td>Detail drawing</td><td>Table 4-1 no. 2 i)</td><td>as far as required for showing the as-built condition</td></tr>
<tr><td colspan="4">Regarding stress analysis (Section 6.2)</td></tr>
<tr><td>Analysis reports</td><td>6.2.5 a); Table 4-1 no. 3 and 5</td><td>none</td><td>prior to installation of the sub-unit/part and prior to the nuclear commissioning of the plant</td></tr>
<tr><td colspan="4">Regarding materials and material testing (Section 7)</td></tr>
<tr><td>Inspection certificate</td><td rowspan="2">—</td><td>none</td><td rowspan="2">prior to manufacture of the part</td></tr>
<tr><td>Review sheet on materials tests and examinations</td><td>The review sheet for non-destructive examination (Form 5-6) shall contain each individual position of RPV internals.
A reference to the respective material test sheet is allowed instead of indicating each individual examination.</td></tr>
<tr><td colspan="4">Regarding Manufacture (Section 8)</td></tr>
<tr><td>Test and inspection sequence plan</td><td>Table 4-1 no. 2 b)</td><td>none</td><td rowspan="16">prior to installation of the sub-unit/part</td></tr>
<tr><td>Marking transfer certificate</td><td>8.8.2</td><td>if required in acc. with Table 8-6</td></tr>
<tr><td>Repair test and inspection sequence plan</td><td>8.5.2; Table 4-1 no. 2 b)</td><td rowspan="3">none</td></tr>
<tr><td>Welding procedure sheet</td><td>8.3.1.2; Table 4-1 no. 2 d)</td></tr>
<tr><td>Repair welding procedure sheet</td><td>8.5.2</td></tr>
<tr><td>Welding record</td><td>8.3.1.5.2</td><td>an overall certificate is permitted</td></tr>
<tr><td>Brazing procedure sheet</td><td>8.3.2.1; Table 4-1 no. 2 d)</td><td rowspan="2">none</td></tr>
<tr><td>Repair brazing procedure sheet</td><td>8.3.2.1</td></tr>
<tr><td>Brazing record</td><td>8.3.2.3</td><td>an overall certificate is permitted</td></tr>
<tr><td>In-process inspection record</td><td>8.8.5</td><td rowspan="7">none</td></tr>
<tr><td>Hot forming record</td><td>8.3.4.4</td></tr>
<tr><td>Non-destructive examination record</td><td>8.8.5</td></tr>
<tr><td>Test instructions for non-destructive testing</td><td>7.3.5.8.1;
Table 4-1 no. Nr. 2 g)</td></tr>
<tr><td>Heat treatment plan</td><td>8.4.1;
Table 4-1 no. 2 e)</td></tr>
<tr><td>Heat treatment record</td><td>8.4.3</td></tr>
</table>

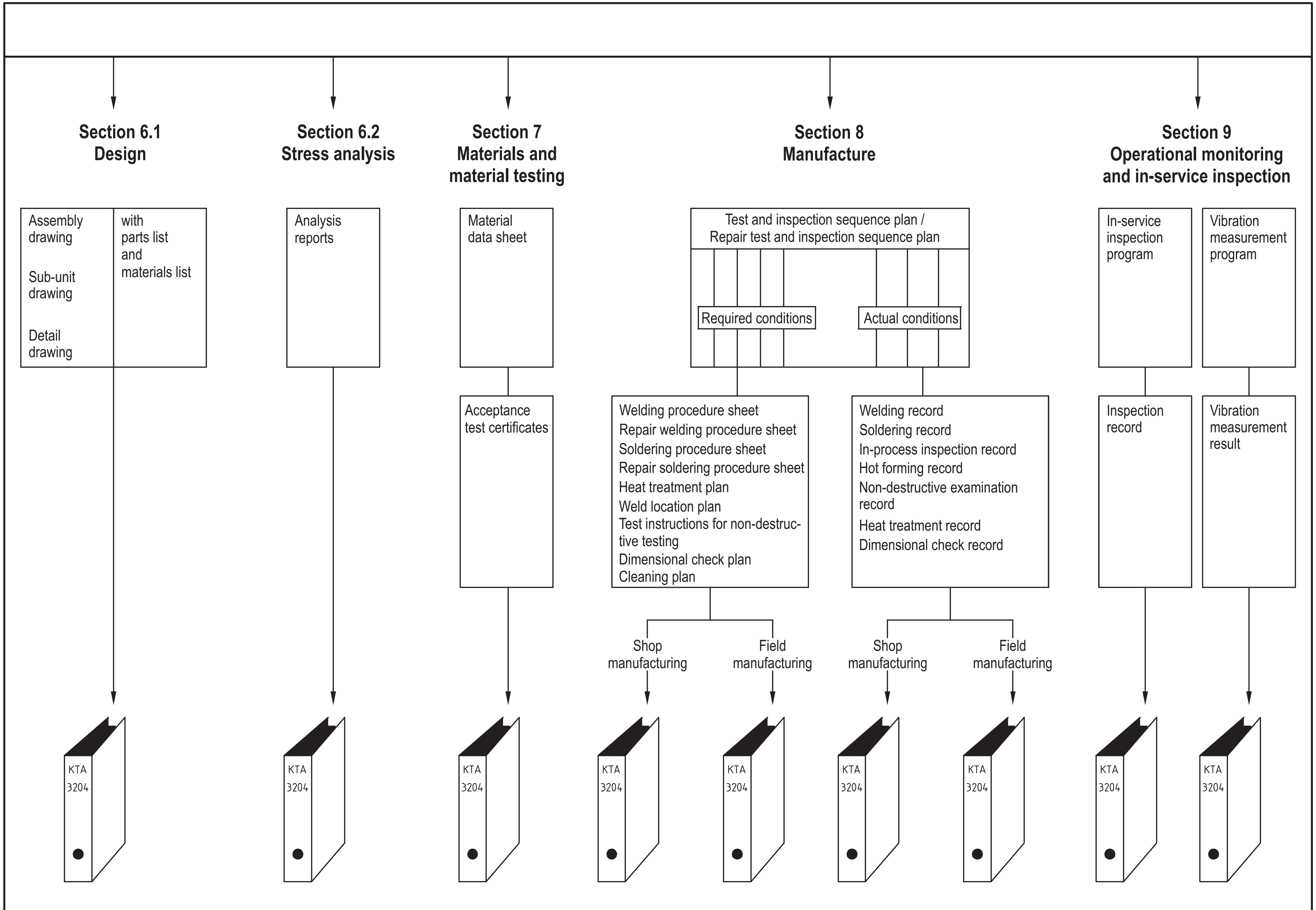
Table 5-1: Extent of documentation filing for parts inside the Reactor Pressure Vessel (continued on next page)

Type of technical document	Referenced in Section/Table	Comments regarding the technical document in question	Point in time at which the technical document shall be collected
Regarding Manufacture (Section 8)			
Weld location plans	Table 4-1 no. 2 f)	none	prior to installation of the sub-unit/part
Dimensional check plan	8.8.4; Table 4-1 no. 2 h) and 3 b)		
Dimensional check record	8.8.5		
Cleaning plan	8.3.5.1.2; Table 4-1 no. 2 j)		
Documentation release certificate	8.8; Table 8-6		
Regarding operational monitoring and in-service inspection (Section 9)			
Inspection program and test/examination manual	9.3.1; 9.3.3; Table 4-1 no. 4	none	see Table 9-1 (B, D, F and G)
Inspection record	9.3.5		after the inspection has been performed
Vibration measurement program	9.4.3.1 (1); 9.4.3.2 (1); Table 4-1 no. 4		prior to performing the measurement
Vibration measurement result	9.4.3.1 (3); 9.4.3.2		see Table 9-1 (A, C and E)

Table 5-1: Extent of documentation filing for parts inside the Reactor Pressure Vessel (continued)

Type of technical document	Referenced in Section/Table	Comments regarding the technical document in question	Point in time at which the technical document shall be collected
Assembly drawing	Table 4-1 no. 2 a)	including parts lists and information about type of welded joints	prior to installation of the sub-unit/part
Detail drawing	Table 4-1 no. 2 i)	as far as required for showing the as-built condition	
Stress analysis report	6.2.5; Table 4-1 no. 3 a)	none	
Inspection certificate of the material	—	collection of certificates	
Welding and brazing procedure sheets	Table 4-1 no. 2 d)	for welded joints in load path only	
Record on non-destructive examination of welded joint	8.8.5	none	
Dimensional check plan	8.8.5; Table 4-1 no. 2 h)		
Dimensional check record	8.8.5		
Cleaning and coating instruction	Table 4-1 no. 2 l)		
Test schedule for functional test	8.8.4; Table 4-1 no. 3 c)		
Record on functional test	8.8.5		
Documentation release certificate	8.8; Table 8-6		

Table 5-2: Extent of documentation filing for parts outside the Reactor Pressure Vessel



[1] In case of components outside the RPV an analogous compilation shall apply.

Figure 5-1: Interrelationship (schematic) of documents for components inside the RPV [1]

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zum PFP-Nr.: *of test and inspection sequence plan no.:*	
Komponente: *component:*	Projekt: *project:*

Lfd. Nr. *serial no.:*	PFP-Nr. *test and inspection sequence plan no.:*	Fortsetzung *continued*	Seiten *pages*	Rev. *revision* Seiten *pages*

Lfd. Nr. *line no.*	Hersteller *manufacturer*			Art der Änderung *type of changes*	Hersteller: *manufacturer:*
	Datum *date*	Erstellt *prepared by*	Geprüft *checked by*		
o					Auftrag.-Nr.: *contract no.:*
a					
b					Seite: *page:*
c					von: *of:*

Form 5-1: Contents of test and inspection sequence plans

1	2	3	4	5	6	7	8	9	10	11
Prüf-Nr. *test no.*	Anforderungen nach *requirements in accordance with*	Beschreibung *description*	Prüfzeitpunkt *date of test*	Prüfart. *type of test*	Prüfung durch: *test performed by*	Nachweisschlüssel *certification key*	Doku.-Ablage *document file*	Durchführungsvermerk *mark, when examination was performed*	Nachweise *certification of examinations*	Bemerkungen *remarks*

12
Hersteller: *manufactorer:*
Anlage/Projekt: *power plant / project:*
Komponente: *component:*
KKS/AKZ/Typ, Antrieb, DN: *code KKS or AKZ/type, drive, DN:*
Spezifikation: *specification:*
Klasse: *classification:*
Prüfgruppe:: *test group:*
Auftrags-Nr. *contract no.:*
Bestell-Nr.: *order no.:*
Werk-Nr./Index-Nr.: *plant no. / index no.:*
Zeichnungs-Nr.: *technical drawing no.:*
WL-Nr.: / *WL no.:* STL-Nr.: / *STL no.:* SP-Nr.: / *SP no:*

Revision *revision*	Hersteller: *manufacturer:* Datum *date*	Erstellt von *prepared by*	Geprüft QST *checked by quality dept.*	Grund der Revision *reason for revision*	Freigabe *release certification*	Prüfvermerk des Sachverständigen gemäß § 20 AtG *certification mark of authorized inspector acc. to § 20 AtG*	Dokumentationsfreigabe *release certification of documents*
00							Hersteller *manufacturer*
01							Sachverständiger *authorized inspector*
02							
03							
04							

Prüffolgeplan
test and inspection sequence plan

PFP-Nr.: *test and inspection sequence plan no:.*

Seite: / *page:*

Von: / *of:*

Form 5-2: Test and inspection sequence plan

Skizze/Schweißfolge/Aufbau der Schweißung/Abmessungen *sketch/welding sequence/build-up of weld/dimensions*	Bemerkungen *remarks*

(15) Grundwerkstoff / Werkstoffuntergruppe nach DIN CEN ISO/TR 15608 *base metal / material subgroup according to DIN CEN ISO/TR 15608*	
Pos. *pos.*	Normbezeichnung *standard designation*

Nachfolg. Wärmebehandlung
subsequent heat treatment

Arbeitsprüfung
associated production control test

Schweißerprüfung
welder's qualification test

(16) Hersteller:
manufacturer:

Anlage/Projekt:
power plant / project:

Komponente:
component:

Spezifikation:
specification:

Klasse:
classification:

EG:
part group:

Schweiß–folge *welding sequence* (1)	Schweiß–verfahren *welding process* / Verfahrens–prüf-Nr. *welding proc. qualification no.* (2)	Schweiß–position *welding position* (3)	Schweißzusätze u. Hilfsstoffe / *filler metals and consumables*: Hersteller und Bezeichnung *manufacturer and designation* (4)	Abmes–sungen *dimension* [mm] (5)	Pulver Hersteller und Bezeichnung *flux manufacturer and designation* (6)	Schutzgas *shield gas* [l/min] DIN EN ISO 14175 / Formiergas *purging gas* [l/min] DIN EN ISO 14175 (7)	Schweißdaten / *welding data*: Stromart *type of current* / Polung der Elektrode *electrode polarity* (8)	Stromstärke Grundstrom/ Pulsstrom *amperage base current / pulse current* [A] / Spannung *voltage* [V] (9)	Geschwin–digkeit *travel speed* [mm/min] / Auszieh–länge *run-out length* [mm] / Puls–frequenz *pulse frequency* (10) [Hz]	Pendel–breite *oscillation width* [mm] / Pendel–frequenz *oscillation frequency* [1/min] (11)	Drahtge–schwindigkeit Heißdraht *wire speed hot wire* [mm/min] / Kaltdraht *cold wire* [m/min] (12)	Vorwärm-/ Halte–temperatur *preheat /holding temp.* [°C] / Zwischenla–gentemperatur *interpass temperature* [°C] (13)	Lagen–zahl *no. of passes* (14)

Schweißnahtart
type of weld

Schweißstellenliste
weld location list

Schweißstellenkennzeichnung
weld identification

Schweißnahtvorbereitung
weld preparation

Ausarbeiten der Wurzel
grooving out of root

Trocknung Elektroden/Pulver (Temp., Zeit)
drying electrodes/flux (temp., time)

KKS/AKZ/Typ, Antrieb, DN:
code KKS or AKZ/ type, drive, DN:

Zeichnungs-Nr.:
technical drawing no.:

Auftrags-Nr.:
contract no.

Bestell-Nr.:
order no.:

Werk-Nr./Index-Nr.:
plant no. / index no.:

PFP-Nr.: / *PFP no.:*

WL-Nr.: / *WL no.:*

(17) Rev. *revision*	Hersteller: *manufacturer:* Datum *date*	Erstellt von *prepared by*	Geprüft QST *checked by quality dept.*	Grund der Revision *reason for revision*	Freigabe *release certification*	Prüfvermerk des Sachverständigen gemäß § 20 AtG *certification mark of authorized inspector acc. to § 20 AtG*
00						
01						
02						
03						
04						

Schweißplan
welding procedure specification

SP-Nr.: / *SP no:.*

Seite:
page:
Von:
of:

Form 5-3a: Welding procedure sheet (welding procedure specification)

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Schweißstellenkennz. *welding location ident. marking*	Skizze der Schweißnaht *scetch of the weld*	Position nach Zeichnung *position as per drawing* Pos. mit Pos. *pos. with pos.*	Grundwerkstoff-bezeichnung *designation of base metal*	Schweißverfahren *welding process*	Schweißposition *welding position*	Schweißzusätze Hersteller Bezeichnung Abmessung *filler metals manufacturer designation dimension*	Trockn.: Temp. und Zeit *drying: temperature and time*	Schweißdaten *welding data*	Vorwärmtemperatur Brennschneiden [°C] *preheat temp.thermal cutting [°C]*	Vorwärmtemperatur Schweißen [°C] *preheat temp. welding [°C]*	Vorwärmtemperatur Fugen [°C] *preheat temp. gouging [°C]*	Zwischenlagentemperatur [°C] *interpass temp [°C]*	Nachfolgende Wärmebehandlung *subsequent heat treatment*	Schweißfolge zum Nahtaufbau *welding sequence for build-up of weld*	Verfahrensprü-fungs-Nr. geforderte Schweißerprüfung Arbeitsprüfungs-Nr. *welding procedure qualification no.* *required welder's qualification test* *production control test no.*

17			
Rev. *revision*	00	01	02
Datum *date*			
Hersteller *manufacturer*			
Geprüft QST *checked by quality department*			
Freigabe *release certification*			
Prüfvermerk des Sachverständigen gemäß § 20 AtG *certification mark of authorized inspector acc. to § 20 AtG*			

Hersteller: *manufacturer:*

Anlage/Projekt: *power plant/project:*

Komponente: *component:*
EG: *part group:*

KKS: *NPP identification system:*

Zugehörige WL-Nr.: *corresponding list of materials no:*

Zeichnungs-Nr.: *technical drawing no.:*

Auftrags-Nr.: *contract no.:*

Werk-Nr./Index-Nr.: *plant no./index no.:*

Zugehörige PFP-Nr.: *corresponding test and inspection sequence plan no.:*

Schweißplan
welding procedure sheet

SP-Nr.: *welding procedure sheet no.:*

Seite: *page:* von: *of:*

Form 5-3b: Welding procedure sheet (welding procedure specification)

Dauer der Schweißung von .... bis ....
duration of welding from until

Schweißplan-Nr.: ....
welding procedure sheet no.:
Bezeichnung der Schweißstelle: ....
weld designation:
Grundwerkstoff: ....
base metal:
Arbeitsprüfungs-Nr.: ....
production control test no.:
Gültige Verfahrensprüfungs-Nr.: ....
valid welding procedure qualification no.:

Verwendete Schweißgeräte:
welding equipment used:

Verfahren *process*	Masch.-Typ *equipment type*	Masch.-Nr. *equipment no.*	Besondere Vorrichtungen *special equipment*

Verwendete Schweißzusätze:
filler metals used:

Schweißfolge *welding sequence*	Verfahren *process*	Bezeichnung *designation*	Abmessung *dimensions*	Los-Nr. *lot no.*	Chargen-Nr. *weld material test no.*

Ausarbeiten der Wurzel durch:
root gouged by:

PFP-Nr.: .... *test and inspection sequence plan no.:*	Legende: *explanations:*	Auftrags-Nr.: .... *contract no.:*
Fertigungs-schritt-Nr.: .... *manufacturing step no.:*		Projekt: *project:* Komponente: *component:*
Registrier-Nr.: .... *registration no.:*	Hersteller: *manufacturer:*	**Schweißprotokoll** *welding record (SPK)*
		SPK-Nr. *welding record no.* / Seite: *page:* von: *of:*

Form 5-4a: Welding record

Protokollierte Parameter:
recorded data:

Schweiß-folge *welding sequence*	Position *position*	Lagenzahl 2) *number of layers*	Stromart *type of current*	Polung *polarity*	A	V	Geschwin-digkeit 1) *travel speed* [mm/min]	Düsen-Nr. *nozzle no.*	Zwischen-lagerung *intermediate storage*	Schweißername und Nr. *welder's name and identification no.*	Abzeichnung der Schweiß-aufsicht *signature of welding supervision*		
1	2	3	4	5	6	7	8	9	10	11	H	A	S

Besonderheiten:
special features:

Skizze:
sketch:

Die Bedingungen des Schweißplans wurden, soweit nicht unter „Besonderheiten“ anders vermerkt, eingehalten.
The requirements of the welding procedure sheet were adhered to, unless described otherwise under „special features“.

Hersteller:
manufacturer:

Form 5-4b: Welding record

1) Nur für mechanisierte Schweißverfahren anzugeben.
1) For mechanized welding only

2) Nicht für Fülllagen anzugeben.
2) Not required for filler passes

Skizze *sketch*	Prüf-Nr. *test no.*	Wärmebehandlungsdiagramm *heat treatment diagram*	Mitlaufende Grundwerkstoff- und Arbeitsprüfstücke *accompanying test coupons of base material and production welds*	5
1	2	3	4	Hersteller: *manufacturer:*
				Anlage/Projekt: *power plant / project:*
				Komponente: *component:*
				KKS/AKZ/Typ, Antrieb, DN: *code KKS or AKZ/ type, drive, DN:*
				Spezifikation: *specification:* Klasse: *classification:*
				Auftrags-Nr.: *contract no.:*
				Bestell-Nr.: *order no.:*
				Zeichnungs-Nr.: *technical drawing no.:*
				Werk-Nr./Index-Nr.: *plant no. / index no.:*
				PFP/WPP-Nr.: *test and inspection sequence plan no. /materials testing and specimen-taking plan no.:*
				SP-Nr.: *welding procedure specification no.:*

Rev. *revision*	Hersteller: *manufacturer:* Datum *date*	Erstellt von *prepared by*	Geprüft QST *checked by quality dept.*	Grund der Revision *reason for revision*	Freigabe *release certification*	Prüfvermerk des Sachverständigen gemäß § 20 AtG *certification mark of authorized inspector acc. to § 20 AtG*		**Wärmebehandlungsplan** ***heat treatment plan***
00								WBP-Nr.: *heat treatment plan no:.*
01								
02								
03								Seite: *page:*
04								von: *of:*

Form 5-5: Heat treatment plan

Angaben zum Bauteil/Erzeugnisform *information about the part/product form*						Prüfvorschrift nach Abschnitt ... *test instruction acc. to Section ...*	Prüfung *test/examination*																		Freigabe der Dokumentation: *release of documentation*		
Lfd. Nr. *line no.*	Benennung *designation* Abmessung *dimension*	Zeichnung/ Stückliste *drawing/ parts list*	Pos. *pos.* An-zahl *number*	Werkstoff/Schweißzusatz *material/filler metal* DIN Bezeichnung oder Stempelung *designation acc. to DIN standard or stamping*	Schmelze-Nr. *melt no.* Probe Nr. *specimen no.*																				H	A	S
							1																				
							2																				
							3																				
							1																				
							2																				
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							3																				
							1																				
							2																				
							3																				

Änd. *rev.*	Hersteller (H) *manufacturer (H)*			Art der Änderung *type of changes*
	Datum *date*	Erstellt *prepared by*	Geprüft *checked by*	
0				
a				
b				
c				

Legende:
explanations:

H = Hersteller *manufacturer*

A = Anlagenlieferer *plant vendor*

S = Sachverständiger *authorized inspector*

Hersteller: *manufacturer:*	Projekt: *project:*
Auftragsnummer: *contract no.:*	Komponente/Baugruppe: *component/sub-unit:*

Erläuterungen
explanations

1 Nachweis nach DIN EN 10204
certificate to DIN EN 10 204

2 Nachweisregistriernummer
certificate registration no.

3 Erfüllungszeichen
certification mark

Kontrollblatt für Werkstoffprüfung
Review sheet on material tests and examinations

Seite:
page:

von:
of:

Form 5-6: Review sheet on materials tests and examinations

6 Design and stress analysis

6.1 Design

6.1.1 General requirements

The design of the reactor pressure vessel internals shall

a) meet the functional requirements

b) not lead to an increase of loadings/stresses

c) meet the specific requirements of the materials

d) meet fabrication and inspection and testing requirements

e) be amenable to maintenance

f) meet the operational requirements.

with respect to the interaction between aforementioned general requirements.

6.1.2 Tolerances

For all dimensions for which no tolerances are shown in the drawings, DIN ISO 2768-1 and DIN ISO 2768-2 (accuracy level: medium) as well as DIN EN ISO 13920 (accuracy level: C) shall apply.

6.1.3 Deviations from specified shape and location

(1) Deviations from specified shape and location shall be indicated in accordance with DIN EN ISO 1101.

(2) The maximum deviations from shape and location shall be specified by the plant vendor.

6.1.4 Surfaces

(1) The surface qualities shall be specified in accordance with sequence 2 of DIN EN ISO 1302.

(2) The root mean square Ra shall be limited to 10 µm.

Note:

The root mean square values to be adhered to shall be specified by the plant vendor.

6.1.5 Fasteners

(1) Only safeguarded fasteners which are not susceptible to cracking (e.g. threaded fasteners, nuts and pins) shall be used.

(2) Austenitic threaded fasteners for structural fasteners that are to be detached regularly shall have rolled threads or threads with additional backlash at thread crest or flank as well as show rounded edges.

6.1.6 Welded joints

(1) For parts inside the reactor pressure vessel the weld factors and fatigue strength reduction factors can be obtained from **Table 6-1** in dependence of the non-destructive examinations performed and the requirements for the welded joint.

(2) The welded joints are assigned to categories A to F (see **Table 8-3**). The type of welded joints shall be determined in consideration of **Tables 8-3** and **6-1**.

(3) For parts outside the reactor pressure vessel the DIN Standards or rules of conventional engineering shall apply.

(4) In the following, the range of application of the welded joints is described. Examples for their application are given in **Figures 6-1** and **6-2**.

a) Welded joint categories A1, A2 and B1

These weld groups are used e.g. for butt, longitudinal or circumferential welds and as T-joints, corner joints or nozzle welds. The examination of the cover pass shall be made from both sides. For the evaluation with respect to the weld factor and fatigue strength reduction factor, line 1 from **Table 6-1** applies.

b) Welded joint categories A3 and B2

For the application the requirements of a) apply. For the evaluation with respect to the weld factor and fatigue strength reduction factor, line 2 of **Table 6-1** applies. Where these weld joint categories do not meet the requirements of 8.3.1.4 on the root side, line 1 of **Table 6-1** applies.

c) Welded joint category C

This category is used for butt welds if the conditions

$a_{min} \geq 1/8\ s_2$ and $s_2 \leq s_1$

are satisfied (s_1 = greater wall thickness; s_2 = smaller wall thickness; a_{min} = minimum throat thickness).

The cover pass shall be examined from both sides.

For the evaluation of the weld factor and fatigue strength reduction factor, line 3 of **Table 6-1** applies.

d) Welded joint category D

This category is e.g. used for T-joints, corner joints and nozzle welds.

The cover pass shall be examined from both sides. For the evaluation of the weld factor and fatigue strength reduction factor, line 4 of **Table 6-1** applies.

e) Welded joint categories E and F

This categories are e.g. used for T-joints, angle joints, corner joints or nozzle welds.

For the evaluation of the weld factor and fatigue strength reduction factor, lines 5 to 7 of **Table 6-1** apply.

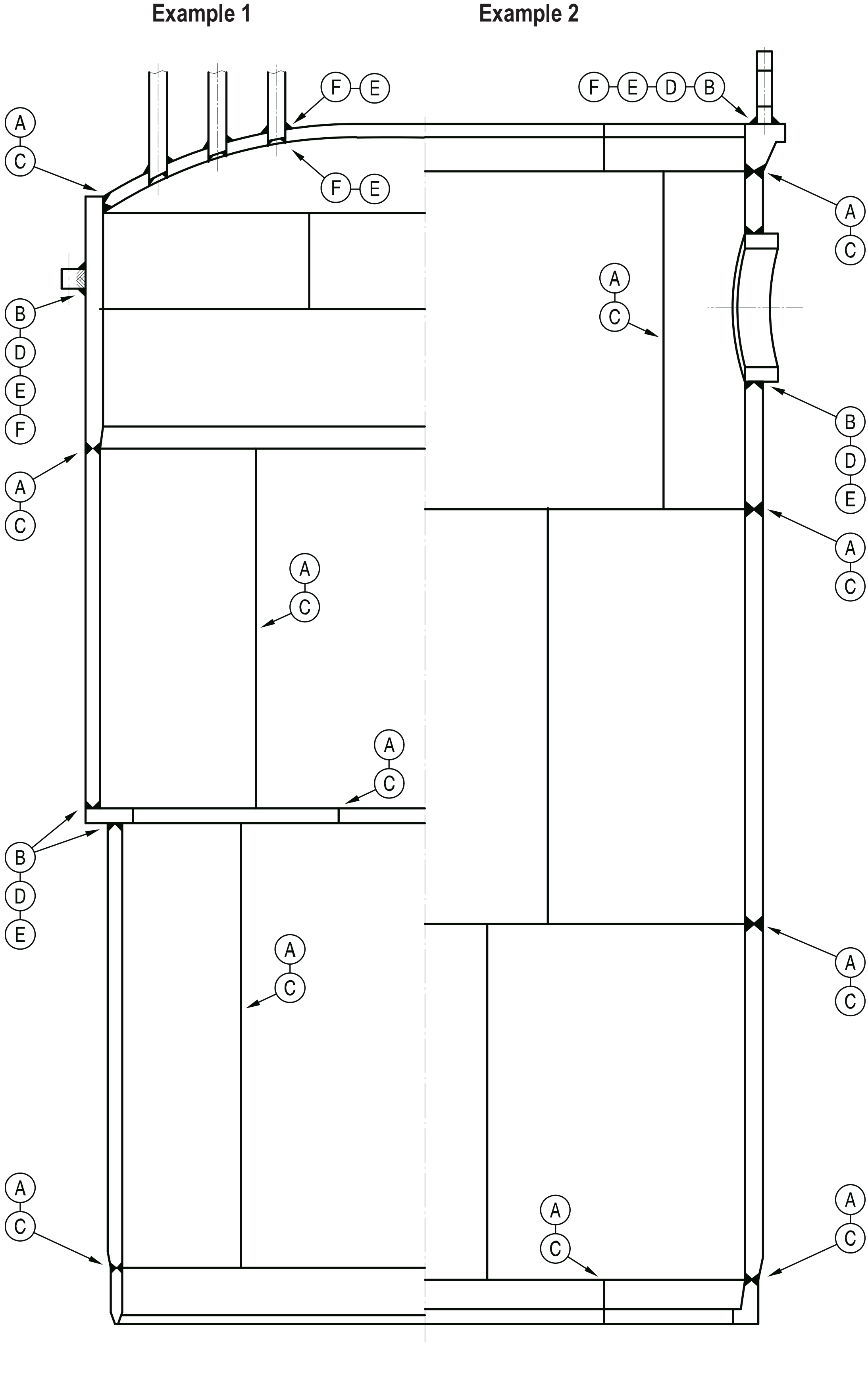


Figure 6-1: Typical weld type locations of welded joint category A to F (see section 6.1.6 and **Table 8-3**)

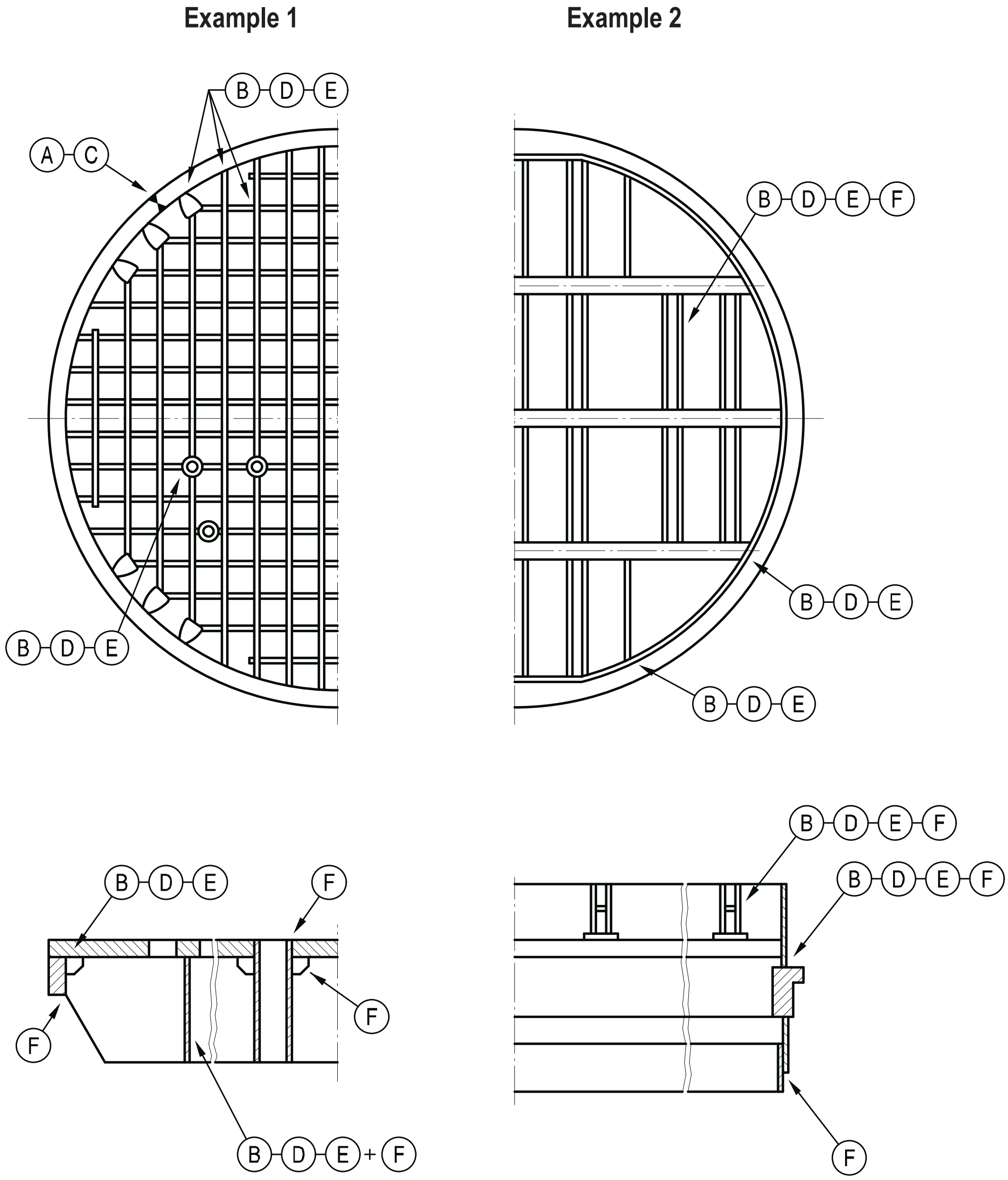


Figure 6-2: Typical weld type locations of welded joint category A to F (see section 6.1.6 and Table 8-3)

Line no.	Welded joint category according to **Table 8-3**	Non-destructive testing									
		RT of finished weld PT of surface layer		PT, progressive		PT of root pass and final run		PT of final run		VT of final run	
		n	f	n	f	n	f	n	f	n	f
1	Category A1, A2 and B1	1.0	1.0	0.9	1.0	0.75	1.0	0.65	1.0	0.5	1.0
2	Category A3 and B2	1.0	2.0	0.9	2.0	0.75	2.0	0.65	2.0	0.5	2.0
3	Category C	—	—	0.45	4.0	0.4	4.0	0.35	4.0	0.25	4.0
4	Category D	—	—	0.8	4.0	0.7	4.0	0.6	4.0	0.4	4.0
5	Category E Category F, fillet weld	—	—	0.55	4.0	0.45	4.0	0.4	4.0	0.35	4.0
6	Category F, double fillet weld	—	—	0.8	4.0	0.7	4.0	0.6	4.0	0.4	4.0
7	Category F, intermittent fillet weld	—	—	0.45	4.0	0.4	4.0	0.35	4.0	0.3	4.0

RT : Radiographic testing
PT : Liquid penetrant testing
VT : Visual testing
n : Weld factor
f : Fatigue strength reduction factor

Table 6-1: Weld factors and fatigue strength reduction factors for welded joints (category A to F)

6.2 Stress analysis

6.2.1 Definitions

(1) Gross structural discontinuity

Gross structural discontinuity is a geometric or material discontinuity which effects the stress or strain distribution through the entire wall thickness of the shell-type member. Gross-discontinuity type stresses are those portions of the actual stress distribution that produce net bending and membrane force resultants when integrated through the wall thickness.

Note:

Examples of gross structural discontinuities are head-to-shell and flange-to-shell junctions, nozzles, and junctions between shells of different thicknesses or materials.

(2) Loadings

Loadings are stresses or strains or a combination of stresses and strains. They are evaluated as equivalent stress or equivalent strain or their stress intensity. In the case of a linear elastic relationship stresses and strains are proportional to each other. In the case of an elastic stress analysis according to 6.2.4.2.2 and a fatigue analysis according to 6.2.4.2.3 this proportional ratio even when in excess of the yield strength or proof stress of the material shall be the basis of analysis (fictitious stresses).

The loadings are (primarily) static loadings, cyclic loadings or dynamic loadings.

(3) Loading limit

Loading limit is a maximum allowable stress or strain value.

(4) Loading level

Loading level is a specific category of loading limits to safeguard against various types of failure.

Note:

Examples of safeguarding against various types of failure are: Limitation of plastic deformation, avoidance of failure due to progressive deformation (ratcheting) and fatigue.

(5) Bending stress

Bending stresses are defined as stresses that can be altered linearly across the considered section and proportionally to the distance from the neutral axis, in the case of plane load-bearing structures as the portion of the stresses distributed across the thickness, that can be altered linearly.

(6) Deformation (= resulting distortion)

Deformations are perceived as the integrals calculated for strain. They constitute changes in geometry of the component, of the part or the idealized structure due to loadings. Deformations can be described by displacements and values derived therefrom (e.g. twisting). If required, they shall be limited such that the functional capability of the component and its adjacent components is not impaired.

(7) Shakedown

Shakedown is the absence of a continuing cycle of plastic deformation if creep effects are excluded. A structure shakes down if after a few cycles of load application the deformation stabilizes and subsequent structural response is elastic.

(8) Interaction equation

Interaction equation is an equation which comprises and evaluates the various types of loadings such as bending and tension, or bending, tension and shear, at the ratio of the effective to the allowable loading. The sum must always be less than 1.0.

Note:

See also Section C 2.

(9) Load case

Load case is a state or change of state in the structure which is a result of events specified for the whole plant and which leads to a loading on the component.

(10) Load case class

Load case class is the assignment of load cases specified in the system documentation, to a specific class, e.g. to normal operational load cases.

(11) Local structural discontinuity

Local structural discontinuity is a geometric or material discontinuity which affects the stress or strain distribution through a fractional part of the wall thickness. The stress distribution associated with a local discontinuity causes only very localized types of deformation or strain and has no significant effect on the shell-type discontinuity deformation.

Note:

Examples are small filled radii, small attachments and partial penetration single-vee and double-level groove welds as well as related types of weld.

(12) Primary stress

Primary stress is a normal or shear stress developed by imposed loading which is necessary to satisfy the laws of equilibrium of forces and moments. Regarding the mechanical behaviour of a structure, the basic characteristic of this stress is that upon initiation of yielding of the cross-section the deformations will increase disproportionally with an increment of the external loads. Upon further inadmissibly high increment of the external loads deformations occur that are not self-limiting. A general primary membrane stress is one which is so distributed in the structure that no redistribution of load occurs as a result of yielding.

Note:

Examples are: general membrane stress (P_m) in a circular cylindrical or spherical shell due to internal pressure difference or distributed live loads; bending stress (P_b) in the central portion of a flat head due to pressure difference.

(13) Ratcheting (progressive deformation)

Ratcheting is a progressive incremental inelastic deformation or strain which can occur in a component that is subjected to variations of mechanical stress, thermal stress, or both.

(14) Ring/shell cross section

The ring/shell cross-section is the equivalent cross-section composed of the combination of structural stiffeners and effective shell-type member which has the same stiffness as the original shell and the reinforcement.

(15) Secondary stress

Secondary stress (Q) is a stress developed under mechanical or thermal loading due to

a) geometric discontinuities,

b) differing elastic constants (e.g. moduli of elasticity) and

c) constraints due to differential thermal expansions.

The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions which cause the stress to occur, and failure from one application of the stress is not to be expected. For the linear-elastic analysis only stresses that are distributed linearly across the cross-section are considered to be secondary stresses.

Note:

Examples of secondary stresses are: general thermal stress; bending stress at a gross structural discontinuity.

(16) Stress limitations

Stress limitations are allowable limits for the given loadings of the structure.

Note:

Basic stress limits are P_m, $P_m + P_b$ and $P_m + P_b + Q$ in accordance with **Tables 6-5** and **6-6**.

(17) Stress concentration factor

Stress concentration factor is that factor with which the nominal stress portions have to be multiplied to obtain the total stress. It may be determined analytically or experimentally.

(18) Peak stress

Peak stress (F) is that increment of stress which is additive to the respective primary and secondary stresses. Peak stresses do not cause any noticeable distortion and are only important to fatigue in conjunction with primary and secondary stresses.

Note:

Examples are: stress due to local structural discontinuity; surface stresses caused by thermal stock; thermal stress in a structure, caused by a cladding; stress caused by the difference of the actual temperature distribution from the equivalent linear temperature distribution.

(19) Stress ratio method

The methods of plastic analysis which utilize the stress ratio combinations are used to compute the maximum load a strain-hardened material can carry.

Note:

(1) See also 6.2.4.2.7.

(2) Stress ratio combinations are useful since the actual shape factor as a function of the cross section and the type and magnitude of different stress fields may be considered in determining the load.

(20) Stress cycle (= Load cycle)

Stress cycle is a condition in which the alternating stress difference goes from an initial value through an algebraic maximum value and an algebraic minimum value and then returns to the initial value. Dynamic conditions shall also be considered stress cycles.

Note:

(1) See also 6.2.4.2.2.2.2.

(2) A single service cycle may result in one or more stress cycles.

(21) Elastic ratio

Elastic ratio is the 0.2% proof stress ($R_{p0.2}$), divided by the tensile strength (R_m).

(22) Thermal stress

Thermal stress is a self-balancing stress produced by a nonuniform distribution of temperature or by differing coefficients of thermal expansion. Thermal stress is developed in a solid body whenever a volume of material is prevented from assuming the size and shape that it normally should under a change in temperature. For the purpose of establishing allowable stresses, two types of thermal stress are recognized depending on the volume or area in which distortion takes place:

a) A **general thermal stress** is associated with distortion of the structure in which it occurs. If a stress of this type, neglecting stress concentrations, exceeds a certain limit value, the elastic analysis may be invalid and successive thermal cycles may produce incremental distortion. Therefore, this type of stress is classified as secondary stress in **Table 6-4.**

   Note:

   Examples are: stress produced by

   a) an axial temperature distribution in a cylindrical shell,

   b) the temperature difference between a nozzle and the shell to which it is attached,

   c) the radial temperature distribution in a cylindrical shell.

b) A **local thermal stress** is associated with almost complete suppression of the differential expansion and thus produces no significant distortion. Such stresses shall only be considered from the fatigue standpoint and are therefore classified as peak stresses in **Table 6-4.** In evaluating local thermal stresses the procedure of 6.2.4.2.2.7, para 5 (b) shall be used.

   Note:

   Examples are: the stress in a small hot spot in a vessel wall; the difference between the actual stress and the equivalent linear stress resulting from a radial temperature distribution in a cylindrical shell.

(23) Trapezoidal stress

Trapezoidal stress is defined as a fictitious stress occurring in the neutral fibre or during zero strain which results from transforming the non-linear stress/stain curve into a trapezoidal stress-strain curve.

Note:

See also Section C 4.1.

6.2.2 Identification of load cases

6.2.2.1 General requirements

(1) All load cases for sub-units of reactor pressure vessel internals shall be classified in accordance with clause 6.2.2.2.

(2) To each load case of the sub-units a loading level according to clause 6.2.2.3 shall be assigned.

6.2.2.2 Load case classification

(1) The load cases shall be assigned to one of the load case classes specified in **Table 6-2.**

(2) With regard to the verification of integrity, each load case class is correlated to one of the following loading levels

a) Specified operation:

   aa) normal operational load cases (NB) are assigned to Level A loading level,

   ab) anomalous operational load cases (AB) are assigned to Level B loading level.

b) Incidents:

   ba) emergencies (NF) are assigned to Level C loading level,

   bb) accidents (SF) are assigned to Level D loading level.

   Note:

   A more detailed explanation is e.g. contained in section 3.2 of KTA 3201.2.

Load case classes		Load cases no.	Frequency
Specified operation	Normal operational load cases (NB) Level A	(are specified for each individual plant)	(are specified depending on the load cases for each individual plant)
	Anomalous operational load cases (AB) Level B		
Incidents	Emergencies (NF) Level C		
	Accidents (SF) Level D		

Table 6-2: Example for classification of load cases

a) Load components for quality class AS-RE 1									
Loading level	Weight	Fluid forces	Differential pressure	Tempera-ture	Pretensio-ning forces	Vibration loading at normal service	Design basis earth-quake [1]	Aircraft crash and chemical explosion	Hydrodynamic loads due to loss-of-coolant accidents
Level A	X	X	X	X	X	X			
Level B	X	X	X	X	X	X			
Level C	X	X	X	(X)	X	X			
Level D	X	[X]	[X]		X	[X]	X (BEB)	X	X
b) Load components for quality class AS-RE 2 and AS-RE 3 inside the RPV									
Loading level	Weight	Fluid forces	Differential pressure	Tempera-ture	Pretensio-ning forces	Vibration loading at normal service	Design basis earth-quake [1]	Aircraft crash and chemical explosion	Hydrodynamic loads due to loss-of-coolant accidents
Level A	X [3]	X	X	X	X	X			
Level B	X	X	X	X	X	X			
Level C									
Level D									
c) Load components for quality class AS-RE 3 outside the RPV									
Loading level	Weight	Fluid forces	Differential pressure	Tempera-ture	Pretensio-ning forces	Vibration loading at normal service	Design basis earth-quake [1]	Aircraft crash and chemical explosion	Hydrodynamic loads due to loss-of-coolant accidents
Level A	X [2]								
Level B									
Level C									
Level D									

[1] See KTA 2201.4

[2] Including specified live loads

[3] For load attachment points a load amplification factor of 1.8 shall be taken into account.

(X) : For fatigue analysis only
X : No superposition shall be made (except blast wave from turbine building)
[X] : In combination with loads caused by external events only
BEB : Design basis earthquake

Table 6-3: Example for the classification of load components into loading levels

6.2.2.3 Loading levels

6.2.2.3.1 General requirements

(1) All load components shall be assigned to loading levels by the plant vendor where the integrity of the component parts shall be ensured at any loading level.

(2) The service limits pertinent to the loading levels are laid down in Section 6.2.4 and shall be determined such that the component integrity is ensured at any loading level for the specific load cases. **Table 6-3** gives an example of the loading component classification into loading levels for each quality class.

6.2.2.3.2 Determination of loading levels

The loading level shall be determined by structural analysis in accordance with Section 6.2.4.

a) Loading levels A and B

For the load cases assigned to Levels A and B service limits the limitation of the stress intensities and equivalent stress intensity range with respect to progressive distortion and fatigue shall be verified in accordance with clauses 6.2.4.2.2.3 and 6.2.4.2.2.9, respectively.

b) Loading level C

For loading level C only such loadings shall be considered which cause primary stresses. In addition, for the load cases assigned to level C the limitation of the stress intensity ranges with respect to progressive distortion and fatigue shall be verified in accordance with clauses 6.2.4.2.2.3 and 6.2.4.2.2.9, respectively. The service limits of level C allow for plastic deformations.

c) Loading level D

For loading level D only loadings shall be considered which cause primary stresses. Here, gross plastic deformation may occur.

6.2.3 Loadings

6.2.3.1 General

(1) The loadings determined shall be documented for each component under the respective quality class according to **Table 6-3** and be listed by the plant vendor.

(2) The stresses resulting from the loadings and deformations, if any, shall be determined and evaluated by a structural analysis.

6.2.3.2 Effects of loadings

The loadings may have direct effect on the component and its parts, thus causing the respective load condition. They may, however, also have indirect effect, e.g. in the case of temperature transients in the coolant which cause non-stationary temperature fields in the component, which in turn leads to stresses from restraint to thermal expansion.

6.2.3.3 Mechanical loads

The following mechanical loads shall be considered:

a) coolant loadings caused by its steady and unsteady pressure differences, its flow, and flow-induced vibrations,

b) loadings from reactor pressure vessel internals caused e.g. by deadweight, prestress forces, and

c) loads from adjacent components caused e.g. by deadweight of fuel assemblies, excitation of reactor pressure vessel and fuel assembly vibrations due to earthquakes.

6.2.3.4 Thermal loads

The following thermal loadings shall be considered:

a) coolant loadings caused by its steady and unsteady temperatures,

b) loadings from the RPV internals due to non-uniform heating and thermal restraints due to heat generated by γ-absorption, and

c) loadings from adjacent components caused by displacements and deformations, differing and restrained thermal expansions.

6.2.4 Structural analysis

6.2.4.1 General requirements

(1) By means of the structural analysis it shall be verified that all RPV internals withstand any loading in accordance with the loading levels per 6.2.2.3. Here, loadings are defined as all effects on the component or part which cause stresses and deformations in the component or part.

(2) Within the structural analysis the loads and deformations, if any, of the component under consideration due to loadings shall be determined by satisfying the boundary conditions and in consideration of the interaction of the individual component parts.

(3) Here, it shall be taken into account that the accuracy of the values determined depends on the quality of the geometric idealization of the component or part, the accuracy of the assumptions on loadings, boundary conditions and material properties as well as on the suitability and performance of the analysis method used.

(4) The loadings and deformations, if any, may be determined analytically or experimentally. Clause 6.2.5 covers the extent of verification. In the following clauses 6.2.4.2 and 6.2.4.3 the methods of performing verifications of structural integrity are given. It will suffice to verify the structural integrity by one method.

(5) The loadings and deformations thus determined shall be checked for acceptability as follows:

a) parts of quality class AS-RE 1 in accordance with Section 6.2.4.2 or 6.2.4.3,

b) parts of quality class AS-RE 2 and AS-RE 3 inside the reactor pressure vessel in accordance with Section 6.2.4.2 or 6.2.4.3; threaded structural fasteners of quality class AS-RE 2 shall be treated like parts (Sections 6.2.4.2.2.3 and 6.2.4.2.2.4) if residual pre-tensioning need not be ensured,

c) parts of quality class AS-RE 3 outside the reactor pressure vessel in accordance with the applicable DIN Standards and rules of conventional engineering.

Note:
These are e.g. KTA 3902, KTA 3205.1.

6.2.4.2 Analyses

6.2.4.2.1 General requirements

(1) Analysis is defined as the verification of load distribution by way of calculation which may also be made to the methods of elementary strength calculations.

(2) The analysis can be performed on assuming an elastic or elasto-plastic material behaviour.

(3) The analysis may be replaced by the vibration measurements as per Section 9.4.

6.2.4.2.2 Stress analysis

By means of a stress analysis along with a classification of stresses and limitation of stress intensities it shall be proved, that no inadmissible stress intensities and deformations occur.

6.2.4.2.2.1 Classification of stresses

(1) Stresses shall be classified in dependence of the cause of stress and its effect on the mechanical behaviour of the structure into primary stresses, secondary stresses and peak stresses and be limited in different ways with regard to their classification.

(2) Stresses shall be classified into the aforementioned stress categories. Where the classification into the stress categories is unclear the effect of plastic deformation on the mechanical behaviour shall be determining where an excess of the intended loading is assumed.

Examples for the classification of stresses are given in **Table 6-4**.

Vessel Part	Location	Origin of Stress	Type of stress	Classification	Structural discontinuity	
					general	local
Cylindrical or spherical shell	Shell plate remote from discontinuities	Differential pressure	General membrane	P_m	No	No
			Gradient through shell thickness	Q	Yes	No
		Axial thermal gradient	Membrane	Q	Yes	No
			Bending	Q	Yes	No
	Junction with head or flange	Differential pressure	Membrane	Q, (P_m) [1)]	Yes	No
			Bending	Q, (P_b) [1)]	Yes	No
Any shell or head	Any section across entire vessel	External load or moment or differential pressure	General membrane averaged across full section. (Stress component perpendicular to cross section)	P_m	No	No
		External load or moment [2)]	Bending across full section. (Stress component perpendicular to cross section)	P_m	No	No
	Near nozzle or other opening	External load or moment or differential pressure	Membrane	Q	Yes	No
			Bending	Q	Yes	No
			Peak (fillet or corner)	F	Yes	Yes
	Any location	Temperature difference between shell and head	Membrane	Q	Yes	No
			Bending	Q	Yes	No
Dished head or conical head	Crown	Differential pressure	Membrane	P_m	No	No
			Bending	P_b	No	No
	Knuckle or junction to shell	Differential pressure	Membrane	Q [2)]	Yes	No
			Bending	Q	Yes	No
Flat head	Centre region	Differential pressure	Membrane	P_m	No	No
			Bending	P_b	No	No
	Junction to shell	Differential pressure	Membrane	Q	Yes	No
			Bending	Q	Yes	No
Perforated head	Typical ligament in a uniform pattern	Differential pressure or external load or moment	Membrane (averaged through cross section)	P_m	No	No
			Bending (averaged through width of ligament, but gradient through plate)	P_b	No	No
			Peak	F	No	Yes
	Isolated or atypical ligament	Differential pressure or external load or moment	Membrane (averaged through cross section)	Q	Yes	No
			Bending (averaged through width of ligament, but gradient through plate)	F	Yes	Yes
			Peak	F	Yes	Yes

Table 6-4: Classification of stress intensity for some typical cases (continued on next page)

Vessel Part	Location	Origin of Stress	Type of stress	Classification	Structural discontinuity general	Structural discontinuity local
Nozzle	Cross section perpendicular to nozzle axis	Differential pressure or external load or moment	General membrane, averaged across full cross section (Stress component perpendicular to section)	P_m	No	No
		External load or moment [2]	Bending across nozzle section	P_m	No	No
	Nozzle wall	Differential pressure	General membrane	P_m	No	No
			Local membrane	Q	Yes	No
			Bending	Q	Yes	No
			Peak	F	Yes	Yes
		Differential expansion	Membrane	Q	Yes	No
			Bending	Q	Yes	No
			Peak	F	Yes	Yes
Cladding	Any	Differential expansion	Membrane	Q	Yes	No
			Bending	Q	Yes	No
			Peak	F	Yes	Yes
Any	Any	Radial temperature distribution [3]	Equivalent linear stress [4]	Q	Yes	No
			Non-linear stress distribution	F	Yes	Yes
Any	Any	Any	Stress concentration by notch effect	F	Yes	Yes

1) This classification is only allowable if the stresses in the flange, without support by the shell, are within the allowable limits. In other cases the classification in parentheses shall apply.
2) Consideration shall be given to the possibility of wrinkling and excessive deformation in thin-walled vessels (large diameter-to-thickness ratio).
3) Consider possibility of failure due to thermal stress ratcheting.
4) The equivalent linear stress is defined as the linear stress distribution which has the same net bending moment as the actual stress distribution.

Table 6-4: Classification of stress intensity for some typical cases (continued)

6.2.4.2.2.2 Superposition of stresses

As shown hereinafter, for each load case the stresses acting simultaneously in the same direction shall be added separately or for different stress categories be added jointly. From these summed-up stresses the stress intensity for the primary stresses and the equivalent stress range each for the sum of primary and secondary stresses or the sum of primary stresses, secondary stresses and peak stresses shall be derived.

6.2.4.2.2.2.1 Stress intensities

(1) The stress intensities classified into one of the primary stress categories shall be determined either in accordance with the von Mises yield criterion or in accordance with the maximum shear stress theory after Tresca.

(2) When performing a plastic analysis, the strain hardening behaviour of the material may be considered as per footnote 6 of **Table 6-5**.

(3) Having chosen a three-dimensional set of coordinates the algebraic sums of all stresses acting simultaneously and in consideration of the respective axis direction shall be calculated for

a) the general primary membrane stresses P_m and

b) the sum of general primary membrane stresses P_m and primary bending stresses P_b

Note:
In general it will be possible to select the structural areas with maximum stresses.

Stress intensities shall be calculated from the primary membrane stress and from the sum of primary membrane and bending stresses. Using the principal stresses σ_1, σ_2, and σ_3 the stress intensity after von Mises is calculated as follows:

$$\sqrt{\frac{(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2}{2}} \qquad (6.2\text{-}1)$$

Alternatively, the stress intensity after Tresca is calculated as the greatest absolute difference between two principal stresses to form

$$\max\left\{\left|\sigma_1-\sigma_2\right|,\left|\sigma_2-\sigma_3\right|,\left|\sigma_3-\sigma_1\right|\right\} \qquad (6.2\text{-}2)$$

(4) The membrane stress intensity P_m shall be derived from the individual stress components averaged across the load-bearing section. With the average values obtained the membrane stress intensity shall be calculated.

6.2.4.2.2.2.2 Equivalent stress ranges (alternating stress intensities and stress differences)

(1) To avoid failure due to progressive distortion (ratcheting) and fatigue the equivalent stress ranges shall be determined from the various stress categories and be limited separately.

(2) In the event of avoiding failure due to progressive distortion the simultaneously acting stresses from primary and secondary stress categories shall be taken into account. For fatigue analysis the simultaneously acting stresses from all stress categories shall be taken into account.

(3) The two sub-clauses hereafter describe calculation procedures on the basis of principal stresses. The equivalent stress intensity may also be derived from stress tensors in an orthogonal set of coordinates in lieu of the principal stresses.

(4) For any case in which the directions of the principal stresses at the point being considered do not change during the stress cycle, the principal stresses $\sigma_1(t)$, $\sigma_2(t)$ and $\sigma_3(t)$ at the point versus time shall be determined first. From the three principal stresses then the three stress differences shall be determined versus time:

$$\left.\begin{aligned} S_{1,2}(t) &= \sigma_1(t)-\sigma_2(t) \\ S_{2,3}(t) &= \sigma_2(t)-\sigma_3(t) \\ S_{3,1}(t) &= \sigma_3(t)-\sigma_1(t) \end{aligned}\right\} \qquad (6.2\text{-}3)$$

Hereafter, the procedure in a) or b) shall be followed:

a) Equivalent stress range after the von Mises theory

Determine the extremes of the range versus all points in time t_i and t_j for the complete stress cycle as follows:

$$\max_{t_i,t_j}\sqrt{\frac{\left(S_{1,2}(t_i)-S_{1,2}(t_j)\right)^2+\left(S_{2,3}(t_i)-S_{2,3}(t_j)\right)^2+\left(S_{3,1}(t_i)-S_{3,1}(t_j)\right)^2}{2}} \qquad (6.2\text{-}4)$$

b) Equivalent stress range after Tresca's theory

Determine, for all points in time t_i and t_j over the complete stress cycle, the extremes of the range through which each stress difference fluctuates and find the absolute magnitude of this range:

$$\max_{t_i,t_j}\left\{\left|S_{1,2}(t_i)-S_{1,2}(t_j)\right|,\left|S_{2,3}(t_i)-S_{2,3}(t_j)\right|,\left|S_{3,1}(t_i)-S_{3,1}(t_j)\right|\right\} \qquad (6.2\text{-}5)$$

(5) For any case in which the directions of the principal stresses at the point being considered do change during the stress cycle, at first the stress differences of direct and shear stress components shall be determined for the two points in time 1 and 2 of a stress cycle "I":

$$\left.\begin{aligned} \Delta\sigma^I_{xx} &= \sigma^{I,2}_{xx}-\sigma^{I,1}_{xx} \\ \Delta\sigma^I_{yy} &= \sigma^{I,2}_{yy}-\sigma^{I,1}_{yy} \\ \Delta\sigma^I_{zz} &= \sigma^{I,2}_{zz}-\sigma^{I,1}_{zz} \\ \Delta\sigma^I_{xy} &= \sigma^{I,2}_{xy}-\sigma^{I,1}_{xy} \\ \Delta\sigma^I_{yz} &= \sigma^{I,2}_{yz}-\sigma^{I,1}_{yz} \\ \Delta\sigma^I_{xz} &= \sigma^{I,2}_{xz}-\sigma^{I,1}_{xz} \end{aligned}\right\} \qquad (6.2\text{-}6)$$

The equivalent stress range which depends on the points in time 1 and 2 shall be determined using the procedure according to von Mises in a) or according to Tresca in b) as follows:

a) Equivalent stress range after the von Mises theory

$$\begin{aligned}\Delta\sigma^I_{eqv,\,v.Mises} = \Big\{&\left(\Delta\sigma^I_{xx}\right)^2+\left(\Delta\sigma^I_{yy}\right)^2+\left(\Delta\sigma^I_{zz}\right)^2 - \\ &\left(\Delta\sigma^I_{xx}\cdot\Delta\sigma^I_{yy}+\Delta\sigma^I_{yy}\cdot\Delta\sigma^I_{zz}+\Delta\sigma^I_{xx}\cdot\Delta\sigma^I_{zz}\right)+ \\ &3\cdot\left[\left(\Delta\sigma^I_{xy}\right)^2+\left(\Delta\sigma^I_{yz}\right)^2+\left(\Delta\sigma^I_{xz}\right)^2\right]\Big\}^{0,5}\end{aligned} \qquad (6.2\text{-}7)$$

The equation (6.2-1) may also be applied analogously in the formulation by using principal stress differences $\Delta\sigma^I_1$, $\Delta\sigma^I_2$ and $\Delta\sigma^I_3$. The set of formulas for determination of the principal stress differences can be seen in sub-clause b).

b) Equivalent stress range after Tresca's theory

From the six time-dependent differences of stress components acc. to equation (6.2-6) the principal stress differences $\Delta\sigma^I_1$, $\Delta\sigma^I_2$ and $\Delta\sigma^I_3$ shall be derived, which depend on the points in time 1 and 2 of an identified stress cycle. They represent the eigenvalues (λ_1, λ_2 and λ_3) of the stress differences tensor given by equation (6.2-6) and are the result of the characteristic polynomial

$$P(\lambda) = -\lambda^3+\Delta I_1\cdot\lambda^2-\Delta I_2\cdot\lambda+\Delta I_3 \qquad (6.2\text{-}8)$$

The invariants ΔI_1, ΔI_2 and ΔI_3 may be determined by

$$\begin{aligned} \Delta I_1 &= \text{trace}\left(\Delta\sigma^I_{ij}\right) = \Delta\sigma^I_{xx}+\Delta\sigma^I_{yy}+\Delta\sigma^I_{zz} \\ \Delta I_2 &= 0.5\cdot\left\{\left(\Delta I_1\right)^2-\text{trace}\left[\left(\Delta\sigma^I_{ij}\right)^2\right]\right\} \\ &= \Delta\sigma^I_{xx}\cdot\Delta\sigma^I_{yy}+\Delta\sigma^I_{yy}\cdot\Delta\sigma^I_{zz}+\Delta\sigma^I_{zz}\cdot\Delta\sigma^I_{xx} - \\ &\quad \left(\Delta\sigma^I_{xy}\right)^2-\left(\Delta\sigma^I_{yz}\right)^2-\left(\Delta\sigma^I_{xz}\right)^2 \\ \Delta I_3 &= \det\left(\Delta\sigma^I_{ij}\right) \\ &= \Delta\sigma^I_{xx}\cdot\left[\Delta\sigma^I_{yy}\cdot\Delta\sigma^I_{zz}-\left(\Delta\sigma^I_{yz}\right)^2\right]- \\ &\quad \Delta\sigma^I_{xy}\cdot\left(\Delta\sigma^I_{xy}\cdot\Delta\sigma^I_{zz}-\Delta\sigma^I_{yz}\cdot\Delta\sigma^I_{xz}\right)+ \\ &\quad \Delta\sigma^I_{xz}\cdot\left(\Delta\sigma^I_{xy}\cdot\Delta\sigma^I_{yz}-\Delta\sigma^I_{yy}\cdot\Delta\sigma^I_{xz}\right) \end{aligned} \qquad (6.2\text{-}9)$$

The characteristic polynomial has three positive roots given by

$$\lambda_i = \frac{1}{3}\cdot\left[\Delta I_1+2\cdot\sqrt{\left(\Delta I_1\right)^2-3\cdot\Delta I_2}\cdot\cos\left(\frac{\beta+(i-1)\cdot 2\pi}{3}\right)\right],$$

where $i = 1,2,3$

$$\beta = \arccos\frac{2\cdot\left(\Delta I_1\right)^3-9\cdot\Delta I_1\cdot\Delta I_2+27\cdot\Delta I_3}{2\cdot\sqrt{\left[\left(\Delta I_1\right)^2-3\cdot\Delta I_2\right]^3}}$$

The values shall be arranged by size $\lambda_1 \geq \lambda_2 \geq \lambda_3$. Then follows

$\Delta\sigma^I_1 = \lambda_1$, $\Delta\sigma^I_2 = \lambda_2$, and $\Delta\sigma^I_3 = \lambda_3$

The stress intensity in accordance with the theory of Tresca is found as

$$\Delta\sigma^I_{eqv,Tresca} = \max\left(\left|\Delta\sigma^I_1-\Delta\sigma^I_2\right|;\left|\Delta\sigma^I_2-\Delta\sigma^I_3\right|;\left|\Delta\sigma^I_3-\Delta\sigma^I_1\right|\right) \qquad (6.2\text{-}10)$$

6.2.4.2.2.3 Limitation of stress intensities and equivalent stress ranges for all parts except threaded structural fasteners

(1) The stress intensities and equivalent stress ranges shall be limited in dependence of the mechanical behaviour of the material and the loading level in accordance with **Table 6-5**.

(2) For welded joints according to section 6.1.6

a) the allowable values of **Table 6-5** shall be multiplied with the weld factor n of **Table 6-1** for primary stresses only,

b) the fatigue strength reduction factor f of **Table 6-1** and the design fatigue curves according to **Figures 6-3** and **6-4** shall be used for fatigue analysis.

(3) The limits fixed in **Table 6-5** only apply to full rectangular sections. For other sections the shape factors shall be fixed in dependence of the respective load behaviour.

(4) In the case of stress intensities derived from primary stresses and of equivalent stress ranges derived from primary and secondary stresses the limitation shall be based on the stress intensity factor S_m, strain limit $R_{p0.2}$ or tensile strength R_m minimum values. The S_m value is obtained on the basis of the respective temperature T at the point of the respective component under consideration versus time and the room temperature RT.

(5) Taking these assignments into account, the S_m value for austenitic materials and nickel alloys is derived as follows:

$$S_m = \min\left\{\frac{R_{p0.2RT}}{1.5};\frac{R_{p0.2T}}{1.1};\frac{R_{mRT}}{3};\frac{R_{mT}}{2.7}\right\} \qquad (6.2\text{-}11)$$

(6) The minimum values for strain limit or tensile strength shall be taken from Section 7. These values shall be interpola-

ted for certain temperatures T and be extrapolated up to a maximum of 425 °C. The S_m value above 40 °C may exceed $0.67 \cdot R_{p0.2RT}$ and reach a maximum of $0.9 \cdot R_{p0.2T}$. This corresponds to a maximum permanent strain of 0.1 %. If this strain assigned to this stress value cannot be permitted, the S_m value shall be reduced such that only allowable deformations can occur. To achieve this only the multiplication factors of **Table B-1** and the $R_{p0.2T}$ values according to Section 7 shall be used.

(7) A fatigue analysis shall be performed using the equivalent stress ranges determined by the primary, secondary and peak stresses.

Stress category [1] [2]		Loading levels		
		Levels A and B	Level C [10]	
Primary stress intensity	P_m	S_m [5] [11]	$1.5 \cdot S_m$	elastic analysis [5]
			$1.5 \cdot S_m$	plastic analysis [6]
	$P_m + P_b$	$1.5 \cdot S_m$ [5] [11]	$2.25 \cdot S_m$	elastic analysis [5]
			$2.25 \cdot S_m$ $0.5 \cdot R_{mT}$	plastic analysis [6] [7] [12]
Primary plus secondary stress intensity	$P_m + P_b + Q$	$3 \cdot S_m$ [3] [8] S_L [4]		
Stress intensity from primary plus secondary plus peak stresses	$P_m + P_b + Q + F$	$D < 1.0$; $2 \cdot S_a$ [9]		

[1] For compressive stresses the requirements of clause 6.2.4.2.5 shall be taken into account.

[2] When loads are transiently applied, consideration shall be given to the use of dynamic load amplification. In addition, a possible change of the modules of elasticity shall be taken into account.

[3] If the $3 \cdot S_m$ limit is exceeded an elastic-plastic analysis shall be made. This analysis may be a simplified elastic-plastic analysis.

[4] S_L denotes the structural action of shakedown load calculated on a plastic basis.

[5] The triaxial stresses represent the algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) for the combination of stress components. Where uniform tension loading is present, triaxial stresses shall be limited to $4 \cdot S_m$ for level A and B service limits and to $6 \cdot S_m$ for level C service limits.

[6] The elastic-plastic analysis is used for determining nominally primary stresses. The strain hardening behaviour of the material may be considered both for the true monotonous stress-strain curve at temperature loading and each approach to the true stress/strain curve in which case the approach shall show lower stresses for the same strains than for the true stress/strain curve. To cover the effects of triaxial stresses either Tresca`s shear stress theory or the von Mises strain energy of distortion theory shall be used.

[7] R_{mT} = tensile strength at temperature. The effects of multi-axial loadings shall be considered.

[8] This limitation applies to the range of stress intensity. When the secondary stress is due to a temperature excursion at the point at which the stresses are being analyzed, the value of S_m shall be taken as the average of the S_m values for the highest and lowest temperature of the metal during the transient. When part or all of the secondary stresses is due to mechanical load, the value of S_m shall be taken as the S_m value for the highest temperature of the metal during the transient.

[9] The value of half the stress intensity composed of the sum of primary plus secondary plus peak stresses S_{alt}, calculated on an elastic basis, shall not exceed the S_a value associated with 10 cycles when using the fatigue curve.

[10] Where deformations of the structure have to be considered, they shall be limited to two thirds of the value specified for level C service limits.

[11] For pressure difference loadings assigned to level B service limits, the allowable stress intensities shall be multiplied by a factor of 1.1. This also applies to the stipulations of clause 6.2.4.3.2 and B 2 a).

[12] The greater value of the allowable limit may be used.

Table 6-5: Allowable stress intensities and equivalent stress ranges for the stress categories of level A, B and C service limits

6.2.4.2.2.4 Requirements for loading levels A and B

(1) The stipulations of clause 6.2.4.2.2.7 may be used in addition to those of **Table 6-5.**

(2) The given deformation limits assigned to loading levels A and B shall be satisfied.

(3) In addition to the limits of **Table 6-5** the following requirements shall apply:

a) Limitation of stress intensity due to strain constraint

The allowable value of the maximum range of expansion stress intensity when combined with all other primary and secondary stress intensities shall be $3 \cdot S_m$.

b) Thermal Stress Ratcheting

Under certain combinations of steady state and cyclic loadings there is a possibility of large distortions developing as a result of thermal stress ratcheting, that is the deformation increases by a nearly equal amount for each cycle. Examples of this phenomenon are treated in the following and in clause 6.2.4.2.2.7.4. Thermal stress ratcheting can be analyzed by means of a plastic analysis and be evaluated in accordance with clause 6.2.4.2.2.8 (2). In the following, an example is given for the prevention of ratcheting in an axisymmetric shell loaded by internal pressure difference. The limiting value of maximum cyclic thermal stress in order to prevent cyclic growth in diameter is as follows:

Let

y´ = maximum allowable range of thermal stress computed on an elastic basis divided by the proof stress $R_{p0.2T}$ or by $1.5 \cdot S_m$ if this value exceeds $R_{p0.2T}$.

x = maximum general membrane stress due to pressure difference divided by the proof stress $R_{p0.2T}$ or by $1.5 \cdot S_m$ if this value exceeds $R_{p0.2T}$.

Case 1: Linear variation of temperature through the wall

$y' = \frac{1}{x}$ for $0 < x \leq 0.5$ (6.2-12)

$y' = 4 \cdot (1 - x)$ for $0.5 < x < 1.0$ (6.2-13)

Case 2: Parabolic constantly increasing or constantly decreasing variation of temperature through the wall

$y' = 5.2 \cdot (1 - x)$ for $0.615 \leq x < 1.0$ (6.2-14)

For $x < 0.615$ the following applies:

x = 0.3; 0.4; 0.5

y' = 4.65; 3.55; 2.70

The use of the proof stress $R_{p0.2T}$ in the above relations instead of the proportional limit allows a small amount of growth during each cycle until strain hardening raises the proportional limit to $R_{p0.2T}$. If the proof stress of the material is higher than the endurance limit of the material, the latter value shall be used if there is to be a large number of cycles because strain softening may occur. For the determination of thermal stress ratcheting the endurance limit shall be taken as two times the S_a value at 10^{11} cycles in **Figure 6-3** or **Figure 6-4**.

6.2.4.2.2.5 Requirements for loading level C

(1) In addition to the stipulations of **Table 6-5** the following points shall be taken into account. Dynamic instability shall be considered in meeting the load, stress and deformation limits.

(2) The allowable values for the special stress limits shall not exceed 150 % of the values given in clauses 6.2.4.2.2.7 and 6.2.4.2.2.8 for this loading level.

(3) The limitation of the allowable stress intensity range composed of primary and secondary stresses need not be determined unless required for subpara (4).

(4) Loadings assigned to loading level C need not be considered if it can be proved in accordance with clause 6.2.4.2.3.3.1 that a fatigue analysis is not required. Otherwise all loadings in loading level C shall be covered by the fatigue analysis according to clause 6.2.4.2.3.

(5) The given deformation limits assigned to loading level C shall be satisfied.

6.2.4.2.2.6 Requirements for loading level D

(1) For the limitation of loadings assigned to loading level D the stipulations of clauses 6.2.4.2.2.6.1 to 6.2.4.2.2.6.4 may be used.

(2) Where the special stress limits to clause 6.2.4.2.2.7 are applicable for loading level D limits, the calculated stresses shall not exceed twice the stress limits given in clause 6.2.4.2.2.7 as applied for loading levels A and B.

6.2.4.2.2.6.1 Plastic analyses

(1) Plastic analysis is a method used to calculate the structural response under given loads taking into account e.g.

a) the material strain hardening behaviour,
b) effects of deformation rate,
c) permanent deformations,
d) redistribution of stresses in the structure are considered.

Note:
Plastic analysis mainly differs from the limit load analysis by the fact that in plastic analysis the actual material strain hardening behaviour is taken into account.

(2) The true stress/strain curve shall be adapted such that it corresponds to the values given in Section 7 for the respective temperatures. This curve must be referred to and justified in the verification of structural integrity. The effects of the deformation rate on the yield curve shall also be considered.

(3) The yield criteria and the related law of material yielding used for performing a plastic analysis can be either assigned to the theory of Tresca or the theory of von Mises.

(4) A plastic analysis may be used to determine the collapse load P_c for a given combination of loadings on a structure. The limit load shall not be reached before the deformation has reached twice the value calculated for the first deviation from linear behaviour. In evaluating the analysis the calculation shall be interpreted such that it corresponds to the evaluation of the experiment (see clause 6.2.4.3). If the interpretation is made in such a way the collapse load obtained from plastic analysis shall be limited to satisfy the rules of the limit analysis (see clause 6.2.4.2.6).

(5) A plastic analysis may be used to determine the plastic instability load for a given combination of loading on a structure. The plastic instability load is a load at which unbound plastic deformation occurs or where the ratio of force to deformation shows a horizontal tangent. P_I denominates the load at which plastic instability occurs.

(6) A plastic analysis may be used to determine the allowable load or combination of loads with regard to the case of the specific application. Where the strain has been limited the load causing this limiting strain is designated as P_s.

6.2.4.2.2.6.2 Analysis procedure

(1) System analysis

For the purpose of system analysis a system is a specific component group selected from the overall facility, which has to be analyzed as a whole such that no essential coupling factors are neglected. For RPV internals system analysis means the analysis of the reactor coolant pressure boundary or part of it where all forces will be determined for the purpose of component stress analysis. Generally the system analysis is a dynamic analysis.

Note:
According to the state-of-the-art the system analysis is performed on an elastic basis.

Where inelastic deformations occur that cannot be neglected, the originally elastic system analysis shall be modified. If required, an inelastic system analysis will become necessary.

Therefore, the type of system analysis, whether elastic or inelastic, and the related forces in the component shall be reported in the stress analysis.

(2) Component analysis

Each of the methods described under a) through e) may be used to calculate the loadings assigned to loading level D. However, the restrictions of the methods as per 6.2.4.2.2.6.3 and 6.2.4.2.2.6.4 shall be considered:

a) elastic analysis,
b) determination of collapse load by plastic analysis,
c) determination of plastic instability load or stress produced due to limited strain by plastic analysis,
d) determination of the loading or stress for the limiting strain by plastic analysis,
e) inelastic analysis by plastic analysis.

The limitation of the primary stress intensity or the allowable loadings as per clauses 6.2.4.2.2.6.3 and 6.2.4.2.2.6.4 is shown in **Table 6-6**.

Method of analysis		Stress or load in acc. with clause [1]	Stress category or load	Allowable limits
System 6.2.4.2.2	Component 6.2.4.2.2			
Elastic analysis	Elastic Analysis	stresses as per 6.2.4.2.2.6.3 (1) 6.2.4.2.2.9.4 [2]	P_m	$2.4 \cdot S_m$, $0.7 \cdot R_{mT}$ [5]
			$P_m + P_b$	$3.6 \cdot S_m$, $1.0 \cdot R_{mT}$ [5]
	Limit analysis	6.2.4.2.2.6.3 (2)	The requirements under 6.2.4.2.6, 6.2.4.2.2.6.1 a) and 6.2.4.3.1 a) shall be applied.	
	Stress ratio method	6.2.4.2.2.6.3 (3)	The requirements under 6.2.4.2.7 and specifically under Section C 3.2 shall be applied.	
	Inelastic Analysis	stresses as per 6.2.4.2.2.6.3 (5)	P_m	$0.7 \cdot R_{mT}$
			$P_m + P_b$	$0.7 \cdot R_{mTt}$, $R_{p0.2T} + \frac{1}{3} \cdot (R_{mT} - R_{p0.2T})$ [6]
Inelastic analysis	Elastic Analysis	stresses as per 6.2.4.2.2.6.4 (1)	P_m	$0.7 \cdot R_{mT}$, $R_{p0.2T} + \frac{1}{3} \cdot (R_{mT} - R_{p0.2T})$ [6]
			$P_m + P_b$	$1.0 \cdot R_{mT}$, $\frac{3}{2} \cdot R_{p0.2T} + \frac{1}{2} \cdot (R_{mT} - R_{p0.2T})$ [6]
	Limit analysis	6.2.4.2.2.6.4 (2)	The requirements under 6.2.4.2.2.6.3 (2) shall be considered.	
	Stress ratio method	6.2.4.2.2.6.4 (3)	The requirements under 6.2.4.2.2.6.3 (3) shall be considered.	
	Plastic instability analysis	6.2.4.2.2.6.4 (4)	P_m, P_l	$0.7 \cdot P_l$ or loads $P < P_m$ where $P_m = R_{p0.2T} + \frac{1}{3} \cdot (R_{mT} - R_{p0.2T})$ [3]
	Strain limiting load analysis	6.2.4.2.2.6.4 (5)	P_m, P_l, P_S [4]	$0.7 \cdot P_l$ or loads $P < P_m$ where $P_m = R_{p0.2T} + \frac{1}{3} \cdot (R_{mT} - R_{p0.2T})$ [3] however $P_m < P_S$
	Inelastic analysis	6.2.4.2.2.6.4 (6)	P_m	$0.7 \cdot R_{mT}$, $R_{p0.2T} + \frac{1}{3} \cdot (R_{mT} - R_{p0.2T})$ [6]
			$P_m + P_b$	$1.0 \cdot R_{mT}$, $\frac{3}{2} \cdot R_{p0.2T} + \frac{1}{2} \cdot (R_{mT} - R_{p0.2T})$ [6]

1) For compressive stresses or loads the requirements of clause 6.2.4.2.5 shall be taken into account.

2) For threaded fasteners with $R_{mRT} \leq 700$ N/mm². For $R_{mRT} > 700$ N/mm² see clause 6.2.4.2.2.9.4 (1) and (2).

3) S_l is the true effective stress occurring at plastic instability.

4) P_S is the loading assigned to the strain limiting load of the component.

5) The smaller value of the allowable limits shall be used.

6) The greater value of the allowable limits may be used.

Table 6-6: Allowable values of primary stress intensities and loads for loading level D

6.2.4.2.2.6.3 Limitation of primary stress intensity or allowable loadings in elastic analysis

(1) Elastic system analysis and elastic component analysis

The primary membrane stress intensity shall be limited to the lesser value of 2.4 · S_m or 0,7 · R_{mT}. The values for R_{mT} shall be taken from Section 7.

The primary membrane plus bending stress intensity shall be limited to the lesser value of 3.6 · S_m or 1.0 · R_{mT}.

(2) Elastic system analysis and analysis of component collapse load

The loadings assigned to the loading level D shall be less than 100 % of the collapse load in which case the collapse load shall either be determined by a limit analysis according to clause 6.2.4.2.6 or plastic analysis according to clause 6.2.4.2.2.6.1 a) or by experiment acc. to clause 6.2.4.3.1 a).

When applying the limit analysis, the stipulations of clause 6.2.4.2.6 and especially those of section B 2 c) shall be considered.

Where deformation limits are adhered to, that part of the component to which these limitations apply shall not be evaluated by this method.

(3) Elastic system analysis and stress ratio method for the component

Here the rules of clause 6.2.4.2.7 and especially of Section C 3.2 apply.

(4) Elastic system analysis and analysis of plastic instability load or analysis of loading for component strain limitation

This combination of system and component analysis is not permitted.

(5) Elastic system analysis and inelastic component analysis

The primary membrane stress intensity shall be limited to 0.7 · R_{mT}. The primary membrane plus bending stress intensity shall be equal to or smaller than the greater value of

$$0.7 \cdot R_{mTt}$$

or

$$R_{p0.2T} + \frac{1}{3} \cdot \left(R_{mTt} - R_{p0.2T}\right)$$

where R_{mTt} is the respective value from the true stress/strain curve at temperature T, i.e. the ultimate tensile load is to be applied on the true section and not on the initial section of the specimen. In such case, the elastic system analysis should be reviewed and the plastic deformation of the component be accounted for.

6.2.4.2.2.6.4 Limitation of primary stress intensity or allowable loading in inelastic analysis

(1) Inelastic system analysis and elastic component analysis

The primary membrane stress intensity shall be equal to or smaller than the greater value of

$$0.7 \cdot R_{mT}$$

or

$$R_{p0.2T} + \frac{1}{3} \cdot \left(R_{mT} - R_{p0.2T}\right)$$

The primary membrane plus bending stress intensity shall be equal to or smaller than

$$1.0 \cdot R_{mT}$$

or

$$\frac{3}{2} \cdot R_{p0.2T} + \frac{1}{2} \cdot \left(R_{mT} - R_{p0.2T}\right)$$

(2) Inelastic system analysis and limit analysis of the component

This analysis may be performed in consideration of the rules of 6.2.4.2.2.6.3 (2).

(3) Inelastic system analysis and stress ratio analysis for the component

This analysis may be used in consideration of the rules of 6.2.4.2.2.6.3 (3).

(4) Inelastic system analysis and analysis of plastic instability load of the component

The loadings applied shall be equal to or smaller than 70 % of the loading to obtain plastic instability load P_I or 100 % of the loading causing a membrane stress intensity with a value of

$$R_{p0.2T} + \frac{1}{3} \cdot \left(S_I - R_{p0.2T}\right)$$

where S_I is the effective stress causing plastic instability.

(5) Inelastic system analysis and analysis of the loading for the limiting strain of the component

This analysis may be used if the loadings applied are smaller than the loadings which must satisfy the rules of (4), and if the loadings do not exceed 100 % of the loadings assigned to the limiting strain S_S.

(6) Inelastic system analysis and inelastic component analysis

The primary membrane plus bending stress intensity shall be equal to or smaller than the greater value of

$$0.7 \cdot R_{mT}$$

or

$$R_{p0.2T} + \frac{1}{3} \cdot \left(R_{mT} - R_{p0.2T}\right)$$

The primary membrane stress intensity shall be equal to or smaller than the greater value of

$$1.0 \cdot R_{mT}$$

or

$$\frac{3}{2} \cdot R_{p0.2T} + \frac{1}{2} \cdot \left(R_{mT} - R_{p0.2T}\right)$$

6.2.4.2.2.7 Special stress limits

6.2.4.2.2.7.1 General requirements

(1) The following deviations from the basic stress limits are provided to cover special service loadings or configurations. Some of these deviations are more restrictive and some are less restrictive than the basic stress limits. Rules governing application of these special stress limits for loading levels C and D are contained in clauses 6.2.4.2.2.5 (1) and 6.2.4.2.2.6, respectively.

(2) In cases of conflict between these requirements and the basic stress limits, the rules of this clause take precedence for the particular situations to which they apply. This clause does not apply to threaded structural fasteners according to clause 6.2.4.1 a).

6.2.4.2.2.7.2 Bearing loads

(1) The average bearing stress for resistance to crushing under the maximum load, experienced as a result of loadings assigned to loading levels A and B shall be equal to or smaller than $R_{p0.2T}$ except that when the distance to a free edge is larger than the distance over which the bearing load is applied, a stress of 1.5 · $R_{p0.2T}$ is permitted.

For clad surfaces the yield strength of the base metal may be used if, when calculating the bearing stress, the bearing area is taken as the lesser of the actual contact area or the area of the base metal supporting the contact surface.

(2) Where required with regard to the point of load application (e.g. bearing loads applied near free edges), the possibility of shear failure shall be considered. In the case of load stress only, the average shear stress shall be limited to $0.6 \cdot S_m$.

In the case of load stress plus secondary stress, the average shear stress shall not exceed the limit values of a) or b) below.

a) For a material whose S_m value above 40 °C exceeds $0{,}67 \cdot R_{p0.2T}$ and may reach a maximum of $0{,}9 \cdot R_{p0.2T}$ the smaller value of $0.5 \cdot R_{p0.2}$ at 40 °C or $0.67 \cdot R_{p0.2T}$ shall be taken. This corresponds to a permanent strain of not more than 0.1 %. If the strain assigned to this stress value cannot be permitted, the S_m value shall be reduced such that only allowable deformation can occur. To achieve this the multiplication factors of **Table B-1** and the $R_{p0.2T}$ values according to Section 7 shall be used.

b) For other materials than listed in a) above the value $0.5 \cdot R_{p0.2T}$ applies. For clad surfaces, if the configuration or thickness is such that a shear failure could occur entirely within the clad material, the allowable shear stress for the cladding shall be determined from the properties of the equivalent wrought material.

   If the configuration is such that a shear failure could occur across a path that is partially base metal and partially clad material, the allowable shear stresses for each material shall be used when evaluating the combined resistance to this type of failure.

(3) When considering bearing stresses in pins and similar members, the elevated temperature proof stress $R_{p0.2T}$ value is applicable, except that a value of $1.5 \cdot R_{p0.2T}$ may be used if no credit is given to bearing area within one pin diameter from a plate edge.

6.2.4.2.2.7.3 Pure shear

(1) The average primary shear stress across a section loaded in pure shear, experienced as a result of loadings assigned to loading levels A and B (e.g. keys, shear rings), shall be limited to $0.6 \cdot S_m$.

(2) The maximum primary shear stress, experienced as a result of torsional loadings assigned to loading levels A and B, exclusive of stress concentration at the periphery of a solid circular section in torsion, shall be limited to $0.8 \cdot S_m$.

(3) Shear stresses (from primary plus secondary and peak stresses) shall be converted to stress intensities (equal to two times pure shear stress) and as such shall not exceed the basic stress limits of **Table 6-5**. In addition, they shall meet the requirements of 6.2.4.2.3.

6.2.4.2.2.7.4 Progressive distortion of non-integral connections

Screwed on caps, screwed in plugs, shear ring closures, and breechlock closures are examples of non-integral connections which are subject to failure by bell mouthing or other types of progressive deformation. If any combination of applied loads produces yielding, such joints are subject to ratcheting because the mating members may become loose at the end of each complete operating cycle and start the next cycle in a new relationship with each other, with or without manual manipulation. Additional distortion may occur in each cycle so that interlocking parts, such as threads, can eventually lose engagement. Therefore, primary plus secondary stress intensities which result in slippage between the parts of a non-integral connection in which disengagement could occur as a result of progressive distortion shall be limited to the value $R_{p0.2T}$.

6.2.4.2.2.7.5 Triaxial stresses

The algebraic sum of the three primary principal stresses ($\sigma_1 + \sigma_2 + \sigma_3$) shall not exceed four times the tabulated value of S_m.

6.2.4.2.2.7.6 Application of elastic analysis for stresses beyond the proof stress $R_{p0.2}$

(1) Certain of the allowable stresses permitted in the design criteria are such that the maximum stress calculated on an elastic basis may exceed the proof stress of the material.

(2) The limit on primary plus secondary stress intensity of $3 \cdot S_m$ has been placed at a level which assures shakedown to elastic action after a few repetitions of the stress cycle except in regions containing significant local structural discontinuities or local thermal stresses. These last two factors are considered only in the performance of a fatigue evaluation. Therefore:

a) in evaluating stresses for comparison with the stress limits on other than fatigue allowables, stresses shall be calculated on an elastic basis;

b) in evaluating stresses for comparison with fatigue allowables, all stresses except those which result from local thermal stresses shall be evaluated on an elastic basis. In evaluating local thermal stresses, the elastic equations shall be used except that the numerical value substituted for Poisson's ratio shall be determined from the expression:

$$\nu = \max \begin{cases} 0.5 - 0.2 \cdot \dfrac{R_{p0.2T}}{S_a} \\ 0.3 \end{cases} \qquad (6.2\text{-}15)$$

where:

$R_{p0.2T}$ Proof stress $R_{p0.2}$ of the material at temperature T

S_a Value obtained from the design fatigue curves for the specified number of load cycles

$$T = 0.25 \cdot \breve{T} + 0.75 \cdot \hat{T} \qquad (6.2\text{-}16)$$

with

$\hat{T}$ maximum temperature at the considered load cycle

$\breve{T}$ minimum temperature at the considered load cycle

6.2.4.2.2.8 Application of plastic analysis

(1) The following subparagraphs provide guidance in the application of plastic analysis and some relaxation of the basic stress limits which are allowed if plastic analysis is used.

(2) The limits on primary plus secondary stress intensity (see **Table 6-5**), the thermal stress ratcheting as per clause 6.2.4.2.2.4 b) and progressive distortion of non-integral connections as per clause 6.2.4.2.2.7.4 need not be satisfied at a specific location if, at the location, the procedures of a) through c) below are used:

a) in evaluating stresses for comparison with the remaining stress limits, the stresses are calculated on an elastic basis,

b) In lieu of satisfying the specific requirements of **Table 6-5** as well as clauses 6.2.4.2.2.4 b) and 6.2.4.2.2.7.4 at a specific location, the structural action is calculated on an elastic-plastic basis, and the design shall be considered to be acceptable if shakedown occurs (as opposed to continuing deformation) and if the deformations which occur prior to shakedown do not exceed specified limits. However, this shakedown requirement need not be satisfied provided the following conditions ba) to be) are met:

ba) The requirements on the limitation of primary plus secondary stress intensity according to **Table 6-5** need not be satisfied at a specific location, provided that at the location the evaluation of stresses for comparison with all the other allowable values specified in 6.2.4.2.2.3 is calculated on an elastic basis.

This shall also apply where it is verified that failure due to thermal stress ratcheting in shells (clause 6.2.4.2.2.4 (3) b) and due to progressive distortion of non-integral connections (clause 6.2.4.2.2.7.4) will not occur.

This rule does not apply to threaded structural fasteners.

bb) The maximum accumulated strain at any point, as a result of cyclic operations to which plastic analysis is applied, does not exceed 5.0 %.

bc) The maximum deformations do not exceed specified limits.

bd) In evaluating stresses for comparison with fatigue allowables, the numerically maximum principal total strain range shall be shall be multiplied by one-half the modulus of elasticity of the material (see Section 7) at the mean value of temperature of the cycle.

be) The material shall have an elastic ratio of less than 0.8.

c) In evaluating stresses for comparison with fatigue allowables (S_a), the numerically maximum principal total strain range which occurs after shakedown shall be multiplied by on-half of the modulus of elasticity of the material (Section 7) at the mean value of the temperature of the cycle.

6.2.4.2.2.9 Limitation of stress intensity and equivalent stress range for threaded structural fasteners

6.2.4.2.2.9.1 General requirements

(1) The rules of this clause apply to threaded structural fasteners for RPV internals as per clause 6.2.4.1 a). The specific stress limits of clause 6.2.4.2.2.7 shall not be used for threaded structural fasteners.

(2) For each loading level the stress intensities and equivalent stress ranges shall be limited in dependence of the mechanical behaviour of the material in accordance with **Table 6-7** and in accordance with the requirements of clause 6.2.4.2.2.9.2 regarding loading levels A and B, clause 6.2.4.2.2.9.3 regarding loading level C and clause 6.2.4.2.2.9.4 regarding loading level D. The stress intensities and equivalent stress ranges derived from primary stresses and from primary and secondary stresses shall be limited based on the stress intensity factor S_m in accordance with clause 6.2.4.2.2.3 or based on the proof stress $R_{p0.2T}$ in accordance with Section 7.

(3) A fatigue analysis shall be performed using the equivalent stress ranges determined by the primary, secondary and peak stresses.

Stress category 5)		Loading level			
		Level A and B		Level C	Level D
Primary membrane plus secondary membrane stress intensity 3)	$P_m + Q_m$ 1)	$0.9 \cdot R_{p0.2T}$, $\frac{2}{3} \cdot R_{mT}$ 7)	shank and thread according to 6.2.4.2.2.9.2 (1) a) 6)	see requirements under 6.2.4.2.2.9.3	see requirements under 6.2.4.2.2.9.4
		$0.6 \cdot R_{p0.2T}$	shear stress acc. to 6.2.4.2.2.9.2 (1) b)		
		$2.7 \cdot R_{p0.2T}$	bearing stress according to 6.2.4.2.2.9.2 (1) c)		
Primary membrane plus secondary membrane plus primary bending plus secondary bending stress intensity	$P_m + Q_m + P_b + Q_b$ 2)	$1.2 \cdot R_{p0.2T}$, $\frac{8}{9} \cdot R_{mT}$ 7)	shank and thread according to 6.2.4.2.2.9.2 (2) a)		
Stress intensity from primary plus secondary plus peak stresses	$P_m + Q_m + P_b + Q_b + F$	$D < 1.0;\ 2 \cdot S_a$ 4)			

1) Q_m are secondary membrane stress intensities.

2) Q_b are secondary bending stress intensities.

3) This sum contains all stress components obtained from preload.

4) The value of half the stress intensity composed of the sum of primary plus secondary plus peak stresses S_{alt}, calculated on an elastic basis, shall not exceed the S_a value associated with 10 cycles on the fatigue curve.

5) When loads are transiently applied, consideration shall be given to the use of dynamic load application. In addition, a possible change of the modules of elasticity shall be taken into account.

6) See clause 6.2.4.2.2.9.2 (2) b).

7) The smaller value of the allowable limits shall be used.

Table 6-7: Allowable values of stress intensities and equivalent stress ranges for threaded fasteners

6.2.4.2.2.9.2 Loading level A and B service limits

The total axial load transferred through the fastener threads shall not go to or through zero during the specified service loadings. If a tight joint is required to be provided by threaded fasteners, sufficient residual preload shall be provided.

(1) Average stress

Elastic analysis of specified conditions shall show that the average primary plus secondary membrane stress intensity including stress from preload meet the requirements of a) through c) below:

a) The maximum value of the membrane stress intensity averaged across either area of the fastener shank or of the threads shall be equal to or smaller than the lesser value of either

$0.9 \cdot R_{p0.2T}$ or $\frac{2}{3} \cdot R_{mT}$

b) The average primary plus secondary shear stress across the threads when loaded in pure shear shall be equal to or smaller than $0.6 \cdot R_{p0.2T}$.

c) The average value of bearing stress under the fastener head shall be equal to or smaller than $2.7 \cdot R_{p0.2T}$.

(2) Maximum stress

a) The maximum primary membrane and bending plus secondary membrane and bending stress intensities, produced by the combination of all primary loads and secondary loads, but excluding effects of stress concentrations, shall be equal to or smaller than 1.33 times the limits of above subpara (1) a).

b) For torquing during installation of fasteners, the maximum value of membrane stress intensity shall be equal to or smaller than 1.2 times the limits of above subpara a) at installation temperature.

6.2.4.2.2.9.3 Loading level C service limits

The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of clause 6.2.4.2.2.5 or the respective stipulations of **Table 6-5** are satisfied. For high strength structural fasteners with R_{mRT} exceeding 700 N/mm^2, the limits of clause 6.2.4.2.2.9.2 shall be used for these service loadings. Any deformation limit prescribed shall be considered.

6.2.4.2.2.9.4 Loading level D service limits

(1) The number and cross-sectional area of threaded structural fasteners shall be such that the requirements of clause 6.2.4.2.2.6 and **Table 6-5** are satisfied. Deviating from the stipulations in clauses 6.2.4.2.2.6.3 and 6.2.4.2.2.6.4, the rules of subparas (2) and (3) shall apply to fasteners with R_{mRT} exceeding 700 N/mm^2. Any deformation limit prescribed shall be considered.

(2) For an elastic component analysis combined either with an elastic or inelastic system analysis the primary stress intensities and the sum of primary membrane and bending stress intensity shall be limited as follows:

$$P_m \leq 2 \cdot S_m \quad (6.2\text{-}17)$$

$$P_m + P_b \leq 3 \cdot S_m \quad (6.2\text{-}18)$$

(3) For a plastic component analysis combined either with an elastic or inelastic system analysis, the primary stress intensities and the sum of primary membrane plus bending stress intensity shall be limited as follows:

$$P_m \leq 2 \cdot S_m \quad (6.2\text{-}19)$$

$$P_m + P_b \leq \max \begin{cases} 0.7 \cdot R_{mTt} \\ R_{p0.2T} + \frac{1}{3} \cdot \left(R_{mTt} - R_{p0.2T}\right) \end{cases} \quad (6.2\text{-}20)$$

where R_{mTt} is the respective value from the stress/strain curve at temperature (see also clause 6.2.4.2.2.6.3 (5)).

6.2.4.2.2.10 Limitation of stress intensity and equivalent stress range for clad components

For the verification of strength of clad components made of materials according to Section 7 the following applies:

a) Primary stresses

When determining the primary stress intensities the cladding provided shall not be considered. In such case

aa) the nominal dimension of the inner cladding surface may be taken as inside diameter for components subject to internal pressure difference

ab) the outer base metal surface shall be taken as external diameter for components subject to external pressure difference.

b) Secondary stresses

In evaluating the equivalent stress range composed of primary and secondary stress intensities and the fatigue, the cladding shall be credited for temperature calculation and structural analysis. In the case of welded cladding of continuous thickness, the presence of cladding may be neglected if the nominal cladding thickness is equal to or smaller than 10 % of the total thickness of the component.

c) Bearing loads

In evaluating the stress intensity limits according to clause 6.2.4.2.2.7 (1) the presence of a cladding shall be credited.

6.2.4.2.3 Fatigue analysis

6.2.4.2.3.1 General requirements

(1) A fatigue analysis shall be performed depending on the type of component, sub-unit and part to avoid fatigue failure due to cyclic loading. Due to loading level and frequency a fatigue analysis is not required for components, sub-units and parts of quality class “AS-RE 3”.

Note:

The fatigue analysis procedure shown in clause 6.2.4.2.3 does not consider the following factors of influence:

a) high-cycle loadings due to vibration excitation in combination with loadings in the endurance limit range (e.g. due to thermal transients),

b) the possible reduction of the endurance limit in the ultra-high cycle range ($N > 2 \cdot 10^7$),

c) the influence of radiation (especial neutron irradiation),

d) the influence of strain hardening in case of austenitic materials subject to the fluid conditions,

e) long-term effect of hydrogen.

According to the current state of knowledge, a significant influence of these factors on fatigue damage is not assumed. These factors of influence are objects of research.

These factors of influence will be taken into consideration, where required, if secured experimental studies are available.

(2) The basis for fatigue evaluation are the design fatigue curves according to clause 6.2.4.2.3.2.

(3) The following fatigue analysis methods are permitted:

a) Simplified fatigue evaluation in accordance with clause 6.2.4.2.3.3.1

This evaluation is based on a limitation of pressure cycle ranges, temperature differences and load stress cyclic ranges with regard to magnitude and number of cycles. If these limits are adhered to, safety against fatigue failure is obtained. This evaluation method is based on a linear-elastic stress strain relationship.

b) Elastic fatigue analysis in accordance with clause 6.2.4.2.3.3.2

This analysis method shall be used especially if the safety against fatigue failure according to clause 6.2.4.2.3.3.1 cannot be demonstrated. The elastic fatigue analysis is only permitted if the equivalent stress range resulting from primary and secondary stresses does not exceed a value of $3 \cdot S_m$ for steels, Ni-Cr-Fe alloys and Ni-Cr alloys and a value of $4 \cdot S_m$ for austenitic stainless precision casting.

c) Simplified elastic-plastic fatigue analysis in accordance with clause 6.2.4.2.3.3.3

This analysis method may be used for load cycles where the equivalent stress range resulting from all primary and secondary stresses exceeds the limit value of $3 \cdot S_m$ for steel, Ni-Cr-Fe alloys and Ni-Cr alloys and a value of $4 \cdot S_m$ for austenitic stainless precision casting, however, these limit values are adhered to by the equivalent stress range resulting from primary and secondary stresses due to mechanical loads. The influences of plastification are considered by using the factor K_e according to clause 6.2.4.2.3.3.3. In lieu of this K_e value other values may be used in individual cases, which have been proved by experiments or calculation or have been taken from literature. Their applicability shall be verified.

In addition, it shall be demonstrated that no ratcheting (progressive distortion) occurs.

d) General elastic-plastic fatigue analysis in accordance with clause 6.2.4.2.3.3.4

While the abovementioned methods are based on linear-elastic material behaviour, a fatigue analysis based on the elasto-plastic behaviour of the material may be made in lieu of the abovementioned methods in which case it shall be demonstrated that no progressive distortion (ratcheting) occurs.

(4) The fatigue analysis of threaded structural fasteners shall be made in accordance with clause 6.2.4.2.3.3.5.

(5) In lieu of the fatigue analysis an experimental proof of fatigue resistance according to 6.2.4.3.5 may be made.

6.2.4.2.3.2 Design fatigue curves

Note:

The fatigue analysis procedures dealt with hereinafter are based on comparison of stresses including peak stresses with fatigue data for cyclic loading. These fatigue data which are based on tests performed at ambient temperature are shown in **Figures 6-3** and **6-4** as well as in **Table 6-8** and indicate, for certain steels, the allowable amplitude of stress intensities (S_a is half the stress intensity S_{rij}) plotted over the number of load cycles. The stress intensity amplitude is calculated on the assumption of elastic response and has the magnitude of a stress, but only represent a true stress in the elastic range.

(1) The fatigue curves shown in **Figure 6-3** for temperatures equal to or less than 80 °C as well as for temperatures exceeding 80 °C shall apply to the austenitic steels X6CrNiNb18-10 (1.4550) and X6CrNiTi18-10 (1.4541). The fatigue curve shown in **Figure 6-4** shall apply to all other austenitic steels.

(2) Fluid effects are to be considered additionally for fluid-wetted surfaces if it is expected that the following thresholds will be exceeded during processes of specified operation that might be relevant to fatigue [1]:

a) strain amplitude $\varepsilon_a > 0.1$ % and

b) average temperature (T > 100 °C in the case of austenitic steels, T > 50 °C in the case of Ni-Cr-Fe alloys).

(3) Where a reduction of fatigue strength due to fluid effects cannot be excluded, then at a threshold for cumulative damage of

D = 0.4 for RPV internals in BWR plants

D = 0.8 for RPV internals made of Ni-Cr-Fe alloys in PWR plants

the following measures shall be taken to ensure consideration of fluid influence on the fatigue behaviour:

a) the components considered shall be included in a monitoring program according to Section 9, or

b) experiments simulating operating conditions shall be performed, or

c) verificationsby calculationshall be made in due consideration of fluid-effected reduction factors and realistic boundary conditions.

The fluid influence on the fatigue behaviour of RPV internals made of austenitic steels shall be evaluated if load cases are to be assumed that are not covered by those given in **Annex I**.

Note:

See explanations in **Annex I**, clause I 3.4 (3), with regard to attention thresholds for austenitic steels in the case that fatigue evaluations are not made on the basis of the fatigue curves in **Figures 6-3** and **6-4**.

(4) The values for S_{alt} determined based on a linear-elastic analysis shall not exceed the S_a value which is assigned to a load cycle number of 10 in **Figure 6-3**. S_{alt} is defined as the calculated values of half the stress intensity and S_a as the design fatigue curve values.

(5) The equations of the fatigue curves for the steels 1.4550 and 1.4541 shown in **Figure 6-3** are:

a) as function $S_a = f(\hat{n}_i)$

$$S_a = 10^{-2} \cdot E \cdot \left[\left(\frac{e^{4.5}}{\hat{n}_i} \right)^{\frac{1}{2.365}} + 0.0478 \right] \qquad (6.2\text{-}21)$$

b) as function $N = f(S_a)$

$$\hat{n}_i = \frac{e^{4.5}}{\left(\frac{S_a}{10^{-2} \cdot E} - 0.0478 \right)^{2.365}} \qquad (6.2\text{-}22)$$

where

S_a : half stress intensity range in N/mm²

$\hat{n}_i$: allowable number of load cycles

E : modulus of elasticity

Themodulus of elasticity $E = 1.79 \cdot 10^5$ N/mm² was used as reference value for the pictured fictitious elastic stress ranges.

6.2.4.2.3.3 Limitation of the cumulative usage factor due to fatigue

6.2.4.2.3.3.1 Simplified evaluation of safety against fatigue failure

The peak stresses need not be considered separately in the fatigue evaluation if for the loading level A of the part the following conditions of sub-clauses a) to d) are satisfied.

Note:

Where load cases of loading levels B and C are to be analysed regarding their fatigue behaviour, the same conditions as for level A apply.

a) Temperature difference during start-up and shutdown

The temperature difference between any two adjacent points of the component during loading level A shall not exceed the value of $S_a/(2 \cdot E \cdot \alpha)$, where S_a is the value obtained from the applicable design fatigue curve for the specified number of start-up-shutdown cycles, α is the value of the instantaneous coefficient of thermal expansion at the mean value of the temperatures at the two points, and E is the modulus of elasticity at the mean value of the temperatures at the two points.

Note:

Adjacent points are defined as points that are less than the distance $2 \cdot \sqrt{R \cdot s_c}$, where R is the radius measured normal to the surface from the axis of rotation to the midwall and s_c is the thickness of the part (e.g. core barrel) at the point under consideration.

b) Temperature difference during services other than start-up and shutdown

The temperature difference between any two adjacent points shall not exceed the value of $S_a/2 \cdot E \cdot \alpha$, where S_a is the value obtained from the applicable design fatigue curve for the total number of significant temperature fluctuations. A temperature difference fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/(2 \cdot E \cdot \alpha)$, where S is defined as follows:

ba) If the specified number of load cycles does not exceed 10^6 S is the value S_a obtained from the design curve for 10^6 cycles.

bb) If the specified number of load cycles is greater than 10^6 S is the value S_a obtained from the design curve for N > 10^6 assuming 10^{11} load cycles.

c) Temperature differences for dissimilar materials

For components fabricated from materials of differing moduli of elasticity or coefficients of thermal expansion, the total algebraic range of temperature fluctuation experienced by the component during normal service shall not exceed the magnitude $S_a/[2 \cdot (E_1 \cdot \alpha_1 - E_2 \cdot \alpha_2)]$. Here S_a is the value obtained from the applicable design fatigue curve for the total specified number of significant temperature fluctuations, E_1 and E_2 are the moduli of elasticity, and α_1 and α_2 are the values of the instantaneous coefficients of thermal expansion at the mean temperature value for the two materials. A temperature fluctuation shall be considered to be significant if its total algebraic range exceeds the quantity $S/[2 \cdot (E_1 \cdot \alpha_1 - E_2 \cdot \alpha_2)]$, where S is defined as follows:

ca) If the specified number of load cycles does not exceed 10^6 S is the value S_a obtained from the design curve for 10^6 cycles.

cb) If the specified number of load cycles is greater than 10^6 S is the value S_a obtained from the design curve for N > 10^6 assuming 10^{11} load cycles.

If the two materials used have different design fatigue curves the smaller value of S_a shall be used in these calculations.

d) Mechanical loads

The specified full range of mechanical loads, including differential pressures and connection loads, shall not result in load stresses whose range exceeds the value of S_a. If the total specified number of significant load fluctuations exceeds the maximum load cycle number of the applicable design curve (**Figure 6-3** or **Figure 6-4**), the S_a value may be taken for the maximum load cycle number of the respective design curve. A load fluctuation shall be considered to be significant if the total excursion of load stress exceeds the value of S obtained from the respective design fatigue curve, where S is defined as follows:

da) If the specified number of load cycles does not exceed 10^6 S is the value S_a obtained from the design curve for 10^6 cycles.

db) If the specified number of load cycles is greater than 10^6 S is the value S_a obtained from the design curve for N > 10^6 assuming 10^{11} load cycles.

6.2.4.2.3.3.2 Elastic fatigue analysis

(1) Prerequisites

Prerequisite to the application of the elastic fatigue analysis is that the stress intensity ranges are limited in accordance with clause 6.2.4.2.2.3.

The stresses for the specified load cycles are taken into account.

(2) Strain concentration factor (fatigue strength reduction factor)

Local structural discontinuities shall be credited by the use of fatigue strength reduction factors or stress concentration factors (maximum = 5) determined analytically or experimentally. The fatigue strength reduction factors of welded joints are given in **Table 6-1**.

(3) Cumulative damage (usage factor)

If there are two or more types of stress cycle which produce significant stresses their cumulative effect shall be accumulated to the linear damage rule as follows:

For each step $S_{alt,i} = S_a$ the allowable number of load cycles N_i from the design fatigue curves to be used in accordance with clause 6.2.4.2.3.2 shall be determined and be compared with the specified number of load cycles n_i.

The sum of these ratios n_i/N_i is the cumulative usage factor D for which the following applies:

$$D = \frac{n_1}{N_1} + \frac{n_2}{N_2} + ... \frac{n_k}{N_k} \leq 1.0 \qquad (6.2\text{-}23)$$

Note:

In determining n_1, n_2, n_3, n_n consideration shall be given to the superposition of cycles of various origins which produce a total stress difference range greater than the stress difference ranges of the individual cycles.

For example: if one type of stress cycle produces 1000 cycles of a stress difference variation from 0 to + 500 N/mm² and another type of stress cycle produces 10.000 cycles of a stress difference variation from 0 to - 400 N/mm², the following types of cycles shall be considered:

1. Stress cycle:
   $n_1 = 1000$
   $S_{alt_1} = 0.5 \cdot (500 + 400) = 450$ N/mm²
2. Stress cycle:
   $n_2 = 9000$
   $S_{alt_2} = 0.5 \cdot (400 + 0) = 200$ N/mm²

6.2.4.2.3.3.3 Simplified elastic plastic fatigue analysis

(1) The $3 \cdot S_m$ limit for stress intensity range resulting from primary plus secondary stresses may be exceeded if the requirements in para (2) to (7) hereinafter are met.

(2) The equivalent stress intensity range resulting from primary plus secondary membrane and bending stresses without thermal bending stresses shall be not greater than $3 \cdot S_m$.

(3) The value of half the equivalent stress intensity range S_a to be compared with the design fatigue curve acc. to **Figure 6-3** or **6-4** shall be multiplied with the factor K_e , where K_e is to be determined as follows:

$$K_e = 1.0 \text{ for } S_n \leq 3 \cdot S_m \qquad (6.2\text{-}24)$$

$$K_e = 1.0 + \frac{(1-n)}{n \cdot (m-1)} \cdot \left(\frac{S_n}{3 \cdot S_m} - 1 \right) \text{ for } 3 \cdot S_m < S_n < m \cdot 3 \cdot S_m \qquad (6.2\text{-}25)$$

$$K_e = \frac{1}{n} \quad \text{for} \quad S_n \geq m \cdot 3 \cdot S_m \qquad (6.2\text{-}26)$$

where

S_n : Range of primary plus secondary stress intensity

m, n : material parameters to be taken from the following table:

Type of material	m	n	T_{max} (°C)
Martensitic stainless steel	2.0	0.2	370
Austenitic stainless steel	1.7	0.3	425
Nickel alloy	1.7	0.3	425

In lieu of these K_e values other values may be used, which have been proved by experiments or calculation or have been taken from literature. Their applicability shall be verified.

Note:

The literature referenced in [2] contains a proposal for the determination of K_e values.

(4) The limitation of the cumulative usage factor due to fatigue shall be in acc. with clause 6.2.4.2.3.3.2.

(5) The temperature for the material used shall not exceed the value of T_{max} in Table of para (3).

(6) The elastic limit/tensile strength ratio of the material used shall be smaller than 0.8.

(7) It must be ensured that cyclic loading from secondary thermal stresses does not lead to impermissible thermal stress ratcheting.

Note:

Only in this case the structure meets the requirements regarding Thermal Stress Ratcheting acc. to clause 6.2.4.2.2.4.

6.2.4.2.3.3.4 General elastic-plastic fatigue analysis

(1) While the abovementioned methods are based on linear-elastic material behaviour, a fatigue analysis based on the elasto-plastic behaviour of the material may be made in lieu of the abovementioned methods in which case it shall be demonstrated that no progressive distortion (ratcheting) occurs.

(2) For the determination of plastic strains at cyclic loading an elasto-plastic analysis may be made. The material model used in this analysis shall be suited to realistically determine the cyclic strains.

(3) Where in the case of strain hardening materials the decrease of the strain increment from cycle to cycle is to be taken for the determination of the total strain, the load histogram shall comprise several cycles. From the strain history determined from the respective load histogram the maximum accumulated strain may be calculated by conservative extrapolation.

(4) At the end of service life, the locally accumulated principal plastic tensile strain shall not exceed, at any point of any cross section, the following maximum value: 5.0% in the base metal, 2.5% in welded joints.

6.2.4.2.3.3.5 Fatigue analysis of threaded structural fasteners

(1) Unless threaded structural fasteners meet the condition of the simplified fatigue analysis acc. to clause 6.2.4.2.3.3.1, the suitability of the fasteners for cyclic service shall be determined in consideration of the stipulations of (2) to (6).

(2) Threaded structural fasteners with R_{mRT} equal to or smaller than 700 N/mm^2

These fasteners shall be treated in accordance with clause 6.2.4.2.3.3.2.

(3) Threaded structural fasteners with R_{mRT} exceeding 700 N/mm^2

These fasteners shall be treated in accordance with clause 6.2.4.2.3.3.2 and satisfy the following supplementary requirements:

a) The maximum primary plus secondary stresses including preload at the periphery of the cross section (resulting from direct tension plus bending and neglecting stress concentrations) shall be equal to or less than 0.9 · $R_{p0.2T}$.

b) the threads shall have a minimum thread root radius no smaller than 0.08 mm.

c) the fillet radii at the end of the shank shall be such that the ratio of fillet radius to shank diameter is not less than 0.060.

(4) Fatigue strength reduction factor

Unless it can be shown by analysis or tests that a lower value is appropriate, the fatigue strength reduction factor to be used in the fatigue evaluation shall be 4.0.

However, when applying the rules of (3) above for threaded structural fasteners, the value used shall not be less than 4.0.

(5) Cumulative damage (usage factor)

The usage factor D for the various types of stress cycles shall be determined in accordance with the equation in clause 6.2.4.2.3.3.2 (3).

6.2.4.2.4 Strain analysis

A strain analysis shall only be made if specified strain limits are to be adhered to for functional reasons.

6.2.4.2.5 Structural analysis

Where under the effect of pressure loading a sudden deformation without considerable increase in load may be expected, a structural analysis according to **Annex A** shall be performed.

6.2.4.2.6 Limit analysis

With regard to the performance and assessment of limit analysis the requirements of **Annex B** shall be met.

6.2.4.2.7 Stress ratio method

With regard to the performance and assessment of stress ratio method the requirements of **Annex C** shall be met.

6.2.4.3 Experimental analysis methods

6.2.4.3.1 General requirements

(1) Experiments may be made to determine the collapse load P_c in conformance with clauses D 2.1.2 and D 2.4.4.

(2) Experiments for determining the plastic instability load P_I of a structure may be made. In such case where the structure collapses before reaching plastic instability, the collapse load shall be used.

(3) Experiments may be made for determining such loads that lead to partial deformations of a structure. Such methods shall be applied to satisfy the rules of **Annex D**. For the case where a deformation limit value has been fixed the load causing this deformation limit is designated with the symbol P_s.

(4) An experimental stress analysis may be made for determining inelastic response data of a component.

(5) All experimental analysis methods shall consider the following parameters:

a) influence of model scale,
b) dimensional tolerances if any, between the actual part and the test part,
c) differences in ultimate tensile strength or other governing material properties.

Consideration of these parameters shall ensure that the loads obtained from the test are a conservative representation of the load carrying capability of the actual structure under the specified service loadings for the respective loading level. For threaded structural fasteners this method can also be used.

6.2.4.3.2 Experimental analysis methods for loading levels A and B

For loading levels A and B, the limits of primary membrane plus primary bending stress intensity need not be satisfied if it can be shown from the test of a prototype or a model that the specified loads (dynamic or static equivalent) do not exceed 44 % of the load L_u where L_u is the ultimate load or load combination used in the test (see also **Table 6-9**).

6.2.4.3.3 Experimental methods for loading level C

(1) For loadings assigned to loading level C the stress intensity limits of clause 6.2.4.2.2.5 need not be satisfied if it can be shown from the test of a prototype or model that the specified loads (dynamic or static equivalent loads) do not exceed 60 % of the load L_e where L_e is the ultimate load or load combination used in the test (see also **Table 6-9**).

(2) For threaded structural fasteners with R_{mRT} exceeding 700 N/mm^2 the stress intensity limits of 6.2.4.3.2 apply. Where deformation limits are prescribed they shall be considered.

6.2.4.3.4 Experimental method for loading level D

The specified dynamic and static equivalent loads of loading level C shall not exceed:

a) 80 % of the collapse load P_t obtained from a prototype or model test, or
b) 80 % of the load combination L_t obtained from a prototype or model test,

where P_t and L_t are defined to be that load or load combination at which the stress/strain curve reaches the horizontal tangent line (see also **Table 6-9**).

6.2.4.3.5 Experimental fatigue analysis

In lieu of a theoretical fatigue analysis an experimental fatigue analysis may be made in accordance with section D 3.

6.2.5 Type and extent of strength analysis and related documents

(1) Within design approval for the substantiation of strength analysis, documents shall be submitted for all parts and subunits of RPV internals mentioned in Section 3. Each analysis shall be performed such that it satisfies the postulated loadings of the respective service limits in consideration of clause 6.2.4.1.

(2) The load cases and load combinations specified in 6.2.2 shall be analysed. Both the structure and loadings shall be presented such that the component loading can be determined with sufficient accuracy.

(3) In the case of an experimental analysis method a test program shall be submitted to the authorized inspector for review, in due time prior to performing the test. The test program shall especially show

a) a description of the test,
b) the type and extent of instrumentation,
c) the specified test data (e.g. test loadings),
d) calibration of measuring instruments.

In case that transferable data of already performed experimental methods are used, the respective documents shall be submitted to the inspector.

(4) Each analysis report shall contain, where applicable:

a) a description of the problem field and the analysis procedure as well as the assumptions made,
b) an indication of the analysis procedure, theoretical bases, computer programs used,
c) an explanation of model structure,
d) the loading data, load combinations and their classification,
e) the geometric data, drawing numbers,
f) the material properties used,
g) the input data results,
h) the evaluation of results and comparison with allowable values,
i) the conclusions from the evaluation of results,
k) literature, bibliographic references.

		Allowable half stress intensity range S_a in N/mm^2 at allowable number of load cycles N															
		$1 \cdot 10^1$	$2 \cdot 10^1$	$5 \cdot 10^1$	$1 \cdot 10^2$	$2 \cdot 10^2$	$5 \cdot 10^2$	$1 \cdot 10^3$	$2 \cdot 10^3$	$5 \cdot 10^3$	$1 \cdot 10^4$	$2 \cdot 10^4$	$5 \cdot 10^4$	$1 \cdot 10^5$	$2 \cdot 10^5$	$5 \cdot 10^5$	$1 \cdot 10^6$
Fig. 6-3	T ≤ 80 °C	4341	3302	2312	1773	1368	981	770	612	461	378	316	257	225	201	178	165
	T > 80 °C	4618	3467	2381	1798	1363	953	732	568	413	330	268	209	178	154	132	120
Fig. 6-4		5508	3947	2522	1816	1322	894	684	542	413	338	275	216	180	154	130	116

		$1 \cdot 10^6$	$2 \cdot 10^6$	$5 \cdot 10^6$	$1 \cdot 10^7$	$2 \cdot 10^7$	$5 \cdot 10^7$	$1 \cdot 10^8$	$1 \cdot 10^9$	$1 \cdot 10^{10}$	$1 \cdot 10^{11}$
Fig. 6-3	T ≤ 80 °C	165	156	147	142	138	135	133	129	128	127
	T > 80 °C	120	112	103	99	95	92	91	87	86	86
Fig. 6-4		116	104	94	91	—	—	89	88	87	86

(1) The values of S_a shown here are based on the respective elastic modulus $E = 1.79 \cdot 10^5$ N/mm^2.

(2) Straight interpolation between tabular values is permitted based upon a double-logarithmic representation: (straight lines between the data points on the log-log plot). Where for a given value of $S_a = S$ the pertinent number of load cycles N is to be determined, this shall be done by means of the adjacent data points $S_j < S < S_i$ and $N_j > N > N_i$ as follows:

$$N / N_i = (N_j / N_i)^{\log\frac{S_i}{S} / \log\frac{S_i}{S_j}}$$

Example: Given: austenitic steel (material identification no. 1.4550), $S_a = 550$ N/mm^2

from which follows: $S_i = 614$ N/mm^2, $S_j = 483$ N/mm^2, $N_i = 2 \cdot 10^3$, $N_j = 5 \cdot 10^3$

$$N / 2000 = (5000 / 2000)^{\log\frac{614}{550} / \log\frac{614}{483}} \rightarrow N = 3045$$

Table 6-8: Table of values of the allowable half stress intensity range S_a for design fatigue curves of Figures 6-3 and 6-4

Stress category 1) 2)		Loading level		
		Level A and B	Level C	Level D
Primary stress intensity	P_m	$0.44 \cdot L_u$ 1)	$0.60 \cdot L_e$ 2)	$0.80 \cdot P_t$ 3) $0.80 \cdot L_t$
	$P_m + P_b$	$0.44 \cdot L_u$	$0.60 \cdot L_e$	$0.80 \cdot P_t$ $0.80 \cdot L_t$
Primary plus secondary stress intensity	$P_m + P_b + Q$	$0.44 \cdot L_u$	not applicable	
Stress intensity from primary plus secondary plus peak stresses	$P_m + P_b + Q + F$	4)	not applicable	

1) Definition of L_u according to clause 6.2.4.3.2.

2) Definition of L_e according to clause 6.2.4.3.3.

3) Definition of P_t and L_t according to clause 6.2.4.3.4.

4) See clauses 6.2.4.2.3, 6.2.4.3.5 and Section D 3.

Table 6-9: Stresses and required test loads for experimental analysis methods

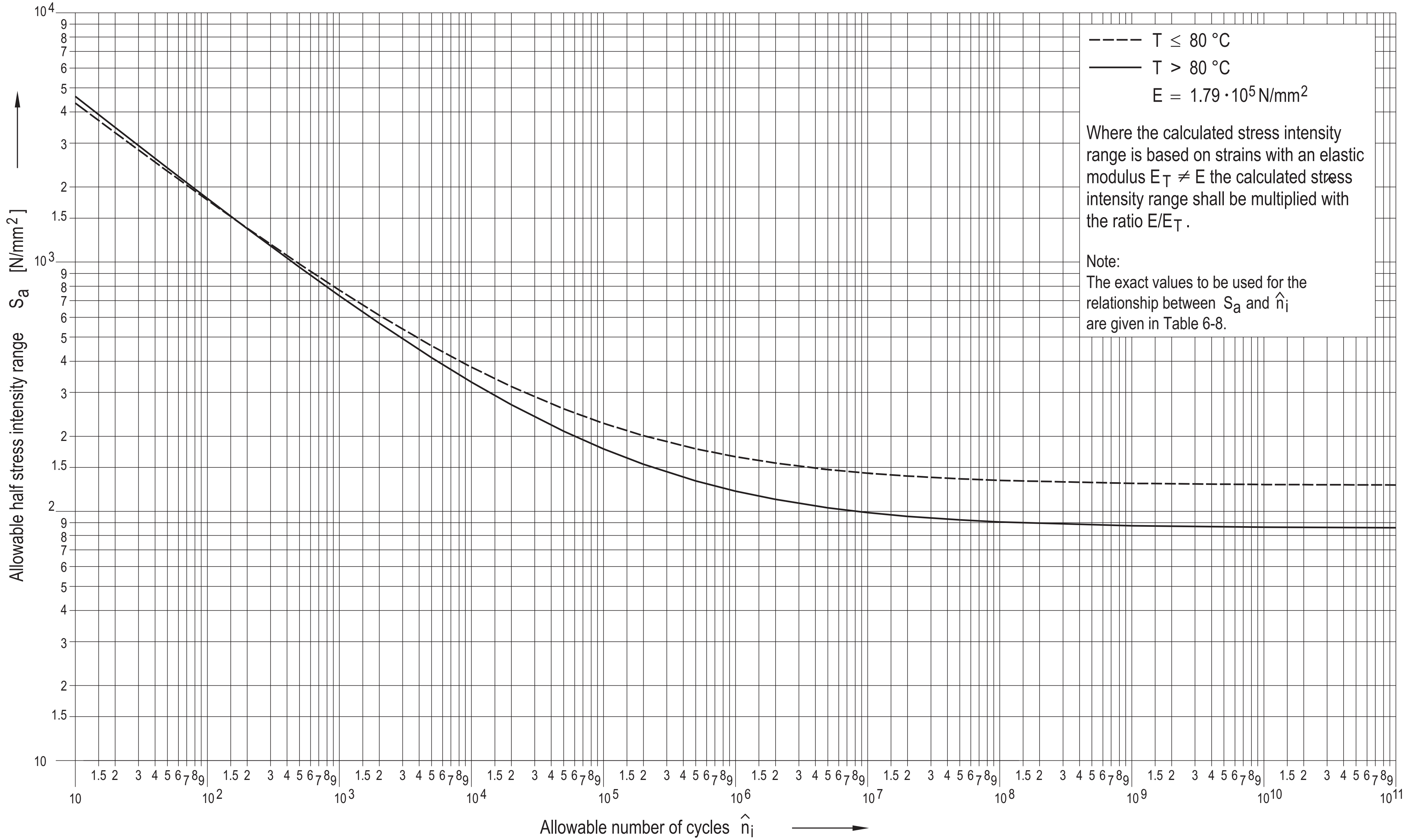


Figure 6-3: Design fatigue curves for the austenitic steels 1.4550 and 1.4541

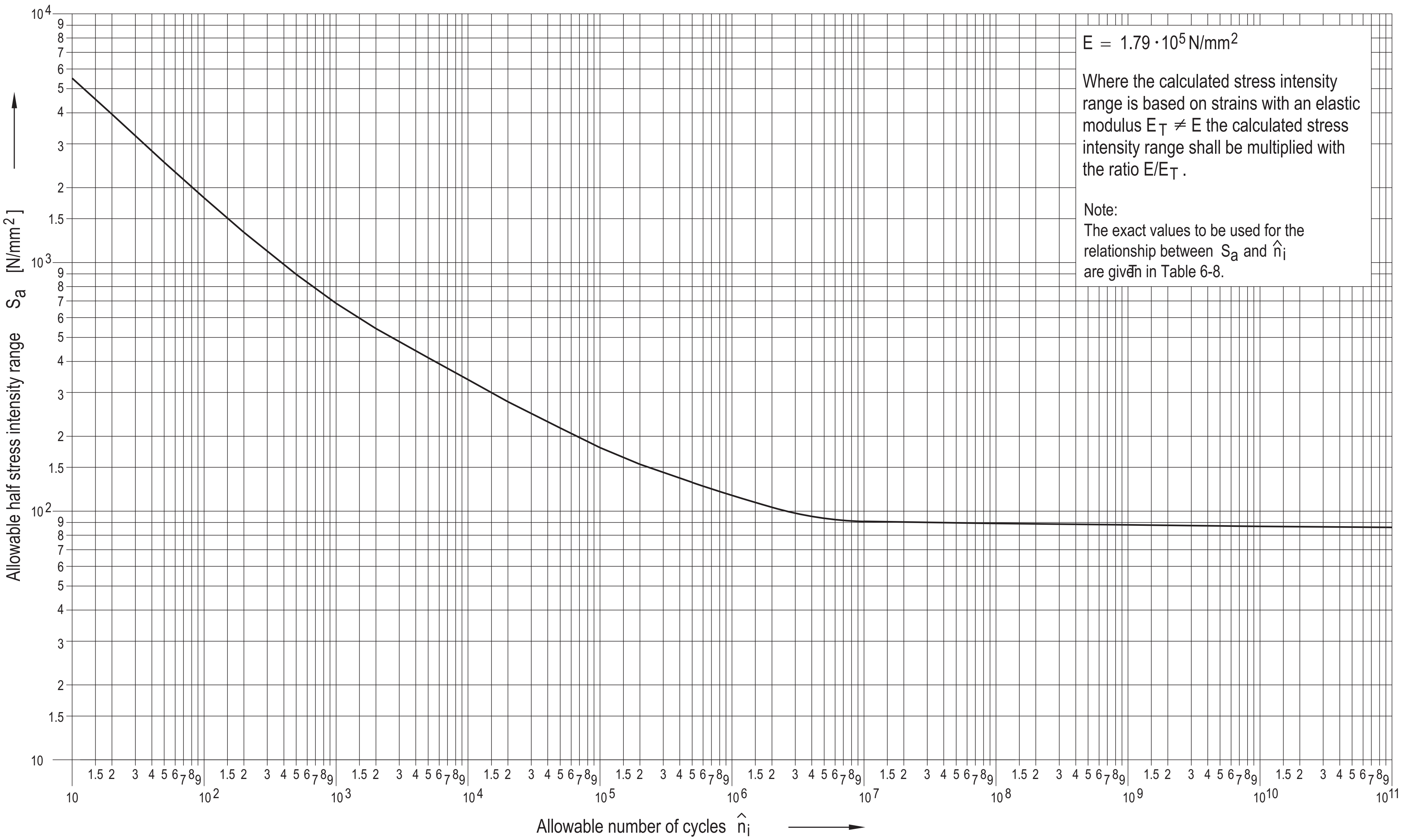


Figure 6-4: Design fatigue curve for austenitic steels except the steels 1.4550 and 1.4541, for Ni-Cr-Fe alloys and for Ni-Cr alloys

7 Materials and material testing

7.1 Scope

This section specifies requirements for materials including weld filler metals, brazing alloy and flux for thermal spraying.

7.2 Requirements for supplies

7.2.1 Requirements to be met by the manufacturer of quality class AS-RE 1 and AS-RE 2 product forms as well as for parts of quality class AS-RE 3 inside the RPV

Note:

The term „manufacturer“ in this Section refers to the manufacturer of material as well as to the manufacturer of weld filler metals, brazing solder and flux for thermal spraying.

(1) The manufacturer shall have manufacturing equipment and personnel at his disposal which permits a proper and state-of-the-art manufacturing of the materials.

(2) Where forming operations, heat treatments and the like are sub-contracted by other organisations, the requirements for such operations shall apply with respect to the scope of manufacturing.

(3) The manufacturers shall have test equipment at their disposal which permits the testing of materials in accordance with the corresponding DIN Standards or with other standards that apply. Test equipment from other organisations may also be employed if the requirements of this Section are met. Upon request, the test certificates of test equipment used for acceptance tests shall be submitted to the authorized inspector.

(4) The manufacturers shall have an organisationally independent quality department to ensure the required quality during fabrication.

(5) The quality surveillance department of the manufacturer shall ensure, and document correspondingly, that the materials and product forms are properly manufactured.

(6) The manufacturer shall only establish inspection certificates if a manufacturer’s authorized inspection representative is employed by him who satisfies the requirements of DIN EN 10204.

(7) The name and stamp of the manufacturer’s authorized inspection representative shall be known to the authorized inspector. This also applies to the test supervisory personnel for the non-destructive examinations

(8) The manufacturer shall prove that he has performed a material appraisal relating to the manufacturing process, product form, wall thickness and heat treatment, for austenitic steels e.g. in accordance with AD 2000-Merkblatt W 2.

(9) Prior to the beginning of manufacture it shall be proved to the inspector, that the aforementioned requirements have been satisfied. The authorized inspector shall certify that all requirements have been met.

(10) All changes of the condition recorded in the first certificate shall be reported to the authorized inspector responsible for the manufacturer’s works. In the case of essential changes the manufacturer shall apply for a new certificate which will be established by the authorized inspector upon fulfilment of the requirements.

(11) In individual cases delivery of product forms by the manufacturer is permitted upon agreement with the authorized inspector even if individual items of the aforementioned requirements have not been fulfilled. In this case the quality characteristics shall be tested on the delivery by representative tests and examinations.

7.2.2 Selection of materials

7.2.2.1 General requirements

The materials shall be selected by the plant vendor according to their intended application by taking into account the mechanical, thermal and chemical loadings and the alteration possible due to neutron irradiation as well as exposure to radiation during operation, e.g. during maintenance.

7.2.2.2 Base metal

(1) Materials with characteristics in accordance with those specified in **Annexes W 1** to **W 3**, **W 5** and **W 6** shall be considered to be applicable because the materials have been completely tested and inspected and proved to be reliable in service.

(2) Special materials of quality classes AS-RE 1 and AS-RE 2 require an initial material test certificate by the authorized inspector. The authorized inspector shall verify that a continuous material quality is ensured by the individual manufacturer. The tests by the authorized inspector required for special materials shall be specified with regard to type and extent such that they form, together with the supplied manufacturer’s documentation, a sufficient basis for the material certification. The proof that the required material characteristics are continuously obtained shall be supported by a mathematical and statistical evaluation of already available test results. If the material is manufactured in more than one works, this shall be considered in the initial certification.

(3) If a material is to be used beyond the scope of its certified applicability, additional test - if required - shall be agreed with the authorized inspector.

(4) For the components of quality class AS-RE 3 materials in addition to those mentioned in **Annexes W 1** to **W 3** and **W 5** and **W 6** are permitted if they are suited for the intended application.

7.2.2.3 Weld filler metals, brazing alloy and flux for thermal spraying

(1) The weld filler metals shall be tested for their suitability. This does not apply to filler metals for hard surfacing applications.

(2) The weld filler metals, brazing alloy and flux for thermal spraying with the material characteristics laid down in **Annex W 4** are deemed to be permitted due to the fact that they have been thoroughly tested and have proved to be reliable in service.

(3) Where a weld filler metal is to be used beyond the scope of its qualified application, additional tests, if any, shall be agreed upon with the authorized inspector, e.g. within a procedure qualification test.

7.3 Test of material quality

7.3.1 General requirements

(1) The quality characteristics of the materials shall be ascertained by testing. The requirements regarding quality characteristics and tests to be performed are specified in **Annexes W 1 to W 6**. Where tensile tests at elevated temperatures are required, the test temperature shall be 350 °C unless agreed otherwise.

(2) The required material tests shall be recorded in inspection certificates according to DIN EN 10204 and shall contain the following information:

a) material,

b) extent and dimensions of the delivery,

c) identification marking,

d) delivery specifications,

e) test results.

Material test certificates 3.2 shall be confirmed or be established by the authorized inspector.

(3) The materials should be tested at the manufacturer's works.

7.3.2 Identification marking of test specimens with regard to the product forms

The test specimens with regard to the product forms shall be identified as follows:

a) Identification with regard to forming direction:

aa) Longitudinal test specimen (L):
Major axis of specimen is parallel to the principal forming direction; the notch of impact test specimens shall be perpendicular to the plane of length/width direction.

ab) Transverse test specimen (Q):
Major axis of specimen is perpendicular to the principal forming direction; the notch of impact specimen tests shall be perpendicular to the plane of length/width direction.

ac) Perpendicular test specimen (S):
Major axis of specimen is perpendicular to the plane of length/width direction; the notch of impact specimen tests shall be parallel to the principal forming direction.

b) Identification with regard to the major direction of the product form shape:

ba) Axial test specimen (A):
Major axis of specimen is parallel to the axis of rotational symmetry of the product form; the notch of impact tests shall be perpendicular to the cylindrical surface.

bb) Tangential test specimen (T):
Major direction of specimen is in the direction of the circumference; the notch of impact tests shall be perpendicular to the cylindrical surface.

bc) Radial test specimen (R):
Major axis of specimen is normal to the cylindrical surface, the notch of impact tests shall be parallel to the principal direction in which the material is formed.

7.3.3 Test coupons, identification marking of test specimens and specimen-taking

7.3.3.1 Base metal

(1) Test coupons

A sufficient amount of material shall be provided for obtaining test specimens such that, in addition to the demonstration of the mechanical properties, a sufficient amount of material remains for re-examination specimens.

(2) Identification marking of test specimens and test coupons

For the acceptance test, the test coupons shall be legibly and unambiguously marked by the authorized inspector charged with the acceptance test prior to taking them from the product form, the test specimens prior to taking them from the test coupon. The marking of the test specimens shall make it possible to exactly determine their original location in the product form.

7.3.3.2 Weld metal

The all-weld metal shall be tested on the test coupons given in **Table 7-1** which shall be welded in accordance with DIN EN ISO 15792-1 and DIN EN ISO 6847.

7.3.3.3 Brazing alloys and fluxes

The brazing alloys and fluxes shall be tested on the delivery and not on specifically manufactured specimens.

Filler metal	Test coupon for chemical analysis	Tensile, notch impact , IGSCC and delta ferrite content test specimens
Rod electrode ∅ ≤ 2.5 mm Welding rod ∅ ≤ 2.5 mm Wire electrode/welding wire ∅ < 1.2 mm	According to DIN EN ISO 6847 weld test coupon for inert gas welding: At least 8 runs shall be welded on a base plate of similar material. Distance at least A = 8 mm or 4 layers. When test coupons according to DIN EN ISO 15792-1 are required they may be used for chemical analysis.	Form 1.1 according to DIN EN ISO 15792-1
Rod electrode ∅ > 2.5 mm Welding rod ∅ > 2.5 mm Wire electrode/welding wire 1.2 mm ≤ ∅ ≤ 2.4 mm		Form 1.3 according to DIN EN ISO 15792-1
Wire electrode/welding wire ∅ > 2.4 mm		Form 1.4 according to DIN EN ISO 15792-1
Electrode-flux combination	Form 1.3 or 1.4 according to DIN EN ISO 15792-1	

Table 7-1: Testing of the all-weld metal

7.3.4 Heat treatment condition of the test specimens

The specimens shall be delivered with the same heat treatment condition as the finished products. A deviating heat treatment condition (e.g. simulation of stress relieving) will be specified in the material annexes for the respective test.

7.3.5 Tests

7.3.5.1 Chemical analysis

(1) The choice of a suitable analysis method is left to the manufacturer.

(2) In case of doubt the chemical composition shall be determined by the test procedure developed by the Chemical Committee of the Association of German Steel Manufacturers [3].

7.3.5.2 Tensile test

The tensile test shall be performed in accordance with DIN EN ISO 6892-1 und DIN EN ISO 6892-2. At the manufacturer's option method A or B may be used. Where method A is used, the strain rates recommended by the standard shall be used. Specimens according to DIN 50125 may also be used.

7.3.5.3 Notched-bar impact bend test

Notched-bar impact bend tests shall be performed in accordance with DIN EN ISO 148-1 on specimens with V-notch using a striker with 2 mm radius (KV_2). One set consisting of three specimens shall be tested.

7.3.5.4 Check for resistance to hot cracking

(1) To ensure resistance to hot cracking the delta ferrite content shall be determined in accordance with Sec. 7.3.5.5 with respect to the requirements in the applicable Annexes for those product forms which, in the course of further fabrication, will be subjected to welding.

(2) For the check of the molten weld metal for susceptibility to hot cracking test welds shall be made in accordance with **Table 7-2** (base plate material no.: 1.4550 according to DIN EN 10088-2). The examination and assessment for hot cracking shall be made by surface examination by means of the liquid penetrant method according to clause 7.3.5.8.3.

7.3.5.5 Determining the delta-ferrite content

(1) Metallographic analysis of delta-ferrite content

a) The metallographic analysis of delta-ferrite content shall be performed in the base metal of bead-on-plate test specimens. Therefore a test specimen of the following size shall be taken from the product form:

   length 200 mm, thickness ≥ 25 mm, width ≥ 40 mm, unless the product form shows smaller dimensions.

b) A melt run with a length of at least 180 mm shall be deposited on the test specimen with a TIG burner without weld filler metals, using the following weld parameters:

   current: 160 A,

   feed rate: about 20 cm/min.

c) In the case of product forms where the required size of test specimens and the required weld parameters cannot be adhered to, the specimen shape and heat input shall be largely adjusted to the welding to be performed later on the product. The specimen shape and the weld parameters shall be contained in the test certificates.

d) The delta-ferrite content in the austenitic weld metal shall be determined on specimens of the molten all-weld metal which are taken within the acceptance testing of the weld filler metals.

e) For metallographic analysis a specimen section shall be removed from the middle of the melt run perpendicular to the surface and to the weld run axis or, in the case of all-weld-metal test coupon, perpendicular to the direction of welding progress and be prepared for metallographic examination.

f) To determine the delta-ferrite content the test specimen shall be ground and polished in the usual way and etched in accordance with Murakami [4]; the metallographic structure of a representative location shall be documented by micrographs (1000:1 magnification).

   Note:

   For the determination of the delta-ferrite content generally the delta-ferrite standards of the “Reference-Atlas for a comparative evaluation of ferrite percentage in the fused zone of austenitic steel welded joints“ of the International Institute of Welding [5] are used.

g) The determination of delta-ferrite content shall be documented. This documentation shall contain at least the following information:

   ga) result of analysis,

   gb) shape and dimension of test specimen,

   gc) weld parameters,

   gd) location of microsection,

   ge) metallographic preparation and examination,

   gf) photomicrographs.

(2) Mathematical estimation of delta-ferrite content

a) Mathematical estimation of delta-ferrite content shall be carried out according to De Long [6].

b) The documentation shall contain at least the following information:

   ba) Cr equivalent,

   bb) Ni equivalent,

   bc) delta-ferrite content.

(3) Magnetic determination of the delta ferrite content

a) The magnetic determination of the delta ferrite content in austenitic steels and welds shall be made by delta ferrite measuring instruments.

b) Prior to the beginning of measurement the delta ferrite measuring instrument shall be calibrated by means of secondary standards according to DIN EN ISO 8249, and the electrical and mechanical instrument zeros shall be adjusted.

c) The delta ferrite content shall be measured at representative locations (e.g. in the middle of a melt run deposited in accordance with 7.3.5.5 (1) b) or in the middle of the weld run on the component.

d) The locations of measurement shall show a bright metal surface (e.g. obtained by grinding in longitudinal direction). In the case of precision casting the cast surface shall be removed.

e) The individual measuring values shall be recorded with indication of the location of measurement.

7.3.5.6 Crystalline structure and determination of grain size

(1) The crystalline structure of formed products shall be evaluated by means of microsections with the plane parallel to the direction of fibres or main forming and perpendicular to the surface at a magnification of 100:1. In the case of precision casting microsections with the plane perpendicular to the surface shall be evaluated.

(2) For this purpose, the halves of tested notch bar impact test specimens shall be used.

(3) The grain size shall be determined by means of standards on microsections for the evaluation of the structure in accordance with DIN EN ISO 643.

Filler metal	Shape of the test coupons
Rod electrode ∅ < 2.5 mm Welding rod ∅ < 2.5 mm Wire electrode/welding wire ∅ < 1.2 mm	Double fillet weld type B, DIN EN ISO 17641-2
Rod electrode ∅ ≥ 2.5 mm Welding rod ∅ ≥ 2.5 mm Wire electrode/welding wire ∅ ≥ 1,2 mm	Ring-segment test coupon according to **Annex E**
Electrode-flux combination	Cylindrical test coupon according to **Annex F**

Table 7-2: Weld test coupons for testing welds susceptible to hot cracking according to clause 7.3.5.4 (2)

7.3.5.7 Test for resistance to intergranular corrosion (IK)

(1) Base metal and all-weld material

a) The resistance to intergranular corrosion shall be demonstrated in accordance with DIN EN ISO 3651-2 procedure A, however with sensitisation annealing according to sub-clause f) below.

b) The evaluation shall be made by means of the bend test specimens described in DIN EN ISO 3651-2. The weld metal specimen shall be taken in the direction of welding from the cover pass.

c) Deviating from DIN EN ISO 3651-2 the weld filler metal test shall be performed on the all-weld metal specimen.

d) Where bend test specimens do not permit an unambiguous evaluation, a metallographic examination may be made with the aim of determining the cause of the crack (e.g. cause of crack: flaw instead of intergranular corrosion).

e) A metallographic evaluation alone is permitted if the dimension of the product form or the weld metal do not allow for a proper bend test specimen-taking.

f) Sensitisation shall be made prior to the test at the given temperature and holding time if

fa) welding is performed on the product form:
650 °C ± 10 K; 0.5 h

fb) stress relieving or welding and stress relieving is performed on the product form:

$$580\,°C\,^{+10\,K}_{-0\,K}\,/\,16\,h$$

fc) weld metal in stress-relieved condition is used:
550 °C ± 10 K; 16 h

The stress relieved condition covers the unannealed condition.

g) Weld filler metals for lock welds need not be subjected to advance sensitisation.

(2) Precision casting

The specimens shall show the following heat treatment condition:

a) where used without stress relieving (only production welding or joint welding) production control test with all heat treatments actually performed and subsequent sensitization:
550 °C ± 10 K; 16 h

b) where used in the stress-relieved condition:
sensitisation:

$$580\,°C\,^{+10\,K}_{-0\,K}\,/\,8\,h$$

The test surface of the specimens tested for resistance to intergranular corrosion shall show the same surface condition as the components.

7.3.5.8 Non-destructive tests and inspections

7.3.5.8.1 General requirements

(1) The following requirements for performing non-destructive examinations on product forms and parts during manufacture apply unless deviating requirements are specified in the materials test sheets.

(2) The suitability of test procedures and techniques the application of which for the respective testing task is not sufficiently described in standards, shall be verified. The type and extent of verification shall be laid down with respect to each component. In the case of materials or complex geometries that are difficult to examine, the suitability of the test procedures shall basically be demonstrated in accordance with the methodology of VGB Guideline R 516 (VGB-ENIQ-Guideline) on reference blocks. Where test procedures or techniques are to be applied for which a qualified test technique is available and the applicability of which has been ascertained by the authorized inspector, no further proof of suitability is required.

Note:
Such verification of suitability is necessary, for example, for the phased-array technique.

(3) Prior to the beginning of the tests and inspections, the manufacturer shall specify the testing, especially the type of tests and inspections, the test requirements and the techniques to be used, and describe it in test instructions.

(4) For surface inspections instructions established by the manufacturer and being independent of the project and test object may be used in lieu of test instructions.

(5) The test instructions shall contain detailed information on:

a) assignment to the individual test objects,

b) time of testing as far as it influences the extent and performance of the test in accordance with the test and inspection sequence plan,

c) test requirements, test methods and test facilities/equipment to be used, type of sensitivity adjustment for ultrasonic testing,

d) if required, additional explanations regarding the performance of the test (e.g. drawing to scale),

e) intended substitute measures to be taken if the applicability of the requirements of this Section is restricted,

f) system of coordinates (reference system and counting direction) for a description of indications or irregularities assigned to a test object,

g) if required, supplementary information for recording and evaluating indications or irregularities (e.g. in the case of technical substitute measures).

(6) A marking identifying the points of origin and major directions of the applied coordinate systems shall be made on the test object and be preserved until the test results have been evaluated.

(7) In the case of random checks or testing of test lots on product forms with indications or irregularities that are not permissible, the extent of testing shall be doubled by applying the same criteria. Where further indications or irregularities are found in these tests that are not permissible, the extent of testing shall be increased to 100 %.

7.3.5.8.2 Requirements for personnel performing non-destructive tests and inspections

(1) Test supervisors shall

a) have the technical knowledge required to perform their tasks and know the possibilities of application as well as limits of test procedures,

b) have basic knowledge of fabrication processes and of the characteristic appearance of fabrication discontinuities.

The test supervisory personnel shall normally be independent from the fabrication department and the authorized inspector shall be notified of their names. The test supervisory personnel is responsible for the application of the test procedure and for the details of the implementation of the test in accordance with the relevant specifications. They are responsible for the employment of qualified and certified operators. This applies also to the employment of personnel not belonging to the works. The test supervisory personnel shall sign the test report.

(2) The test supervisory personnel shall have been qualified and certified for the examination procedures in the relevant

product or industrial sectors at least with level 2 according to DIN EN ISO 9712. In the case of welded joints between RPV internals and butterings or claddings on the RPV as well as between RPV internals and welded-on load attachment points, level 3 qualification and certification is required for radiographic and ultrasonic testing.

(3) The NDT operators shall be capable of conducting the tests described in clauses 7.3.5.8.3 to 7.3.5.8.7 and in Section 8.9 as well as in the material annexes. They shall have been qualified and certified according to DIN EN ISO 9712 for the applicable test procedure in the relevant product or industrial sectors. For radiographic and ultrasonic testing at least level 2 qualification and certification is required. If the phased array technique is used, the NDT operator shall additionally be qualified for the phased array technique.

7.3.5.8.3 Surface inspection by means of the liquid penetrant method

7.3.5.8.3.1 General requirements

(1) The test surfaces shall be free from impurities. Discontinuities affecting the test results shall be removed. The arithmetical mean deviation of the assessed profile (average roughness) Ra shall not exceed the following values depending on the process of surface treatment:

a) unmachined surfaces $R_a < 20$ μm

b) machined surfaces $R_a < 10$ μm

The proof shall be performed by determination of the arithmetical mean deviation of the assessed profile (average roughness) Ra according to DIN EN 10049 by means of electrical stylus-type instruments or by visual examination for comparison with respective standards.

(2) Liquid penetrants shall preferably be used. Fluorescent penetrants or fluorescent dye penetrants may be used. Where testing for susceptibility to hot cracking in accordance with clause 7.3.5.4 (2) is performed, fluorescent penetrants shall be used.

(3) Solvents or water or both in combination may be used as penetrant remover.

(4) Only wet developers suspended in an aqueous solvent shall be used. Dry developers may only be applied on the surface to be inspected by electrostatic charging.

(5) For the examination system at least sensitivity class 3 acc. to DIN EN ISO 3452-2 Section 4.2.2 or sensitivity class 2 acc. to DIN EN ISO 3452-2 Section 4.2.3 shall be adhered to. Where testing for susceptibility to hot cracking in accordance with clause 7.3.5.4 (2) is performed, sensitivity class 4 acc. to DIN EN ISO 3452-2, clause 4.2.2 shall be satisfied.

(6) The suitability of the examination system (penetrant, solvent remover and developer) shall be demonstrated by means of a sample examination as per DIN EN ISO 3452-2. Verification shall be submitted to the authorized inspector.

(7) Liquid penetrants in test equipment and partly used open tanks (except for aerosol cans) shall be monitored by the user with flux indicator 2 according to DIN EN ISO 3452-3. In this test the maximum penetration and development times shall not exceed the minimum times specified for the inspection. The inspection sensitivity obtained shall be recorded.

7.3.5.8.3.2 Performance of the inspection

(1) Liquid penetrant inspections shall be performed on the component part in the finish-machined condition in accordance with DIN EN ISO 3452-1, in the case of precision casting in accordance with DIN EN 1371-2. Where testing for susceptibility to hot cracking in accordance with clause 7.3.5.4 (2) is performed, the entire weld and heat-affected zone of the austenitic base metal shall be inspected.

(2) The penetration time shall normally be at least half an hour.

(3) Immediately after drying of the developer a first inspection shall normally be made. A further inspection should be made not earlier than half an hour after the first inspection has passed. Where testing for susceptibility to hot cracking in accordance with clause 7.3.5.4 (2) is performed, the following inspection times apply: directly upon drying of the developer, after 15 minutes, 30 minutes and 60 minutes.

(4) Further inspection times are required if during the second inspection crack-like indications are detected which were not visible during the first inspection.

Note:

Further inspection times may also be suitable if during the second inspection significant changings or additional indications are detected.

(5) The evaluation shall be made in consideration of the results of all inspections.

7.3.5.8.3.3 Acceptance criteria

(1) Forged and rolled product forms

The requirements under **Table 7-3** apply. The frequency of acceptable indications shall locally not be higher than 10 per square decimetre and, with respect to the entire surface area, not higher than 5 per square decimetre.

(2) Welded pipes

The requirements under **Table 8-7** apply.

(3) Precision castings

The following applies:

a) Indications, the largest dimension of which is smaller or equal to 1.5 mm, shall not be included in the evaluation.

b) No linear indication and indications that might indicate the existence of cracks are allowed.

c) Round indications with a diameter exceeding 3 mm are not allowed.

d) More than 10 allowable indications with an extension exceeding 1.5 mm and equal to or smaller than 3 mm are not permitted:

for each 100 cm^2 or for the entire surface area of components with surfaces less than 100 cm^2.

(4) Testing for hot cracks

Linear indications and regularly occurring indications shall be documented by means of photographs with 200 times magnification and be examined by microsections. Hot cracks are not permitted, individual irregular dendrite separations are permitted.

Indications ≤ 3 mm		Indications > 3 mm and ≤ 6 mm			Indications > 6 mm
Individual	clustered	rounded indications	linear [1] indications, caused by carbides or nitrides or carbonitrides [2]	other linear indications [1]	
Acceptable; not to be included in the evaluation	Acceptable; to be included in frequency	Acceptable; to be included in frequency	Acceptable; to be included in frequency	Not acceptable	Not acceptable

[1] A liquid penetrant indication is considered to be linear (linear indication) if the length of its longest dimension is at least three times larger than the length in transverse direction.

[2] Carbides, nitrides and carbonitrides shall be proven as such. The proof may be made for similar indications by spot checking the area of indications.

Table 7-3: Acceptance criteria for liquid penetrant testing of forged and rolled product forms according to clause 7.3.5.8.3.3 (1)

7.3.5.8.4 Ultrasonic testing

(1) Condition of surfaces

a) The scanning surfaces shall be free from discontinuities and impurities affecting the test result.

b) Where an opposite face is used as reflecting surface it shall meet the same requirements as the scanning surface.

c) The arithmetical mean deviation of the assessed profile (average roughness) Ra of the scanning and reflecting surfaces should not exceed the value 20 µm. The proof shall be performed by determination of the arithmetical mean deviation of the assessed profile (average roughness) Ra according to DIN EN ISO 4287 by means of electrical stylus-type instruments or by visual examination for comparison with respective standards.

d) The scanning surfaces' waviness shall be so little that the distance between probe shoe surface and scanning surface does not exceed 0.5 mm at any point, not taking into account the radius of surface curvature.

(2) Requirements regarding test equipment and search units

a) Test equipment

The test equipment used including the required measuring instruments and auxiliary equipment shall show appropriate exactness and stability suited for the intended use.

Test instruments shall normally meet the requirements of DIN EN 12668-1 and probes the requirements of DIN EN 12668-2. The requirements of DIN EN 12668-3 shall apply to checking the properties of the entire test equipment. If the phased array technique is used, the testing equipment including test instruments and probes shall be qualified according to clause 7.3.5.8.1 (2).

It shall be possible to determine all possible echo signal height ratios used in the equipment sensitivity range with an accuracy of ± 1 dB, viz. with the aid of a dB calibrated attenuator and a suitable scale division on the screen.

The scanning areas that can be chosen on the equipment shall overlap. Within each individual scanning area the time-base sweep shall be continuously adjustable and be linear with an accuracy better than 5 % of the scanning area.

The combination of equipment, cables and probes of various manufacturers is permitted if it is ensured (e.g. by measurements on reference reflectors) that the exactness of results is not affected.

b) Probes

Probes with common (dual-element probes) or separate transmitter and receiver probes may be used.

The test frequency shall normally be between 2 and 4 MHz. In the case of testing materials with large sound attenuations test frequencies less than 2 MHz are permitted if it can be proved that the required recording level is satisfied.

In the case of curved scanning surfaces the search unit (probe) shall be located with the probe index on the centre of the surface. At no point shall the probe shoes have a distance greater than 0.5 to the scanning surface. Where the distance is greater, the probe shall be ground. This is the case if L^2 exceeds $2 \cdot d$.

where L : search unit dimension in direction of curvature
d : curvature diameter of test object

(3) Preparation and performance of the test

a) Range calibration and adjustment of testing level

The range calibration and testing level adjustment shall be made on the test object or on a similar reference block. All echo indications to be recorded shall reach at least 1/5 of the screen scale height at the largest possible sound path travel distance.

For calibration and testing the same couplant shall be used. Only such couplants shall be used which do not damage the object (e.g. corrosion). Upon testing, all couplant residues shall be removed from the test object.

Test object, reference block and probes shall normally have approximately the same temperature.

When setting the testing level and during testing only the gain control, but no other control element affecting the echo height (e.g. for frequency range, pulse energy, resolution, threshold value) shall be adjusted. A threshold value may only be used in exceptional justified cases.

Prior to testing, the testing level adjustment and range adjustment shall be made after the warm-up periods given by the instrument manufacturer. Both adjustments shall be checked at suitable intervals. Where in this check clear deviations from the check made before are found, all tests performed after that check shall be repeated with a corrected adjustment.

b) Correction of testing level adjustment

Where the testing level is adjusted on reference blocks, transfer measurements shall be made on the reference block and the test object to take account of sound attenuation and coupling differences in order to attain the same sensitivity levels by gain corrections, if required. When using differing materials for reference block and test object the difference in sound velocity shall be taken into account for range adjustment and for the angular deviation in case of angle beam scanning.

The highest sound attenuation values shall be considered for all search units and sound entry directions.

The evaluation of the indications shall be made in due consideration of the actual sound attenuation values measured adjacent to the indicated echoes.

c) Sound entry directions

Under consideration of the product form the sound entry directions are specified in the Material Annexes.

d) Recording levels

All indications reaching or exceeding the recording levels specified in the product-form related Material Annexes shall be recorded. The testing level shall be adjusted in consideration of the transfer correction and the sound attenuation, if any. The DGS method as well as the reference block method or the DAC method may be used. In the case of probes with adjusted contact surfaces, the DGS method shall not be used. The maximum echo signal height of a reflector shall be recorded related to the applicable recording level in dB. The sound attenuation values to be considered shall be recorded. A back wall echo downturn equal to or greater than 18 dB shall be recorded. In the case of austenitic materials and nickel alloys the recording level may, if required, be increased accordingly to attain a signal-to-noise ratio of at least 6 dB, but only up to 6 dB below the acceptance level. The recording level attained in the test shall be recorded in such a case. Where reflectors accumulate whose distance from each other is smaller than the effective crystal diameter and for longitudinally extended reflectors the applicable recording level shall be lowered by 6 dB.

e) Size of reflectors

In the case of straight-beam scanning the extension of indications transverse to the direction of sound propagation shall be measured according to the half-amplitude method in which case the sound path travel distance shall attain once the near-field length, if possible.

The accuracy of determination of the reflector extension may be increased by additional examinations (e.g. by considering the sound beam spread angle or by the use of special probes).

If this leads to values measured below the noise level the recorded length shall be indicated to the point where the echo disappears.

Recorded lengths exceeding 10 mm shall be measured, shorter recorded length shall be recorded as "< 10 mm".

f) Location of reflectors

For all indications liable to recording the length, depth and width shall be recorded in a proper coordinate system.

g) Time of testing

The acceptance test shall be performed in the delivery condition according to Section 7 at the most favourable point in time for testing and in the most simple geometric condition, where possible.

(4) Acceptance criteria

The acceptance criteria are specified in the product-form related Material Annexes. In addition, the following applies:

a) Reflections from regions which will definitely be removed during finish-machining shall not be considered, but be recorded. All echo indications that have been proved resulting from the structure shall not be part of the evaluation but shall be recorded in the test record.

b) Where during straight-beam scanning using the DGS method liable-to-record echo indications of reflections are found in the area of lateral wall effect influence, these indications shall be verified by means of straight-beam scanning using the reference reflector method or by means of purposive angle beam scanning.
Where the area of lateral wall effect is omitted due to the cutting-to size of the test object, this condition shall preferably be re-examined. The results of the re-examination shall be considered in the evaluation.

c) In regions with signal-to-noise ratios smaller than or equal to 6 dB, or if the back-wall echo falls down to the recording level for which no explanation is found, examinations (e.g. sound attenuation measurements) shall be made which make a decision on the usability of the component possible.

d) Where indications below the recording level accumulate which cannot be resolved into single echo indications for one search unit position or in the case of search unit displacement, or which cannot be clearly correlated to the sound beam angles used, supplementary examinations (e.g. by scanning in different directions) shall be performed. The indications are not permitted, if these investigations reveal signs of areal separations, e.g., by loss of intensity of a sound-transmission signal by comparison with indication-free zones of the product form.

e) In the case of test objects with a wall thickness exceeding 15 mm, the reference reflector method with a rectangular notch of 1 mm depth as reference reflector may be used for testing level adjustment for near-surface areas.

7.3.5.8.5 Radiographic testing

(1) Surface condition

All visible surfaces discontinuities that may adversely affect the evaluation of radiographs shall be removed.

(2) Performance of the test

a) The tests shall be performed as follows:

aa) tests on welded joints during fabrication according to Section 8 in accordance with DIN EN ISO 17636-1,

ab) tests on welded pipes in accordance with DIN EN ISO 10893-6,

ac) tests on precision castings in accordance with DIN EN ISO 5579 in correspondence with DIN EN 12681.

b) The requirements of class B acc. to DIN EN ISO 17636-1, DIN EN ISO 10893-6 or DIN EN ISO 5579 shall be met. The substitute solution mentioned in Section 5 of DIN EN ISO 17636-1 as well as in Section 4 of DIN EN ISO 5579 shall not be applied in this case. The image quality values of image quality class B acc. to DIN EN ISO 19232-3 shall be adhered to in which case the image quality indicators acc. to DIN EN ISO 19232-1 shall be used.

c) Stipulations shall be made to clearly indicate the film location and film number, referred to the reference system.

d) The radiation sources shall be selected so as to ensure an optimal detectability of defects. Therefore X-ray tubes shall be used to examine weld seams if the thickness of the radiographed wall does not exceed 40 mm unless an at least equivalent informative value is possible by the use of other radiation sources, e.g. iridium.

e) Film/screen combinations with an as high as possible resolution and preferably vacuum cassettes shall be used.

f) The film shall be marked with such an identification as to make the traceability to the test object possible.

g) Imaging plates may be used instead of films if at least the same image quality as with the required film/screen combinations can be obtained. In this case the requirements of DIN EN ISO 17636-2 apply instead of DIN EN ISO 17636-1 and of DIN EN ISO 10893-7 instead of DIN EN ISO 10893-6.

(3) Evaluation of test results

The acceptance criteria are specified in clause 8.9.2.1.2 or depending on the product form in the Material Annexes.

7.3.5.8.6 Examination of surface condition

The examination shall be made by visual inspection. The type of treatment and surface condition shall be laid down in the order to meet the requirements of **Table 7-4**.

7.3.5.8.7 Visual testing

(1) Product forms shall be subject to visual testing in the delivery condition, components in its finish-machined condition. Visual testing shall be performed as local visual testing acc. to DIN EN ISO 13018 in the form of direct visual testing.

(2) Cracks are not permitted.

(3) Linear conspicuous indications the acceptability of which cannot be clearly assessed, shall be subject to a surface inspection according to clause 7.3.5.8.3.2. The evaluation shall be made in accordance with the pertinent material specification sheet. Where no requirements are laid down in this sheet, **Table 7-3** applies.

7.3.5.8.8 Check for freedom of external ferrite

(1) The surfaces shall be examined by immersion in, or continuous wetting with fully demineralized water. Wetting may be achieved by sprinkling, spraying or applying filter paper soaked in demineralized water. The contact time of the water on the examined surface shall be at least 6 hours. The fully demineralized water used for this treatment shall satisfy the following guide values:

Appearance:	clear, colourless and odourless
Conductivity at 25 °C:	≤ 10 µS/cm
Chloride:	≤ 0.5 mg/kg
Sulphate:	≤ 0.5 mg/kg

Note:
Where external ferrite is present on the surface, local rust-brown discolouration will appear at the location of the ferrite particles.

(2) The surfaces shall be examined by visual inspection and be evaluated as follows:

a) Where indications are found on the examined surface, examination areas of approximately 1 dm^2 shall be arranged around these indications. The examination surface shall be arranged such that it covers the most unfavourable distribution of indications.

b) Ferrite contamination is only permitted if

ba) at least 75 % of the surface subdivided in areas of 1 dm^2 do not show any indication,

bb) the extension of indication does not exceed 3 mm,

bc) a maximum of 5 indications exists on an area of 1 dm^2.

7.3.6 Re-examination

(1) Test results that are based on incorrect performance of the test, on incorrect preparation of the test specimens, or on a random narrow flaw location in one test specimen may be disregarded in determining the fulfillment of test requirements, and the individual examination may be repeated (re-examination).

(2) If the test results of a properly performed examination do not meet the requirements, the further procedure is as follows:

a) In the case of individual examination for each inadequate test two additional tests shall be carried out on specimen taken from the same location. If at least one test result of the re-examinations does not meet the requirements the test unit shall be rejected.

b) In the case of lot examination the piece that does not meet the requirements may be excluded from the lot and be subjected to an individual examination. It shall be replaced by two other pieces from the lot which shall both be subjected to the required examinations. If at least one test result of the re-examinations does not meet the requirements the lot shall basically be rejected. In exceptional cases an individual examination may be agreed upon with the authorized inspector.

(3) If the cause for the inadequacy of an examination can be removed, e.g. by an adequate post treatment, this post treatment may be carried out provided, the characteristics influenced by this procedure are subsequently re-examined.

7.4 Identification marking of the product forms

(1) All product forms shall be marked clearly, durably, and such that an unambiguous correlation to the test certificates is possible at all times.

(2) The identification marking of the base metal shall normally contain the following information:

a) material identification (abbreviated name or identification code),

b) identification of the material manufacturer,

c) melt number,

d) test specimen number (plate mark, piece mark, ring mark, lot number), if required,

e) certification stamp of the operator for non-destructive examinations, if applicable.

f) for bolts, nuts and small parts a short symbol instead of the data required as per a) to e), which shall ensure the traceability of the parts to the inspection certificate,

g) certification stamp of the authorized inspector, if required,

(3) Weld filler metals shall be identified to meet the requirements of DIN EN ISO 3581, DIN EN ISO 14172, DIN EN ISO 14343, DIN EN ISO 17633 or DIN EN ISO 18274.

(4) The marking shall be effected:

a) by means of low-stress steel stamps,

b) by means of colour markings insoluble in water (e.g. for plates with a thickness equal to or smaller than 6 mm, thin-walled tubes and weld filler metals),

c) by means of attachment plates (e.g. tubes with an outer diameter equal to or smaller than 18 mm, for bars with an outer diameter equal to or smaller than 25 mm, flux),

d) for threaded structural fasteners according to DIN EN ISO 3506-1 and DIN EN ISO 3506-2 with the stipulations specified therein.

(5) Identification marking for small parts may be omitted if

a) stamping is not possible or only difficult to apply, and

b) a certificate examined by the quality department of the manufacturer or the authorized inspector is available.

Symbol	Type of treatment	Surface condition	Remarks
Flat products (plate, sheet and strip), bars, sections			
1E	Hot formed, heat treated, mechanically descaled	Largely free from scale (however, individual black spots may be present); not without surface defects	The type of mechanical descaling, e.g. tube grinding or shot blasting, depends on the type of steel and product from and is left to the manufacturer unless agreed otherwise
1D	Hot formed, heat treated, pickled	Free from scale (locally ground if required); not without surface defects	Usual standard for most of the steel types to ensure proper corrosion resistance; also usual type of treatment for further processing. Grinding marks shall not be present. Not as smooth as 2D or 2B
1X	Hot formed, heat treated, rough-machined (peeled or rough-turned)	Free from scale (however some processing indentations may be present); not without surface defects	Products in the as-processed condition to be used or be processed further (hot or cold)
1G	Hot formed, heat treated, descaled, prepared or peeled off in the case of wire rod; dressed by machining	More or less uniform and bright appearance; without surface defects	Suited for special applications (flow forming and/or cold or hot heading). Surface roughness may be specified
2E	Cold formed, heat treated, mechanically descaled	Raw and blunt	Usually used for steels with high resistance to scaling. Pickling may be performed subsequently
2D	Cold formed, heat treated, pickled	Smooth	Type of treatment to ensure adequate forming properties, but not so smooth as 2B or 2R
2B	Cold formed, heat treated, pickled, cold dressed	Smoother than 2D	Most frequent type of treatment for most of the steel types to ensure proper corrosion resistance, smoothness and evenness. Also usual type of treatment intended for further processing. Re-rolling may be effected by stretch levelling.
2G	Ground	Smooth, uniform and bright; without surface defects	Type of treatment for maximum tolerance deviations. Unless agreed otherwise, the surface roughness shall be Ra ≤ 1.2.
2R	Cold formed, bright-annealed	Smooth, bright and reflecting	Smoother and brighter than 2B. Also usual type of treatment for further processing.
Pipes and tubes			
HFD	Hot formed, heat treated, descaled	Clean metal surface	—
CFD	Cold finished, heat treated, descaled	Clean metal surface	—
CFA	Cold finished, bright-annealed	Bright metal surface	—
CFG	Cold finished, heat treated, ground	Ground to bright metal surface; the type of grinding and the roughness to be obtained shall be agreed at the inquiry and order	—
W0 1)	Welded from hot or cold rolled sheet or strip 1D, 2D, 2E, 2B	Welded	—
W1 1)	Welded from hot rolled sheet or strip 1D, descaled		—
W1A 1)	Welded from hot rolled sheet or strip 1D, heat treated, descaled	Clean metal surface	—
W1R 1)	Treatment condition W1 plus heat treatment in controlled atmosphere	Bright metal surface	—
W2 1)	Welded from cold rolled sheet or strip 2D, 2E, 2B, descaled	Clean metal surface	—
W2A 1)	Welded from cold rolled sheet or strip 2D, 2E, 2B, descaled	Except for the weld, substantially smoother than W1 and W1A	—

Table 7-4: Type of treatment and surface condition of product forms as per clause 7.3.5.8.6
(continued on next page)

Symbol	Type of treatment	Surface condition	Remarks
Pipes and tubes			
W2R 1)	Welded from cold rolled sheet or strip 2D, 2E, 2B, bright-annealed	Bright metal surface	—
WCA	Welded from hot or cold rolled sheet or strip 1D, 2D, 2E, 2B, where practicable heat treated, at least with a cold-forming degree of 20%, heat treated, with weld metal being annealed just below critical point, descaled	Clean metal surface, weld hardly visible	—
WCR	Welded from hot or cold rolled sheet or strip 1D, 2D, 2E, 2B, where practicable heat treated, at least with a cold-forming degree of 20%, bright-annealed, with weld metal being annealed just below critical point	Clean metal surface, weld hardly visible	—
WG	Ground	Ground to bright metal surface; the type of grinding and the roughness to be obtained shall be agreed at the inquiry and order.	—
Precision castings			
1/0S1 2)	as-cast	Casting surface	—
2S2 2)	Ground or blasted	Cleaned mechanically	—

1) Where tubes are ordered with flattened welds („dressed welds“), the letter “b“ shall be added to the delivery condition symbol (Example: W2Ab)”.

2) BNIF-visualtactile comparators according to DIN EN 1370

Table 7-4: Type of treatment and surface condition of product forms as per clause 7.3.5.8.6 (continued)

8 Manufacture

8.1 General requirements

This section applies to the manufacture beginning with the receiving inspection of the product form and ending with the erection on the construction site.

8.2 Requirements to be met by the manufacturer

8.2.1 General requirements

(1) Prior to the beginning of manufacture it shall be proved to the plant vendor and to the authorized inspector, within the manufacturer’s evaluation (audit), that the requirements of Sections 8.2.2 to 8.2.6 have been satisfied. For components, sub-units and parts of quality class AS-RE 2 and AS-RE 3 where no welding is performed the manufacturer’s evaluation submitted by the plant supplier will suffice. Where the fulfilment of the fabrication requirements is checked, available documentation on reviews made by other agencies may be taken into account. The requirements in question shall be considered to have been met, provided the criteria of this Safety Standard have been fulfilled.

Note:
Other standards are, e.g. other KTA Safety Standards, DIN EN ISO 3834-1 and DIN EN ISO 3834-2 or AD 2000-Merkblatt HP 0.

(2) The manufacturer shall have equipment and personnel at his disposal to be capable of properly carrying out the processing, testing and inspection as well as transport of product forms according to this Safety Standard. The test and inspection facilities shall meet the requirements of Section 7. Equipment and personnel from other organisations meeting these requirements may also be employed.

(3) The plant vendor shall establish a certificate on the manufacturer’s works audit. The acceptance of the manufacturer by the authorized inspector shall also be available as written document.

(4) The manufacturer’s works audit shall be valid for 3 years upon receipt of the certificate by the plant vendor and upon acceptance by the authorized inspector. If fabrication testing has been done within this period of validity, the latter may be extended by 3 years upon application of the manufacturer.

(5) In the case of essential changes with respect to welding and inspection supervision as well as to organisation, fabrication and test and inspection facilities, compared to the condition certified in the manufacturer’s works audit, the manufacturer shall apply for a supplemental audit.

(6) Within the course of manufacture the plant vendor and the authorized inspector are entitled at any time to satisfy themselves that the requirements have been fulfilled.

(7) In the case of manufacturers of components outside the reactor pressure vessel of quality class AS-RE 3, who perform welding work, the requirements of DIN EN ISO 3834-1 und DIN EN ISO 3834-2 apply. In this case, a manufacturer’s works audit and certification need not be performed.

8.2.2 Organizational prerequisites

(1) The manufacturer shall ensure that the required quality of the parts to be manufactured is obtained. The persons or organisations conducting quality assurance activities shall be independent of the persons or organizations responsible for fabrication.

(2) The quality assuring activities shall be described and the areas of responsibility of persons or agencies involved shall be laid down in writing.

(3) The welding supervisory personnel shall satisfy DIN EN ISO 3834-1 and DIN EN ISO 3834-2. Personnel involved in the supervision of tests and inspections shall be in the employ of the manufacturer's works. In the case of subcontractor's inspection, supervisory personnel may be employed.

8.2.3 Requirements for the performance of welding work

(1) Welding supervision

For the welding supervision the requirements of DIN EN ISO 3834-1 and DIN EN ISO 3834-2 shall be met.

(2) Welders

a) For welders the requirements of DIN EN ISO 3834-1 and DIN EN ISO 3834-2 shall be met.

b) The welders shall be qualified either by the authorized inspector responsible for the works or training facility or by an inspection agency recognized by the authorised inspector. The welder's qualification shall be valid for a period of 2 years. However, the qualification of welders or welding operators for mechanised welding equipment shall be repeated after an interruption of welding work of more than 6 months prior to restarting welding work. The welder's qualification test shall be performed in accordance with DIN EN ISO 9606-1 to include the examination of the welder's technical knowledge, and shall comply with the essential variables requirement of Section 5 of DIN EN ISO 9606-1 in conjunction with AD 2000-Merkblatt HP 3. The welder's qualification shall be renewed in accordance with DIN EN ISO 9606-1, clause 9.3 a) or clause 9.3 b). For weldments on nickel alloys DIN EN ISO 9606-4 shall be used, including the technical knowledge of welders and operating personnel of fully mechanized welding equipment.

c) It shall be demonstrated by a test in accordance with DIN EN ISO 14732 to the authorized inspector that the personnel operating fully mechanized welding equipment has sufficient knowledge to operate the equipment. The qualification test shall be performed

   ca) by the personnel during welding procedure qualification or pre-manufacturing production control tests according to DIN EN ISO 14732 Section 4.1 a),

   or

   cb) as test prior to the beginning of fabrication in accordance with clause 4.1 b) of DIN EN ISO 14732.

   For test as per cb), the extent of testing laid down in DIN EN ISO 9606-1, Section 5.5, and the requirements of DIN EN ISO 9606-1, Section 7, apply to steel, and the extent of testing laid down in DIN EN ISO 9604-4, Section 7.4, and the requirements of DIN EN ISO 9604-4, Section 8, apply to nickel alloys.

(3) The proof of technical knowledge shall be rendered by the examination according to DIN EN ISO 14732, Annex B.

(4) Welding equipment

When using welding equipment instruments for monitoring the welding parameters shall be available.

8.2.4 Requirements for the performance of brazing work

For the performance of high-temperature brazing heating equipment is required which is capable of creating a high vacuum so that brazing is possible with little discolouration. The heating equipment shall be provided with measuring instruments that record temperature and vacuum versus time.

8.2.5 Requirements for the performance of heat treatments

(1) The heat treatment facilities shall make possible a sufficiently accurate and uniform temperature control on the work piece for the heat treatment selected. To this end, temperature-versus-time recording instruments shall be available to show a measuring accuracy of $\pm$ 10 K.

(2) Stationary heat treatment facilities which are used for components not provided with thermocouples, shall have been tested within the last six months. In this case, the accuracy of indication of the measuring instruments shall be checked at intervals of not more than 3 months. Where components are provided with thermocouples, the accuracy of indication of the measuring instrument and the functional capability of the thermocouples shall be checked prior to each heat treatment. The temperature measuring instruments shall have been checked within the last six months.

(3) In the case of mobile heat treatment equipment, a functional test shall be performed after each transport. This test shall not have been performed more than six months before the last use of the equipment.

(4) The performance of these tests shall be recorded. The records shall be filed at the manufacturer's works.

8.2.6 Requirements for the performance of non-destructive tests

The requirements of Section 7 apply to the test supervisory personnel, the personnel performing tests and inspections and the test inspection facilities.

8.3 Manufacturing process

8.3.1 Welding

8.3.1.1 Weld design

The weld design shall meet the following requirements:

a) The welded joints shall be designed such that they are easily accessible for non-destructive testing.

b) The welds should be prepared to show the weld forms as per DIN EN ISO 9692-1 and DIN EN ISO 9692-2.

c) The welds should be full penetration welds.

d) Where design and construction permit, filled welds shall be laid such as to be welded over the full circumference of the parts.

e) Cruciform joints, corner joints and accumulation of welded joints shall normally be avoided where the design permits.

f) The location and form of welds shall normally be such as the minimize shrinkage and stresses due to welding.

g) The weld sequence shall be selected such that the welds are accessible during welding and the required component tolerances are ensured.

h) The weld surfaces shall be such as to meet design requirements and to permit the performance of non-destructive tests as per **Table 8-1**. Notches as shown in **Figure 8-1** are not permitted. Weld edge zones and weld bead transitions according to **Figure 8-1** are permitted unless the evaluation of non-destructive tests is impaired.

8.3.1.2 Prerequisites for welding

(1) Welding work may only be started if the required tests and examinations of the product forms and filler metals according to Section 7 have been completed and documented.

(2) The guidelines of the filler metal producers for the storage and handling of filler metals shall be met.

(3) A welding procedure specification (**Form 5-3**) shall be drawn up for all welds. The specifications concerning the weld preparation shall be contained in either the drawing or the welding procedure specification. The welding procedure specification may be drawn up as a standard specification.

(4) For the design approval, the welding procedure specification shall be accompanied by the manufacturer's report on the welding procedure qualification with the certificate of the authorized inspector.

(5) If no valid welding procedure qualification is available at the time of the design approval,

a) the welding procedure specification reviewed by the authorized inspector and the heat treatment plan for the welding procedure qualification to be conducted shall be submitted and

b) the manufacturer's report as well as the certificate of the authorized inspector on this welding procedure qualification shall be submitted prior to the beginning of fabrication.

(6) For all weldments on the part the following items shall be contained in the welding procedure sheet (**Form 5-3**) irrespective of the type of weld:

a) weld preparation with form of weld and shaping of fusion faces,

b) base metal designation,

c) weld build-up, if required sequence of individual welding steps,

d) welding process/combination of welding processes,

e) welding parameters,

f) welding position,

g) weld filler metals and consumables,

h) drying of filler metals and consumables,

i) heating prior to, during and after welding,

k) welding procedure qualification.

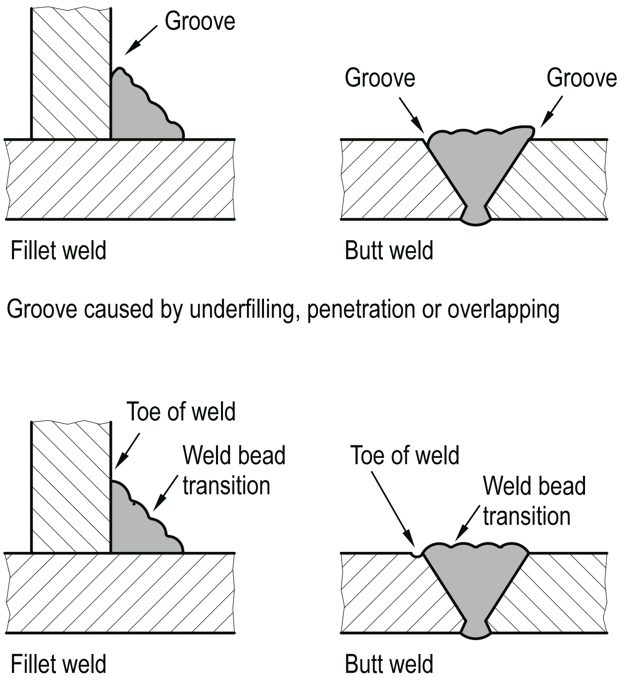


Figure 8-1: Illustration of the terms "groove", "toe of weld" and "weld bead transition"

8.3.1.3 Preparation for welding

(1) Fusion faces shall normally be dressed by machining. Where fusion faces are dressed by thermal processes they shall be finish-dressed mechanically.

(2) Weld edges shall be free from rust, scale, paint, fat, moisture or other contaminants which may essentially affect welding.

8.3.1.4 Requirements for welded joints

The welded joint shall satisfy the requirements of quality level B according to DIN EN ISO 5817 and the requirements of Section 8.9. For fillet welds, testing for inner imperfections is not required. Additional requirements for the weld surfaces according to **Table 8-1** shall be met depending on the weld design.

8.3.1.5 Performance of welding work

8.3.1.5.1 General requirements

(1) The welding conditions laid down within the scope of the procedure qualification shall be satisfied during welding of parts.

(2) Arc striking outside the groove shall be avoided. If, however, arc strikes occur they shall be ground and subjected to a surface examination.

(3) To avoid tungsten inclusions during gas-tungsten are welding electrode contacts with the work piece for igniting the arc are not permitted.

(4) During submerged are welding a contact between the work piece and the contact tip or contact jam shall be avoided. Damage, if any, shall be ground and the grinding areas be subjected to a surface examination.

(5) In the case of full penetration welds, tack welds shall be removed during grooving out. In the case of one-sided full penetration welds, the welding over of tack welds is only permitted if measures are taken to ensure a proper transition from the root to the tack weld.

(6) Temporary welded attachments shall consist of similar material.

(7) Areas where temporary welds have been removed shall be smoothed by grinding and be subjected to a surface inspection.

(8) The range of welding parameters and handling guidelines recommended by the filler metal manufacturer shall normally be adhered to.

(9) For the welding on the parts the same type of equipments as for the procedure qualification tests shall be used, i.e. the equipment shall have

a) the same type of current,

b) the same polarity,

c) in the case of fully mechanized welding processes the same type of control.

(10) Wire-brushes, deslagging hammers or other cleaning equipment for the mechanical cleaning of stainless steel components shall be made of stainless steel.

(11) Carbon electrodes shall not be used.

(12) The welding equipment and auxiliary derives (e.g. supports, clamping devices or covers) shall be designed such as to avoid ferritic contamination of the components due to fabrication processes.

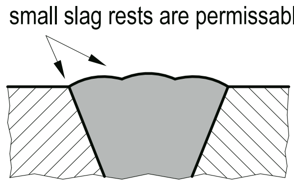
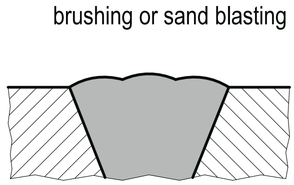
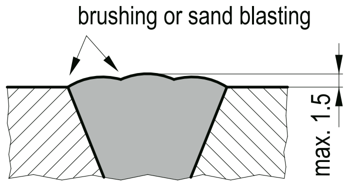
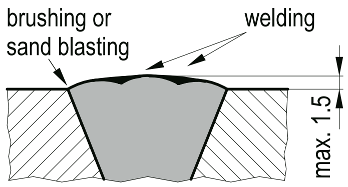
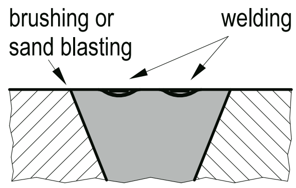
Finished condition	1	2	3
Requirements	Visual inspection	Surface examination	Surface examination and radiography
Appearance of weld seams (cover passes)	 Larger weld surface roughness shall be ground flush to weld surface. Weld spatter shall be removed.	 Larger weld surface roughness shall be ground over. Weld spatter and slag rests shall be removed. The weld edge zones and bead transitions shall be brushed or sand blasted.	 Larger weld surface roughness shall be ground over. Weld spatter and slag rests shall be removed. The difference between excess weld metal and sheet metal surface shall not exceed 1.5 mm. The weld edge zones and bead transitions shall be brushed or sand blasted.
Finished condition	4	5	6
Requirements	Surface examination and radiography	Surface examination and radiography	In-service inspections
Appearance of weld seams (cover passes)	 The weld surface shall be ground. Weld spatter and slag rests shall be removed. The difference between excess weld metal and sheet metal surface shall not exceed 1.5 mm. Any remaining bead transition shall be filled by welding and ground flush to weld surface. The weld edge zones shall be brushed or sand blasted.	 The weld shall be ground flush to sheet metal surface and shall not show transitions between the beads. Weld spatter and slag rests shall be removed. Any remaining bead transitions shall be filled by welding and ground flush to the weld surface. The weld edge zones shall be brushed or sand blasted.	In addition to the requirements of 4 or 5 large-area roughness (waviness) referred to an area of 50 mm · 50 mm shall not exceed 1 mm. In the vicinity of weld edge zones and bead transitions additional local cavities of not more than 0.5 mm are permitted.

Table 8-1: Finished condition of weld surfaces (terms see Fig. 8-1)

8.3.1.5.2 Welding records

(1) Welding records shall be established according to Section 5 by the welding supervisory personnel during welding work. By means of the welding record it shall be demonstrated that the requirements of the design-approved welding procedure sheet are complied with during fabrication.

(2) Deviations from the welding procedure sheet and special features shall be included in the welding record.

Note:

Changes and special features may be, e.g.:

a) change of welders,
b) change of batches (fabrication lots) of filler metals and consumables,
c) failure of welding machine,
d) failure of measuring devices,
e) arc strikes outside the weld groove,
f) positioning of contact tip or contact jaw,
g) failure of welding fixtures,
h) excess of the allowable tolerances,
i) exchange of welding head,
j) removal of defects.

(3) Similar welds on the same component which are welded by one welding process at the same time may be entered in the welding record.

(4) Auxiliary welds for temporary weld attachments on a component in its final condition or at locations with an oversize of less than 5 mm shall be entered in a dimension record and be attached to the welding record.

(5) For auxiliary welds at oversize locations which later will achieve a reduction of at least 5 mm, neither a welding record nor a dimensional record is required.

(6) For each welding sequence provided in the welding procedure sheet and each similar weld on the same component at least one entry is required in the welding record. However, at least two entries shall be made per shift.

8.3.2 High-temperature brazing

8.3.2.1 Requirements for high-temperature brazing

(1) Brazing work shall not be started before all tests and examinations of the product forms and brazing metals have been successfully completed and been documented in accordance with Section 7.

(2) Brazing procedure sheets shall be established in accordance with Section 5.

8.3.2.2 Performance of brazing

(1) The brazing conditions specified by the range of application of the brazing qualification procedure shall be satisfied when brazing components.

(2) The brazing equipment and auxiliary devices shall be designed such as to avoid ferritic contamination of the components due to fabrication processes.

(3) A single repetition of brazing is permitted.

(4) Brazing work shall be monitored by production control test.

8.3.2.3 Brazing records

(1) The supervisory personnel shall establish brazing records acc. to Section 5 during brazing work for each furnace brazing to specifically document that the requirements of the brazing procedure sheet are complied with during fabrication.

(2) Particularities shall be entered in the brazing record.

Note:
Particularities are e.g.
a) failure of furnace,
b) failure of measuring devices,
c) repeated brazing.

(3) The temperature control and vacuum shall be recorded during the brazing process and the recorded data shall be entered in the brazing record.

8.3.3 Hard surfacing and thermal spraying

8.3.3.1 Requirements for hard surfacing and thermal spraying

(1) Hard surfacing work and thermal spraying shall not be started before all tests and examinations on the product forms and on the welding filler or surfacing metals have been performed successfully and been documented in accordance with Section 7.

(2) Production plans and test and inspection sequence plans as well as additional welding procedure sheets shall be established for hard-surfacing in accordance with Section 5.

8.3.3.2 Performance of hard-surfacing and thermal spraying

(1) When surfacing or spraying a component, the conditions specific to the manufacturer and the layer shall be satisfied within the range of application of the hard-surfacing procedure qualification test and during thermal spraying.

(2) The welding and spraying equipment and the auxiliary devices shall be designed such as to avoid ferritic contamination of the components.

(3) Double repetition of thermal spraying is permitted.

(4) Thermal spraying work shall be monitored by production control tests.

8.3.3.3 Thermal spraying records

(1) The supervisory personnel shall establish records during thermal spraying work to specifically document that the spraying conditions have been satisfied during manufacture.

(2) Particularities shall be entered in the spraying record.

Note:
Particularities are e.g.
a) failure of spraying equipment,
b) failure of measuring devices,
c) repeated spraying.

(3) The thermal spraying record shall document that the essential parameters of the thermal spraying process have been adhered to.

8.3.4 Forming and straightening

8.3.4.1 Hot forming

(1) The requirements of Section 7 shall be met during hot forming.

(2) Hot-formed components shall be monitored by production control tests. In the case of welded hot formed components, the test piece shall contain a weld with the same degree of forming. A test piece is required for each melt and forming lot.

(3) The tests on test specimen shall be repeated to meet the requirements of Section 7, except for the chemical analysis. In the case of welded hot formed components, the tests and examinations of welded joints as per Section 8.6 shall be performed, except for the chemical analysis of the weld metal.

8.3.4.2 Cold forming

(1) Cold forming of austenitic steels means the forming at temperatures between room temperature and 400 °C.

(2) When cold forming austenitic steels in the quenched or stabilised condition, the following requirements shall basically be met:

a) Structural components
   - aa) Cold forming rate greater than 15 %:
     Proof of elongation at fracture A_5 equal to or greater than 15 %.
   - ab) Cold forming rate equal to or smaller than 15 %, determined elongation at fracture A_5 equal to or smaller than 30 % on the starting material:
     Proof of elongation at fracture A_5 equal to or greater than 15 %.
   - ac) Cold forming rate equal to or smaller than 15 %, determined elongation at fracture A_5 greater than 30 % on the starting material:
     No proof required.

b) Non-structural components:
   No restrictions.

c) In the case of cold bent tubes, the average bending radius shall be equal to or greater than 1.3 times the outside diameter.

d) For BWR plants the cold forming rate shall be limited to a value equal to or smaller than 5 % where the risk of corrosion cracking exists. except for fasteners and thin-walled components on which no welding work is performed.

(3) When cold forming other materials for structural components, the conditions shall be agreed by the plant vendor and the authorized inspector.

8.3.4.3 Flame straightening

When flame straightening austenitic steels the following conditions shall be met:

a) During heating up the carburization of the material shall be avoided.

   Note:
   The acetylene burner shall be set to neutral or with an oxygen surplus.

b) Flame straightening shall be performed at temperatures of not more than 750 °C.

c) The sum of holding times shall not exceed 10 minutes.

8.3.4.4 Records

A record shall be established by the manufacture on the forming work done to state:

a) the heat treatment facilities and forming equipment used,

b) the forming steps,

c) the temperature control and monitoring during forming,

d) the test results of the production control test specimens during hot forming.

8.3.5 Cleaning, check for cleanliness and requirements for surface conditions

8.3.5.1 Cleaning

8.3.5.1.1 Cleaning procedures

For the cleaning of components of reactor pressure vessel internals made of austenitic Cr Ni steels, Cr steels and nickel-based alloys, mechanical and chemical cleaning procedures are permitted.

8.3.5.1.2 Cleaning plans

(1) Prior to cleaning operations the manufacturer shall establish cleaning plans.

(2) The cleaning plans shall contain at least:

a) components with specification of materials,

b) course of cleaning operations,

c) cleaning agents and their concentration,

d) penetration time of cleaning agents,

e) temperatures to be observed,

f) checks for cleanliness.

8.3.5.1.3 Performance of cleaning and requirements for cleaning agents

(1) Mechanical cleaning

a) Blasting

The following blasting agent may be used e.g.:

aa) high-quality corundum types WA 0.2 to 0.5 according to DIN EN ISO 11126-7.

ab) glass pearls MGL 0.14 to 0.4 according to DIN 8201-7.

b) Grinding

The grinding material used shall normally be single crystal corundum and high-quality ruby corundum

c) Brushing

Only brushes with bristles made of austenitic Cr Ni steels without ferritic contamination are allowed.

(2) Chemical cleaning

a) Degreasing

aa) In the case of aqueous alkaline or phosphatic degreasing agents the content of water-soluble chlorides shall be limited to 50 mg/kg for the ready-to-use solution.

ab) Chloric/fluoric hydrocarbons (e.g. trichloric tri-fluoric ethane) shall be limited to the following values:

evaporation residue:	≤ 2	mg/kg
water-soluble chlorides:	≤ 0.5	mg/kg
acid value:	≤ 0.002	mg KOH/g
pH value:	< 5	

ac) Stabilized chloric hydrocarbons shall be limited to the following values:

pH value:	≥ 8.5
acid absorption capability (SAV value):	≥ 0.06 % NaOH

ad) Non-stabilized chloric hydrocarbons shall not be used.

b) Pickling

Only austenitic Cr Ni steels and the nickel alloy NiCr 15 Fe (material no. 2.4816 according to Section 7) as well as similar weld filler metals may be subjected to acid pickling.

When using aqueous solutions only those on the basis of nitric acid are permitted. The portion of hydrofluoric acid shall not exceed 3 % by weight.

The acid cleaning solution shall not exceed the following values:

Chlorides:	≤ 50	mg/kg
Sulfides:	≤ 5	mg/kg
Iron content:	≤ 8	g/kg

Where pickling pastes are used the hydrofluoric acid content shall be raised to 4.5 % by weight.

The pickling time shall be reduced to an absolute minimum.

The pickling solution temperature shall not exceed 30 °C.

c) Passivation

Aqueous solutions of nitric acid shall be used and shall not exceed the following values:

Chlorides:	≤ 50	mg/kg
Sulfides:	≤ 5	mg/kg

The portion of nitric acid shall be between 10 and 30 % by weight.

The passivation time shall be at least 30 minutes at room temperature.

(3) Rinsing

a) Pre-rinsing

The water used for pre-rinsing shall be clear, colourless and odourless, and shall not exceed the following values:

Conductivity:	≤ 600	µS/cm at 25 °C
Chlorides:	≤ 50	mg/kg
Sulphates:	≤ 250	mg/kg

b) Final rinsing

For final rinsing fully demineralized water or distilled water (condensate) shall be used which shall be clear, colourless and odourless and shall not exceed the following values:

Conductivity:	≤ 10	µS/cm at 25 °C
Chlorides:	≤ 0.5	mg/kg
Sulphates:	≤ 0.5	mg/kg

Final rinsing shall be performed directly after pre-rinsing (wet in wet). Final rinsing shall be continued until the increase in conductivity of the rinse water in relation to the initially used water does not exceed 2 µS/cm.

8.3.5.2 Checks for cleanliness and requirements for surface condition

8.3.5.2.1 General requirements

Upon cleaning tests and inspections as per **Table 8-2** shall be performed.

Type of Test	Check for
Check for ferrite a) water treatment or b) ferrite indicator test	ferritic impurities
Visual inspection	a) impurities b) acid-cleaning damage c) discolouration

Table 8-2: Tests and inspections required after cleaning

8.3.5.2.2 Examination for ferrite content

(1) For the determination of the ferrite contamination the following procedures shall be performed with the acceptance criteria mentioned therein.

(2) The specified acceptance criteria do not apply to small parts such as bolts, pins, retaining plates etc. These parts shall be free from ferrite indications.

8.3.5.2.3 Water treatment

(1) Water treatment may be performed during pre-rinsing or final rinsing. The component surfaces shall be wetted with water for a period of at least 6 hours. The water used shall satisfy the limit values given in 8.3.5.1.3 (3). Wetting shall be done by sprinkling, spraying or immersion. The evaluation shall be made on the dry component surface after final rinsing.

Note:
Where external ferrite is present on the surface, local rust brown discolouration will appear at the location of the ferrite particles.

(2) Ferrite contamination is only permitted if

a) at least 75 % of the surface subdivided in areas of 1 dm^2 do not show any indication,

b) the extension of indication does not exceed 3 mm,

c) a maximum of 5 indications exists on an area of 1 dm^2.

8.3.5.2.4 Ferrite indicator test

Note:
The ferrite indicator test is used for local random examination on components made of austenitic Cr Ni steel and nickel alloys for the detection of ferrite contamination.

(1) The ferrite indicator test shall not be used for components made of Cr steels. In such cases, the examination shall be made by means of water treatment according to 8.3.5.2.3.

(2) The following solutions shall be prepared for the ferrite indicator test:

a) Solution A: 10 g $K_4Fe(CN)_6$
(potassium hexacyano ferrate II)
50 ml distilled water
3 drops wetting agent (surfactant)

b) Solution B: 50 ml destilled water
15 ml HNO_3 (65 % nitric acid by weight)

(3) The solutions shall be prepared and stored separately.

(4) Prior to the test, equal volumes of the two solutions shall be mixed and upon mixing the indicator shall be used immediately.

(5) The prepared indicator solution shall be prepared anew after about 2 hours because it will turn blue by self-decomposition.

(6) To avoid indication errors, a passivation shall be performed after a mechanical surface treatment (e.g. brushing, grinding, turning, blasting) or 24 hours shall pass before a ferrite indicator test can be performed.

(7) The results shall be evaluated after 30 to 60 seconds.

Note:
Where ferrite particles are present on the component surface, the indicator will turn blue. This change in colour will only occur locally at locations with ferrite particles.

(8) Indications that prove the presence of pickling agent residues (by large area blue colouring) are not permitted.

(9) Immediately after the test the examined surface areas shall be cleaned to remove the indicator solution and be rinsed with water in accordance with 8.3.5.1.3 (3) b) (final rinsing).

(10) The following ferrite contamination is permitted:

a) extension of indication not to exceed 3 mm,

b) a maximum of 5 allowable indications on an area of 1 dm^2.

8.3.5.2.5 Proof of required surface condition

(1) It shall be proved by visual inspection that the surfaces are free from visible contamination (e.g. grease, oil, machining blasting, cleaning agent and lime residues), corrosion products and metallic residues and do not show any pickling damage and inadmissible discolouration.

(2) Discolouration of weld seams shall be permitted up to a semi-blue colouration according to the tempering colours no. 1 to 3 of DIN 25410, Fig. F.1. Discolouration upon grinding is not permitted.

Note:
Passivation or protective layers specific to some materials shall not be considered a contamination and need not be removed.

8.4 Heat treatment

8.4.1 General requirements

(1) It is the responsibility of the manufacturer to select the components to be subjected to stress relieving. Other heat treatments shall be agreed upon by the plant vendor and the authorized inspector for components of quality class AS-RE 1 and by the plant vendor for components of quality classes AS-RE 2 and AS-RE 3.

(2) Components or sub-units shall basically be heat treated as a whole. Local heat treatments are permitted if abrupt temperature changes are avoided. The temperature distribution to be observed shall be specified in the heat treatment plan.

(3) For temperature control during heat treatment thermocouples shall be provided on the part or on reference parts. For smaller parts adequate instrumentation of furnaces, e.g. with tracking thermocouples will suffice.

(4) Each heat treatment shall be documented in a temperature-versus-time log using automatically recording measuring instruments.

(5) Heat treatment plans shall have been established according to Section 5.

8.4.2 Performance of heat treatment

(1) Stress relieving may be performed as heat treatment of stainless austenitic steels for the relief of stresses and for ensuring a sufficient geometrical accuracy.

(2) The stress relief temperature shall be 580 °C +10 K/-20 K. The holding time at this temperature shall be at least 20 minutes for this part.

(3) The heat-up and cooling rates shall be 20 to 70 K/h.

8.4.3 Certificates

(1) The manufacturer shall establish a certificate of each heat treatment to contain the following:

a) a confirmation of compliance with all specifications of the heat treatment plan,

b) the heat treatment equipment used including the type of heat supply and a specification of the furnace atmosphere,

c) the location of parts and test coupons, if any, in the heat treatment equipment as well as statements on the temperature measuring techniques,

d) the analyzed short form of the original time-temperature charts.

(2) In the case of local heat treatment data on the width of the annealed zones as well as the thermal gradient in the heat-input area shall also be documented.

8.5 Removal of defects

8.5.1 General requirements

Note:

Removal of defects means measures to remove defects on base metals, welds and surfacings (e.g. weld claddings) by means of rectification, repairs or finishing.

(1) The point in time for removing defects shall be specified by the manufacturer such that the

a) quality of the parts is still ensured,

b) required in-process inspections can be performed without restrictions.

(2) Where the sequence of inspections is changed due to repair measures, this shall be documented in the test and inspection sequence plan in the column “remarks”.

(3) Where the requirements of the fabrication documents are not met, the measures of Section 5 shall be taken.

a) finishing

Defects without the use of welding procedures shall be removed by finishing under the following conditions: The requirements of the fabrication documents shall be met.

b) Rectification

The removal of defects by welding on welded joints and deposition weldings shall be made as rectifications on the following conditions:

ba) the requirements of the welding procedure documents shall be met,

bb) none of the values given in (c) of **Figure 8-2** shall be exceeded when changing the actual weld geometry.

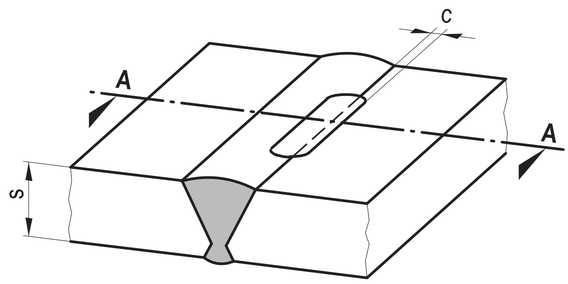
c) Repairs

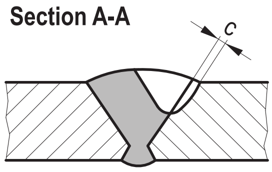
Removal of defects by welding shall be made as repairs under the following conditions:

ca) the requirements of the welding procedure documents are changed,

cb) the values given in (c) of **Figure 8-2** for a change of the actual weld geometry are exceeded,

cc) removal of defects on the base metal.





s	c
< 10 mm	max. 1 mm
≥ 10 mm	$0.1 \cdot s$ but max. 3 mm

Figure 8-2: Change of the actual weld seam geometry

8.5.2 Fabrication documents for removal of defects

(1) Where repairs are performed to remove defects, the fabrication documents specified in Section 4 shall be established in accordance with Section 5:

a) repair test and inspection sequence plan,

b) repair welding procedure sheet.

(2) The repair test and inspection sequence plan including the assigned plans and the description of defects shall be submitted to the authorized inspector for review. Repairs shall only be performed in accordance with reviewed repair plans.

(3) The repair test and inspection sequence plan and the repair welding procedure sheet for typical repair work may be established prior to the beginning of fabrication and may be available to the manufacturer as reviewed documents.

(4) In the case of finishing work and rectification no additional fabrication documents are required.

8.5.3 Performance of defect removal

When performing defect removal, the following conditions shall be met:

(1) Finishing

a) The defects detected shall be reported to the independent quality department of the manufacturer’s works.

b) Upon dressing of defects a smooth transition shall be obtained in all directions from the surrounding surfaces.

c) The shape and finish of the surface shall not effect subsequent examination or the function of the part.

d) All non-destructive examinations the results of which are no longer valid due to the removal of material shall be repeated.

(2) Rectifications

a) The size and location of the dressed defects shall be entered in the welding record if their depth exceeds 10 % of the wall thickness.

b) Where more than 2 rectifications are made on the same location, the rectification method shall be reviewed.

c) The in-process inspections listed in the test and inspection sequence plan shall be performed on the rectified locations.

(3) Repairs

a) The defects detected shall be reported to the welding supervisor and the independent quality department of the manufacturer's works.
b) Records shall be established on the size and location of the dressed defects.
c) Where more than 2 repairs are made on the same location, the repair method shall be reviewed.
d) The in-process inspections listed in the test and inspection sequence plan shall be performed on the repaired locations.
e) Upon welding on the base metal, at least one surface examination shall be performed. Where required, further examinations shall be fixed in the repair test and inspection sequence plan depending on the extent and geometry of the repair work.

8.5.4 Documentation of defect removal

The manufacturer shall establish test records on all required tests and examinations and shall enter them in the documentation.

8.6 Welding, brazing, hard surfacing and thermal spraying procedure qualification tests

8.6.1 General requirements

(1) Prior to the beginning of fabrication the manufacturer of quality class AS-RE 1 and AS-RE 2 components shall demonstrate to the authorized inspector by means of a procedure qualification test that he is capable of performing the specified welding, brazing, hard surfacing or thermal spraying procedure in accordance with the requirements laid down hereinafter. Welding and brazing procedure qualification tests shall be performed according to Sections 8.6.4.3 to 8.6.4.5 and 8.6.4.9 in the presence of the authorized inspector and the manufacturer's welding supervisors, procedure qualification tests according to Sections 8.6.4.6 to 8.6.4.8 and 8.6.4.10 shall be performed in the presence of the plant vendor and the manufacturer's welding or spraying supervisors.

(2) The type and extent of the procedure qualifications shall be based on the manufacturer's requirements for welding and brazing. The procedure qualifications shall be adapted to:

a) the materials to be welded or brazed,
b) the welding or brazing process used,
c) the conditions specific to the welding or brazing process,
d) the range of variables specific to the welding or brazing process,
e) the dimensions of the parts,
f) the filler metals (type and dimension),
g) the shape of the joint,
h) the weld build-up
i) the welding positions,
k) the heat treatment condition intended for the part.

(3) Prior to performing the procedure qualification the manufacturer shall establish the following documents:

a) the test and inspection sequence plan,
b) the welding or brazing procedure sheet,
c) the specimen-taking plan, provided the specimen-taking is not already sufficiently covered by **Figures 8-3** to **8-11**.
d) the heat treatment plan, if heat treatment is required.

(4) These documents shall meet the requirements of Section 5.

(5) The written statement according to Section 8.6.5 shall normally be available prior to the beginning of fabrication.

8.6.2 Scope of the procedure qualification

8.6.2.1 General requirements

(1) The scope of the procedure qualification shall be laid down in the written statement according to Section 8.6.5.

(2) In the case of welding work the procedure qualification being valid for one manufacturer's works also applies to welding work done outside the works, e.g. on construction sites if the welding personnel of the manufacturer's works is employed in accordance with Section 8.2.

8.6.2.2 Materials

(1) In the case of stainless austenitic steels and nickel alloys the scope of the welding procedure qualification with regard to the base metals is given by the scope of the qualification procedure of the weld filler metals used.

(2) Weld filler metals of the same type may be exchanged. The scope of the qualification procedure may be extended, when using filler metals of the same type, in accordance with the scope of the qualification procedure of these filler metals.

(3) Regarding connections between stainless austenitic steels and nickel alloys the scope of the procedure qualification shall be limited to the filler metals used in the qualification.

(4) Regarding high-temperature brazed connections and thermal spraying the scope of the qualification procedure for the base metal shall be limited to the base metals used in the qualification.

8.6.2.3 Welding procedures and conditions

(1) The welding procedure used in the qualification procedure including the welding conditions shall be applied in the welding of components.

(2) Under more complicate conditions (e.g. in case of narrow spaces and fixed position welding), the welding procedure qualifications shall be adapted to these conditions.

(3) If procedure qualifications have already been performed, supplementary qualification may be performed under more complicate conditions.

8.6.2.4 Brazing procedures and conditions

The brazing procedure used in the qualification test including the brazing condition shall be adhered to when brazing components.

8.6.2.5 Thermal spraying procedures and conditions

The thermal spraying procedure used in the qualification test including the spraying conditions shall be adhered to when spraying components.

8.6.2.6 Dimensions

(1) Dimensions for full-penetration welds

The dimension of the test piece for procedure qualification limits the scope of this procedure qualification for the welding of parts with different dimensions as follows:

a) A welding procedure qualification conducted on a test piece of a wall thickness s equal to or smaller than 100 mm applies:
    aa) for multi-pass arc welds for the wall thickness range of 0.75 · s up to 1.5 · s,
    ab) for submerged-arc narrow-gap welding for the wall thickness range of 0.5 · s to 1.25 · s,

ac) for special welding procedures for the wall thickness range of 0.75 · s to 1.25 · s.

ad) in the case of single-layer metal arc welds for the wall thickness range to be laid down with the authorized inspector.

b) A procedure qualification test performed on a test piece wall thickness s greater than 100 mm applies:

ba) for semi- or fully automatic welding to the wall thickness range 0.5 · s up to 1.5 · s,

bb) for manual arc welding to the wall thickness range to be laid down with the authorized inspector.

c) A procedure qualification test for circumferential welds performed on a tube diameter “d” applies:

ca) in the case of manual welding with

caa) d equal to or less than 168.3 mm for pipe diameters 0.5 · d up to 2.0 · d,

cab) d greater than 168.3 mm for all pipe diameters equal to or greater than 0.5 · d,

cb) in the case of semi- or fully mechanized welding with

cba) d equal to or less than 168.3 mm for pipe diameters 1.0 · d up to 2.0 · d,

cbb) d greater than 168.3 mm for all pipe diameters equal to or greater than 1.0 · d.

(2) Dimensions for partial penetration welds, brazed joints, hard surfacing, thermal spray coatings and other welded joints

a) The dimensions of the test coupon may be selected arbitrarily with respect to the scope of qualification procedure unless specified otherwise in 8.6.4.

b) With respect to the procedure qualification according to 8.6.4.5 the part’s dimensions shall be equal to those of the test coupons regarding the brazed joint.

c) With respect to 8.6.4.10 the qualification on plate thicknesses s_1 and s_2 only applies to these plate thicknesses.

8.6.2.7 Weld and braze filler metals, flux for thermal spraying

(1) The weld and braze filler metals used in procedure qualification (in rod electrode including type of coating, strip or wire electrode, welding wire and rod, shielding gases and fluxes as well as fluxes for thermal spraying) shall be used in component welding, brazing or spraying. Where the weld and braze filler metals are of the same type and their suitability has been proved, no requalification is required when changing from one brand to another. The exchange of basic and rutile coated rod electrode types is permitted when welding the cover layer.

(2) During component welding it is permitted, in the case of gas tungsten arc welding, to use the welding rod nominal diameter with one grade higher or lower than that used in procedure qualification. In the case of fillet welds for the first layer an exchange only by one grade lower is permitted.

(3) Only the brazing flux or alloy used in the procedure qualification shall be used in component brazing.

(4) In the case of shielding gases, a change of supplier is permitted if identical analysis results are ensured.

(5) In the case of submerged-arc welding only the electrode-flux combination used in the procedure qualification shall be valid for welding of parts; an exchange of wire or strip electrodes of the same type is permitted irrespective of the manufacturer.

(6) The flux for submerged-arc welding or thermal spraying to be used is limited to the same flux type of one manufacturer.

8.6.2.8 Form of welded or brazed joint

(1) The form of welded or brazed joint used in the procedure qualification shall be adapted to the requirements of the intended fabrication. Abnormal conditions, e.g. weld restraint, shall be taken into account.

(2) The joint category used in procedure qualification may include other joint categories for component welding in accordance with **Table 8-3**.

(3) Where a procedure qualification test has already been performed for forms of welded or brazed joints not laid down in **Table 8-3** a supplementary test will suffice. The extent of the supplementary test shall be agreed with the authorized inspector.

(4) Deviations of the angle of fusion faces or the fillet angle from those of the welded joint as used in the procedure qualification test are permitted for the welding of parts as per **Table 8-4**.

(5) In component brazing changes of the joint forms used in brazing procedure qualification are not permitted.

8.6.2.9 Weld build-up

(1) Where several welding procedures are used during a procedure qualification test, the portion of the filler metals of the various welding procedures used, referred to the weight of the deposited weld metal, may deviate from the portion of filler metals used in the welding of the parts or components, provided, a qualification according to Section 8.6.4 has been performed. The sequence of the welding procedures used may basically be changed. In the case of single-sided welds the root layer welding procedure shall not be changed.

(2) The root welding process for single-sided welds is considered to have qualified as single welding process only if the full extent of testing as per **Table 8-3** with specimen location in accordance with column 3 of **Table 8-3** has been performed successfully.

(3) For the welding of notches and weld eges by means of the inert-gas tungsten arc welding a procedure qualification for TIG root welding may be used.

(4) In the case of hard surfacings separate procedure qualification according to 8.6.4.6 shall be performed for single-layer and multi-layer welds.

8.6.2.10 Welding and brazing positions

(1) Butt welds on plates

a) Only the welding position used in the procedure qualification shall be used for component welding. The transverse position (PC) and overhead position (PE) include the flat position (PA).

b) When using fully mechanised welding procedures in the flat position (PA), this procedure qualification also applies to pipe longitudinal and pipe circumferential welds with an internal diameter greater than 150 mm in the case of TIG welding or greater than 500 mm in the case of submerged arc welding if component welding is also performed in position PA.

c) Where during a procedure qualification welding is performed in flat position (PA), vertical-up position (PF) and transverse position (PC), the following extent of testing will suffice for position PC:

ca) one round tensile test specimen from the all-weld metal in accordance with **Table 8-5**, specimen location III according to **Figure 8-3** or **Figure 8-4**,

cb) one set of notched-bar impact specimens in accordance with **Table 8-5**, specimen location V according to **Figure 8-3** or **Figure 8-4**,

cc) metallographic examination on polished section transverse to the weld in accordance with **Table 8-5**

Joint category		A			B		C	D	E	F
		1	2	3	1	2				
Procedure qualification performed	Symbol / weld designation	double-vee butt weld with wide root faces	single-vee butt weld with wide root faces	single-vee butt weld with wide root faces	double-bevel butt weld	single-bevel butt weld without root faces	double-vee butt weld with wide root faces	double-bevel butt weld	single-vee butt weld with wide root faces	fillet weld
		double-vee butt weld without root face	single-vee butt weld without root face	single-vee butt weld without root face	double-J butt weld	single-J butt weld	double-vee butt weld without root face	double-J butt weld	single-vee butt weld without root face	double fillet weld
		double-U butt weld	single-U butt weld	single-U butt weld	single-bevel butt weld without root face		double-U butt weld	single-bevel butt weld without root face	single-U butt weld	
		double-bevel butt weld	single-bevel butt weld without root face	single-bevel butt weld without root face	single-J butt weld		double-bevel butt weld	single-J butt weld	single-bevel butt weld without root face	
		double-J butt weld	single-J butt weld	single-J butt weld			double-J butt weld		single-J butt weld	
	Weld design	double side welded		single side welded	double side welded	single side welded	double side welded		single side welded	—
		full penetration weld					non full penetration weld			
	Type of welded joint	butt weld			T-joint, corner joint nozzle weld		butt weld	T-joint, corner joint nozzle weld	T-joint, corner joint nozzle weld	—
Scope		all types of groove,[1)] not for A3 and B2		all types of groove	all types of groove,[1)] not for A3 and B2	all types of groove	only for C, D, E, F			only for F

1) Procedure qualifications with fully penetrating root pass also apply to welds with chipped-out root pass.
Procedure qualifications with chipped-out root pass do not apply to welds with fully penetrating root passes.

Table 8-3: Scope of procedure qualification performed with groove type according to DIN EN ISO 9692-1 and DIN EN ISO 9692-2

Procedure qualified for	Included or fillet angle	Angular tolerance for individual procedure qualification	Scope of qualification if several procedures have been qualified		
			a) and b)	b) and c)	a) and c)
a) welded joint	0 to 30 degrees		0 to 60 degrees		
b) welded joint	45 degrees	± 15 degrees		30 to 110 degrees	
c) welded joint	90 degrees	+ 20 degrees [1)] - 45 degrees			0 to 110 degrees

Note:
Where procedures have been qualified with included angles between the values given, the angular tolerance shall be interpolated accordingly.

1) Where nickel alloy filler metals are used, ± 20 degrees applies, for fillet welds - 20 degrees, there is no upper limitation.

Table 8-4: Scope of included angle or fillet angle for procedure qualification

(2) Butt welds on tubes

a) Only the welding position used in the welding procedure qualification test shall be used in component welding.

b) The procedure qualification made on circumferential welds of tubes shall also apply to plates and sheets and to longitudinal welds on tubes.

(3) Other welded and brazed joints and thermal spray coatings

Only the welding positions used in the procedure qualification shall be used in component welding, brazing or spraying.

8.6.2.11 Heat treatment

(1) The stress relieving period used in the procedure qualification shall not be exceeded during annealing of components.

(2) The maximum annealing time of the component shall be the sum of the holding times of stress relieving

(3) Procedure qualifications with heat treatments shall also apply to non-heat treated component welds, but not vice versa.

8.6.2.12 Period of validity

(1) The period of validity shall be 24 months upon successful completion of procedure qualification. The beginning date for the period of validity shall be the date of submission of the written comments by the authorized inspector or the plant vendor in accordance with 8.6.5. Where the fabrication is started within this 24 months, the period of validity shall be extended by additional 24 months in accordance with the following requirements.

(2) The period of validity of the procedure qualification in accordance with 8.6.4.3 to 8.6.4.5 and 8.6.4.9 shall be extended if production control tests acc. to Section 8.7 are made. If the fabrication is not started within 24 months upon successful completion of the procedure qualification, or if it is interrupted by more than 24 months, the welding or brazing control test to be performed at the beginning or resumption of fabrication is considered to be a re-qualification. The extent of tests and examinations of these production control tests shall be specified in accordance with that of the initial procedure qualification.

(3) The period of validity of the procedure qualification in accordance with 8.6.4.6 to 8.6.4.8 and 8.6.4.10 shall be extended if inspections and control tests according to Section 8.8 are performed. The beginning date for extending the period of validity is the date of issuance of the test report.

8.6.3 Welding, brazing, thermal spraying and heat treatment of test coupons

(1) From the total number of welders to perform welding work within the scope of procedure qualification, the welders shall be chosen by the welding supervisor, by agreement with the authorized inspector, for the procedure qualification.

(2) The base metal, welding filler metals, brazing alloys and fluxes for thermal spraying shall meet the requirements of Section 7.

(3) The requirements of Section 8.2 and 8.3.1 shall be met in the procedure qualification for welded joints.

(4) The requirements of Sections 8.2 and 8.3.2 shall be met in the procedure qualification for brazed joints.

(5) The requirements of Sections 8.2 and 8.3.3 shall be met in the procedure qualification for thermal sprayings.

(6) The test coupon shall be sized such that the required non-destructive examinations can be performed and the specimens specified in the specimen-taking plan can be taken. Sufficient material for retest specimens shall be provided.

(7) Where the presence of defects requires dressing work during welding, this shall only be permitted by agreement with the authorized inspector. The test coupon shall remain representative of the welding procedure qualification. All dressing work shall be recorded with the record showing the cause, type and extent of dressing work, and shall be included in the procedure qualification test report by the manufacturer.

(8) Where heat treatments are performed on components according to Section 8.4, the heat treatment requirements shall be met in the procedure qualification.

8.6.4 Tests, examinations and requirements

8.6.4.1 General requirements

The procedural requirements regarding non-destructive testing are laid down in 7.3.5.8 and the acceptance criteria of non-destructive testing in Section 8.9.

8.6.4.2 Re-examination

(1) Where a specimen or set of specimens does not obtain the specified values, two additional specimens or set of specimens shall be examined. All substitute specimens shall meet the requirements.

(2) Where insufficient test results are due to influences caused by the examination itself or due to a small imperfection in a specimen, this specimen may be left out when deciding whether the requirements have been met. The respective examination shall be repeated on a substitute specimen.

Line no.	Test and type of specimens	Test temperature	Test in accordance with	Values to be determined	Specimen location acc. to Figures 8-3 and 8-4	Number of specimens: Welded joint	Number of specimens: Simulated repair weld	Requirements	Certification by inspection certificate according to DIN EN 10204	Remarks
1	Analysis of all-weld metal	—	test method see Section 7	chemical analysis	—	1	—		3.1	chemical elements to be determined and evaluated in accordance with Section 7
2	Resistance to intergranular corrosion of austenitic welded joints	—	DIN EN ISO 3651-2 procedure A	intergranular corrosion resistance	I	1	1	DIN EN ISO 3651-2 procedure A	3.1	annealing in accordance with Section 7 if no heat treatment during procedure qualification
3	Micrograph of a microsection transverse to the welded joint	—	—	macrosection	—	1	1	The structure of the all-weld metal shall show a perfect bead sequence and a complete penetration of the joint (macrosection) as well as a perfect crystalline structure (microsection). Material discontinuities (microsection) are allowed provided, they are definitely individual defects judged by their number and location. Not allowed are accumulations of such defects in the form of connected fields.	3.1	overview photograph of the entire weld seam
		—	—	microsection	—	2	2			micrograph of 1 area in the all-weld metal and of 1 area in the heat affected zone including photograph of the microstructure
		—	Section 7	delta-ferrite content for austenitic steels	—	1	—	no ferritic lattice structure		Evaluation of delta-ferrite content by metallographic analysis
4 [1]	Tensile test specimens according to DIN EN ISO 4136	Room temp.	DIN EN ISO 6892-1	R_m, location of fracture	II	1	1	as specified for base metal or for filler metal in accordance with Section 7	3.2	—

Table 8-5: Extent of tests and requirements for mechanical properties and metallographic examination during procedure qualification weld tests of austenitic steels and nickel alloys (continued on next page)

Line no.	Test and type of specimens	Test temperature	Test in accordance with	Values to be determined	Specimen location acc. to Figures 8-3 and 8-4	Number of specimens		Requirements	Certification by inspection certificate according to DIN EN 10204	Remarks
						Welded joint	Simulated repair weld			
5 [1]	Tensile test specimens according to DIN 50125 of the weld metal	350 °C	DIN EN ISO 6892-2	R_m, $R_{p0.2}$, A, Z	III	1	1	as specified for base metal or for filler metal in accordance with Section 7	3.2	Where specimen-taking is not possible due to dimensions, substitute test on tensile specimens to serial no. 4 at 350 °C.
6 [1]	Bend test									
6.1	Transverse bend test specimens	Room temp.	DIN EN ISO 5173	Bending angle for d/a = 2	IV	4	—	α = 180 degrees 180 Grad are deemed to have been satisfied if the specimens have been pressed through the supports without incipient cracking	3.2	Two transverse bend specimens each subject to tensile loading from the two sides of the weld
6.2	Side-bend test specimens					—	2			—
7 [1]	Notched bar impact test	Room temp.	DIN EN ISO 148-1	KV_2	V	3/2/1 sets of specimens	1 set	as specified for base metal or for filler metal in accordance with Section 7	3.2	Only for s exceeding 10 mm

[1] For circumferential welds on tubes with a diameter smaller than or equal to 30 mm the tests of serial no. 4 to 7 can be omitted; testing shall be performed according to DIN EN ISO 4136 Section 5.5.3.3 on tubes.

Table 8-5: Extent of tests and requirements for mechanical properties and metallographic examination during procedure qualification weld tests of austenitic steels and nickel alloys (continued)

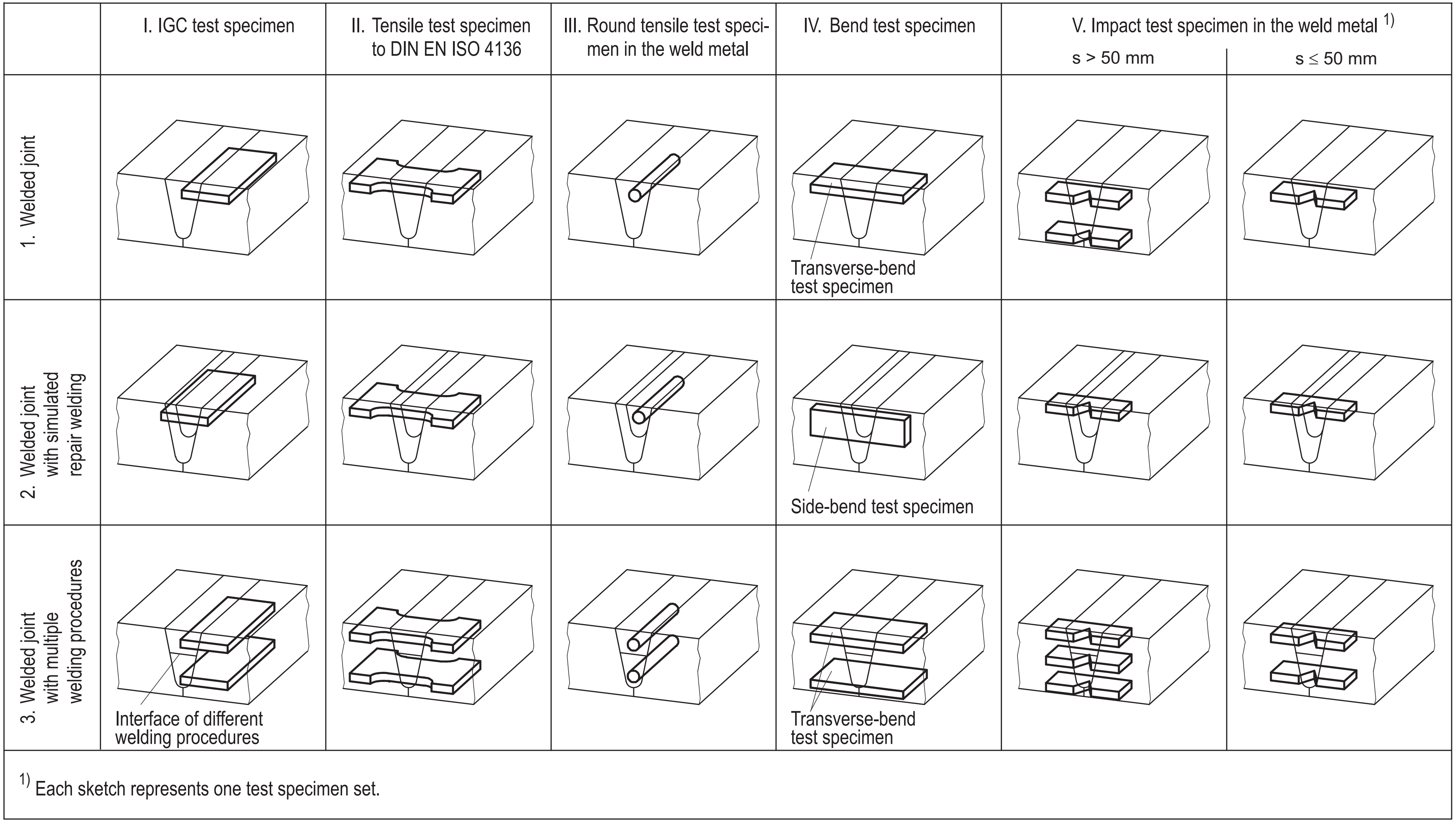
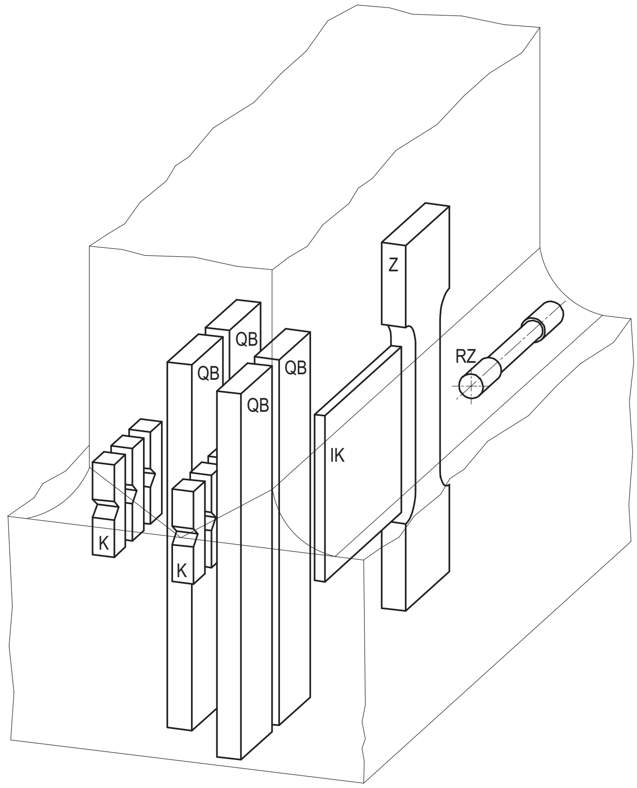


Figure 8-3: Location of test specimens (schematic)



I IK : IGC test specimen
II Z : Tensile test specimen to DIN EN ISO 4136
III RZ: Round tensile test specimen to DIN 50125 from weld metal
IV QB: Transverse bend test specimen
V K : Impact test specimen

Figure 8-4: Location of test specimens (schematic) [see clause 8.6.2.10 (1) c) and 8.6.4.3 (2) b)]

8.6.4.3 Procedure qualifications for welded joints of category A and B according to **Table 8-3**

(1) Non-destructive examination

Upon final heat treatment the test coupons shall be subjected to the following tests and examinations:

a) radiography of the welded joint over its full length,
b) surface examination of all weld surfaces.

(2) Mechanical tests and metallographic examinations

a) The tests as per **Table 8-5** shall be performed.
b) All specimens shall be shown to scale in the specimen-taking plan. For procedure qualifications of weld joint categories B1 and B2 the specimen location shall be taken from **Figure 8-4**.
c) Where several welding processes are used in the procedure qualification test, the specimen-taking shall be selected such that each welding process can be qualified.

(3) Evaluation

a) The results of non-destructive examination shall meet the requirements of Section 8.9.
b) The results of the mechanical tests including the metallographic examinations shall meet the requirements of **Table-8-5**.

(4) Simulated repair welding

a) Repair welds on welded connections, which are to be made with a welding process other than that used for the original weld shall be simulated within the procedure qualification test, unless other procedure qualification tests cover the welding process used for repair welding.
b) For the simulated repair weld 50 % of the wall thickness shall be repaired such that the faces of the repaired location cover both the weld metal and base metal.
c) **Table 8-5** applies with regard to the extent of the examination.

(5) Certificates

a) The manufacturer shall establish test records on all non-destructive examinations required according to this Section, which shall be signed by himself and countersigned by the authorized inspector.
b) All other tests/inspections required according to this Section shall be verified by means of the inspection certificates according to DIN EN 10204 as specified in **Table 8-5**.

8.6.4.4 Welding procedure qualification for welded joints of categories C, D, E and F according to **Table 8-3**

8.6.4.4.1 General requirements

(1) Where a procedure qualification according to 8.6.4.2 has been performed, it shall apply also to non-penetration welded joints of categories C, D, E and F in accordance with its scope.

(2) For fillet welds with a fillet angle smaller than 70 degrees, two fillet weld break test specimens according to DIN EN ISO 9017, however with the component fillet angle, are required for a supplementary test.

(3) The supplementary test shall be performed as follows:

a) Surface examination

   Upon final heat treatment, a surface examination shall be performed on the weld surface.

b) Metallographic examination

   A macrosection transverse to the weld shall be taken from the fillet weld break test specimen. The requirements of **Table 8-5** apply. The end face edges shall be largely covered. Little continuous root concavity is permitted. The macrosection shall be documented by macrographs.

c) Further examinations

   The examination and evaluation of the other fillet weld break test specimen shall be performed in accordance with DIN EN ISO 9017.

(4) Where a procedure qualification acc. to 8.6.4.3 has not been performed, a procedure qualification shall be performed in accordance with the following paragraph, as appropriate.

8.6.4.4.2 Welding procedure qualification for welded joints of category C, D and E according to **Table 8-3**

(1) A test coupon shall be welded in accordance with **Figure 8-5**.

(2) Upon final heat treatment, the test coupon shall be subjected to the following tests and examinations:

a) Surface examination

   A surface examination shall be performed on the weld surface.

b) Metallographic examinations

   One macrosection as well as two microsections (one location in the weld metal, one in the HAZ) transverse to the weld shall be taken. The requirements of **Table 8-5** apply. The weld edge shall be covered. The metallographic examination shall be documented by macrographs and micrographs respectively.

c) Resistance to intergranular corrosion

   The check for resistance to intergranular corrosion on austenitic welded joints shall be made according to

DIN EN ISO 3651-2 procedure A with a metallographic evaluation. Bending of the specimen may be omitted.

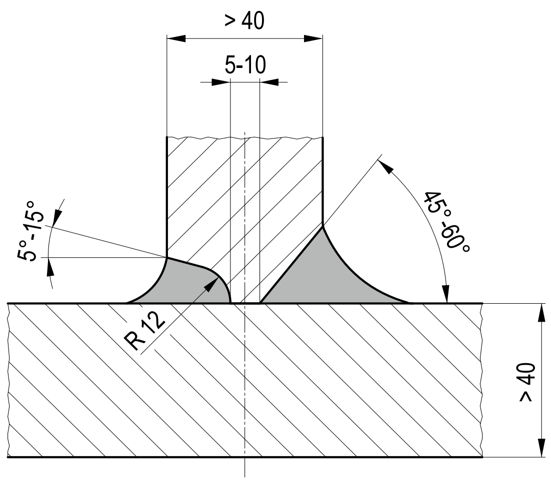


Figure 8-5: Dimensions of test coupon to clause 8.6.4.4.2 (1)

8.6.4.4.3 Welding procedure qualification for welded joints of category F according to **Table 8-3**

(1) Two fillet weld break test specimens according to DIN EN ISO 9017 are required. For fillet welds with a fillet angle smaller than 70 degrees, the fillet weld break test specimens shall be welded with the component fillet angle.

(2) Upon final heat treatment, the test coupons shall be subjected to the following tests and examinations:

a) Surface examination

A surface examination shall be performed on the weld surface.

b) Metallographic examinations

One macrosection as well as two microsections (one location in the weld metal, one in the HAZ) transverse to the weld shall be taken from one of the fillet weld break test specimens. The requirements of **Table 8-5** apply. The end face edges shall be largely covered. Little continuous root concavity is permitted. The macrosection shall be documented by macrographs.

c) Resistance to intergranular corrosion

The check for resistance to intergranular corrosion on austenitic welded joints shall be made according to DIN EN ISO 3651-2 procedure A with a metallographic evaluation. Bending of the specimen may be omitted.

d) Further examinations

The examination and evaluation of the other fillet weld break test specimen shall be performed in accordance with DIN EN ISO 9017.

8.6.4.4.4 Certificates

(1) The manufacturer shall establish test records on all non-destructive examinations required in 8.6.4.4, which shall be signed by himself and countersigned by the authorized inspector.

(2) The manufacturer shall establish an inspection certificate 3.1 in accordance with DIN EN 10204 on the results of the IGSCC test.

(3) The metallographic examinations and destructive tests shall be verified by means of an inspection certificate 3.2 in accordance with DIN EN 10204.

8.6.4.5 Brazing procedure qualification for high-temperature brazed control rod guide inserts

(1) Test coupon

One test coupon shall be brazed to the same procedure as the component. See example in **Figure 8-6**.

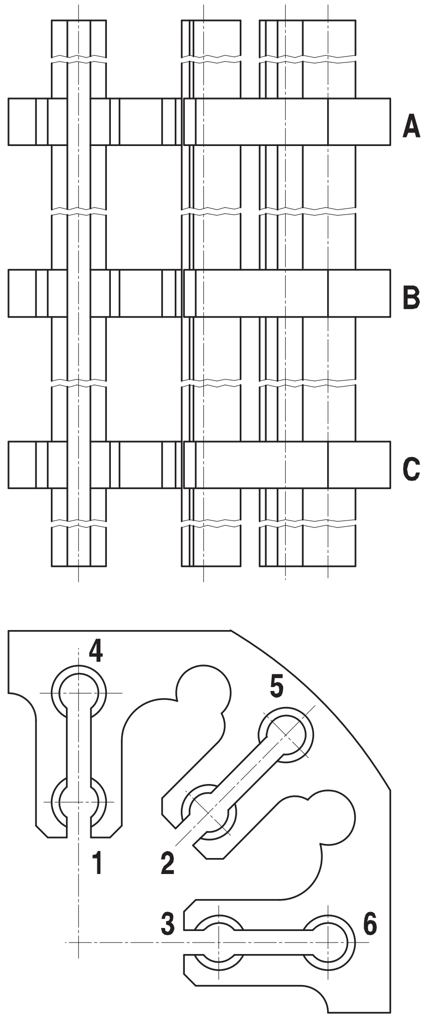


Figure 8-6: Example of test coupon for high-temperature brazed control rod guide assemblies

(2) Tests, examinations and requirements

For the specimen taking **Figure 8-6** applies:

a) Visual examination

The brazed joint shall be visually examined on both sides where the sum of brazed joint lengths on both sides of the brazed joint shall have an average value of 75 % of twice the diameter of the brazed joint.

b) Check for annealing colour

The test coupon shall be checked for annealing colours in which case a colouration to brown colour is permitted.

c) Shear test

The specimens A5, B4 and C6 shall be subjected to a shear test in which case the shear strength of the brazed joint shall be greater than the tensile strength of the tubes.

d) Examination of brazing filler metal distribution

By means of longitudinal sections on the specimens A4 and C2 the distribution of the brazing filler metal shall be examined to ascertain that 80 % of the examined cross-section is brazed. This shall be documented by an overview photograph.

e) Resistance to intergranular corrosion

The check for resistance to intergranular corrosion on the brazed joint shall be made acc. to DIN EN ISO 3651-2 procedure A on specimens A1 and C5 with a metallographic evaluation. Bending of the specimen may be omitted.

(3) Certificates

a) The manufacturer shall establish test record on all the aforementioned non-destructive examinations which shall be signed by himself and be countersigned by the authorized inspector.

b) The manufacturer shall establish an inspection certificate 3.1 in accordance with DIN EN 10204 on the results of the check for resistance to intergranular corrosion.

c) All mechanical tests and metallographic examinations shall be verified by means of inspection certificates 3.2 in accordance with DIN EN 10204.

8.6.4.6 Welding procedure qualification for hard surfacings

(1) Test coupon

A test coupon shall be welded in accordance with **Figure 8-7**.

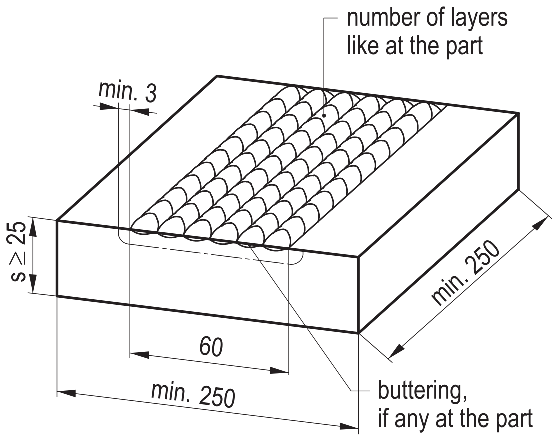


Figure 8-7: Dimensions of test coupon for hard surfacings

(2) Tests, examinations and requirements

Upon final heat treatment and dressing of the last layer the test coupon shall be subjected to the following tests and examinations:

a) Surface examination

A surface examination shall be performed on the weld surface.

b) Hardness test

A hardness test with several indentations on the surface of the hard surfacing layer shall be performed. The surface hardness shall normally attain the values guaranteed by the filler metal manufacturer.

c) Bend test

Two transverse bend test specimens with a hard surfacing thickness dressed down to 0.5 mm and d/a = 6 shall be tested in accordance with DIN EN ISO 5173 (see **Figure 8-8**). The specimen shall be bent by 180 degree or until break occurs. Here, no spalling of the hard surfacing layer (falling off of cladding portions) shall occur.

For test coupons with a thickness greater than 10 mm the bend test specimen thickness shall be dressed to 10 mm. The width of the bend test specimen shall normally be 25 to 30 mm.

To obtain definite results, the hard surfacing layer shall be uniformly cracked prior to the bend test (see **Figure 8-9**).

Note:

It is recommended to grind transverse grooves into the hard surfacing layer by means of a flexible grinder prior to creating the artificial cracks in the hard surfacing layer (see **Figure 8-8**).

Then, cracking is performed in the same equipment as used for bending in which case the support rollers and mandrel should be chosen as small as possible.

During this operation, care should be taken to ensure that only the hard surfacing layer is cracked. It is recommended to select a low travel speed of the mandrel.

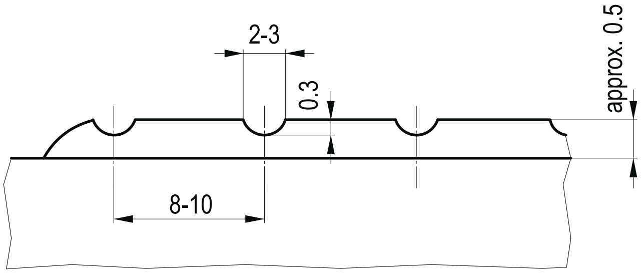


Figure 8-8: Dimensions of test coupon for the bend test of hard surfacings

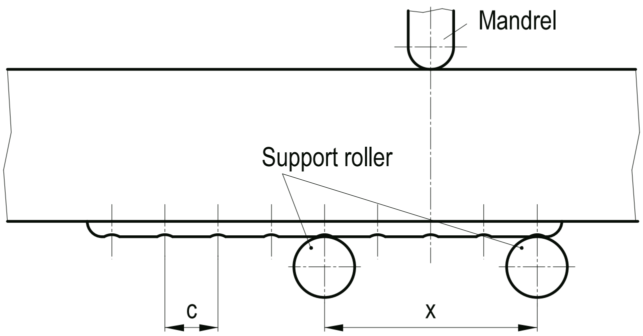


Figure 8-9: Distance of cracks in hard surface layer

d) Metallographic examination and measurement of clad thickness

One macrosection transverse to the weld orientation of the entire welded joint as well as microsections of the weld metal, heat affected zone and the clad metal shall be taken.

The clad thickness shall be determined by manual measurements of the actual depth or on the transverse macrosection.

The macrosection shall be evaluated with respect to clad thickness, build-up of layers and inter-pass flaws.

The microsections shall be evaluated with respect to weld metal, fusion line and HAZ.

(3) Certificates

a) The manufacturer shall establish and sign a test certificate on the non-destructive examination performed by him.

b) All other tests and examinations shall be certified by inspection certificate 3.1 in accordance with DIN EN 10204.

8.6.4.7 Procedure qualification for thermal spraying

(1) Test coupon

A test coupon shall be thermally sprayed to be representative of a thermally sprayed layer.

(2) Tests, examinations and requirements

The test coupon, in its original condition, shall be subjected to the following tests and examinations:

a) Visual examination

The sprayed layer shall be free from cracks, overlapping and layer spalling as well as inclusions. Isolated pores with a diameter equal to or smaller than 0.5 mm are permitted, but shall not pass through the thickness to the base metal.

b) Hardness test

A hardness test with at least 5 indentations shall be performed. The hardness in the microsection shall obtain the values guaranteed by the spraying layer producer.

c) Metallographic examination and measurement of sprayed layer thickness

A microsection transverse to the spraying direction of the layer and the base metal shall be taken.

The layer thickness shall be determined by measurement on the microsection.

The layer shall be evaluated with respect to microcracks, porosity, inclusions and spalling from the base metal and in the layer itself.

(3) Certificates

All tests/inspections required according to this Section shall be verified by means of an inspection certificate 3.1 in accordance with DIN EN 10204.

8.6.4.8 Procedure qualification for lock welds

(1) Test coupons

The test coupons for qualification on lock welds (e.g. on threaded mechanical fasteners such as bolts, studs, nuts and similar threaded parts) shall be adapted to the performance and conditions of component welding.

(2) Inspections, examinations and requirements

The test coupons shall be subjected to the following inspection and examination:

a) Visual examination

The weld surfaces shall be subjected to a visual examination for surface cracks.

b) Metallographic examination

A macrosection transverse to the weld including the heat affected zone and the base metal shall be taken. Macroscopic overview photographs shall be taken from the entire weld including heat affected zone and base metal. The examination shall be documented by overview photographs.

In the course of this process an examination for lack of fusion and weld imperfections shall be made.

(3) Certificates

The manufacturer shall establish test records on all the aforementioned non-destructive examinations which shall be signed by himself and be countersigned by the plant vendor.

The manufacturer shall establish an inspection certificate 3.1 in accordance with DIN EN 10204 which shall be countersigned by the plant vendor.

8.6.4.9 Procedure qualification for welded control rod guide inserts

(1) Test coupon

A test coupon shall be welded in accordance with **Figure 8-10**.

(2) Inspections, examinations and requirements

The test coupons shall be subjected to the following inspection and examination:

a) Visual examination

The weld surfaces shall be subjected to a visual examination for surface cracks.

b) Metallographic examination

One macrosection each transverse to the weld connection between tube/plate and rod/plate shall be prepared. A macroscopic overview photograph shall be made of the entire weld including the heat affected zone and the base metal. The macrosection shall be documented by an overview photograph.

In the course of this process an examination shall be made for lack of fusion and weld imperfections.

(3) Certificates

The manufacturer shall establish a record on all the aforementioned non-destructive examinations which shall be signed by himself and be countersigned by the authorized inspector.

All metallographic examinations shall be certified by inspection certificate 3.2 in accordance with DIN EN 10204.

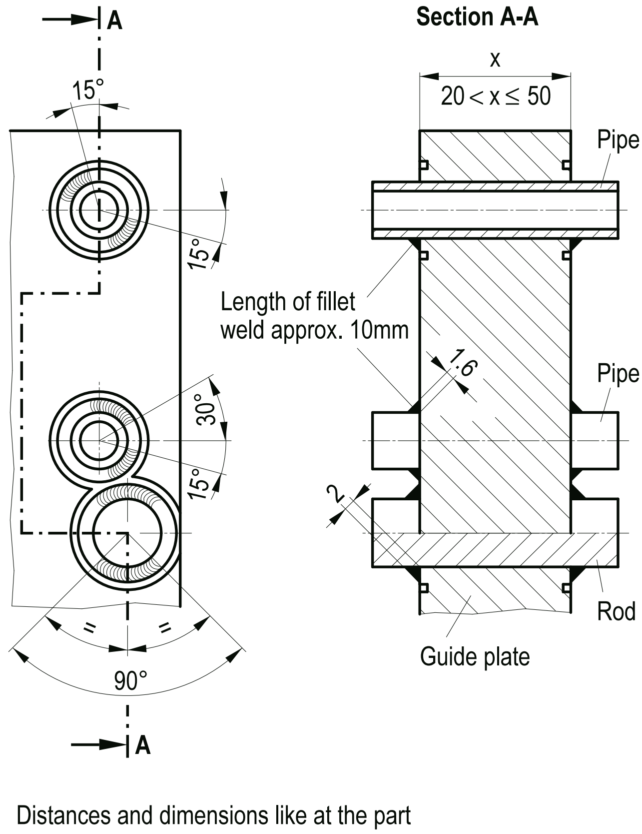


Figure 8-10: Dimensions of test coupon for welded control rod guide assemblies

8.6.4.10 Procedure qualification for spot welds

(1) Test coupons

The test coupons shall be prepared to meet the performance requirements and conditions, of component welding. At least one test coupon with ten spot welds per electrode pair used shall be welded.

(2) Test, examinations and requirements

The test coupons shall be subjected to the following tests and examinations:

a) Visual examination

A visual examination for surface condition and surface defects shall be made on all test coupons.

Light-brown to light-blue discolouration is permitted. Discolouration beyond that like dark-blue to black is not permitted.

The plate surface shall be smooth and free from cracks as well as from material and electrode deposits and sharp weld upsets.

b) Peel test

The welded plates shall be pulled apart vertically to their surfaces until the individual connections break apart.

The plates shall be separated by peeling outside the weld nugget.

c) Metallographic examinations

On two weld spots per electrode pair one macrosection and transverse to the specimen longitudinal axis shall be prepared. The dimensions D, s'_1, and s'_2 of the weld nugget and the electrode indentation depth shall be determined (see **Figure 8-11**). The examination shall be documented by overview photographs and microsection photographs.

The fusion shall be not more than 80 % of the respective wall thickness. End-of-gap cracks are not permitted. Process-related inclusions and shrinkage cavities are only permitted in the middle of the weld nugget.

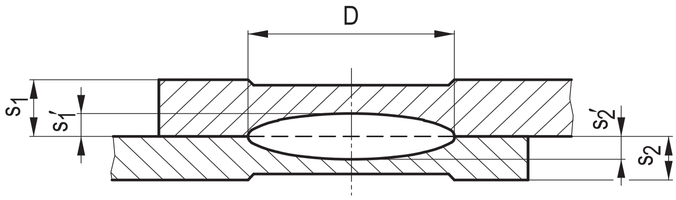


Figure 8-11: Dimensions of weld nugget and depth of electrode marking for spot welds

(3) Certificates

The manufacturer shall establish a test record on the non-destructive examination which shall be signed by him and be countersigned by the plant vendor.

All mechanical tests and metallographic examinations shall be documented by inspection certificates 3.1 acc. to DIN EN 10204 and shall be countersigned by the plant vendor.

8.6.5 Report about procedure qualification test

(1) Within 6 weeks after completion of welding, brazing or spraying work the manufacturer shall draw up a report on the procedure qualification test which shall be accompanied within another 6 weeks by a written statement of the authorized inspector (in the case of procedure qualification tests according to Sections 8.6.4.3 to 8.6.4.5 and 8.6.4.9), or by the plant vendor (in the case of procedure qualification tests according to Sections 8.6.4.6 to 8.6.4.8 and 8.6.4.10).

(2) The manufacturer's report shall contain the following:

a) certificates for base metals, welding and brazing filler metals and consumables as well as for fluxes for thermal spraying,
b) test and inspection sequence plan,
c) information on the performance of welding, brazing or thermal spraying (e.g. type of equipment),
d) welding or brazing procedure sheet or thermal spraying instruction and welding, brazing or thermal spraying record,
e) heat treatment plan and heat treatment record,
f) specimen-taking plan,
g) results of all tests/examinations.

(3) The authorized inspector's or plant vendor's written statement shall contain:

a) a summarized final result,
b) a final evaluation,
c) a limitation of the scope.

8.6.6 Retention of remainders

Remainders of specimens and test pieces and untested specimens shall be kept at the manufacturer's works until successful completion of the first production control test for extending the period of validity of the procedure qualification test, however no longer than 24 months.

8.7 Production control test

(1) The period of validity of the procedure qualification test according to clause 8.6.2.12 may be extended by production control tests.

(2) The period of validity of the procedure qualification test is extended in its entire scope, provided the production control test is within the scope of the procedure qualification.

(3) The requirements specified in Section 8.6.4 shall be met for tests, examinations, requirements and certifications of production control test.

(4) The report about production control test shall be shall drawn up according to Section 8.6.5.

(5) Remainders of specimens and test pieces and untested specimens shall be kept at the manufacturer's works until successful completion of the next production control test for extending the period of validity of the procedure qualification test, however no longer than 24 months.

8.8 In-process inspections

8.8.1 Final inspections

(1) Required tests and examinations shall be performed as specified in the final inspection sheet, **Table 8-6**.

(2) Requirements regarding the type and extent of non-destructive examinations result from stipulations in **Table 8-6**, in Section 6.1.6 and in **Table 6-1** and shall be specified in the course of design approval.

(3) The radiographic examinations may be performed before the final heat treatment.

(4) The tests and examinations shall be performed by the manufacturer. The plant vendor and the authorized inspector shall take part in these tests and examinations to the required extent.

8.8.2 Preservation of identification marking on materials and parts

(1) The material identification marking of the product forms as laid down in Section 7 shall be maintained during fabrication, testing and further processing or be transferred in due consideration of the following sections.

(2) During transfer of identification marking abbreviations may be used. They shall be clear enough such that all test results can be easily retraced.

(3) Of the parts in quality class AS-RE 3 only the parts for inside the Reactor Pressure Vessel have to be marked.

(4) In the case of product forms to be certified with inspection certificate 3.2 acc. to DIN EN 10204 the transfer of identification marking shall be effected by the authorized inspector.

(5) In the case of parts from product forms to be certified with inspection certificate 3.1 acc. to DIN EN 10204 the transfer of identification marks shall be effected by the manufacturer's employee authorized to transfer identification marks by stamping.

(6) Marking shall normally be effected by means of low-stress steel stamps.

(7) In the case of limited possibility of transferring identification markings, vibration markers may be used.

(8) For parts which for functional or material related reasons cannot be identification marked as described above, colour stamps or tags may be used to ensure correlation between certificate and part until the part has been installed in the component (e.g. springs). In the case of small parts, no marking is required if the manufacturer takes measures to ensure that a correlation between the part and the starting material certificate is possible.

8.8.3 Production control tests for brazing work, spot welding and thermal spraying

The following production control tests shall be performed:

(1) High-temperature brazing

a) To confirm the results obtained from procedure qualification production control test specimens shall be submitted. For high-temperature brazed control rod guide inserts this may e.g. be done by placing accompanying production control specimens in the top, middle and bottom part of each furnace lot.

b) The test specimen shall show the same geometry as the brazed component.

c) Regarding the tests, examinations and requirements 8.6.4.5 applies.

(2) Spot welding

a) In the case of spot welds a production control test at the beginning of each shift and in the case of change of electrode as well as with the occurrence of any abnormality in the weld shall be performed.

b) Regarding the test examinations and requirements 8.6.4.10 applies.

(3) Thermal spraying

a) In the case of thermal spraying a production control test shall be performed at the beginning of each shift, in the case of readjustment of the spraying equipment as well as when a new flux batch is used.

b) Regarding the tests, examinations and requirements 8.6.4.7 applies.

8.8.4 Dimensional checks and functional testing

(1) Dimensional checks

a) All dimensions of parts that have alignment, limiting or guiding functions to ensure an operationally safe assembly, disassembly and handling of reactor pressure vessel internals of quality classes AS-RE 1 to 3 and the core components shall be measured.

b) Dimensional checks shall be performed on components of reactor pressure vessel internals of quality classes AS-RE 1 to 3 which guide and align the fuel assemblies control rods and the core instrumentation.

c) The major dimensions required for the verification of strength of components of quality class AS-RE 1 shall be measured.

(2) Functional testing

For components of quality class AS-RE 3 functional tests under operational conditions shall be performed on all types of interlocking devices, motive equipment and operational controls.

8.8.5 Certificates

(1) The results of the tests and examinations shall be documented either in test records or as certification stamping in the test and inspection sequence plan.

(2) The certification stamping in the test and inspection sequence plan shall be performed only after the test has been performed and all requirements have been met.

(3) Test records shall be established by the manufacturer and shall be signed by the involved persons. Marking transfer certificates shall be established when short designations are introduced.

IN-PROCESS AND FINAL INSPECTION SHEET	Certification		Participation of		
- reactor pressure vessel internals	Records	Stamping	AS-RE 1	AS-RE 2	AS-RE 3
0 Check of manufacturer's evaluation (audit)	—	X	A, S	A, S	A, S 2)
1 Tests/examinations prior to manufacture **1.1** Identification of product forms, filler metals and brazing alloys a) Check for completeness of the materials documentation b) Check of product forms for identification marking	—	X	H	H	H
1.2 Marking transfer a) product forms with certificates 3.1 in accordance with DIN EN 10204 b) product forms with certificates 3.2 in accordance with DIN EN 10204	 X 1) X 1)	 X X	 H S	 H S	 H S
1.3 Receiving inspection of prefabricated subcontracted parts a) Check for completeness of the documentation b) Check for identification marking	—	X	H	H	H
1.4 Check for procedure qualification	—	X	H, S	H, S	—
1.5 Check for welder's qualification	—	X	H, S	H, S	H
2 Welding works **2.1** Welding supervisory a) establishment of welding records by the manufacturer b) signing of the welding record by the authorized inspector	X	—	H, S	H	H
2.2 Liquid penetrant examination of the root run or machined flush root	—	X	H, S 3)	H	H 2)
2.3 Progressive liquid penetrant examination	—	X	H, S 3)	H	H 2)
2.4 Liquid penetrant examination of the welding surface in finished condition Note: a) in the as-welded condition or b) after the final heat treatment c) after the last machining	X	—	H, S	H	H
2.5 Liquid penetrant examination on areas of removed auxiliary welds (oversize ≤ 5 mm)	—	—	H	H	H 2)
2.6 Visual testing of the welding surface in finished condition	—	X	H, S	H	H
2.7 Radiography	—	X	H, S	H	H 2)
2.8 Supervision of heat treatment	X	—	H	H	H 2)
2.9 Evaluation of the spot-welding in-process inspection data	X	—	H	H	H 2)
3 Tests / examinations during brazing works **3.1** Visual inspection of tack welds	—	X	H	H	H 2)
3.2 Supervision of brazing process - signing of the brazing record	X	—	H, S	H	H 2)

Table 8-6: In-process and final inspection sheet [see clause 8.8.1 (1)]
(continued on next page)

IN-PROCESS AND FINAL INSPECTION SHEET	Certification		Participation of		
- reactor pressure vessel internals	Record	Stamping	AS-RE 1	AS-RE 2	AS-RE 3
3.3 Visual examination of the brazed joint Check for completeness and discolouration of the brazed joint	—	X	H, S	H	H 2)
3.4 Evaluation of the in-process inspection data	X	—	H, S	H	H 2)
4 Dimensional check in accordance with the measurement plan					
4.1 Check of measuring equipment and templates before each use	—	X	H	H	H
4.2 Functional dimensions measurement	X	—	H, A	H, A	H
4.3 Integral measurement of dimensions with influence on the free passage of control rods	X	—	H, A, S	H, A, S	H, A, S
4.4 Measurement of dimensions relevant for stress analysis	X	—	H, A, S	—	—
5 Functional test of tools	X	—	—	—	H, A, S
6 Cleanliness inspection a) upon completion of manufacturing b) randomly upon assembly on the site	—	X	H, A	H, A	H, A 2)
7 Check and release of documentation	X	—	H, A, S	H, A, S	H, A 2), S 2)

1) Record only required if abbreviations have been established.

2) Only for parts inside the Reactor Pressure Vessel

3) Participation of authorized inspector only in the case of weld quality classes A and B in accordance with **Table 8-3**.

A : Plant vendor
H : Manufacturer
S : Authorized inspector

Table 8-7: In-process and final inspection sheet [see clause 8.8.1 (1)] (continued)

8.9 Requirements for non-destructive examinations and evaluation of test results

8.9.1 General requirements

(1) Procedural requirements for non-destructive examinations are specified in 7.3.5.8. Visual testing shall be performed according to DIN EN ISO 17637 in consideration of the requirements of DIN EN 13018 for local visual testing.

(2) Where several test methods are used to detect internal or external defects, the final evaluation of the usability of the part shall be made taking the test results obtained from all test methods into account.

(3) When examining the cover and back weld passes of completed welded joints for surface defects, all accessible surfaces of the weld including the adjacent base metal surfaces shall be examined.

(4) The progressive surface examination shall be performed as follows:

a) For workpiece thicknesses smaller than or equal to 13 mm the root and each subsequent pass, for workpiece thickness greater than 13 mm the root and the subsequent passes upon reaching 1/3 of the workpiece thickness, but at least upon reaching approx. 13 mm, shall be checked for surface cracks. The cover passes shall be examined.

b) For single-layer welds this condition is covered by the examination of the cover pass.

8.9.2 Evaluation of test results

8.9.2.1 Evaluation of welded joints, locations of removed temporary welds and hard surfacing layers

8.9.2.1.1 Surface examination

(1) The requirements of **Table 8-7** are considered acceptance standards for the surface examination of welded joints.

(2) At locations where temporary weld attachments have been removed, no crack-like discontinuities are permitted.

(3) On hard-surfacing layers

a) linear indications are not permitted,

b) single pores with a bleed-out smaller than or equal to 6 mm and an effective extension smaller than or equal to 1.5 mm up to 10 in number per square decimetre of hard-surfacing layer at a minimum distance of 3 mm of the edges of indications are permitted.

8.9.2.1.2 Radiography

(1) Cracks and lack of fusion detected by radiography are not permitted. In the evaluation of the undressed root of single-side welds acceptance level B according to DIN EN ISO 5817 shall apply to root imperfections.

(2) The allowable individual and cumulated lengths are specified in **Table 8-8**. If the distance between two adjacent

inclusions in the weld direction is greater than two times the length of the larger of the two inclusions, each of the two inclusions shall constitute an individual defect. In the case of inclusions smaller than 10 mm in length, these distance conditions do not apply, provided the total length of this area does not exceed the maximum permissible length for individual defects.

(3) Pores not occurring systematically are permitted. If pore clusters occur over larger weld lengths (greater than 6 times the wall thickness), they shall be regarded as systematic defects. Local pore concentrations in the form of pore clusters (e.g. more than 10 pores at an area with a diameter of approximately 20 mm) are only permitted if they are isolated (e.g. three clusters per meter of weld length). Worm-holes which are vertical to the surface are only permitted as isolated defects in multi-layer welds. Worm-holes which are parallel to the surface shall be evaluated like inclusions in accordance with para (2).

8.9.2.1.3 Visual testing

The following acceptance levels acc. to DIN EN ISO 5817 shall apply to surface imperfections; however, the imperfection type micro-lack of fusion shall not be considered for the assessment:

a) acceptance level B for parts of quality classes “AS-RE 1”, “AS-RE 2” and “AS-RE 3 inside the RPV”,

b) acceptance level C for parts of quality class “AS-RE 3 outside the RPV”.

8.9.2.2 Evaluation of brazed joints

The evaluation of the visual brazed joint examination shall be performed in accordance with 8.6.4.5 (2) a).

8.9.2.3 Evaluation of thermally sprayed layers

The evaluation of the visual examination of thermally sprayed layers shall be performed in accordance with 8.6.4.7 (2) a).

Wall thickness of welded joint	Indications ≤ 1.5 mm	Indications > 1.5 mm up to ≤ 3 mm	Indications > 3 mm
s > 3 mm	Not to be included in the evaluation	Up to 10 indications per metre of weld length	Not permitted
s ≤ 3 mm	No indications permitted		
The last evaluation time is decisive for the evaluation of the size of the indication, see clause 7.3.5.8.3.2.			

Table 8-7: Acceptance criteria for liquid penetrant testing of welded joints (see clauses 7.3.5.8.3.3 and 8.9.2.1.1)

Nominal wall thickness s [1)] of the connecting joint, mm	Allowable width, mm	Allowable individual length l, mm	Allowable accumulated length Σ l per reference length L = 6 · s [1)], mm
s ≤ 10	< 0.2 · s	≤ s	≤ s
10 < s ≤ 25	≤ 2	≤ s	≤ 1,5 · s
25 < s ≤ 40		≤ 25	
40 < s ≤ 60		≤ 30	
60 < s ≤ 120		≤ 40	≤ 2 · s
s >120		≤ 50	
[1)] s_1 for welds on set-on nozzles and attachment welds (single bevel and double bevel groove welds)			

Table 8-8: Acceptance criteria for the evaluation of inclusion-type indications detected by radiographic testing

9 Operational monitoring and inspection

9.1 Scope

This section covers the inspections and measurements to be performed and the monitoring of reactor pressure vessel internals during commissioning, operation and refuelling.

9.2 Points in time of inspection

Table 9-1 contains a list of points in time of inspection as well as data for pressurized water reactors to specify which inspections may be or shall be performed at the mentioned points in time. The points in time at which vibration measurements and inspections have to be performed are necessarily bound to the individual steps of commissioning. Depending on which commissioning steps are to be taken, differing procedures are to be followed.

9.3 Inspections

9.3.1 General requirements

(1) At the points in time specified in **Table 9-1**, the components shall be subjected to the inspections specified in **Tables 9-2** to **9-5**. In this case the inspections prescribed for point in time B in **Tables 9-2** and **9-3** may be performed in full or in part already at the time of completion of fabrication on the site.

(2) The components mentioned are shown in **Figure 3-1** for typical reactor pressure vessel internals for pressurized water reactors and in **Figure 3-2** for typical reactor pressure vessel internals for boiling water reactors.

(3) The inspections mentioned in **Tables 9-2** to **9-5** may also be performed simultaneously during one inspection step.

(4) Additional disassembly of RPV internals or other components in the reactor pressure vessel in excess of the planned

inspections is not required for the performance of the integral visual examination in accordance with **Tables 9-2** to **9-5**.

For the selective visual examination as per **Tables 9-2** to **9-5** the disassembly of additional components in the RPV may be required. The extent of these required measures shall be fixed with respect to the plant in consideration of the planned inspection activities, especially in the case of the operationally required disassembly of RPV internals or e.g. internal axial pumps or fuel assembly peripheral location. The knowledge on the materials used, the fabrication, the operational loadings on the RPV internals shall be considered when fixing the plant-related extent of selective visual inspections. It is permitted to limit selective visual examinations to representative locations of RPV internals.

(5) At each refuelling, a selective visual examination shall be performed at the load attachment points of components the disassembly of which is required for operational reasons with the components located on the internals storage pit. Load-attachment points of components the disassembly of which is not required for operational reasons, shall be subjected to a selective visual examination prior to using them. Where defects impairing safety are detected, the load-attachment points shall not be used until removal of the defects.

9.3.2 Requirements for visual examination

(1) DIN 25435-4 applies regarding the requirements for the inspection procedure, inspection personnel, the authorized inspector involved and auxiliary equipment used as well as for the performance of visual examinations.

(2) To provide a basis for comparison of integral visual examinations, image records (e.g. photographs, video records) shall be made prior to the first trial run. The details shall be fixed in relation to the plant.

(3) The selective visual examination for cracks shall guarantee that details of a wire with a diameter 0.025 mm or actual cracks in a reference block can be recognized. The reference block shall consider the surface condition of the areas to be inspected. The recognizability of details with the equipment used including the required boundary conditions, such as distance, orientation, lighting equipment selected shall be documented.

9.3.3 Inspection sequence program for inspections

(1) The inspections and examinations to be performed in accordance with **Tables 9-2** to **9-5** shall be listed in a plant-related test and inspection sequence program. The plant-related test and inspection sequence program shall contain at least the following information:

a) the exact inspection areas,

b) the inspection intervals,

c) the extent of inspection for each component, sub-unit or part, which within the inspection interval may be subdivided into partial inspections,

d) the inspections and examinations to be performed after each refuelling cycle (e.g. integral visual examination for presence of foreign matter),

e) the mechanized inspection equipment,

f) the parties involved in the inspection.

(2) The tests and inspections to be performed at points in F and G shall be entered in the test and inspection handbook. The requirements of KTA 1202 shall be considered.

(3) The inspection intervals shall be fixed in consideration of the in-service test and inspection intervals on the reactor pressure vessel.

(4) When determining the type and extent as well as locations of tests and inspections to be performed for the approaching refuelling activities, the results of vibration and loose-parts monitoring shall be evaluated to find out whether relevant changes with respect to former results of operational monitoring are available and have to be evaluated.

9.3.4 Assessment of as-built condition

Where conspicuous features are detected by the inspections, decision shall be made in each individual case whether and which additional examinations and measures are required (e.g. increase of extent of inspections, use of supplementary examination procedures). If additional non-destructive test methods are applied, the tests shall be performed in accordance with the relevant standard of standard series DIN 25435.

Note:

The images recorded of representative locations as per clause 9.3.3 serve as reference for the selective visual and the other inspections.

When assessing the as-built condition, it shall be taken into account that components are subject to changes of the surface during plant operation (e.g. discolouration, flow marks, die marks due to handling).

9.3.5 Documentation of inspections

(1) A record shall be established on each inspection performed to document the type, extent, auxiliary and other equipment used, as well as the results of the inspections including the deviations, if any, from the reference condition (e.g. by photographs).

(2) The documentation shall be made in accordance with Section 5. DIN 25435-4 applies with respect to the extent of documentation.

(3) The inspections of the load-attachment points and the repair work performed shall be documented in accordance with Section 5.

9.4 Vibration measurements

9.4.1 General requirements

For reactor pressure vessel internals it shall be proved that they are capable of withstanding the permanent or temporary vibration loadings during the reactor service life. For components of quality class AS-RE 2 vibratory loadings shall only be determined if no operational experience with these components exist. In the following only experimental measures are dealt with to demonstrate the acceptability of operational vibratory loadings. The stress analysis is dealt with in Section 6.2.

The experimental analysis (vibration measurement program) is an alternative to substitute an analytical proof. The measurement program may deliver:

a) dynamic characteristics, e.g. natural frequency,

and

b) dynamic load and stress values for selected measurement location and measured values, which occur during the possible operational conditions.

9.4.2 Classification of reactor pressure vessel internals for vibration measurements

With respect to the objectives of the vibration measurement program there are differing requirements as to its extent which depends on the extent of assured knowledge of the characteristic and stress values required for the structural analysis and the stress analysis. To this end, reactor pressure vessel internals shall be classified into various classes with respect to vibration measurements depending on the design, operational parameters and experience:

(1) Prototype plant

An arrangement of reactor pressure vessel internals which due to their design, size or operating conditions represent the first plant of this kind for which no reference plant is available.

(2) Reference plant

A plant for which a vibration measurement program was performed successfully with the result during commissioning no inadmissible dynamic loadings occurred.

(3) Modified prototype plant

An arrangement of reactor pressure vessel internals the loadings or operating conditions of which deviate in part from the reference plant and where in some cases it cannot be demonstrated by available measuring results and analyses or a combination of measuring results and analyses, that deviations from the reference plant do not have any essential influence on the dynamic behaviour of the reactor pressure vessel internals.

(4) Follow-up plant

An arrangement of reactor pressure vessel internals with essentially the same loading and operating conditions as well as the same design dimensions as the reference plant. By available measuring results and analyses it can be demonstrated that deviations, if any, do not have an essential influence on the dynamic behaviour of the reactor pressure vessel internals.

9.4.3 Measures

The structural analysis (6.2.4.2) or the experimental fatigue analysis (6.2.4.3.5) may be replaced by the vibration measurement program and the inspection sequence program acc. to 9.3.3 for inspection points in time A to F acc. to **Table 9-1**.

9.4.3.1 Vibration measurement program for prototype plant

During commissioning a vibration measurement program shall be performed to demonstrate dynamic loadings and the resulting dynamic movements and loadings occurring during steady-state and non-steady-state normal operation.

(1) Test program

Prior to the beginning of measurements a test program shall be established to describe:

a) the locations and orientations of measurement as well as the measured variables including the frequency and amplitude ranges to be considered. The locations of measurement shall be selected such that all movements, loadings and stresses of the component required for experimental fatigue evaluation are covered.

b) the measurement procedure to indicate which signals are to be processed, stored and indicated in which way. In addition, it shall be indicated which signals are to be evaluated in which way immediately on the site to ensure the required measuring quality and to avoid inadmissible dynamic loadings.

c) the steady-state and non-steady-state operating conditions at which measurements are to be made as well as - assigned to the operating conditions - the duration of recording (measuring time).

d) the planned duration of operation under normal operating conditions to ensure that each component subject to dynamic loading has been subjected to at least 10^6 load cycles (for the lowest frequency at which the component shows a considerable frequency response) prior to the final inspection of the RPV internals.

e) the sensors and their characteristic data including usable frequency and amplitude values.

f) the equipment for signal processing, storage, indication and evaluation with respect to the properties influencing the quality of the results.

g) deviations, if any, from normal operating conditions.

h) further boundary conditions influencing the measuring result.

(2) Performance of measurements

The measurements shall be made to comply with the test program. Where unexpected measured values are taken, the responsible head of the test program shall supplement or modify the test program. Where required, recommendations regarding the various operating conditions shall be given to the person responsible for operation or structural analysis.

(3) Documentation of results

The results of the measurements made including all considerable deviations from the test program as well as defaults on the measuring equipment that have occurred during the measuring process shall be documented.

The results of the measurements and the inspections according to Section 9.2 shall be correlated.

9.4.3.2 Vibration measurement program for modified prototype plant

(1) The extent of the measuring program may be reduced to a representative movement or loading (control measurement) if it can be shown by comparison of the magnitudes relevant to vibration behaviour that the deviations compared to a valid reference plant are negligible.

(2) If this proof cannot be rendered partially the measurement shall be extended such that besides the control measurement for the proved component sufficient experimental data are also available for the part deviating from the reference plant.

(3) The requirements of 9.4.3.1 apply to the control program, performance of measurements and documentation of results.

9.4.3.3 Vibration measurement program for follow-up plants

For follow-up plants no vibration measurement program is required.

9.5 Vibration monitoring

(1) For the early detection of changes in the vibration behaviour of reactor pressure vessel internals the latter shall be monitored during operation.

(2) In pressurized water reactors the system shall be designed and monitoring be performed in accordance with DIN 25475-2.

(3) Monitoring shall be performed such that changes in the vibration behaviour can be detected at a representative location of the reactor pressure vessel internals.

Note:

The information is obtained by indirect measuring procedures (e.g. by measuring the neutron flux noise or the reactor pressure vessel movement).

With these measuring methods correspondence to the measure variables to be monitored shall be established.

(4) It shall be possible to perform vibration measurements at any time. Vibration measurements may be performed discontinuously.

(5) At least three measurements shall be performed during each fuel cycle. One of these measurements shall be per-

formed immediately after refuelling and one prior to the next refuelling at steady-state operation of the nuclear facility.

Note:

It is advisable to install a fixed vibration monitoring system such that the required measurements can be performed without additional installations.

(6) Where vibration monitoring is entirely or partially impossible due to failure of the measuring devices, it may be suspended until the next plant shutdown.

(7) The measures for performing vibration measurements as well as the measures to be taken if changes in the vibration behaviour of the reactor pressure vessel internals are detected, shall be fixed for each individual plant.

Note:

At the time being, there is no safeguarded indirect measuring method available for boiling water reactors.

9.6 Monitoring for loose parts

(1) For the early detection of damage the reactor pressure vessel internals shall be monitored for loose parts by means of a structure-borne sound measuring system. This system shall be designed and monitoring be performed in accordance with DIN 25475-1.

(2) Even in the case of failure of individual measuring channels of the structure-borne-sound measuring system, monitoring is considered to be ensured as long as loose parts can be detected in each monitored area in compliance with DIN 25474-1.

(3) In the case of failure of the entire structure-borne-sound measuring system monitoring may temporarily be carried out by other measures (e.g. activity measurements and chemical analysis of the primary coolant, vibration measurements on components).

<table>
<tr><th rowspan="3">Points in time of tests and inspections</th><th colspan="2">Inspections</th><th colspan="2">Vibration measurements</th></tr>
<tr><th rowspan="2">PWR</th><th rowspan="2">BWR</th><th colspan="2">Prototype plant and modified prototype plant</th></tr>
<tr><th>PWR</th><th>BWR</th></tr>
<tr><td>A
Trial run without core</td><td>none</td><td>none</td><td colspan="2">That part of the measuring program which is not influenced by the loading of the reactor core may be performed.</td></tr>
<tr><td>B
Prior to first loading of the reactor core with fuel assemblies</td><td colspan="2">The inspections mentioned in Tables 9-2 and 9-3 shall be performed prior to the first loading of the reactor core. Where a trial run to A has been performed, the inspections shall be performed after the trial run.</td><td>none</td><td>none</td></tr>
<tr><td>C
Trial run with core</td><td>none</td><td>none</td><td>The measurement program shall be performed except for that part which has been performed successfully at point in time of inspection A.</td><td>That part of the measurement program may be performed which is not influenced by duty operation such that the results deviate for the specified values.</td></tr>
<tr><td>D
Upon trial run with core, however, prior to nuclear operation</td><td>The inspections mentioned in Table 9-2 shall be performed. This does not apply to follow-up plants according to 9.4.2(4).</td><td>none</td><td>none</td><td>none</td></tr>
<tr><td>E
Duty operation, first fuel cycle</td><td>none</td><td>none</td><td>none</td><td>The measurement program shall be performed except for that part which has been successfully performed at points in time of inspection A and C.</td></tr>
<tr><td>F
Upon completion of the first and prior to the beginning of the second fuel cycle</td><td rowspan="2">The inspections mentioned in Table 9-4 shall be performed in accordance with a plant-related test and inspection sequence program according to clause 9.3.3.</td><td rowspan="2">The inspections and selective visual inspections mentioned in Table 9-5 shall be performed in accordance with a plant-related test and inspection sequence program according to clause 9.3.3.</td><td>none</td><td>none</td></tr>
<tr><td>G
Specified normal operation after beginning of the second fuel cycle</td><td>none</td><td>none</td></tr>
</table>

Table 9-1: Points in time of inspections and vibration measurements for pressurized water reactors (PWR) and boiling water reactors (BWR)

no.	Components, sub-units and parts	Time of testing	
		B	D
1	Upper core structure	(1), (2), (3), (4), (5), 8	(1), (2), (3), (4), (5), 8
1.1	Top plate / upper support plate	—	—
1.2	a) Vertical support / Control rod guide tubes b) Support structure shroud	—	—
1.3	Tie plate /upper tie plate	—	—
1.4	In-core instrumentation tube	7 [a)]	7 [f)]
1.5	Spring assembly	3, 4, 7	3, 4, 7
1.6	Control rod guide assembly	7 [a)]	7 [f)]
1.7	Load attachment points	—	—
2	Lower core structure	(1), (2), (3), (4), (5)	(1), (2), (3), (4), (5)
2.1	Tie plate alignment / upper tie plate	—	—
2.2	Core shroud (KU) including bolts	6 [b)]	6 [b)]
2.3	Core support / lower tie plate	—	—
2.4	Flow distribution plate	—	—
2.5	Core barrel flange	6 [c)]	6 [c)], 8
2.6	Core barrel including bolts	2, 6 [d)]	6 [d)]
2.7	In-core instrumentation tube	7 [a)]	7 [f)]
2.8	Bypass assembly	7 [e)]	7 [e)]
2.9	Specimen container tubes	2, 3, 4	2, 3, 4
2.10	Load attachment points	—	—
3	Stand / flow skirt	1, 2, 3, 4, 5	1, 2, 3, 4, 5, 8
4	Stand brackets	1, 3, 4, 5	1, 3, 4, 5, 8
5	Core barrel alignment	1, 3, 4, 5	1, 3, 4, 5, 8
6	In-core instrumentation nozzles	1, 2, 3, 4, 5	1, 2, 3, 4, 5, 8
7	Deflection limiters / Core alignment palms	1, 2, 4, 5	1, 3, 4, 5, 8

Explanations:

Type of inspection required:

1 : search for foreign matter
2 : visual inspection of welded joints
3 : visual inspection for completeness
4 : visual inspection for mechanical damage
5 : visual inspection of bolting joints
6 : dimensional check
7 : functional test
8 : visual inspection of mating surfaces
(1), (2) ... (5) : The inspection shall be performed at the specified point in time as integral inspection of large component surfaces. Individual sub-units shall only be inspected randomly.
1, 2, ... 8 : A selective inspection shall be performed at the specified point in time.

Footnotes:

a) check for free passage
Upon trial operation without core this inspection is only required if it has not been performed during fabrication on the construction site.

b) check of core shroud reference dimensions

c) check of radial clearance between core barrel flange and RPV

d) check of exit nozzle clearance between core barrel and RPV

e) check of flexibility

f) check for free passage
only required if the check has not been performed after trial operation without core

Note:
An inspection after fabrication on the construction site will not replace this inspection.

Table 9-2: Inspections on reactor pressure vessel internals of PWR at times B and D as per Table 9-1

no.	Components, sub-units and parts	Time of testing
		B
1	Core shroud	(1), (2) [a], (3), (4), 8 [b]
2	Downcomer space cover	(1), (2), (3), (4), 6 [c], 8 [c]
3	Pump seals	1, 2, 3, 4, 5, 6 [d], 7, 8
4	Control rod guide tubes	(1), (3), (4)
5	Core plate	(1), (2), (3), (4), (5)
6	Upper core grid	(1), (2), (3), (4), (5), 8 [e]
7	Feed water sparger	(1), (2), (3), (4), (5), 7 [f], 8
8	Alignment tracks	3, 4
9	Steam separator	(1), (2), (3), (4), (5), 7 [g], 8
10	Steam dryer	(1), (2), (3), (4) [h], (5), 7 [j], 8
11	Core flux measurement tube assembly	(2) [k], (3) [k], (4) [k]
12 12.1	RPV parts Brackets for a) Steam dryer b) Alignment tracks c) Specimen containers d) Feed water sparger e) Downcomer space cover f) Instrumentation	(1) [k], (3) [k], (4) [k], (5) [k], (8) [k]
12.2	Thermal sleeves for a) Feed water sparger b) Core flooding system c) Head spray cooling device	(1) [k], (3) [k], (4) [k], (5) [k], (8) [k]
13	Core flooding system	(1), (2), (3), (4), (5), 7 [f], 8

Explanations:

Type of inspection required:

1 : search for foreign matter
2 : visual inspection of welded joints
3 : visual inspection for completeness
4 : visual inspection for mechanical damage
5 : visual inspection of bolting joints
6 : dimensional check
7 : functional test
8 : visual inspection of mating surfaces

(1), (2) ... (8) : The inspection shall be performed at the specified point in time as integral inspection of large component surfaces. Individual sub-units shall only be inspected randomly.

1, 2, ... 8 : A selective inspection shall be performed at the specified point in time.

Footnotes:

a) except weld between core shroud and RPV

b) mating surface with steam separator

c) ca) gap downcomer space cover / RPV
cb) seat downcomer space cover / core shroud
cc) aps downcomer space cover / support on RPV or core shroud

d) gap pump seal / pump

e) mating surface with steam separator

f) functional test of locking devices

g) functional test of locking devices during installation after refuelling

h) visual inspection of locking devices

j) functional test of hold-down elements

k) where accessible

Table 9-3: Inspections on reactor pressure vessel internals of BWR at time B as per Table 9-1

No.	Components, sub-units and parts	Extent of inspection	Inspection interval [1] [2]
1	Upper core structure	Integral visual inspection a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints f) of contact surfaces	Interval for non-destructive examination on RPV
1.1	Top plate/upper support plate	Integral visual inspection for search of foreign matter	1 refuelling cycle
1.2	a) Vertical supports/control rod guide tubes	Integral visual inspection a) of welded joints b) for mechanical damage c) of bolted joints	Interval for non-destructive examination on RPV
	b) Support structure shroud	Integral visual inspection a) of welded joints b) of bolted joints	
1.3	Tie plate/upper tie plate	Integral visual inspection a) of fuel assembly centering for completeness b) of contact surfaces of the support plate centering guide, of the fuel assembly centering and of pressure marks of fuel element hold-down plate for mechanical damage	1 refuelling cycle
1.4	Spring assembly	1. Selective visual inspection of projecting bolts and attachment of hold-down plates for mechanical damage	Interval for non-destructive examination on RPV
		2. Functional test of hold-down assembly a) by checking of spring characteristic or	Interval for non-destructive examination on RPV
		b) by combination of [3] ba) continuous measurements and monitoring of tendency of rocking motion of the RP/core barrel and	Evaluation at least three times between two refuelling cycles
		bb) checking of spring characteristic	Triple interval for non-destructive examination on RPV
1.5	Control rod guide assembly	Functional test for checking freedom of movement , e.g. with control rod, test block	1 refuelling cycle
1.6	Load attachment points	a) Selective visual inspection for completeness, cracks, deformation, wear and corrosion [4] b) Selective visual inspection of welded joints [4]	Acc. to para. 9.3.1 sub-cl. 5
2	Lower core structure	Integral visual inspection a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints f) of contact surfaces	Interval for non-destructive examination on RPV
2.1	Alignment of tie plate/upper tie plate on core barrel side	Integral visual inspection for mechanical damage (frictional damage)	Interval for non-destructive examination on RPV
2.2	Core shroud including core shroud bolts both on the core shroud and core barrel side	a) Integral visual inspection [5] of bolt heads, of locking weld or mechanical locking of core shroud bolts both on the core shroud and core barrel side b) Integral visual inspection of the core shrouds for contact points of fuel assembly top end pieces and bottom end pieces	Interval for non-destructive examination on RPV
2.3	Core support/lower tie plate	Integral visual inspection a) of fuel element set-down plate for foreign matter b) for completeness (especially of fuel assembly centering) c) for mechanical damage	
2.4	Flow distribution plate	Integral visual inspection for foreign matter	
2.5	Bypass assembly	Check for freedom of movement	

Table 9-4: Tests and inspections of RPV internals for pressurized water reactors (PWR) at points in time of inspection F and G as per Table 9-1 (continued on next page)

No.	Components, sub-units and parts	Extent of inspection	Inspection interval 1) 2)
2.6	Specimen container tubes	Integral visual inspection a) of welded joints b) for completeness c) for mechanical damage d) of bolted joints	Interval for non-destructive examination on RPV
2.7	Load attachment points	a) Selective visual inspection for completeness, cracks, deformation, wear and corrosion 4) b) Selective visual inspection of welded joints 4)	Acc. to para. 9.3.1 sub-cl. 5
3	Stand/flow skirt	1. Integral visual inspection a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints 2. Selective visual inspection of welded joints 4)	Interval for non-destructive examination on RPV
4	In-core instrumentation nozzles		
5	Core barrel alignment	1. Integral visual inspection a) search for foreign matter b) for completeness c) of bolted joints (if any) d) of contact surfaces 2. Selective visual inspection for mechanical damage	
6	Stand brackets		
7	Deflection limiters / core alignment palms		

1) The inspection interval is based on an average yearly interval between two refuelling cycles.

2) For inspection intervals as regards the RPV, see KTA 3201.4.

3) If operational monitoring measures are available with which deviations from the service function of the hold-down assembly can be detected.

4) The sensitivity shall such as to detect a wire with a diameter of 0.025 mm or natural defects (cracks) in the reference block.

5) Where the visual inspection leads to conspicuous indications, upon agreement with the authorized inspector ultrasonic testing shall be provided and be performed on a representative number of core shroud/barrel bolts.

Table 9-4: Tests and inspections of RPV internals for pressurized water reactors (PWR) at points in time of inspection F and G as per Table 9-1 (continued)

No.	Components, sub-units and parts	Extent of inspection	Inspection interval [4)]
1	Core shroud		
1.1	Outside surface of core shroud above downcomer space cover incl. upper and lower core shroud flange as well as internal surface of core shroud above upper core grid	Integral visual inspection a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage	4 refuelling cycles
1.2	Welded joints on core shroud outside above downcomer space cover	Selective visual inspection of welded joints and weld-adjacent zones [1) 3)]	4 refuelling cycles
1.3	Welded joints on core shroud outside below downcomer space cover	Selective visual inspection of welded joints and weld-adjacent zones [1) 2) 3)]	Depending on event [5)]
1.4	Welded joints on inside surface of core shroud	Selective visual inspection of welded joints and weld-adjacent zones [1) 2) 3)]	8 refuelling cycles
2	Downcomer space cover		
2.1	Downcomer space cover from the top	Integral visual inspection a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage	4 refuelling cycles
2.2	Welded joints in downcomer space cover from the top	Selective visual inspection of welded joints and weld-adjacent zones [3)]	4 refuelling cycles
2.3	Welded joints in downcomer space cover from the bottom	Selective visual inspection of welded joints and weld-adjacent zones [1) 2) 3)]	Depending on event [5)]
3	Pump seals	As far as accessible without the necessity of disassembling the pump: Integral visual inspection a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints f) of contact surfaces	4 refuelling cycles
4	Control rod guide tubes/ control rod guide thimbles	1. Integral visual inspection [1)] a) search for foreign matter b) for completeness c) for mechanical damage	8 refuelling cycles
		2. Selective visual inspection on dismounted control rod guide tube a) for mechanical damage b) of welded joints	Depending on event [5)]
5	Core plate		
5.1	Core plate from the top	1. Integral visual inspection [1)] a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage incl. the visible areas of T-head bolts as-installed and related brackets	8 refuelling cycles
		2. Selective visual inspection of welded joints and weld-adjacent zones [1) 2) 3)]	
5.2	Core plate from the bottom	Selective visual inspection of welded joints and weld-adjacent zones [1) 2) 3)]	Depending on event [5)]
6	Upper core grid	1. Integral visual inspection [1)] a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage incl. the visible areas of T-head bolts as-installed and related brackets	4 refuelling cycles
		2. Selective visual inspection of welded joints and weld-adjacent zones [1) 2) 3)]	8 refuelling cycles

Table 9-5: Test and inspections on RPV internals boiling water reactors (BWR) at points in time of inspection F and G as per Table 9-1 (continued on next page)

Nr.	Components, sub-units and parts	Extent of inspection	Inspection interval [4]
7	Feed water sparger	1. Integral visual inspection [1] a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints	4 refuelling cycles
		2. Functional testing of locking devices	
8	Alignment tracks	Integral visual inspection a) for completeness b) for mechanical damage	4 refuelling cycles
9	Steam separator	1. Integral visual inspection [1] a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints	4 refuelling cycles
		2. Functional testing of locking devices during re-installation	
		3. Selective visual inspection of load attachment points for completeness, cracks [3], deformation, wear and corrosion	Acc. to para. 9.3.1 sub-cl. 5
10	Steam dryer	1. Integral visual inspection [1] a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints	4 refuelling cycles
		2. Selective visual inspection of load attachment points for completeness, cracks [3], deformation, wear and corrosion	Acc. to para. 9.3.1 sub-cl. 5
11	Core flux measurement tube assembly	Integral visual inspection for mechanical damage [1]	Depending on event [5]
12	RPV parts		
12.1	Brackets for a) steam dryer b) alignment tracks c) specimen containers d) feed water sparger e) downcomer space cover (hold-down elements) f) instrumentation	Integral visual inspection a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints f) of contact surfaces	4 refuelling cycles
12.2	Thermal sleeves for a) feed water sparger b) core flooding system/ core spray system c) head spray cooling system	Integral visual inspection [1] a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage	4 refuelling cycles
13	Core flooding system / core spray system	Integral visual inspection [1] a) search for foreign matter b) of welded joints c) for completeness d) for mechanical damage e) of bolted joints f) of contact surfaces	4 refuelling cycles
14	Head spray cooling device	Integral visual inspection a) for completeness b) for mechanical damage	

[1] When selecting the inspection area, their accessibility shall be taken into account.
[2] Accessible areas without endangering the test equipment (no loose parts in the RPV).
[3] The sensitivity shall be such as to detect a wire with a diameter of 0.025 mm or natural defects (cracks) in the reference block.
[4] The point in time of inspection refers to a period of approximately 1 year between two refuelling cycles.
[5] The inspections (extent and intervals) depend on the events (e.g. dismantling of internal axial pumps, control rod guide tubes or edge fuel assembly elements, replacement of neutron flux measuring lances) and shall be determined for each facility.

Table 9-5: Test and inspections on RPV internals boiling water reactors (BWR) at points in time of inspection F and G as per Table 9-1 (continued)

Annex W
Materials

Annex W 1
Austenitic stainless steels

Contents:

W 1.1 Scope

This annex lays down the requirements regarding quality characteristics, type and extent of tests and examinations as well as the type of certificates for austenitic stainless steels. The requirements shall apply for the quenched or stabilised condition unless specified otherwise hereinafter.

W 1.2 Materials

W 1.2.1 Materials for quality class AS-RE 3 outside the RPV

All materials meeting the quality requirements in accordance with DIN EN 10088-2, DIN EN 10088-3, DIN EN 10216-5, DIN EN 10217-7, DIN EN 10222-5, DIN EN 10028-7, DIN EN 10250-4 or DIN EN 10272 are allowable. The tests and examinations to be performed, the extent of testing and the attestation of quality characteristics shall be taken from the materials test sheets (WPB) W 1.5.4 to W 1.5.6.

W 1.2.2 Materials for quality classes AS-RE 1 and AS-RE 2 as well as for parts of quality class AS-RE 3 inside the RPV

W 1.2.2.1 General requirements

(1) Materials no. 1.4306, 1.4541, 1.4550, 1.4571 and 1.4580 in accordance with DIN EN 10222-5, DIN EN 10216-5, DIN EN 10217-7, DIN EN 10028-7 or DIN EN 10272 with restricted chemical composition and mechanical properties in accordance with Sections W 1.2.2.2 to W 1.2.2.9 may be used.

(2) For parts inside the RPV of boiling-water reactors, which are subject to welding work (except for single-layer lock welds, the material no. 1.4450 shall be used.

(3) The requirements to be met by the manufacturers of the various product forms are laid down in clause 7.2.1.

(4) The tests and examinations as well as the certificates required are given in the materials test sheets (WPB) in Sections W 1.5.1 to W 1.5.3.

W 1.2.2.2 Steel-making process

The steel-making process is left to the manufacturer unless agreed otherwise in the order. Upon request, it shall, however, be made known to the purchaser.

W 1.2.2.3 Chemical composition

The materials shall only be used with the chemical composition according to **Table W 1-1**, which is restricted compared to the standard composition to the standards mentioned in Section W 1.2.2.1.

W 1.2.2.4 Heat treatment

Deviating from and in addition to the requirements of the standards mentioned in W 1.2.2.1

a) solution annealing shall be performed in any case,
b) a temperature of 1100 °C shall be the upper limit for solution annealing,
c) upon solution annealing cooling shall be effected at a sufficiently rapid cooling rate to exclude carbide precipitations.

W 1.2.2.5 Mechanical properties

The stipulations of the standards mentioned in Section W 1.2.2.1 apply.

Deviating from this requirement for the material with the material no. 1.4550 the requirements of **Table W 1-2** and **W 1-3** apply.

For forgings, bars and rings with a heat treated wall thickness not covered by DIN EN 10222-5 and DIN EN 10272 the stipulations of the material certification apply.

W 1.2.2.6 Physical characteristics

Typical values for the physical characteristics are specified in Annex E of DIN EN 10088-1 and in **Table W 1-4**.

W 1.2.2.7 Delta-ferrite content

The base material of parts which, in the course of further fabrication, will be subjected to welding, shall show a delta-ferrite content in the weld zone of between 2 and 10 %.

A continuous ferritic structure is not allowed in either case.

W 1.2.2.8 Evaluation of microstructure and determination of grain size

(1) The average grain size shall be determined and correspond to a characteristic index equal to or greater than 4 in accordance with DIN EN ISO 643. Deviations are allowed provided requirements regarding ultrasonic examinations according to Section 7.3.5.8.4 are not obstructed in any way.

(2) Structural constituents of the σ-phase that can be determined by metallography are not permitted.

W 1.2.2.9 Resistance to intergranular corrosion

The resistance to intergranular corrosion shall be demonstrated in accordance with DIN EN ISO 3651-2 procedure A.

The solution annealing shall be performed in accordance with clause 7.3.5.7 (1) f).

W 1.3 Non-destructive examinations

W 1.3.1 Ultrasonic examination

(1) Plate, sheet and strip

The stipulations of **Table W 1-5** shall apply for the ultrasonic examination of plates, sheets and strip.

(2) Forgings and bars
(heat treated wall thickness > 30 mm)

The stipulations of **Table W 1-6** shall apply for the ultrasonic examination of forgings and bars with heat treated wall thicknesses greater than 30 mm.

(3) Forged and rolled bars (heat treated wall thickness ≥ 20 mm up to ≤ 30 mm) for fasteners

The stipulations of **Table W 1-7** shall apply for the ultrasonic examination of forged and rolled bars with heat treated wall thicknesses greater than or equal to 20 mm and up to 30 mm for fasteners.

Facilities for mechanised nondestructive testing may be used.

(4) Seamless tubes

Seamless tubes shall be examined for longitudinal defects in accordance with DIN EN ISO 10893-10, acceptance level U 2 A, with a notch of the "N"-type.

(5) Forgings and rolled rings

The stipulations of **Table W 1-8** shall apply for the ultrasonic examination of forgings and rolled rings.

Two adjacent indications located at the same depth shall be distanced from each other by at least one times the length of the longer indication.

W 1.3.2 Examination of surface condition

The requirements of clause 7.3.5.8.6 shall apply.

W 1.3.3 Surface examination by means of the liquid penetrant method

(1) Forged and rolled product forms

The stipulations of clause 7.3.5.8.3 shall apply. The frequency of acceptable indications shall locally not be higher than 10 per square decimetre and, with respect to the entire surface area, not higher than 5 per square decimetre.

No indication that might indicate the existence of cracks is allowed.

(2) Welded tubes

The stipulations of **Table 8-7** shall apply.

No indication that might indicate the existence of cracks is allowed within the weld and the weld-adjacent zone.

W 1.3.4 Radiography of welded tubes

The acceptance criteria of DIN EN ISO 10893-6 shall apply.

W 1.4 Specimen-taking locations and specimen orientation

The stipulations of the standards mentioned in Section W 1.2 shall apply for the specimen-taking locations and specimen orientation. If other requirements are given in the materials test sheets in Section W 1.5 these stipulations apply.

Material no.	Content by mass, %					Nb/C	Ti/C
	C	P	Nb	Co	Ti		
1.4306 1) 2)	≤ 0.030	≤ 0.035	—	≤ 0.2	—	—	—
1.4541 1) 2) 3)	≤ 0.060		—		≤ 0.7	—	≥ 8
1.4550 1) 2)	≤ 0.040		≤ 0.65		—	≥ 13	—
1.4571 1) 2) 3)	≤ 0.060		—		≤ 0.7	—	≥ 8
1.4580 1) 2)	≤ 0.040		≤ 0.65		—	≥ 13	—

1) The nitrogen content shall be determined during ladle analysis.
2) For tubes according to DIN EN 10216-5: S ≤ 0,015 %.
3) For fasteners without subsequent heat treatment: Ti/C > 7.

Table W 1-1: Restricted chemical composition

Specimen orientation	$R_{p0,2RT}$ in N/mm^2	R_{mRT} in N/mm^2	R_{mT} in N/mm^2	A_T in %	Z_{RT} in % 3)	Z_T in % 3)
transverse / tangential	≥ 205 2)	510 to 740 2)	see Table W 1-3	≥ 20	≥ 45	to be determined
longitudinal 1)						

1) Bars D ≤ 160 mm and tubes D_a ≤ 146 mm
2) Only for plates and sheets, for other product forms the requirements of the standards apply.
3) Not for tubes.

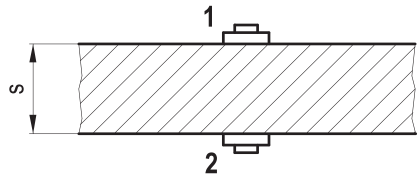
Table W 1-2: Minimum values of mechanical properties

Temperature, °C	R_m, N/mm^2 min.	
	Plate, sheet ≤ 50 mm and strip	Plate, sheet > 50 mm; seamless tubes; bars, forgings, rings
Room temperature	≥ 510	≥ 510
50	≥ 495	≥ 495
100	≥ 470	≥ 465
150	≥ 430	≥ 420
200	≥ 405	≥ 390
250	≥ 395	≥ 370
300	≥ 385	≥ 360
350	≥ 380	≥ 350

Table W 1-3: Minimum values of tensile strength for material no. 1.4550

Temperature in °C	Average thermal conductivity W/(m·K)
Room temperature	15.00
100	15.95
200	17.15
300	18.40
400	19.70

Table W 1-4: Typical values for the average thermal conductivity of austenitic stainless steels



Search unit	Scanning direction	Requirements
SE	1 or 2	S < as the scan area of the search unit
N + SE	1 or 2	Dual-element probe for the near-surface area
N	1 and 2	Areas that can be evaluated shall overlap

N : Straight beam transceiver search unit
SE : Transmitter-receiver straight beam search unit

Recording levels

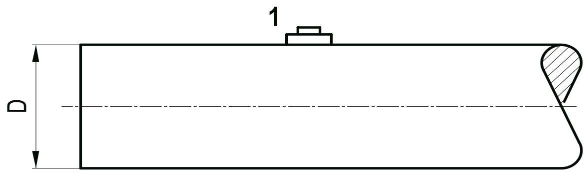
Smallest indication to be included in the evaluation: 100 mm^2

Acceptance criteria

Area, mm^2	Frequency of recordable indications	
	individual indications	Referred to the entire surface of the plate, sheet
≤ 1000	≤ $3/m^2$	≤ $2/m^2$

The distance between any two indications located at the same depth shall be at least longer than the length of the longer indication.

Table W 1-5: Scanning directions, recording levels and acceptance criteria for plates, sheets and strip



Search unit	Scanning direction	Requirements
SE or N	1	

N : Straight beam transceiver search unit
SE : Transmitter-receiver straight beam search unit

Recording levels

Scanning direction	Diameter D in test condition, mm	DAC method Echo amplitude referenced to the echo amplitude of a 4 mm cylindrical bore hole	DGS method Disc shaped reflector, mm
1	≤ 60	50 % (-6 dB)	3
	> 60	100 %	4

Acceptance criteria

Scanning direction	Echo amplitudes	Length of recordable indications	Frequency of recordable indications
1	Echo amplitudes up to 12 dB above the respective recording level are acceptable	1 · D	D ≤ 60: ≤ 3/m
			D > 60: ≤ 5/m

Table W 1-6: Scanning directions, recording levels und acceptance criteria for forgings and bars (heat treated wall thickness > 30 mm)

Scanning directions	Reference reflector
1 Straight-beam scanning in radial direction When using N = straight beam transceiver search unit over the whole circumference; when using SE = transmitter-receiver straight beam search unit on half the circumference	2 mm cylindrical bore hole in radial direction
2 Angled beam scanning from the cylindrical shell surface in both axis directions with an angle of 70 degrees	Rectangular notch of following dimensions: Width: ≤ 1.5 mm Depth: 0.05 · D in mm
3 On bar steel used for fasteners (e. g. core barrel / core shroud bolts), for which ultrasonic examination is intended during operation, examination for back wall echo shall be performed on one specimen per lot (length 150 mm). The lot weight shall be as defined under 3 (2) a) of material test sheet W 1.5.2.	The amplitude of the back wall echo, referenced to the cylindrical bore hole, shall be recorded.
Evaluation: For scanning directions 1 and 2 no indications which reach or exceed the echo amplitude of the reference reflector are acceptable.	

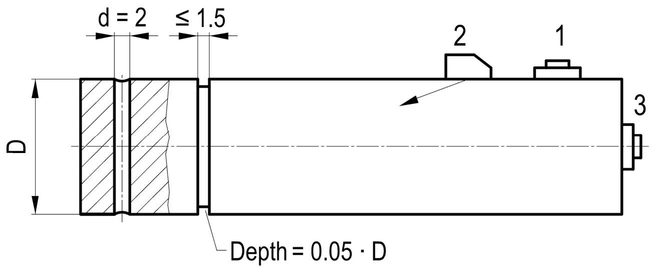
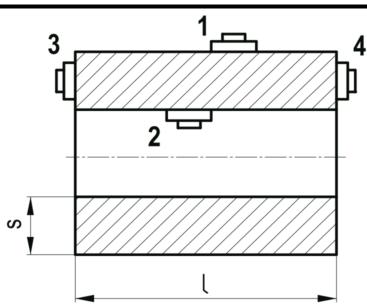


Table W 1-7: Scanning directions, reference reflector and evaluation for forged and rolled bars (heat treated wall thickness ≥ 20 up to ≤ 30 mm) for fasteners



Sound path without lateral wall influence for scanning directions 3 and 4:

$$S = \frac{s \cdot D_{eff}}{2 \cdot \lambda}$$

λ : wave length, mm

D_{eff} : effective transducer dimension

s : wall thickness

Search unit	Scanning direction	Requirements
SE	1 or 2 and 3 or 4	S < as the scan area of the search unit
N + SE	1 or 2 and 3 or 4	Dual-element probe for the near-surface area
N	1, 2, 3, 4	Areas that can be evaluated shall overlap

N : Straight beam transceiver search unit
SE : Transmitter-receiver straight beam search unit

Recording levels

Scanning directions	Wall thickness s in test condition, mm	DAC method Echo amplitude referenced to the echo amplitude of a 4 mm cylindrical bore hole	DGS method Disc shaped reflector, mm
1 to 4	≤ 60	50 % (-6 dB)	4
	> 60	100 %	6

Acceptance criteria

Scanning directions	Echo amplitudes	Length of recordable indications	Frequency of recordable indications
1 to 4	Echo amplitudes up to 12 dB above the respective recording level are acceptable	max. 50 mm, however ≤ s	individual indications: ≤ 5/m referred to the entire surface: ≤ 3/m

[1)] In scanning directions 3 and 4 no reflectors with dimensions exceeding 10 mm are acceptable.

Table W 1-8: Scanning directions, recording levels und acceptance criteria for forgings and rolled rings

W 1.5 Materials test sheets

MATERIALS TEST SHEET		**W 1.5.1**
Product form: Plate, sheet or strip		
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Materials:	Austenitic stainless steels Material no. 1.4306, 1.4541, 1.4550, 1.4571, 1.4580	
Requirements:	As specified in Sections W 1.2 to W 1.4	

	Tests and examinations per test lot	Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment condition	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature a) for s ≤ 20 mm 1 specimen for each melt, dimension and heat treatment batch, at least 1 specimen per 20 plates or sheets or at the beginning and end of stripe	3.1
	b) for s > 20 mm up to s ≤ 75 mm 1 specimen of each rolled plate	3.1
	c) for s > 75 mm 1 specimen from the middle of the head and the edge of the tail of each rolled plate	3.2
4.	Tensile test according to Section 7.3.5.2 at 350 °C 1 specimen per tensile test specimen (room temperature) if s > 10 mm a) for s ≤ 75 mm	3.1
	b) for s > 75 mm	3.2
5.	Notched bar impact test according to Section 7.3.5.3 at room temperature 1 set of test specimens per tensile test if s > 10 mm a) for s ≤ 75 mm	3.1
	b) for s > 75 mm	3.2
6.	Test for resistance to intergranular corrosion according to Section 7.3.5.7 a) for s ≤ 75 mm 1 specimen for melt and heat treatment batch	3.1
	b) for s > 75 mm 1 specimen for each rolled plate	3.1
7.	Determination of the delta-ferrite content according to Section 7.3.5.5 Mathematical estimation for each melt If the mathematical estimation results below 2 %, the delta ferrite content shall be determined by metallographic or magnetic measures. In the case of values larger than 8 %, then the delta ferrite content shall additionally be determined by a metallographic analysis.	3.1
8.	Evaluation of microstructure and grain size according to Section 7.3.5.6 1 specimen for each dimension, melt and heat treatment batch	3.1
9.	Ultrasonic examination according to Section 7.3.5.8.4 Ultrasonic examination for s > 10 mm in a grid of 200 mm by 200 mm for each plate, sheet or strip a) for s ≤ 75 mm	3.1
	b) for s > 75 mm	3.2
10.	Visual inspection according to Section 7.3.5.8.6 100 % inspection of each plate or sheet, for strip randomly	3.1
11.	Dimensional check in accordance with ordering data Each plate, sheet or strip a) for s ≤ 75 mm	3.1
	b) for s > 75 mm	3.2
12.	Materials identification check Each plate, sheet or strip by qualitative determination of typical alloying elements	3.1

MATERIALS TEST SHEET (Part 1)	**W 1.5.2**
Product form: Forgings, forged rings and bars	
Quality classes: AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Materials: Austenitic stainless steels Material no. 1.4306, 1.4541, 1.4550, 1.4571, 1.4580	
Requirements: As specified in Sections W 1.2 to W 1.4	

Tests and examinations per test lot (Where the geometry of bars largely deviates from the specimen location sketches according to Figure 2 of DIN EN 10272, a specimen location plan shall be established. For forgings and rolled rings a specimen location plan shall be established in accordance with Section 12 of DIN EN 10222-1.)	Certificate acc. to DIN EN 10204
1. Chemical composition a) Ladle analysis	 3.1
b) Product analysis: ba) for product weight ≤ 5000 kg: 1 analysis for melt bb) for product weight > 5000 kg: 1 analysis for each product	3.1
2. Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment condition	3.1
3. Tensile test according to Section 7.3.5.2 at room temperature (1) Forgings and rings: a) product weight ≤ 500 kg 2 specimens for 500 kg net shipping weight of same dimension, melt and heat treatment each, however only 1 specimen for each component. Transverse or tangential specimens b) product weight > 500 kg up to ≤ 5000 kg 2 specimens for each component, for D_a ≥ L at head or tail, for D_a < L one at head and one at tail. Transverse- or tangential specimens c) product weight > 5000 kg at least 3 specimens for each component (2) Bars a) Bars of the same melt and heat treatment and of similar dimensions shall be grouped into lots of 2000 kg each. 1 specimen for each lot b) Bars > 2000 kg and ≤ 3000 kg 1 specimen for each bar c) Bars > 3000 kg 1 specimen from the end of each bar for D ≤ 160 mm: longitudinal specimens for D > 160 mm: transverse specimens	3.2 [1)]
4. Tensile test according to Section 7.3.5.2 at 350 °C 1 specimen per tensile test specimen at room temperature	3.2 [1)]
5. Notched bar impact test according to Section 7.3.5.3 at room temperature 1 set of test specimens per tensile test specimen (room temperature) for parts D > 20 mm for D ≤ 160 mm: longitudinal specimens for D > 160 mm: transverse specimens	3.2 [1)]
6. Test for resistance to intergranular corrosion according to Section 7.3.5.7 1 specimen for melt and heat treatment batch	3.1
7. Determination of the delta-ferrite content according to Section 7.3.5.5 Mathematical estimation for each melt If the mathematical estimation results below 2 %, the delta ferrite content shall be determined by metallographic or magnetic measures. In the case of values larger than 8 %, then the delta ferrite content shall additionally be determined by a metallographic analysis.	3.1
8. Evaluation of microstructure and grain size according to Section 7.3.5.6 for forgings: 1 specimen for each lot if product weight ≤ 500 kg, 1 specimen for each product if product weight > 500 kg for bars: 1 specimen for each melt, dimension range and heat treatment batch	3.1
9. Ultrasonic examination according to Section 7.3.5.8.4 Volumetric examination shall basically be conducted on each product. Volumetric examination is required for bars at D > 30 mm and for bars for fasteners at D > 20 mm.	3.2 [1)]

MATERIALS TEST SHEET (Part 2)	W 1.5.2
10. Visual inspection according to Section 7.3.5.8.3 100 % inspection according to Section 7.3.5.8.6 and additionally 100 % visual testing according to Section 7.3.5.8.7 of each component	3.2 1)
11. Dimensional check in accordance with ordering data Each component	3.2 1)
12. Materials identification check Each component by qualitative determination of typical alloying elements	3.1
1) Certificate 3.1 if thickness ≤ 250 mm	

MATERIALS TEST SHEET (Part 1)	W 1.5.3
Product form: Welded and seamless tubes	
Quality classes: AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Materials: Austenitic stainless steels Material no.no. 1.4306, 1.4541, 1.4550, 1.4571, 1.4580 1)	
Requirements: As specified in Sections W 1.2 to W 1.4	
Tests and examinations per test lot (For the specimen taking locations and specimen orientation the requirements of Section 10 of DIN EN 10216-5 as well as of DIN EN 10217-7 apply.)	Certificate acc. to DIN EN 10204
1. Chemical composition Ladle analysis	3.1
2. Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment condition (solution annealing or bright annealing)	3.1
3. Tensile test according to Section 7.3.5.2 at room temperature 1 specimen for each lot in accordance with Section 10.1 of DIN EN 10216-5 or Section 10.1 of DIN EN 10217-7. For welded tubes additionally: if outer diameter D > 200 mm: 2 tensile test specimens shall be taken for each test lot Specimen orientation in accordance with clauses 10.2.2.2 and 10.2.2.3 of DIN EN 10217-7	3.2 2)
4. Tensile test according to Section 7.3.5.2 at 350 °C 1 specimen per tensile test specimen at room temperature	3.2 2)
5. Notched bar impact test according to Section 7.3.5.3 at room temperature a) Seamless tubes: One set of impact test specimens per tensile test (room temperature) if s > 20 mm b) Welded tubes: One set of impact test specimens per tensile test (room temperature) if s > 12 mm and outer diameter D > 200 mm Specimen orientation transverse to weld in accordance with Section 10.2.2.6 of DIN EN 10217-7	3.2 2)
6. Test for resistance to intergranular corrosion according to Section 7.3.5.7 1 specimen for melt and heat treatment batch	3.1
7. Determination of the delta-ferrite content according to Section 7.3.5.5 Mathematical estimation for each melt. If the mathematical estimation results below 2 %, the delta ferrite content shall be determined by metallographic or magnetic measures. In the case of values larger than 8 %, then the delta ferrite content shall additionally be determined by a metallographic analysis.	3.1
8. Evaluation of microstructure and grain size according to Section 7.3.5.6 1 specimen for each dimension, melt and heat treatment batch	3.1
9. Ultrasonic examination for longitudinal defects according to DIN EN ISO 10893-10, acceptance level U 2 A, with a notch of the “N”-type (only for seamless tubes) For outer diameter ≤ 101.6 mm and wall thickness ≤ 5.6 mm at 10 % of the tubes, for larger dimensions at each tube.	3.2 2)
10. Surface examination according to Section 7.3.5.8.3 (only for welded tubes) 100 % surface examination of the outer surface and – where technical possible – of the inner surface of the weld by liquid penetrant method	3.2 2)
11. Radiography according to Section 7.3.5.8.5 (only for welded tubes with a weld factor n = 1) 100 % of each welded joint. Other test methods are permitted if these methods have been qualified in cooperation with the authorized inspector.	3.2 2)
12. Visual inspection according to Section 7.3.5.8.6 100 % inspection of each tube, where accessible	3.1

MATERIALS TEST SHEET (Part 2)	**W 1.5.3**
13. Dimensional check in accordance with ordering data Each tube	3.2 [2)]
14. Materials identification check Each tube by qualitative determination of typical alloying elements	3.1
1) Only for seamless tubes 2) Certificate 3.1 if wall thickness ≤ 5.6 mm	

MATERIALS TEST SHEET		**W 1.5.4**
Product form: Plate, sheet or strip		
Quality class:	AS-RE 3 outside the RPV	
Material:	Austenitic stainless steels in accordance with DIN EN 10088-2	
Requirements:	According to DIN EN 10088-2	
Tests and examinations per test lot		Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment condition	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature 1 specimen for each melt, dimension and heat treatment batch, at least for every 20th plate or sheet or for start and end of each strip	3.1
4.	Test for resistance to intergranular corrosion according to Section 7.3.5.7 1 specimen for melt and heat treatment batch	3.1
5.	Visual inspection according to Section 7.3.5.8.6 100 % inspection of each plate or sheet, for strip randomly	3.1
6.	Dimensional check in accordance with ordering data Each plate, sheet or strip	3.1
7.	Materials identification check Each plate, sheet or strip by qualitative determination of typical alloying elements	3.1

MATERIALS TEST SHEET		**W 1.5.5**
Product form: Forgings, bars and sections		
Quality class:	AS-RE 3 outside the RPV	
Material:	Austenitic stainless steels in accordance with DIN EN 10250-4 for forgings and in accordance with DIN EN 10088-3 for bars and sections	
Requirements:	According to DIN EN 10250-4 and DIN EN 10088-3	
Tests and examinations per test lot		Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment condition	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature (1) Forgings and sections 1 specimen for each melt, dimension and heat treatment batch (2) Bars 1 specimen for melt and heat treatment batch For D ≤ 160 mm longitudinal specimens For D > 160 mm transverse specimens	3.1
4.	Test for resistance to intergranular corrosion according to Section 7.3.5.7 1 specimen for melt and heat treatment batch	3.1
5.	Visual inspection according to Section 7.3.5.8.6 100 % inspection of each component	3.1
6.	Dimensional check in accordance with ordering data Each component	3.1
7.	Materials identification check Each component by qualitative determination of typical alloying elements	3.1

MATERIALS TEST SHEET		**W 1.5.6**
Product form:	Welded and seamless tubes	
Quality class:	AS-RE 3 outside the RPV	
Material:	Austenitic stainless steels	
Requirements:	to DIN EN 10216-5 and DIN EN 10217-7	

	Tests and examinations per test lot	Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment condition (solution annealing or bright annealing)	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature 1 specimen for lot	3.1
4.	Test for resistance to intergranular corrosion according to Section 7.3.5.7 1 specimen for melt and heat treatment batch	3.1
5.	Visual inspection according to Section 7.3.5.8.6 100 % inspection each tube where accessible	3.1
6.	Dimensional check in accordance with ordering data Each tube	3.1
7.	Materials identification check Each tube by qualitative determination of typical alloying elements	3.1

Annex W 2
Nickel alloys

Contents:

W 2.1 Scope

This annex lays down the requirements regarding quality characteristics, type and extent of tests and examinations as well as the type of certificates for nickel alloys. The requirements shall apply for the heat treatment condition according to **Table W 2-3** unless specified otherwise hereinafter.

W 2.2 Materials

W 2.2.1 Materials for quality class AS-RE 3 outside the RPV

The following materials are allowable: NiCr15Fe (material no. 2.4816), NiCr29Fe (material no. 2.4642), NiCr15Fe7TiAl (material no. 2.4669) and NiCr19Fe19Nb5Mo3 (material no. 2.4668) in accordance with the stipulations of the respective standards or manufacturer's specifications. Wire made of material no. 2.4669 shall be delivered with a cold forming degree of 10 % to 20 % upon solution annealing (prior to precipitation hardening).

W 2.2.2 Materials for quality classes AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV

W 2.2.2.1 General requirements

The materials NiCr15Fe (material no. 2.4816), NiCr29Fe (material no. 2.4642), NiCr15Fe7TiAl (material no. 2.4669) and NiCr19Fe19Nb5Mo3 (material no. 2.4668) are allowable according to the stipulations hereinafter if these materials are only used for constructions and product forms, for which positive experience has been gained during the respective service conditions. Where these materials are used for other locations, their use shall be reviewed from case to case. Wire made of material no. 2.4669 shall be delivered with a cold forming degree of 10 % to 20 % upon solution annealing (prior to precipitation hardening).

(2) Clause 7.2.1 covers the requirements for manufacturers of product forms.

(3) The tests and examinations to be performed, the extent of testing and the attestation of quality characteristics shall be taken from the materials test sheets (WPB), Sections W 2.5.1 to W 2.5.4.

W 2.2.2.2 Steel-making process

The steel-making process is left to the manufacturer unless agreed otherwise in the order. Upon request, it shall, however, be made known to the purchaser.

W 2.2.2.3 Chemical composition

The stipulations of **Tables W 2-1** and **W 2-2** shall apply for the chemical composition of the materials.

W 2.2.2.4 Heat treatment

The materials shall be subjected to any heat treatment specified for the respective product form in **Table W 2-3**. Prior to stabilizing, the material NiCr15Fe (Material no. 2.4816) shall either be subjected to soft annealing or solution annealing.

Note:
The delivery condition of the product forms is not necessarily the final heat treatment condition.

W 2.2.2.5 Mechanical properties

The mechanical properties required are specified in **Tables W 2-4** to **W 2-6**. Where the delivery condition of the product form is not the final heat treatment condition as per **Table W 2-3** (precipitation hardened or stabilised) the specimens shall be tested in the simulated final heat treatment condition.

As regards the testing of deformability of wire, a wire-wrapped specimen in the delivery condition according to DIN ISO 7802 shall be wrapped with at least 5 close coils around a cylindrical mandrel the diameter of which shall be 3 times greater than the wire nominal diameter. Upon wrapping, the antifriction coating shall be removed and the specimen be subjected to penetrant testing (PT) as per clause 7.3.5.8.3. The specimen freedom from cracks shall be proved.

W 2.2.2.6 Physical characteristics

Typical values for the physical characteristics are specified in **Table W 2-7**.

W 2.2.2.7 Microstructure

(1) The mean grain size shall be determined and shall have a value equal to or greater than 3 acc. to DIN EN ISO 643. The difference between maximum and minimum grain size shall be a maximum of 3. Deviations here from are permitted if the ultrasonic examination as per clause 7.3.5.8.4 is not impaired.

(2) The structure shall be such that the required quality characteristics are obtained.

W 2.2.2.8 Identification marking

The identification marking of the product forms shall contain the identification of the manufacturer, type of material, melt number, test lot number and certification stamp of the test personnel.

W 2.3 Non-destructive examinations

W 2.3.1 Ultrasonic examination

(1) Plates and sheets

For ultrasonic examination of plates and sheets **Table W 2-8** shall apply.

(2) Forged and rolled round bars (diameter > 30 mm)

The requirements in **Table W 2-9** shall apply for the ultrasonic examination of forged and rolled round bars with diameters exceeding 30 mm.

(3) Forged und rolled bars (heat treated wall thickness ≥ 20 up to ≤ 30 mm) for fasteners

The requirements in **Table W 2-10** shall apply for the ultrasonic examination of forged and rolled bars with heat treated wall thickness exceeding 20 mm up to 30 mm including those for fasteners.

Facilities for mechanised non-destructive testing by immersion method may be used.

(4) Seamless tubes

Seamless tubes shall be examined for longitudinal defects in accordance with DIN EN ISO 10893-10, acceptance level U 2 A, with a notch of the "N"-type.

(5) Forgings and rolled rings

The requirements in **Table W 2-11** shall apply for the ultrasonic examination of forgings and rolled rings.

The distance between any two indications located at the same depth shall be at least longer than the length of the longer indication.

W 2.3.2 Examination of surface condition

The requirements of clause 7.3.5.8.6 shall apply.

W 2.3.3 Surface examination by means of the liquid penetrant method for forged und rolled product forms

The requirements of Section 7.3.5.8.3 apply**.** The frequency of acceptable indications shall locally not be higher than 10 per square decimetre and, with respect to the entire surface area, not higher than 5 per square decimetre.

No indication that might indicate the existence of cracks is allowed.

W 2.4 Specimen-taking locations and specimen orientation

The stipulations of DIN EN 10088-2 (for plates, sheets and stripe), DIN EN 10088-3 (for bars and filler metal wire), DIN EN 10250-1 (for forgings) as well as DIN EN 10216-5 (for tubes) shall apply for the specimen-taking locations and the specimen orientation. If other requirements are given in the materials test sheets in Section W 2.5 these stipulations apply.

Element	Content by mass, %			
	Material			
	NiCr15Fe (2.4816)	NiCr29Fe (2.4642)	NiCr15Fe7TiAl (2.4669)	NiCr19Fe19Nb5Mo3 (2.4668)
C	≤ 0.080	≥ 0.015 up to ≤ 0.040	≤ 0.080	≤ 0.080
Mn	≤ 1.00	≤ 0.50	≤ 0.35 2)	≤ 0.35
Si	≤ 0.50	≤ 0.50	≤ 0.35 2)	≤ 0.35
P	≤ 0.015	≤ 0.015	≤ 0.015	≤ 0.015
S	≤ 0.015	≤ 0.010	≤ 0.010	≤ 0.015
Cr	≥ 14.0 up to ≤ 17.0	≥ 28.0 up to ≤ 31.0	≥ 14.0 up to ≤ 17.0	≥ 17.0 up to ≤ 21.0
Ni 1)	≥ 72.0	≥ 58.0 up to ≤ 62.0	≥ 70.0	≥ 50.0 up to ≤ 55.0
Co	≤ 0.20	≤ 0.20	≤ 0.20	≤ 0.20
Nb 3)	—	≤ 0.10	≥ 0.70 up to ≤ 1.20	≥ 4.75 up to ≤ 5.50
Ti	—	≤ 0.50	≥ 2.25 up to ≤ 2.75	≥ 0.65 up to ≤ 1.15
Al	—	≤ 0.50	≥ 0.40 up to ≤ 1.00	≥ 0.20 up to ≤ 0.80
Fe	≥ 6.0 up to ≤ 10.0	≥ 8.0 up to ≤ 11.0	≥ 5.0 up to ≤ 9.0	Rest
Cu	≤ 0.50	≤ 0.50	≤ 0.50	≤ 0.30
B	—	≤ 0.007	—	≤ 0.006
Mo	—	≤ 0.20	—	≥ 2.80 up to ≤ 3.30
N	—	≤ 0.050	—	—

1) The Ni content includes the Co content.
2) For filler metal wire Mn ≤ 1.00 % and Si ≤ 0.50 % is allowed.
3) including Ta.

Table W 2-1: Chemical composition determined by ladle analysis

Chemical element	Range of chemical element content, %	Allowable deviation below minimum or above maximum value, %
C	≤ 0.020	0.005
	> 0.020 up to ≤ 0.200	0.010
Mn	≤ 1.00	0.03
Si	≤ 0.50	0.03
P	≤ 0.040	0.005
S	≤ 0.020	0.003
Cr	> 5.0 up to ≤ 15.0	0.15
	> 15.0 up to ≤ 25.0	0.25
	> 25.0 up to ≤ 35.0	0.30
Ni	> 40.0 up to ≤ 60.0	0.35
	> 60.0 up to ≤ 80.0	0.45
Co	≤ 0.20	0.02
	> 0.20 up to ≤ 1.00	0.03
Nb and/or Ta	≤ 0.10	0.02
	> 0.10 up to ≤ 1.50	0.05
	> 3.00 up to ≤ 5.00	0.15
	> 5.00 up to ≤ 7.00	0.20
Ti	≤ 0.5	0.03
	> 0.5 up to ≤ 1.00	0.04
	> 1.00 up to ≤ 2.00	0.05
	> 2.00 up to ≤ 3.50	0.07
Al	> 0.10 up to ≤ 0.50	0.05
	> 0.50 up to ≤ 2.00	0.10
Fe	> 5.0 up to ≤ 10.0	0.10
	> 10.0 up to ≤ 15.0	0.15
	> 15.0 up to ≤ 30.0	0.30
Cu	> 0.20 up to ≤ 0.50	0.03
B	≤ 0.010	0.002
Mo	≤ 1.00	0.03
	> 1.00 up to ≤ 3.00	0.05
	> 3.00 up to ≤ 5.00	0.10
N	> 0.02 up to ≤ 0.19	0.01

Table W 2-2: Allowable deviations of the chemical composition determined by the product analysis from the range limit of the composition determined by the ladle analysis

Material	Product form	Heat treatment		
		Soft annealing	Solution annealing	Precipitation hardening / Stabilising
NiCr15Fe (2.4816)	Plate, sheet, bar, forging, tube	920 °C up to 1000 °C 1) holding time at temperature acc. to thickness 2) 3)	1080 °C up to 1150 °C 1) holding time at temperature acc. to thickness 2) 3)	700 °C up to 730 °C ± 10 K, at least 10 h 4)
NiCr29Fe (2.4642)	bar	—	1070 °C up to 1120 °C 1) holding time at temperature acc. to thickness 2) 3)	700 °C up to 730 °C ± 10 K, at least 10 h 4)
NiCr15Fe7TiAl (2.4669)	Bar, forging, plate, sheet	—	1050 °C up to 1100 °C 1) holding time at temperature acc. to thickness 2) 3)	730 °C ± 10 K, 8 h ± 0.5 h / with 60 K/h ± 10 K to 620 °C ± 10 K / 620 °C ± 10 K, 8 h ± 0.5 h 4)
	Wire, strip	—	1090 °C up to 1180 °C 1), heat treatment cycle depending on thickness 3)	730 °C ± 15 K, 16 h ± 0.5 h 4)
NiCr19Fe19Nb5Mo3 (2.4668)	Plate, sheet, strip, bar, forging, wire	—	1050 °C up to 1120 °C 1) holding time at temperature acc. to thickness 2) 3)	720 °C ± 10 K, 8 h ± 0.5 h / with 60 K/h ± 10 K to 620 °C ± 10 K / 620 °C ± 10 K, 8 h ± 0.5 h 4)

1) Tolerance range at selected temperature: ± 20 K within the permitted temperature range.
2) Holding time at temperature: approximately 1 min. up to 2 min. per mm to ensure complete soaking.
3) Cooling rate corresponding to cooling in air or faster.
4) Cooling in furnace or faster.

Table W 2-3: Heat treatment

Material	Product form	Dimension thickness / diameter 1), mm	Specimen orientation	Heat treatment condition	$R_{p0.2}$ N/mm^2	R_m N/mm^2	A %	A_4 or $A_{l_0 = 50\ mm}$ %	Z 2) %
NiCr15Fe (2.4816)	bar	≤ 160	l/q	2)	≥ 200	550 up to 750	≥ 30	—	to be determined
	forging	≤ 160	l/q/t						
	plate, sheet	≤ 50	q	3)	≥ 180	500 up to 700	≥ 35		
	tube	≤ 25 / ≤ 170	l						
NiCr29Fe (2.4642)	bar	≤ 160	l/q	3)	≥ 220	≥ 586	≥ 30	≥ 30	to be determined
NiCr15Fe7TiAl (2.4669)	strip	≥ 0.25 up to ≤ 6.35	l/q	Solution annealed and precipitation hardened	≥ 790	≥ 1170	—	≥ 18	to be determined
	plate, sheet	≥ 4.75 up to ≤ 100	q		≥ 720	≥ 1100		≥ 18	
	bar	≤ 60	l		≥ 790	≥ 1170		≥ 18	≥ 18
		> 60 up to ≤ 160	l		≥ 790	≥ 1170		≥ 15	≥ 15
			q		≥ 720	≥ 1100		≥ 12	≥ 12
	wire	≥ 0.4 up to ≤ 3,0	l		≥ 880	≥ 1140		≥ 10	—
		> 3.0 up to ≤ 15	l		≥ 880	≥ 1140		≥ 14	—
	forging	≤ 100	l		≥ 790	≥ 1170		≥ 18	≥ 18
			q		≥ 760	≥ 1140		≥ 15	≥ 15
		> 100 up to ≤ 160	q/t		≥ 720	≥ 1100		≥ 12	≥ 12
NiCr19Fe19Nb5Mo3 (2.4668)	bar	≤ 60	l	Solution annealed and precipitation hardened	≥ 1000	≥ 1240	—	≥ 12	≥ 15
		> 60 up to ≤ 160	l/q		≥ 1000	≥ 1200		≥ 6	≥ 8
	forging	≤ 160	l/q/t		≥ 1000	≥ 1200		≥ 10	≥ 12
	strip	≥ 0.25 up to ≤ 6.35	l/q		≥ 1035	≥ 1240		≥ 12	—
	plate, sheet	≥ 4.75 up to ≤ 100	q		≥ 1000	≥ 1200		≥ 12	to be determined
	wire	≥ 0.4 up to ≤ 15	l		≥ 1000	≥ 1240		≥ 12	—

1) Heat treated wall thickness/diameter
2) Z value (%) as far as possible
3) Soft annealed and stabilized
4) Solution annealed and stabilized

q : transverse
l : longitudinal
t : tangential

Table W 2-4: Minimum values of the mechanical properties in the tensile test at room temperature

Material	Product form	Dimension thickness / diameter, mm	Specimen orientation	Heat treatment condition	$R_{p0.2}$ N/mm²	R_m N/mm²	A %	A_4 or $A_{l_0 = 50\,mm}$ %	Z %
NiCr15Fe (2.4816)	bar	≤ 160	l/q	soft annealed and stabilized or solution annealed and stabilized	≥ 150	to be determined	to be determined	—	to be determined
	forging	≤ 160	l/q/t						
	plate, sheet	≤ 50	q						
	tube	≤ 25 / ≤ 170	l						
NiCr29Fe (2.4642)	bar	≤ 160	l/q	solution annealed and stabilized	≥ 160	≥ 480 [1]	—	to be determined	to be determined
NiCr15Fe7TiAl (2.4669)	strip/plate, sheet	≥ 0.25 up to ≤ 100	l/q	solution annealed and precipitation hardened	≥ 700	≥ 1050	—	≥ 16	≥ 16 [2]
	bar	≤ 160	l/q		≥ 700	≥ 1050		≥ 16	≥ 16
	forging	≤ 100	l		≥ 700	≥ 1050		≥ 16	≥ 16
		> 100 up to ≤ 160	q/t		≥ 700	≥ 1050		to be determined	to be determined
	wire	≥ 0.4 up to ≤ 15	l		to be determined	≥ 1050			
NiCr19Fe19Nb5Mo3 (2.4668)	strip/plate, sheet	≥ 0.25 up to ≤ 100	l/q	solution annealed and precipitation hardened	≥ 800 [1]	≥ 960 [1]	—	≥ 5	to be determined [2]
	bar	≤ 60	l		≥ 830 [1]	≥ 960 [1]		≥ 12	≥ 15
		> 60 up to ≤ 160	l/q		≥ 800 [1]	≥ 930 [1]		≥ 6	≥ 8
	forging	≤ 160	l/q/t		≥ 800 [1]	≥ 930 [1]		≥ 10	≥ 12
	wire	≥ 0.4 up to ≤ 15	l		≥ 830 [1]	≥ 960 [1]		to be determined	—

[1] These values still need to be ensured statistically. q : transverse t : tangential
[2] Required only for the product forms plate and sheet. l : longitudinal

Table W 2-5: Minimum values of the mechanical properties in the tensile test at 350 °C

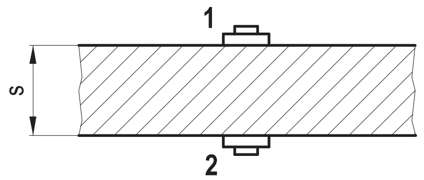
Material	Product form	Dimension thickness/ diameter mm	Specimen orientation	Heat treatment condition	KV_2 J Average value	KV_2 J single value
NiCr15Fe (2.4816)	bar	≤ 160	l	soft annealed and stabilized or solution annealed and stabilized	≥ 160	≥ 112
			q		≥ 120	≥ 84
	tube	≤ 25 / ≤ 170	l		≥ 160	≥ 112
	plate, sheet	≤ 50	q		≥ 120	≥ 84
	forging	≤ 160	l/q/t		≥ 96	≥ 67
NiCr29Fe (2.4642)	bar	≤ 160	l	solution annealed and stabilized	≥ 125	≥ 90
			q		≥ 95	≥ 70
NiCr15Fe7TiAl (2.4669)	plate, sheet	≥ 0.25 up to ≤ 100	l/q	solution annealed and precipitation hardened	to be determined	
	bar	≤ 160	l/q		≥ 38	≥ 30
	forging	≤ 160	l/q/t		to be determined	
NiCr19Fe19Nb5Mo3 (2.4668)	plate, sheet	≤ 100	q	solution annealed and precipitation hardened	to be determined	
	bar	≤ 160	l/q		—	≥ 20
	forging	≤ 160	l/q/t		—	≥ 20

For sheets and forgings (s ≤ 10 mm), bars (D ≤ 15 mm), tubes (s ≤ 15 mm), strip and wire no impact test is required.
q : transverse
l : longitudinal
t : tangential

Table W 2-6: Minimum values of the impact energy at room temperature

Physical characteristics	Unit	Temperature T °C	NiCr15Fe (2.4816)	NiCr29Fe (2.4642)	NiCr19Fe19Nb5Mo3 (2.4668)	NiCr15Fe7TiAl (2.4669)
Density	g/cm^3	Room temp.	8.47	8.19	8.22	8.25
Modulus of elasticityl	10^3 N/mm^2	Room temp.	214	211	200	214
		100	210	206	195	210
		150	207	203	193	207
		200	205	201	191	204
		250	202	198	187	201
		300	200	195	185	198
		350	196	192	182	195
		400	193	189	179	192
Average thermal conductivity	W/(m·K)	Room temp.	14.83	12.02	11.37	11.95
		100	15.80	13.51	12.64	12.89
		150	16.58	14.42	13.48	13.48
		200	17.35	15.33	14.33	14.06
		250	18.13	16.29	15.11	14.76
		300	18.91	17.27	15.89	15.47
		350	19.69	18.19	16.66	16.19
		400	20.47	19.10	17.44	16.90
Average linear thermal expansion coefficient between 20 °C and T	10^{-6}/K	100	13.35	14.06	13.18	12.62
		150	13.60	14.20	13.36	12.78
		200	13.84	14.33	13.54	12.95
		250	14.00	14.45	13.70	13.17
		300	14.16	14.56	13.87	13.42
		350	14.33	14.70	14.06	13.67
		400	14.49	14.84	14.24	13.91

Table W 2-7: Typical values for the physical characteristics



Search unit	Scanning direction	Requirements
SE	1 or 2	S < as the scan area of the search unit
N + SE	1 or 2	Dual-element probe for the near-surface area
N	1 and 2	Areas that can be evaluated shall overlap

N : Straight beam transceiver search unit
SE : Transmitter-receiver straight beam search unit

Recording levels

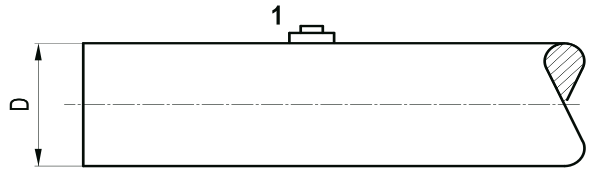
Smallest indication to be included in the evaluation: 100 mm^2

Acceptance criteria

Area, mm^2	Frequency of recordable indications	
	individual indications	referred to the entire surface of the plate or sheet
≤ 1000	≤ 3/m^2	≤ 2/m^2

The distance between any two indications located at the same depth shall be at least longer than the length of the longer indication.

Table W 2-8: Scanning directions, recording limits and acceptance criteria for plate or sheet



Search unit	Scanning direction	Requirements
SE or N	1	

N : Straight beam transceiver search unit
SE : Transmitter-receiver straight beam search unit

Recording levels

Scanning direction	Diameter D in test condition, mm	DAC method Echo amplitude referenced to the echo amplitude of a 4 mm cylindrical bore hole	DGS method Disc shaped reflector, mm
1	≤ 60	50 % (-6 dB)	3
	> 60	100 %	4

Acceptance criteria

Scanning direction	Echo amplitudes	Length of recordable indications	Frequency of recordable indications
1	Echo amplitudes up to 12 dB above the respective recording levels are acceptable	1 · D	D ≤ 60: ≤ 3/m
			D > 60: ≤ 5/m

Table W 2-9: Scanning directions, recording levels und acceptance criteria for forged and rolled round bars (heat treated wall thickness > 30 mm)

Scanning directions	Reference reflector
1 Straight-beam scanning in radial direction When using N = straight beam transceiver search unit over the whole circumference; when using SE = transmitter-receiver straight beam search unit on half the circumference	2 mm cylindrical bore hole in radial direction
2 Angled beam scanning from the cylindrical shell surface in both axis directions with an angle of 70 degrees	Rectangular notch of following dimensions: Width: ≤ 1.5 mm Depth: 0.05 · D in mm
3 On bar steel used for fasteners (e.g. core barrel / core shroud bolts), for which ultrasonic examination is intended during operation, examination for back wall echo shall be performed on one specimen per lot (length 150 mm). The lot weight shall be as defined under 3 (2) a) of material test sheet W 1.5.2.	The amplitude of the back wall echo, referenced to the cylindrical bore hole, shall be recorded.

Evaluation: For scanning directions 1 and 2 no indications which reach or exceed the echo amplitude of the reference reflector are acceptable.

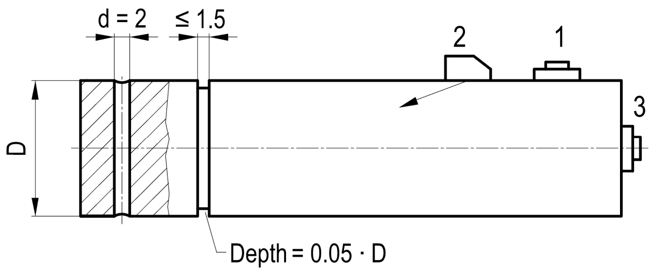
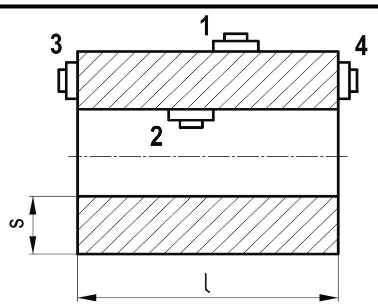


Table W 2-10: Scanning directions, reference reflector and evaluation for forged and rolled bars (heat treated wall thickness ≥ 20 up to ≤ 30 mm) for fasteners



Sound path without lateral wall influence for scanning directions 3 and 4:

$$S = \frac{s \cdot D_{eff}}{2 \cdot \lambda}$$

λ : wave length, mm

D_{eff} : effective transducer dimension

s : wall thickness

Search unit	Scanning direction	Requirements
SE	1 or 2 and 3 or 4	S < as the scan area of the search unit
N + SE	1 or 2 and 3 or 4	Dual-element probe for the near-surface area
N	1, 2, 3, 4	Areas that can be evaluated shall overlap

N : Straight beam transceiver search unit
SE : Transmitter-receiver straight beam search unit

Recording levels

Scanning directions	Wall thickness s in test condition, mm	DAC method Echo amplitude referenced to the echo amplitude of a 4 mm cylindrical bore hole	DGS method Disc shaped reflector, mm
1 to 4	≤ 60	50 % (-6 dB)	4
	> 60	100 %	6

Acceptance criteria

Scanning directions	Echo amplitudes	Length of recordable indications	Frequency of recordable indications
1 to 4	Echo amplitudes up to 12 dB above the respective recording level are acceptable	max. 50 mm, however ≤ s	individual indications: ≤ 5/m referred to the entire surface: ≤ 3/m

1) In scanning directions 3 and 4 no reflectors with dimensions exceeding 10 mm are acceptable.

Table W 2-11: Scanning directions, recording levels und acceptance criteria for forgings and rolled rings

W 2.5 Materials test sheets

MATERIALS TEST SHEET		**W 2.5.1**
Product form:	Plate, sheet or strip	
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Materials:	NiCr15Fe (material no. 2.4816) s ≤ 50 mm NiCr19Fe19Nb5Mo3 (material no. 2.4668) s ≤ 100 mm NiCr15Fe7TiAl (material no. 2.4669) s ≤ 100 mm	
Requirements:	As specified in Sections W 2.2 to W 2.4	

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment in as-delivered condition	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature in final heat treatment condition a) up to s ≤ 20 mm 1 specimen for each melt, dimension and heat treatment batch; at least for every 20th plate or sheet or for start and end of each strip	3.1
	b) for s > 20 mm up to s ≤ 50 mm 1 specimen for each rolled plate	3.2
	c) for s > 50 mm 1 specimen from the middle of the head and the edge of the tail of each rolled plate	3.2
4.	Tensile test according to Section 7.3.5.2 at 350 °C in final heat treatment condition 1 specimen per tensile test specimen (room temperature) a) for s ≤ 20 mm	3.1
	b) for s > 20 mm	3.2
5.	Notched bar impact test according to Section 7.3.5.3 at room temperature in final heat treatment condition 1 set of test specimens per tensile test (room temperature) for s > 10 mm a) up to s ≤ 20 mm	3.1
	b) for s > 20 mm	3.2
6.	Evaluation of microstructure and grain size according to Section 7.3.5.6 1 specimen for each dimension, melt and heat treatment batch	3.1
7.	Ultrasonic examination according to Section 7.3.5.8.4 Ultrasonic examination for s > 10 mm in a grid of 200 mm by 200 mm for each plate or sheet a) up to s ≤ 20 mm	3.1
	b) for s > 20 mm	3.2
8.	Visual inspection according to Section 7.3.5.8.6 100 % inspection of each plate or sheet, for strip randomly a) up to s ≤ 20 mm	3.1
	b) for s > 20 mm	3.2
9.	Dimensional check in accordance with ordering data Each plate, sheet or strip a) up to s ≤ 20 mm	3.1
	b) for s > 20 mm	3.2
10.	Materials identification check Each plate, sheet or strip by qualitative determination of typical alloying elements	3.1
11.	Check of identification marking according to Section 2.2.2.8 Each plate, sheet or strip	3.1

MATERIALS TEST SHEET		**W 2.5.2**
Product form:	Bars and forgings	
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Materials:	NiCr15Fe (material no. 2.4816) Diameter ≤ 160 mm (Heat treated wall thickness) NiCr29Fe (material no. 2.4642) Diameter ≤ 160 mm (Heat treated wall thickness) NiCr15Fe7TiAl (material no. 2.4669) Diameter ≤ 160 mm (Heat treated wall thickness) NiCr19Fe19Nb5Mo3 (material no. 2.4668) Diameter ≤ 160 mm (Heat treated wall thickness)	
Requirements:	As specified in Sections W 2.2 to W 2.4	

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment in as-delivered condition	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature in final heat treatment condition a) for diameters ≤ 100 mm 2 longitudinal specimens for each melt, dimension and heat treatment batch, however for maximum 500 kg b) for diameters > 100 mm 1 transverse specimens for each bar or forging	3.2
4.	Tensile test according to Section 7.3.5.2 at 350 °C in final heat treatment condition 1 specimen per tensile test specimen (room temperature)	3.2
5.	Notched bar impact test according to Section 7.3.5.3 at room temperature in final heat treatment condition 1 set of impact test specimens per tensile test (room temperature) for diameters s > 15 mm a) for diameters ≤ 100 mm: longitudinal b) for diameters > 100 mm: transverse	3.2
6.	Evaluation of microstructure and grain size according to Section 7.3.5.6 1 specimen for each dimension, melt and heat treatment batch	3.1
7.	Ultrasonic examination according to Section 7.3.5.8.4 Ultrasonic examination of each component, in the case of bars with diameters > 30 mm, in the case of bars for fasteners with diameters ≥ 20 mm	3.2
8.	Visual inspection according to Section 7.3.5.8.6 and visual testing according to Section 7.3.5.8.7 100 % inspection and examination of each bar or forging	3.1
9.	Dimensional check in accordance with ordering data Each bar or forging	3.2
10.	Materials identification check Each bar or forging by qualitative determination of typical alloying elements	3.1
11.	Check of identification marking according to Section 2.2.2.8 Each bar or forging	3.1

MATERIALS TEST SHEET		**W 2.5.3**
Product form: Seamless tubes		
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Material:	NiCr15Fe (material no. 2.4816) s ≤ 25 mm, diameter ≤ 170 mm	
Requirements:	As specified in W 2.2 to W 2.4	

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment in as-delivered condition	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature in final heat treatment condition 1 specimen for each melt, dimension, heat treatment batch and 100 tubes	3.1
4.	Tensile test according to Section 7.3.5.2 at 350 °C in final heat treatment condition Extent of test like tensile test (room temperature)	3.1
5.	Notched bar impact test according to Section 7.3.5.3 at room temperature in final heat treatment condition 1 set of test specimens per tensile test specimen (room temperature) for wall thickness s > 15 mm	3.1
6.	Evaluation of microstructure and grain size according to Section 7.3.5.6 1 specimen for each dimension, melt and heat treatment batch	3.1
7.	Visual inspection according to Section 7.3.5.8.6 100 % inspection of each tube (where accessible)	3.1
8.	Dimensional check in accordance with ordering data Each tube	3.1
9.	Materials identification check Each tube by qualitative determination of typical alloying elements	3.1
10.	Ultrasonic examination for longitudinal defects according to DIN EN ISO 10893-10, acceptance level U 2 A, with a notch of the “N”-type. for D_a ≤ 101.6 mm and wall thickness ≤ 5.6 mm at 10 % of the tubes for larger dimensions at each tube	3.1
11.	Check of identification marking according to Section 2.2.2.8 Each tube	3.1

MATERIALS TEST SHEET		**W 2.5.4**
Product form: Filler metal wire		
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Material:	NiCr19Fe19Nb5Mo3 (material no. 2.4668) Diameter ≤ 15 mm NiCr15Fe7TiAl (material no. 2.4669) Diameter ≤ 15 mm	
Requirements:	As specified in Sections W 2.2 to W 2.4	

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of solution annealing; for NiCr15Fe7TiAl (material no. 2.4669) additionally attestation of the degree of cold forming ≥ 10 % up to ≤ 20 %	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature in final heat treatment condition 1 specimen for each bundle/coil	3.2
4.	Tensile test according to Section 7.3.5.2 at 350 °C in final heat treatment condition 1 specimen per tensile test specimen (room temperature)	3.2
5.	Wire wrapping test according to DIN ISO 7802 One specimen each per bundle/coil from the start and end of wrapping	3.1
6.	Evaluation of microstructure and grain size according to Section 7.3.5.6 1 specimen for each dimension, melt and heat treatment batch	3.1
7.	Visual inspection according to Section 7.3.5.8.6 Spot-check inspection of each bundle/coil	3.1
8.	Dimensional check in accordance with ordering data Each bundle/coil	3.2
9.	Materials identification check Each bundle/coil by qualitative determination of typical alloying elements	3.1
10.	Check of identification marking according to Section 2.2.2.8 Each bundle/coil	3.1

Annex W 3
Austenitic stainless precision casting

Contents:

W 3.1 Scope

This annex lays down the requirements regarding quality characteristics, type and extent of tests and examinations as well as the type of certificates for austenitic stainless precision casting. The requirements shall apply for the quenched condition unless specified otherwise hereinafter.

W 3.2 Materials

W 3.2.1 Materials for quality class AS-RE 3 outside the RPV

All materials meeting the quality requirements according to DIN EN 10283 are allowable. The tests and examinations to be performed, the extent of testing and the attestation of quality characteristics shall be taken from DIN EN 10283, DIN EN 1559-1 and DIN EN 1559-2.

W 3.2.2 Materials for quality classes AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV

W 3.2.2.1 General requirements

Materials no. no. 1.4552 and 1.4309 acc. to DIN EN 10213 with restricted chemical composition and mechanical properties in accordance with the following requirements may be used.

The tests and examinations as well as the certificates required are given in the materials test sheet (WPB) in Section W 3.5.1.

W 3.2.2.2 Steel-making process

The steel-making process is left to the manufacturer unless agreed otherwise in the order. Upon request, it shall, however, be made known to the purchaser.

W 3.2.2.3 Chemical composition

The materials shall only be used with the chemical composition according to **Table W 3-1**, which is restricted compared to the standard composition according to DIN EN 10213.

Material	Content by mass, %				Nb/C
	C	Co	Cu	Nb	
1.4552	≤ 0.040	≤ 0.20	≤ 0.30	≤ 0.65	≥ 10
1.4309	≤ 0.030			—	—
The nitrogen content shall be determined and shown in the certificate.					

Table W 3-1: Restricted chemical composition

W 3.2.2.4 Heat treatment

Deviating from the requirements of DIN EN 10213 a temperature of 1120 °C shall be the upper limit for solution annealing.

W 3.2.2.5 Mechanical properties at room temperature

The stipulations of DIN EN 10213 apply.

W 3.2.2.6 Physical characteristics

Typical values for the physical characteristics are specified in DIN EN 10213.

W 3.2.2.7 Delta-ferrite content

The delta-ferrite content in the as cast condition shall be between 6 and 12 %.

W 3.2.2.8 Resistance to intergranular corrosion

The resistance to intergranular corrosion shall be demonstrated in accordance with DIN EN ISO 3651-2 procedure A.

The solution annealing shall be performed in accordance with clause 7.3.5.7 (2).

W 3.2.3 Non-destructive examinations and quality requirements

(1) Radiography

Cracks and planar defects are not permitted.

a) Basis for evaluation:

Evaluation according to [7] for wall thicknesses 1/8" to 3/8" and 3/4".

Scope: defect level a) and b) for parts with product weight > 2 kg
defect level a) for parts with product weight ≤ 2 kg

b) Acceptance standards for regions, where a clear evaluation of the radiographed volume is possible.

A) Shrinkage cavities

[7] 574 - 4, Steel, Shrinkage cavity	3/4"	
a) any location	Fig. 3	
b) near nodal points	Fig. 4	

B) Gas holes

[7] 574 - 2, Steel - Gas holes	3/8"	1/8"
a) any location	Fig. 6	5

C) Shrinkage, sponge

[7] 574 - 6, Steel - Shrinkage, sponge	3/8"	1/8"
a) any location	Fig. 4	4
b) near nodal points	Fig. 5	5

D) Foreign material less dense
Steel - Foreign material less dense

D1) Individual inclusions

[7] 574 - 4	3/8"	1/8"
a) any location	Fig. 3	3

D2) Flakes

[7] 473 - 13

a)	any location	Fig. 6	5
b)	near nodal points	Fig. 7	6

E) Dendritic shrinkage

[7] 574 - 9,

Steel - Shrinkage, dendritic		3/8"	1/8"
a)	any location	Fig. 4	4
b)	near nodal points	Fig. 5	5

F) Filamentary shrinkage

[7] 574 - 11,

Steel - Shrinkage, filamentary		3/8"	3/4"	1/8"
a)	any location	Fig. 2	2	1
b)	near nodal points	Fig. 3	3	2

G) Foreign material more dense

[7] 574 - 15,

Steel - Discrete discontinuities

Foreign material more dense

a) any location:

1 inclusion of maximum 2 mm diameter at an evaluation area of maximum 24 cm^2.

(2) Surface examination by liquid penetrant method

The stipulations of a) through d) below shall apply:

a) Indications shall not be included in the evaluation if its maximum extension is equal to or smaller than 1.5 mm.

b) Linear indications and indication that may indicate the existence of cracks are not acceptable.

c) Circular indications with a diameter exceeding 3 mm are not acceptable.

d) A number of more than 10 permissible indications, the extension of which is between 1.5 mm and 3 mm, is not acceptable on an area of 100 cm^2 or referred to the entire component surface for surfaces smaller than 100 cm^2:

(3) Check for freedom of external ferrite

Any efflorescence at the casting surface due to corrosion shall be evaluated.

Not acceptable are:

a) indications on an area exceeding 25 % of the fluid-wetted surface, divided into test areas of 1 dm^2 each,

b) circular indications with a diameter exceeding 2 mm,

c) linear indications with a length exceeding 3 mm.

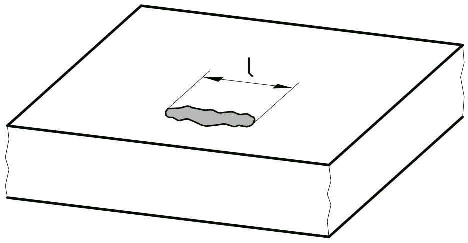


Figure W 3-1: Linear indication

d) linear oriented indications

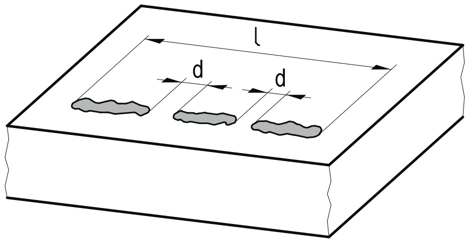


Figure W 3-2: Linear oriented indications with l exceeding 15 mm and d ≤ 3 mm

e) more than 5 permissible indications on the test area ($S_1 = S_2 = 1$ dm; A = 1 dm^2).

(4) Roughness average value

The arithmetical mean deviation of the assessed profile (average roughness) Ra according to DIN EN ISO 4287 shall normally not exceed 10 µm.

W 3.3 Specimen-taking locations and specimen orientation

The stipulations of DIN EN 10213 shall apply for the specimen-taking locations.

W 3.4 Fabrication welding

Note:

Fabrication welds are welds relating to casting irregularities which are made during production of the casting. Non-tolerable defects may be equalized by fabrication welding.

(1) The location and shape of fabrication welds shall be documented such as to ensure unambiguous allocation. Fabrication welds shall be qualified by proper test welds.

(2) Weld procedure sheets shall be established for fabrication welds. Only filler metals acc. to Annex W 4 shall be used.

W 3.5 Materials test sheet

MATERIALS TEST SHEET		W 3.5.1
Product form:	Precision castings	
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Materials:	Austenitic stainless precision casting Material no. 1.4552 Material no. 1.4309	
Requirements:	As specified in Sections W 3.2 to W 3.4	

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Chemical composition 1 product analysis for each cast melt [1)]	3.1
2.	Steel-making process Information about steel-making process and, if required, about remelting process	3.1
3.	Information about forming and casting processes used	3.1
4.	Heat treatment a) Information about the heat treatment process used b) Attestation of heat treatment condition	3.1
5.	Tensile test according to Section 7.3.5.2 at room temperature 1 specimen per test lot [2)]	3.1
6.	Notched bar impact test according to Section 7.3.5.3 at room temperature 1 set of test specimens per test lot [2)] for s > 10 mm	3.1
7.	Test for resistance to intergranular corrosion according to Section 7.3.5.7 1 specimen per test lot [2)]	3.1
8.	Determination of the delta-ferrite content according to clause 7.3.5.5 (2) Mathematical estimation per cast lot	3.1
9.	Radiography according to Section 7.3.5.8.5 The first two castings of the first test lot [2)] shall be fully examined. Where the examination method does not allow the assessment of difficult-to-cast locations, these castings shall be subjected to destructive testing, where required. For each further test lot [2)] two castings shall be tested at fixed locations that have been found to be difficult-to-cast. Where inadmissible defects are detected by this test, each casting of the lot shall be tested.	3.1
10.	Dimensional check in accordance with ordering data Each component	3.1
11.	Check for roughness average value in accordance with and clause W 3.2.3 (4) Each component	3.1
12.	Check for freedom of external ferrite according to Section 7.3.5.8.8 Each component in the final condition	3.1
13.	Surface examination according to Section 7.3.5.8.3 Each component 100 % examination, where accessible, by liquid penetrant method in the final condition	3.1
14.	Materials identification check Per test lot by qualitative determination of typical alloying elements	3.1

1) A cast melt is still available if it is proved that during remelting from a basis heat the uniformity of chemical composition is maintained.

2) One test lot shall only consist of precision castings from one cast melt and from one heat treatment lot and shall contain not more than:
20 castings for product weight > 2 kg
60 castings for product weight ≤ 2 kg.

Annex W 4

Filler metals, brazing alloy and flux for thermal spraying

Contents:

W 4.1 Scope

This annex lays down the requirements regarding quality characteristics, type and extent of tests and examinations as well as the type of certificates for filler metals for manual metal arc welding, gas tungsten arc welding, gas metal arc welding and submerged arc welding as well as for brazing alloy and flux for thermal spraying. The requirements shall apply for all-weld filler metals for the as-welded condition, for brazing alloy and flux for thermal spraying for the as-delivered condition unless specified otherwise hereinafter.

W 4.2 Materials

W 4.2.1 Filler metals and flux for thermal spraying for quality class AS-RE 3 outside the RPV

(1) Austenitic chrome/nickel steels

All filler metals with the abbreviated identification 19 9 L, 19 9 Nb, 19 9 Nb Si, 19 12 3 Nb, 19 12 3 Nb Si and 19 12 3 L meeting the quality requirements according to DIN EN ISO 3581, DIN EN ISO 14343 or DIN EN ISO 17633 are allowable. The tests and examinations to be performed and the attestation of quality characteristics shall be taken from the materials test sheet (WPB) according to Section W 4.3.2.

(2) Nickel alloys

Filler metals with the abbreviated identification NiCr20Mn3Nb (NI 6082) (material no. 2.4648), NiCr20Mn3Nb (NI 6082) (material no. 2.4806) and S-NiCr15Fe6Mn (material no. 2.4620) according to DIN EN ISO 14172 and DIN EN ISO 18274 are allowable. For lock weldings filler metals with the abbreviated identification NiCr15Ti3Mn (NI 7092) (material no. 2.4803) are allowable additionally. The mechanical properties required are specified in **Tables W 4-5** and **W 4-6**.

The tests and examinations to be performed and the attestation of quality characteristics shall be taken from the materials test sheet (WPB) according to Section W 4.3.4.

(3) Martensitic and ferritic steel

Filler metals with the abbreviated identification 13, 13 4 and 17 meeting the quality characteristics according to DIN EN ISO 3581, DIN EN ISO 14343 or DIN EN ISO 17633 as well as filler metals according to DIN EN ISO 2560 for parts outside the reactor pressure vessel during operation are allowable.

The tests and examinations to be performed and the attestation of quality characteristics shall be taken from the materials test sheet (WPB) according to Section W 4.3.5.

W 4.2.2 Filler metals for quality classes AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV

(1) Austenitic chrome/nickel steels

Filler metals with the abbreviated identifications 19 9 L, 19 9 Nb, 19 9 Nb Si, 19 12 3 Nb, 19 12 3 Nb Si according to DIN EN ISO 3581 and DIN EN ISO 14343 with restricted chemical composition and mechanical properties given below are allowed.

The tests and examinations to be performed and the attestation of quality characteristics shall be taken from the materials test sheet (WPB) according to Section W 4.3.1.

A. Chemical composition and delta-ferrite content

The materials shall only be used with the chemical composition according to **Table W 4-1**, which is restricted compared to the standard composition according to DIN EN ISO 3581 and DIN EN ISO 14343.

<table>
<tr><th rowspan="2">Material</th><th colspan="4">Content by mass, %</th><th rowspan="2">Nb/C</th><th rowspan="2">Delta-ferrite content as-welded condition, %</th></tr>
<tr><th>C</th><th>Nb 1)</th><th>Co</th><th>Cu</th></tr>
<tr><td>19 9 L</td><td>≤ 0.030</td><td>—</td><td rowspan="2">≤ 0.20</td><td rowspan="2">≤ 0.30</td><td>—</td><td rowspan="2">4 up to 12</td></tr>
<tr><td>19 9 Nb
19 9 Nb Si
19 12 3 Nb
19 12 3 Nb Si</td><td>≤ 0.040</td><td>≤ 0.65 2)</td><td>≥ 13</td></tr>
</table>

In any case the nitrogen content shall be determined and shown in the certificate.

In any case S ≤ 0.015 % (for rod electrodes according to DIN EN ISO 3581 with rutile coating however S ≤ 0.020 %) shall apply.

For submerged arc welding metals Ni ≤ 12 % shall apply.

1) It is not permitted to substitute Nb by Ta.

2) For basic coated electrodes Nb ≤ 0.75 % shall apply.

Table W 4-1: Restricted chemical composition and delta-ferrite content of austenitic filler metals

B. Mechanical properties

The mechanical properties required are specified in **Tables W 4-2** and **W 4-3**.

Property	Test temperature	
	Room temperature	350 °C
$R_{p0.2}$, N/mm²	≥ 350	≥ 180
$R_{p1.0}$, N/mm²	≥ 380	≥ 210
R_m , N/mm²	≥ 550 up to ≤ 750	≥ 380
A , %	≥ 30	≥ 20
Z , %	to be determined	

Table W 4-2: Minimum values of the mechanical properties of austenitic filler metals in the tensile test

	KV_2 J Heat treatment condition unannealed and annealed
Average value	≥ 55
Single value	≥ 40

Table W 4-3: Minimum values of the absorbed impact energy of austenitic filler metals at room temperature (Charpy-V test specimens)

(2) Nickel alloys

All filler metals with the abbreviated identifications NiCr20Mn3Nb (NI 6082) (material no. 2.4648), NiCr20Mn3Nb (NI 6082) (material no. 2.4806) and NiCr15Fe6Mn (NI 6182) (material no. 2.4620) according to DIN EN ISO 14172 and DIN EN ISO 18274 with restricted chemical composition and mechanical properties in accordance with the requirements given below are allowable.

In addition, the specifications of the mentioned above standards apply.

For lock weldings filler metals with the abbreviated identification NiCr15Ti3Mn (NI 7092) (material no. 2.4803) are allowable additionally.

The tests and examinations to be performed and the attestation of quality characteristics shall be taken from the materials test sheet (WPB) according to Section W 4.3.3.

A. Chemical composition

The chemical composition required is specified in **Table W 4-4**.

B. Mechanical properties

The mechanical properties required are specified in **Tables W 4-5** and **W 4-6**.

W 4.2.3 Brazing alloy for quality classes AS-RE 1, AS-RE 2 and AS-RE 3

Nickel brazing alloys with the chemical composition according to **Table W 4-7** are allowable to join austenitic steels.

The tests and examinations to be performed and the attestation of quality characteristics shall be taken from the materials test sheet (WPB) according to Section W 4.3.6.

W 4.2.4 Filler metals for hard surfacing and flux for thermal spraying for quality classes AS-RE 1, AS-RE 2 and AS-RE 3

The selection of filler metals for hard surfacing and of flux for thermal spraying of austenitic steels is left to the manufacturer.

The tests and examinations to be performed and the attestation of quality characteristics shall be taken from the materials test sheets (WPB) according to Sections W 4.3.7 and W 4.3.8.

Chemical element	Content by mass, %			
	Material			
	NiCr20Mn3Nb (NI 6082) (2.4648)	NiCr20Mn3Nb (NI 6082) (2.4806)	NiCr15Fe6Mn (NI 6182) (2.4620)	NiCr15Ti3Mn (NI 7092) (2.4803)
C	≤ 0.050	≤ 0.050	≤ 0.050	≤ 0.050
Si	≤ 0.50	≤ 0.20	≤ 0.50	≤ 0.30
Mn	≥ 4.00 up to ≤ 6.00	≥ 2.50 up to ≤ 3.50	≥ 5.00 up to ≤ 7.00	≥ 2.00 up to ≤ 2.70
P	≤ 0.020	≤ 0.020	≤ 0.020	≤ 0.020
S	≤ 0.010	≤ 0.010	≤ 0.010	≤ 0.010
Cr	≥ 18.0 up to ≤ 22.0	≥ 18.0 up to ≤ 22.0	≥ 15.0 up to ≤ 17.0	≥ 14.0 up to ≤ 17.0
Ni	≥ 63.0	≥ 67.0	≥ 60.0	≥ 67.0
Fe	≤ 4.0	≤ 3.0	≥ 5.0 up to ≤ 8.0	≥ 6.0 up to ≤ 8.0
Nb	≥ 2.00 up to ≤ 3.00	≥ 2.00 up to ≤ 3.00	≥ 2.00 up to ≤ 3.00	—
Co	≤ 0.10	≤ 0.10	≤ 0.10	≤ 0.10
Cu	≤ 0.20	≤ 0.20	≤ 0.20	≤ 0.50
Ti	≤ 0.50	≤ 0.70	≤ 0.50	≥ 2.50 up to ≤ 3.50
Mo	≤ 2.00	≤ 2.00	≤ 2.00	—

Table W 4-4: Chemical composition of nickel alloy filler metals

	Test temperature Room temperature	350 °C
$R_{p0.2}$, N/mm²	≥ 360	≥ 290
$R_{p1.0}$, N/mm²	≥ 380	≥ 305
R_m , N/mm²	≥ 600	≥ 500
A , %	≥ 25 [1)]	≥ 25

1) For filler metals of NiCr15Fe6Mn: A ≥ 27 J

Table W 4-5: Minimum values of the mechanical properties of nickel alloy filler metals in the tensile test

	KV_2 J
Average value	≥ 64
Single value	≥ 50

Table W 4-6: Minimum values of the absorbed impact energy of nickel alloy filler metals at room temperature

Chemical element	Content by mass %
Cr	≥ 17 up to ≤ 21
Si	≥ 9 up to ≤ 11
C	≤ 0.100
Co	≤ 0.10
P	≤ 0.035
S	≤ 0.025
Ni	Remainder

Table W 4-7: Chemical composition of brazing alloys

W 4.3 Materials test sheets

MATERIALS TEST SHEET	**W 4.3.1**
Product form: Filler metals	
Quality classes: AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Material: Austenitic stainless filler metals with the abbreviated identifications: 19 9 L 19 9 Nb 19 9 Nb Si 19 12 3 Nb 19 12 3 Nb Si	
Requirements: As specified in Section W 4.2.2	
Tests and examinations on test coupons to Section 7.3.3.2	Certificate acc. to DIN EN 10204
1. Chemical composition 1 analysis per test lot [2)]	3.1
2. Tensile test according to Section 7.3.5.2 at room temperature 1 specimen per test lot [1)]	3.1
3. Tensile test according to Section 7.3.5.2 at 350 °C 1 specimen per tensile test specimen (room temperature)	3.1
4. Notched bar impact test according to Section 7.3.5.3 at room temperature 1 set of test specimens per test lot [1)]	3.1
5. Test for resistance to intergranular corrosion according to Section 7.3.5.7 1 specimen per test lot [1)]	3.1
6. Determination of the delta-ferrite content according to Section 7.3.5.5 1 specimen per test lot [1)]	3.1
7. Check for resistance to hot cracking acc. to clause 7.3.5.4 (2), if the delta-ferrite content is ≤ 5 % 1 specimen per test lot [2)]	3.1
The following are considered test lots: Rod electrodes: Product lot produced in one shift on a press from a heat of core wire with one single diameter and a specified coating. Welding rods and wire electrodes for gas metal arc welding: Product lot produced from one heat with one single diameter. Electrode-flux combination: Combination of one heat of wire and one heat of flux with one diameter.	

1) However, a maximum of 5000 kg.

2) For welding rods and welding wire, however, a maximum of 1000 kg.

MATERIALS TEST SHEET		W 4.3.2
Product form:	Filler metals	
Quality class:	AS-RE 3 outside the RPV	
Material:	Austenitic stainless filler metals with the abbreviated identifications: 19 9 L 19 9 Nb 19 9 Nb Si 19 12 3 Nb 19 12 3 Nb Si 19 12 3 L	
Requirements:	According to DIN EN ISO 3581, DIN EN ISO 14343 and DIN EN ISO 17633	

Tests and examinations per test lot [1] on test coupons according to Section 7.3.3.2	Certificate acc. to DIN EN 10204
Chemical composition 1 analysis per test lot	3.1
The following are considered test lots: Rod electrodes: Product lot produced in one shift on a press from a heat of core wire with one single diameter and a specified coating. Welding rods and wire electrodes for gas metal arc welding: Product lot produced from one heat with one single diameter. Electrode-flux combination: Combination of one heat of wire and one heat of flux with one diameter. Flux-cored wire: Product lot produced in one shift in one production line with uniform combination of flux mixture of the same composition and heat of the electrode coating and its diameter.	

1) For welding rods and welding wire, however, a maximum of 1000 kg.

MATERIALS TEST SHEET			W 4.3.3
Product form:	Filler metals		
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV		
Material:	Filler metals made of nickel alloys with the abbreviated identifications: NiCr20Mn3Nb (NI 6082) NiCr20Mn3Nb (NI 6082) NiCr15Fe6Mn (NI 6182) NiCr15Ti3Mn (NI 7092)	 (material no. 2.4648) (material no. 2.4806) (material no. 2.4620) (material no. 2.4803)	
Requirements:	As specified in Section W 4.2.2		

Tests and examinations [1] on test coupons according to Section 7.3.3.2	Certificate acc. to DIN EN 10204
1. Chemical composition 1 analysis per test lot [2]	3.1
2. Tensile test according to Section 7.3.5.2 at room temperature 1 specimen per test lot [3]	3.1
3. Tensile test according to Section 7.3.5.2 at 350 °C to DIN EN 10002-5 1 specimen per tensile test specimen (room temperature)	3.1
4. Notched bar impact test according to Section 7.3.5.3 at room temperature 1 set of test specimens per test lot [3]	3.1
5. Check for resistance to hot cracking according to clause 7.3.5.4 (2) 1 specimen per test lot [2]	3.1
The following are considered test lots: Rod electrodes: Product lot produced in one shift on a press from a heat of core wire with one single diameter and a specified coating. Welding rods and wire electrodes for gas metal arc welding: Product lot produced from one heat with one single diameter.	

1) When filler metals are used for lock welding only the attestation of chemical composition and resistance to hot cracking is required.

2) For welding rods and welding wire, however, a maximum of 500 kg.

3) However, a maximum of 5000 kg.

MATERIALS TEST SHEET	W 4.3.4
Product form:	Filler metals
Quality class:	AS-RE 3 outside the RPV
Material:	Filler metals made of nickel alloys with the abbreviated identifications: NiCr20Mn3Nb (NI 6082) (material no. 2.4648) NiCr20Mn3Nb (NI 6082) (material no. 2.4806) NiCr15Fe6Mn (NI 6182) (material no. 2.4620) NiCr15Ti3Mn (NI 7092) (material no. 2.4803)
Requirements:	According to DIN EN ISO 14172 and DIN EN ISO 18274

Tests and examinations per test lot 1) on test coupons to Section 7.3.3.2	Certificate acc. to DIN EN 10204
1. Chemical composition 1 analysis per test lot	3.1
2. Check for resistance to hot cracking according to clause 7.3.5.4 (2) 1 specimen per test lot	3.1
The following are considered test lots: Rod electrodes: Product lot produced in one shift on a press from a heat of core wire with one single diameter and a specified coating. Welding rods and wire electrodes for gas metal arc welding: Product lot produced from one heat with one single diameter. Electrode-flux combination: Combination of one heat of wire and one heat of flux with one diameter.	

1) For welding rods and welding wire, however, a maximum of 500 kg.

MATERIALS TEST SHEET	W 4.3.5
Product form:	Filler metals
Quality class:	AS-RE 3 outside the RPV
Material:	Martensitic and ferritic filler metals with the abbreviated identifications 13, 13 4 and 17 as well as unalloyed and low-alloyed filler metals
Requirements:	According to DIN EN ISO 3581, DIN EN ISO 14343 and DIN EN ISO 17633 as well as DIN EN ISO 2560

Tests and examinations per test lot 1) on test coupons to Section 7.3.3.2	Certificate acc. to DIN EN 10204
Chemical composition 1 analysis per test lot	3.1
The following are considered test lots: Rod electrodes: Product lot produced in one shift on a press from a heat of core wire with one single diameter and a specified coating. Welding rods and wire electrodes for gas metal arc welding: Product lot produced from one heat with one single diameter. Electrode-flux combination: Combination of one heat of wire and one heat of flux with one diameter. Flux-cored wire: Product lot produced in one shift in one production line with uniform combination of flux mixture of the same composition and heat of the electrode coating and its diameter.	

1) For welding rods and welding wire, however, a maximum of 1000 kg.

MATERIALS TEST SHEET		W 4.3.6
Product form:	Brazing alloy	
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Material:	Brazing alloy made of nickel alloys	
Requirements:	As specified in Section W 4.2.3	
Tests and examinations		Certificate acc. to DIN EN 10204
Chemical composition 1 analysis for each quality ordered		3.1

MATERIALS TEST SHEET		W 4.3.7
Product form:	Filler metals for hard surfacing	
Quality classes:	AS-RE 1, AS-RE 2 and AS-RE 3	
Material:	According to manufacturer's specification	
Requirements:	As specified in Section W 4.2.4	
Tests and examinations		Certificate acc. to DIN EN 10204
1. Chemical composition 1.1 Welding rod and welding wire Information about chemical analysis of the welding wire for each test lot [1)]		3.1
1.2 Rod electrodes Information about chemical analysis of the bead material for each test lot [1)]		3.1
The following are considered test lots: Rod electrodes: Product lot produced in one shift on a press from a heat of core wire with one single diameter and a specified coating. Welding rods and wire electrodes for gas metal arc welding: Product lot produced from one heat with one single diameter.		
1) However, a maximum of 1000 kg.		

MATERIALS TEST SHEET		W 4.3.8
Product form: Flux for thermal spraying		
Quality classes:	AS-RE 1, AS-RE 2 and AS-RE 3	
Material:	Acc. to manufacturer's specification	
Requirements:	As specified in Section W 4.2.4	
Tests and examinations		Certificate acc. to DIN EN 10204
1. Chemical composition Information about chemical analysis for each quality ordered [1)]		3.1
2. Sieve analysis Information about grain size		3.1
1) However, a maximum of 500 kg.		

Annex W 5

Machine elements

Contents:

W 5.1 Scope

This annex lays down the requirements regarding quality characteristics, type and extent of tests and examinations as well as the type of certificates for machine elements.

W 5.2 Requirements

W 5.2.1 Machine elements of quality class AS-RE 3 outside the RPV

For product forms, structural fasteners, springs, gaskets, sleeves, collars, bearings, rings, hoses, instruments, and similar machine elements made of metal or plastics an inspection certificate according to DIN EN 10204 shall be established to confirm that the product forms or machine elements delivered meet the respective standards or manufacturer's specifications regarding materials and quality characteristics.

W 5.2.2 Machine elements of quality classes AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV

(1) For machine elements the materials meeting the requirements of the materials test sheets (WPB) given in Sections W 5.3.1 to W 5.3.5 are allowable. Other materials are allowable if specified in the course of the design review.

(2) The tests and examinations to be performed, the extent of testing and the attestation of quality characteristics for machine elements shall be taken from the materials test sheets (WPB) W 5.2.1 to W 5.3.5.

(3) For small parts, e.g. washers, retaining plates, pins, made of austenitic steels according to DIN EN 10088-2 and DIN EN 10088-3 an inspection certificate according to DIN EN 10204 shall be established to confirm, that the small parts delivered meet the respective standards regarding materials and quality characteristics.

(4) The mechanical properties of fasteners (bolts) with reduced shank (shank diameter d_0) according to materials test sheet 5.3.2 shall be determined using the test procedures according to Section 9.5 of DIN EN ISO 898-1. The requirements according to Table 8 (solution annealed) and Table 25 (tensile strength class +C 700) of DIN EN 10088-3 apply. The requirements for the material no. 1.4571 shall also apply for the material no. 1.4550. The determination shall be made on the reduced shank of a bolt with a measured length $L_0 = 5 \cdot d_0$. For specimens with deviating lengths $L_0 = x \cdot d_0$ the elongation at fracture A may be calculated by means of the evaluated tensile test curve (machine diagram) using the formula

$$A = A_{gx} + A_{einx} \cdot \frac{x}{5} \quad \text{(W 5-1)}$$

provided that [8], [9] the uniform elongation A_{gx} is independent of the specimen length ($A_{gx} = A_{g5}$) and the portion of the reduction of area A_{einx} is proportional to

$$\frac{d_0}{L_0} = \frac{1}{x} \quad \text{(W 5-2)}$$

When determining the A_{gx} and A_{einx} strain portions from the machine diagram it shall be considered that the related portions of the extended specimen Δl_g and Δl_{ein} have to be referred to the test length L_c of the specimen, i.e. $x = L_c/d_0$.

(5) For the tensile strength at elevated temperatures the conversion factors for the 0.2% proof stress given in **Table W 5-1** apply.

(6) The sampling plan given in **Table W 5-2** shall be used. Details of the sampling rate to be used are laid down in the respective materials test sheet.

Steel grade	+ 100 °C	+ 200 °C	+ 300 °C	+ 400 °C
Acc. to materials test sheets 5.3.1 and 5.3.2	85 [1)]	80 [1)]	75 [1)]	70 [1)]

1) These values shall apply only for fasteners of tensile strength class +C 700 acc. to DIN EN 10088-3 and of strength grade 70 acc. to DIN EN ISO 3506-1, for fasteners of tensile strength class 50 acc. to DIN EN ISO 3506-1 the values given in Table 23 of DIN EN 10088-3 shall apply.

Table W 5-1: 0.2% proof stress ($R_{p0.2}$) at elevated temperatures, in % of the values at room temperature

Lot size N		Number of random samples n		Acceptance number A_c
exceeding	up to and incl.	AQL 1	AQL 4	
	15	2	1	0
15	60	6	2	0
60	150	13	3	0
150	1200	50	13	1
1200	3200	80	20	2
3200	10000	125	32	3

Table W 5-2: Sampling plan

W 5.3 Materials test sheets

MATERIALS TEST SHEET	**W 5.3.1**
Product form:	Structural fasteners according to DIN EN ISO 3506-1 and DIN EN ISO 3506-2
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV
Materials:	Material no. no. 1.4571 (A5), 1.4550 (A3), 1.4541 (A3) according to DIN EN ISO 3506-1 strength grade 50 or 70, DIN EN ISO 3506-2 strength grade 50 or 70, in each case with chemical composition according to Annex W 1
Requirements: Test lot:	According to DIN EN ISO 3506-1, DIN EN ISO 3506-2 and Annex W 1, Section W 1.2.2.3 According to [1]

Tests and examinations	Certificate acc. to DIN EN 10204
1. Test of material Chemical composition Ladle analysis according to Annex W 1	3.1
2. Tests/examinations of the finished parts 2.1 Check of dimensions in accordance with ordering data and of tolerances according to DIN EN ISO 4759-1 Execution acc. to product grade A in accordance with DIN EN ISO 4759-1; tests/examinations acc. to Tables 1 to 3 and acc. to Tables 6 to 8 of DIN EN ISO 3269. The sampling plan in accordance with **Table W 5-2** for AQL 1 shall be used, regarding all characteristics except the characteristic “all others” independent from the number of random samples an acceptance number A_c = 0 shall apply for each test lot. All characteristics (dimensions) [2] shall be checked which are specified in the table applicable to the relevant product group.	3.1
2.2 Determination of mechanical properties: Tensile test at room temperature of bolts: Performance acc. to Section 7 of DIN EN ISO 3506-1 The sampling plan in accordance with **Table W 5-2** for AQL 4 shall be used. Independent from the number of random samples an acceptance number A_c = 0 shall apply for each test lot. The values to be guaranteed given in Table 2 of DIN EN ISO 3506-1 shall be met. Proof load test on nuts: Performance acc. to Section 7.2 of DIN EN ISO 3506-2. The sampling plan in accordance with **Table W 5-2** for AQL 4 shall be used. Independent from the number of random samples an acceptance number A_c = 0 shall apply for each test lot. The values to be guaranteed given in Table 2 of DIN EN ISO 3506-2 shall be met.	3.1
2.3 Surface examination according to Section 7.3.5.8.3 of bolts and pins The sampling plan in accordance with **Table W 5-2** for AQL 1 shall be used. Evaluation: Crack-like indications are not permitted. Structural discontinuities shall not be evaluated. If indications are found that are caused neither by design nor by fabrication the extent of testing shall be increased up to 100 %.	3.1
2.4 Visual inspection according to Section 7.3.5.6.6 Inspection of bolts and pins not subjected to surface examination as per no. 2.3.	3.1
2.5 Check for freedom of external ferrite according to Section 7.3.5.6.7 The sampling plan in accordance with **Table W 5-2** for AQL 1 shall be used. Independent from the number of random samples an acceptance number A_c = 0 shall apply for each test lot.	3.1
2.6 Materials identification check By qualitative determination of typical alloying elements and check of the identification marking [3] Extent: 1 %, at least 2 components of each test lot	3.1

[1] Similar parts of the same strength grade, the same design and the same melt.

[2] The characteristic “nonconforming fasteners” specified in Table 1 of DIN EN ISO 3269 is not permitted.

[3] For identification marking the stipulations in Section 4.2 of DIN EN ISO 3506-1 and in Section 4.2 of DIN EN ISO 3506-2 shall apply.

MATERIALS TEST SHEET	**W 5.3.2**
Product form: Structural fasteners made of material acc. to Annex W 1, Annex W 2 and Annex W 6 (only material no. 1.4980)	
Quality classes: AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Materials: According to Annex W 1, W 2 and W 6 (only material no. 1.4980) Materials according to Annex W 1 for fasteners < M 33 shall be hot/cold work hardened or cold work hardened to meet the strength characteristic required.	
Requirements: Source material according to Annex W 1 and clause W 5.2.2 (4), Annex W 2 and Annex W 6 (only material no. 1.4980) Test lot: According to [1)]	

Tests and examinations	Certificate acc. to DIN EN 10204
1. Tests/examinations of the material (source material) Tests/examinations and certification in accordance with Annex W 1, Annex W 2 and Annex W 6 (only material no. 1.4980) for each test lot 1.1 For materials according to Annex W 1 for bolts and nuts ≤ M 33 the following shall apply: The chemical composition shall meet the requirements of Section W 1.2.2.3 and the mechanical properties shall meet the requirements of DIN EN 10088-3 (tensile strength class +C 700) and **Table W 5-1**. The other values required in Annex W 1 for tensile test at room temperature and at elevated temperatures as well as for notched bar impact test shall be determined for information. The elongation after fracture shall meet the requirements given in clause W 5.2.2 (2). For dimensions > M 33 the mechanical properties given in Annex W 1 are required. Specimen shape and specimen dimensions: Bolts shall be tested, for pins and studs short proportional specimens with $L_0 = 5 \cdot d_0$ according to DIN 50125 (where possible with regard to geometry, in other cases specimens on the basis of this standard) shall be used. The specimens for bolts ≤ M 33 shall be taken concentricly. The specimen diameter d_0 shall be selected depending on the component dimensions. 1.2 The mechanical properties of materials according to Annexes W 2 and W 6 (material no. 1.4980) for bolts and nuts shall meet the requirements given in Annexes W 2 and W 6.	
2. Tests/examinations of the finished parts 2.1 Tensile test at room temperature of bolts Performance acc. to Section 9.5, 9.6 or 9.7 of DIN EN ISO 898-1 The sampling plan in accordance with **Table W 5-2** for AQL 4 shall be used. Independent from the number of random samples an acceptance number $A_c = 0$ shall apply for each test lot.	3.1
2.2 Proof load test on nuts Performance acc. to Section 9.1 of DIN EN ISO 3506-2. The sampling plan in accordance with **Table W 5-2** for AQL 4 shall be used. Independent from the number of random samples an acceptance number $A_c = 0$ shall apply for each test lot.	3.1
2.3 Check of dimensions in accordance with ordering data and of tolerances acc. to DIN EN ISO 4759-1 Execution acc. to product grade A according to DIN EN ISO 4759-1; tests/examinations acc. to Tables 1 to 3 and acc. to Tables 6 to 8 of DIN EN ISO 3269. The sampling plan in accordance with **Table W 5-2** for AQL 1 shall be used, regarding all characteristics except the characteristic “all others” independent from the number of random samples an acceptance number $A_c = 0$ shall apply for each test lot. All characteristics (dimensions) [2)] shall be checked which are specified in the table applicable to the relevant product group.	3.1
2.4 Surface examination according to Section 7.3.5.8.3 of bolts and pins The sampling plan in accordance with **Table W 5-2** for AQL 1 shall be used. Evaluation: Crack-like indications are not permitted. Structural discontinuities shall not be evaluated. If indications are found that are not allowed the extent of testing shall be increased up to 100 %.	3.1
2.5 Visual inspection according to Section 7.3.5.8.6 Inspection of bolts and pins not subjected to surface examination as per no. 2.4.	3.1
2.6 Check for freedom of external ferrite according to Section 7.3.5.8.8 The sampling plan in accordance with **Table W 5-2** for AQL 1 shall be used. Independent from the number of random samples an acceptance number $A_c = 0$ shall apply for each test lot.	3.1
2.7 Materials identification check By qualitative determination of typical alloying elements and check of the identification marking [3)]. Extent: 1 %, at least 2 components of each test lot	3.1

[1)] Similar parts of the same strength grade, the same design and the same melt. Similar parts of the same strength grade, the same design and the same melt, which only differ e.g. in length or in design with or without reduced shank, may be considered to be parts of the same test lot.
[2)] The characteristic “nonconforming fasteners” specified in Table 1 of DIN EN ISO 3269 is not permitted.
[3)] For identification marking the stipulations in Section 4.2 of DIN EN ISO 3506-1 and in Section 4.2 of DIN EN ISO 3506-2 shall apply.

MATERIALS TEST SHEET	**W 5.3.3**
Product form:	Disc springs
Quality class:	AS-RE 2
Materials:	According to Annex W 2
Requirements:	According to Annex W 2, DIN EN 16983 or technical drawing

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Tests/examinations of the material (source material) Tests/examinations and certification in accordance with Annex W 2 for each test lot	
2.	Tests/examinations of the finished parts and accompanying test coupons	
2.1	Attestation of heat treatment of the accompanying test coupons and finished springs Performance of the heat treatment in accordance with Annex W 2	3.1
2.2	Tensile test according to Section 7.3.5.2 at room temperature and at 350 °C on accompanying heat treated test coupons 1 specimen for each melt, dimension and heat treatment batch. The minimum values of mechanical properties required in Annex W 2 shall be met.	3.1
2.3	Dimensional check on 100 % of the springs according to DIN EN 16983 or technical drawing	3.1
2.4	Visual inspection according to Section 7.3.5.8.6 on 100 % of the springs	3.1
2.5	Surface examination according to Section 7.3.5.8.3 Extent: 100 % of the springs No indications are allowed.	3.1
2.6	Check for freedom of external ferrite according to Section 7.3.5.6.8 Extent: 100 % of the springs No indications are allowed.	3.1
2.7	Hardness test according to DIN EN ISO 6508-1 Extent: Test of 1 %, at least 2 finished springs for each melt, dimension and heat treatment batch with 3 hardness indentations each For lots < 20 components: test of 1 spring Requirements: HRC = 32 up to 42 (material no. 2.4669) HRC = 35 up to 50 (material no. 2.4668) Springs subjected to the hardness test shall not be delivered	3.1
2.8	Fatigue test at room temperature Extent: Test of 2 finished springs for each melt, dimension and heat treatment batch For lots < 20 components: test of 1 spring Fatigue loading to be setted:	3.1

Disc springs according to DIN EN 16983	σ_U N/mm^2	σ_O [1] N/mm^2
Group 1	400	1100
Group 2	400	1075
Group 3	200	810

Load cycles: at least $2 \cdot 10^5$
The test shall be performed until fracture or maximum $2 \cdot 10^6$ load cycles
The number of load cycles obtained shall be recorded.

2.9	24-hours proof load test at room temperature and 70 % of nominal load Extent: Test of 10 %, at least 5 finished springs for each melt, dimension and heat treatment batch. Where the springs do not meet the allowable range of deviations acc. to Table 9 of DIN EN 16983 after proof load test, the extent of tested disc springs shall be increased up to 100 %.	3.1
2.10	Determination of spring characteristics and dimensional check of disk spring columns The disc springs shall be combined to form spring columns in accordance with the ordering data and be set to the working point prior to achieving the spring characteristics at room temperature.	3.1
2.11	Materials identification check Test of 1 %, at least of 2 finished springs for each melt, dimension and heat treatment batch by qualitative determination of typical alloying elements For lots < 20 components: test of 1 spring	3.1

[1] Where the spring characteristics permit (e.g. no total compression of the spring).

MATERIALS TEST SHEET		W 5.3.4
Product form:	Helical springs	
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Materials:	According to Annex W 2	
Requirements:	Source material according to Annex W 2, DIN EN 15800	

Tests and examinations	Certificate acc. to DIN EN 10204
1. Tests/examinations of the material (source material) Tests/examinations and certification in accordance with Annex W 2 for each test lot	
2. Tests/examinations of the finished parts and accompanying test coupons 2.1 Attestation of heat treatment of the accompanying test coupons and finished springs Performance of the heat treatment in accordance with Annex W 2	3.1
2.2 Tensile test according to Section 7.3.5.2 at room temperature and at 350 °C on accompanying heat treated test coupons 1 specimen for each melt, dimension and heat treatment batch The minimum values of mechanical properties required in Annex W 2 shall be met.	3.1
2.3 Dimensional check on 100 % of the springs according to DIN EN 15800	3.1
2.4 Visual inspection according to Section 7.3.5.8.6 on 100 % of the springs	3.1
2.5 Surface examination according to Section 7.3.5.8.3 Extent: 10 % of the springs, at least 2 springs No indications are allowed.	3.1
2.6 Check for freedom of external ferrite according to Section 7.3.5.8.8 Extent: 100 % of the springs. No indications are allowed.	3.1
2.7 Hardness test according to DIN EN ISO 6508-1 Extent: Test of 1 %, at least 2 finished springs for each melt, dimension and heat treatment batch with 3 hardness indentations each For lots < 20 components: test of 1 spring Requirements: HRC = 32 up to 42 (material no. 2.4669) HRC = 35 up to 50 (material no. 2.4668)	3.1
2.8 Determination of spring characteristics and dimensional check of each spring	3.1
2.9 Materials identification check Test of 1 %, at least of 2 finished springs for each melt, dimension and heat treatment batch by qualitative determination of typical alloying elements For lots < 20 components: test of 1 spring	3.1

MATERIALS TEST SHEET		**W 5.3.5**
Product form:	Bolts and washers	
Quality classes:	AS-RE 1 und AS-RE 2 as well as AS-RE 3 inside the RPV	
Material:	Material no. 1.4122	
Requirements:	Source material according to Annex W 6	

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Tests/examinations of the material Tests/examinations and certification in accordance with Annex W 6 for each test lot As-delivered condition: quenched and tempered	
2.	Tests/examinations of the finished parts and accompanying test coupons [1)]	
2.1	Attestation of heat treatment condition The pre-turned parts and accompanying test coupons shall be heat treated in accordance with ordering data.	3.1
2.2	Hardness test according to DIN EN ISO 6508-1 or DIN EN ISO 6506-1 (on pre-turned parts and accompanying test coupons) Test of one end face Extent: 5 parts for each melt, dimension and heat treatment batch and the accompanying test coupons Requirements: ≥ 42 HRC (at the surface)	3.1
2.3	Tensile test at room temperature Performance according to Section 7.3.5.2 on accompanying test coupons. One specimen for each accompanying test coupon Specimen orientation in accordance with Annex W 6 Values to be determined: $R_{p0.2}$; R_m; A and Z	3.1
2.4	Surface examination according to Section 7.3.5.8.3 of the finished parts Extent: 10 % of the parts, however at least 5 parts per dimension. If indications are found that are not allowed the extent of testing shall be increased up to 100 %. Evaluation: Crack-like indications are not permitted.	3.1
2.5	Visual inspection according to Section 7.3.5.8.6 Inspection of bolts and pins not subjected to surface examination as per no. 2.4.	3.1
2.6	Check for freedom of external ferrite according to Section 7.3.5.8.8 Extent: 100 % of the parts No indications are allowed.	3.1
2.7	Dimensional check Dimensional check of the finished parts in accordance with ordering data Extent: 100 % of the parts	3.1
2.8	Materials identification check Test of 1 %, at least of 2 finished springs for each melt, dimension and heat treatment batch by qualitative determination of typical alloying elements For lots < 20 components: test of 1 part	3.1

1) One accompanying test coupons for each melt, dimension and heat treatment batch.

Annex W 6

Special materials

(Product forms: plate, sheet, strip, tubes, bars, forgings, welding wire)

Contents:

W 6.1 Scope

This annex lays down the requirements regarding quality characteristics, type and extent of tests and examinations as well as the type of certificates for quality characteristics not included in Annexes W 1 to W 4. The requirements shall apply for the as-delivered condition unless specified otherwise hereinafter.

W 6.2 Materials

W 6.2.1 Materials for quality class AS-RE 3 outside the RPV

All ferritic and martensitic materials according to DIN EN 10025-2, DIN EN 10083-2, DIN EN 10084, DIN EN 10088-2, DIN EN 10088-3 and DIN EN 10272 as well as all austenitic materials according to DIN EN 10028-7, DIN EN 10088-2, DIN EN 10088-3, DIN EN 10216-5, DIN EN 10217-7, DIN EN 10222-5, DIN EN 10250-4, DIN EN 10272 as well as all highly heat resisting steels and nickel alloys according to DIN EN 10302 meeting the requirements of the respective standards or the respective manufacturer's specifications are allowable for parts outside the RPV during operation.

W 6.2.2 Materials for quality classes AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV

(1) Materials no. no. 1.4980 and 1.4122 meeting the requirements specified hereinafter are allowable, provided, these materials have been used on structures and product forms for which sufficient experience on operating conditions exists. If these materials are to be used at other locations, their use shall be reviewed for each individual case.

(2) Clause 7.2.1 covers the requirements for manufacturers of product forms.

(3) The tests and examinations to be performed, the extent of testing and the attestation of quality characteristics shall be taken from the materials test sheets (WPB) W 6.3.1 and W 6.3.2.

W 6.2.2.1 Material no. 1.4980

(1) Steel-making process

The steel-making processs is left to the manufacturer unless agreed otherwise in the order. Upon request, it shall, however, be made known to the purchaser.

(2) Chemical composition

The material shall only be used with the chemical composition according to **Table W 6-1**.

(3) Heat treatment

The material shall be heat treated in accordance with **Table W 6-2**.

Chemical element	Content by mass, %
C	≥ 0.030 up to ≤ 0.080
Ni	≥ 24.0 up to ≤ 27.0
Cr	≥ 13.5 up to ≤ 16.0
Si	≤ 1.00
Mo	≥ 1.00 up to ≤ 1.50
Mn	≥ 1.00 up to ≤ 2.00
Ti	≥ 1.90 up to ≤ 2.30
V	≥ 0.10 up to ≤ 0.50
Al	≤ 0.35
B	≥ 0.0030 up to ≤ 0.0100
P	≤ 0.025
S	≤ 0.015
Co	≤ 0.20
Cu	≤ 0.50
Fe	Remainder

Table W 6-1: Chemical composition (material no. 1.4980)

(4) Mechanical properties

The mechanical properties required are specified in **Tables W 6-3** and **W 6-4**.

(5) Physical characteristics

Typical values for the physical characteristics are specified in **Table W 6-5**.

(6) Non-destructive examinations and quality characteristics

a) Forged und rolled bars (diameter exceeding 30 mm)
   The requirements of **Table W 6-6** shall apply for the ultrasonic examination of forged and rolled bars which diameter exceeds 30 mm.
b) Forgings
   The requirements of **Table W 6-7** shall apply for the ultrasonic examination of forgings.

(7) Specimen-taking locations and specimen orientation

The stipulations of DIN EN 10302 shall apply for specimen-taking locations and specimen orientation.

W 6.2.2.2 Material no. 1.4122

(1) Steel-making process

The steel-making processs is left to the manufacturer unless agreed otherwise in the order. Upon request, it shall, however, be made known to the purchaser.

(2) Chemical composition

The material shall only be used with the chemical composition according to Tables 5 and 6 of DIN EN 10088-3.

(3) Heat treatment

The material shall be heat treated in accordance with Table A.4 of DIN EN 10088-3.

(4) Mechanical properties

The mechanical properties required are specified in Tables 11 and 16 of DIN EN 10088-3.

(5) Physical characteristics

Typical values for the physical characteristics are specified in Annex E of DIN EN 10088-1.

(6) Non-destructive examinations and quality characteristics

The requirements of **Table W 6-6** shall apply for the ultrasonic examination of forged and rolled bars which diameter exceeds 30 mm.

(7) Specimen-taking locations and specimen orientation

The stipulations of DIN EN 10088-3 shall apply for specimen-taking locations and specimen orientation.

Material no.	Product form	Heat treatment	
		Solution annealing	Precipitation hardening
1.4980	Bar, forging	980 °C ± 10 K, 0.5 up to 1 h / oil or water	720 °C ± 10 K 16 h / air

Table W 6-2: Heat treatment condition

Material no.	Product form	Dimension thickness / diameter mm	Specimen orientation	$R_{p0.2}$ N/mm²	R_m N/mm²	A %	Z %	KV_2 J
1.4980	Bar	≤ 100	longitudinal	≥ 600	≥ 900 and ≤ 1150	≥ 18	2)	≥ 40
		> 100 up to ≤ 160	transverse	≥ 600	≥ 900 and ≤ 1150	≥ 15	2)	2)
	Forging	≤ 250 1)	transverse / tangential	≥ 590	≥ 880	≥ 15	2)	2)

1) Heat treated wall thickness
2) to be determined

Table W 6-3: Requirements for mechanical properties at room temperature

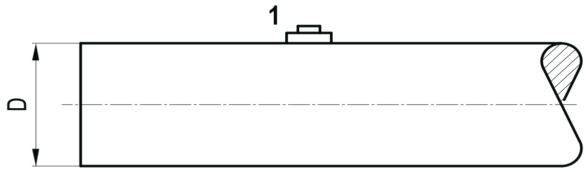
Material no.	Product form	Dimension thickness / diameter mm	Specimen orientation	$R_{p0.2}$ N/mm²	R_m N/mm²	A %	Z %
1.4980	Bar	≤ 100	longitudinal	≥ 520	≥ 590	to be determined	
		> 100 up to ≤ 160	transverse	≥ 520	≥ 590		
	Forging	≤ 250 1)	transverse / tangential	≥ 520	≥ 590		

1) Heat treated wall thickness

Table W 6-4: Requirements for mechanical properties at 350 °C

Physical characteristic	Unit	Temperature T, °C	Material no. 1.4980
Density	g/cm³	room temperature	7.95
Modulus of elasticity	10^3 N/mm²	room temperature	211
		100	206
		200	200
		300	192
		400	182
Average thermal conductivity	W/(m·K)	room temperature	13.0
		100	14.5
		200	16.0
		300	18.0
		400	20.0
Average linear thermal expansion coefficient between 20 °C and T	10^{-6}/K	100	17.0
		200	17.5
		300	17.8
		400	18.0

Table W 6-5: Typical values for the physical characteristics



Search unit	Scanning direction	Requirements
SE or N	1	

N : Straight beam transceiver search unit
SE : Transmitter-receiver straight beam search unit

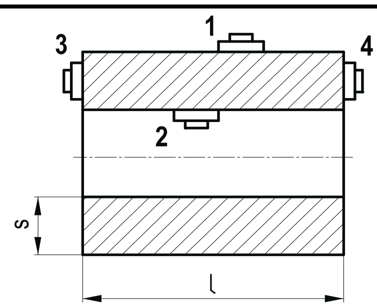
Recording levels

Scanning direction	Diameter D in test condition, mm	DAC method Echo amplitude referenced to the echo amplitude of a 4 mm cylindrical bore hole	DGS method Disc shaped reflector, mm
1	≤ 60	50 % (-6 dB)	3
	> 60	100 %	4

Acceptance criteria

Scanning direction	Echo amplitudes	Length of recordable indications	Frequency of recordable indications
1	Echo amplitudes up to 12 dB above the respective recording level are acceptable	1 · D	D ≤ 60: ≤ 3/m
			D > 60: ≤ 5/m

Table W 6-6: Scanning directions, recording levels und acceptance criteria for forged and rolled bars



Sound path without lateral wall influence for scanning directions 3 and 4:

$$S = \frac{s \cdot D_{eff}}{2 \cdot \lambda}$$

λ : wave length, mm
D_{eff} : effective transducer dimension
s : wall thickness

Search unit	Scanning direction	Requirements
SE	1 or 2 and 3 or 4	S < as the scan area of the search unit
N + SE	1 or 2 and 3 or 4	Dual-element probe for the near-surface area
N	1, 2, 3, 4	Areas that can be evaluated shall overlap

N : Straight beam transceiver search unit
SE : Transmitter-receiver straight beam search unit

Recording levels

Scanning directions	Wall thickness s in test condition, mm	DAC method Echo amplitude referenced to the echo amplitude of a 4 mm cylindrical bore hole	DGS method Disc shaped reflector, mm
1 to 4	≤ 60	50 % (-6 dB)	4
	> 60	100 %	6

Acceptance criteria

Scanning directions	Echo amplitudes	Length of recordable indications	Frequency of recordable indications
1 to 4	Echo amplitudes up to 12 dB above the respective recording level are acceptable	max. 50 mm, however ≤ s	individual indications: ≤ 5/m referred to the entire surface: ≤ 3/m

[1] In scanning directions 3 and 4 no reflectors with dimensions exceeding 10 mm are acceptable.

Table W 6-7: Scanning directions, recording levels and acceptance criteria for forgings

W 6.3 Materials test sheets

MATERIALS TEST SHEET		**W 6.3.1**
Product form:	Bars and forgings	
Quality classes:	AS-RE 1 and AS-RE 2 as well as AS-RE 3 inside the RPV	
Material:	Material no. 1.4980, diameter ≤ 250 mm (heat treated wall thickness)	
Requirements:	As specified in Section W 6.2.2.1	

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment condition Information about steel-making process and attestation of heat treatment condition	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature a) for diameters ≤ 100 mm 2 longitudinal specimens for each dimension, melt, heat treatment batch and 500 kg b) for diameters > 100 mm 1 transverse specimen for each component	3.2
4.	Tensile test according to Section 7.3.5.2 at 350 °C 1 specimen per tensile test specimen (room temperature)	3.2
5.	Notched bar impact test according to Section 7.3.5.3 at room temperature 1 set of test specimens per tensile test (room temperature) if diameter ≥ 15 mm a) for diameters ≤ 100 mm: longitudinal b) for diameters > 100 mm: transverse	3.2
6.	Crystalline structure and determination of grain size according to Section 7.3.5.6 1 specimen for dimension, melt and heat treatment batch	3.1
7.	Ultrasonic examination according to Section 7.3.5.8.4 Each component if diameter exceeds 30 mm	3.2
8.	Surface examination 100 % visual inspection according to Section 7.3.5.8.6 and additionally visual testing according to Section 7.3.5.8.7 on each component	3.2
9.	Dimensional check in accordance with ordering data Each component	3.2
10.	Materials identification check Each component by qualitative determination of typical alloying elements	3.1

MATERIALS TEST SHEET		**W 6.3.2**
Product form:	Bars	
Quality classes:	AS-RE 1 and AS-RE 2	
Material:	Material no. 1.4122, diameter ≤ 160 mm (heat treated wall thickness)	
Requirements:	According to DIN EN 10088-3	

	Tests and examinations	Certificate acc. to DIN EN 10204
1.	Chemical composition Ladle analysis	3.1
2.	Steel-making process and heat treatment Information about steel-making process and attestation of heat treatment condition	3.1
3.	Tensile test according to Section 7.3.5.2 at room temperature 1 specimen for each dimension, melt and heat treatment batch	3.1
4.	Notched bar impact test according to Section 7.3.5.3 at room temperature (RT) 1 set of test specimens (longitudinal) per tensile test (room temperature) if diameter ≥ 15 mm	3.1
5.	Evaluation of microstructure and grain size according to Section 7.3.5.6 1 specimen for each dimension, melt and heat treatment batch	3.1
6.	Ultrasonic examination according to Section 7.3.5.8.4 Each bar if diameter exceeds 30 mm	3.1
7.	Visual inspection according to Section 7.3.5.8.6 and visual testing according to Section 7.3.5.8.7 100 % inspection and examination of each bar	3.1
8.	Dimensional check in accordance with ordering data Each bar	3.1
9.	Materials identification check Each bar by qualitative determination of typical alloying elements	3.1

Annex A

Verification of structural integrity by analysis

A 1 Structural analysis for loading levels A and B

A 1.1 Verification by generally applicable standards and rules

The following may be applied:

a) AD 2000-Technical leaflets:
B 0, B 1, B 3, B 6

b) DIN EN 13480-3 (Section 9),

c) DIN EN 13445-3 (Section 8).

A 1.2 Verification by means of equivalent analysis methods for shells under external pressure difference

A 1.2.1 General

(1) Rules are given in this paragraph for determining the stresses under external pressure difference loading in spherical shells, cylindrical shells with or without stiffening rings, and tubular products. Curves for determining the stresses in shells, hemispherical heads, and tubular products are given in clause A 1.2.7.

(2) Where dynamic pressure differences occur, the limitations of this paragraph shall apply or the allowable internal pressure difference shall be limited to 25 % of the dynamic instability pressure.

A 1.2.2 Nomenclature

Symbol	Variable	Unit
A	Factor determined from Figure A-1 and used to enter the applicable material chart. For the case of cylindrical shells having D_o/s values less than 10, see clause A 1.2.3.2. Also, factor determined from the applicable chart in clause A 2.1.7 for the material used in a stiffening ring, corresponding to the factor B and the design metal temperature for the shell under consideration.	—
A_s	Cross-sectional area of a stiffening ring	mm^2
B	Factor determined from the applicable chart in clause A 1.2.7 for the material used in a shell or stiffening ring at the design metal temperature	N/mm^2
D_o	Outside diameter of the cylindrical shell or tube under consideration	mm
E	Modulus of elasticity of material at design temperature. Use the curve with this value on the material/temperature line of the applicable chart in clause A 1.2.7.	N/mm^2
I	Available moment of inertia of the combined ring-shell section about its neutral axis, parallel to the axis of the shell. The width of the shell which is taken as contributing to the combined moment of inertia shall not be greater than $1.1 \cdot \sqrt{D_o / s}$ and shall be taken as lying one-half on each side of the centroid of the ring. Portions of shell plates shall not be considered as contributing area to more than one stiffening ring.	mm^4
I_s	Required moment of inertia of the combined ring-shell section about its neutral axis parallel to the axis of the shell	mm^4
L	Total length of a tube or design length of a cylindrical shell section, taken as the largest of the following (all measured parallel to the axis of the cylinder): a) the distance between head tangent lines (transition from cylindrical section to curved head) plus one-third of the depth of each head if there are no stiffening rings b) the greatest centre-to-centre distance between any two adjacent stiffening rings, or c) the distance from the centre of the first stiffening ring to the head tangent line plus one-third of the depth of the head	mm
L_s	One-half of the distance from the centre line of the stiffening ring to the next line of support on one side, plus one-half of the centre line distance to the next line of support on the other side of the stiffening ring, both measured parallel to the axis of the component. A line of support is: a) a stiffening ring that meets the requirements of this paragraph b) a circumferential line on a head at one-third the depth of the head from the head tangent line	mm
P	External pressure difference loading	N/mm^2
P_a	Additional allowable external pressure difference loading	N/mm^2
R	Inside radius of spherical shell	mm
S	The lesser of $1.5 \cdot S_m$ or $0.9 \cdot R_{p0.2T}$, where S_m is obtained from clause 6.2.4.2.2.3 and $R_{p0,2T}$ from Section 7	N/mm^2
s	Minimum required thickness of cylindrical shell, or tube, or spherical shell	mm
s_n	Nominal thickness of shell less corrosion allowance	mm

A 1.2.3 Cylindrical shells and tubular products

A 1.2.3.1 Diameter to thickness ratio ≥ 10

The minimum thickness of cylindrical shells or tubular products under external pressure difference having D_o/s values equal to or greater than 10 shall be determined by the procedure given in a) through h) as follows:

a) Assume a value for s. Determine the ratios L/D_o, D_o/s.

b) Enter **Figure A-1** at the value of L/D_o determined in a). For values of L/D_o greater than 50 enter the chart at a value of L/D_o of 50. For values of L/D_o less than 0.05, enter the chart at a value of L/D_o of 0.05.

c) Move horizontally to the line for the value of D_o/s. Interpolation may be made for intermediate values of D_o/s. From this intersection move vertically downwards and read the value of factor A.

d) Using the value of A calculated in c) above, enter the applicable material chart in clause A 1.2.7 for the material/temperature under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value of A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material line, see g) below.

e) From the intersection obtained in d) above move horizontally to the right and read the value of B.

f) Using this value of B, calculate the maximum allowable pressure difference P_a by the following formula:

$$P_a = \frac{4 \cdot B}{3 \cdot (D_o / s)} \quad \text{(A 1-1)}$$

g) For values of A falling to the left of the applicable material/temperature line, the value of P_a can be calculated using the following formula:

$$P_a = \frac{2 \cdot A \cdot E}{3 \cdot (D_o / s)} \quad \text{(A 1-2)}$$

h) Compare P_a with P. If P_a is smaller than P, select a larger value for s and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

A 1.2.3.2 Diameter to thickness ratio < 10

The minimum thickness of cylindrical shells or tubular products under external pressure difference having D_o/s values less than 10 shall be determined by the procedure given in a) through d) as follows:

a) Using the same procedure as given in A 1.2.3.1, obtain the value of B. For values of D_o/s less than 4, the value of factor A can be calculated using the following formula:

$$A = \frac{1.1}{(D_o / s)^2} \quad \text{(A 1-3)}$$

For values of A greater than 0.10 use a value of 0.10.

b) Using the value of B obtained in a) calculate a value P_{a1} using the following formula:

$$P_{a1} = \left[\frac{2.167}{D_o / s} - 0.0833 \right] \cdot B \quad \text{(A 1-4)}$$

c) Calculate a value P_{a2} using the following formula:

$$P_{a2} = \frac{2 \cdot S}{D_o / s} \cdot \left[1 - \frac{1}{D_o / s} \right] \quad \text{(A 1-5)}$$

d) The smaller of the values of P_{a1} calculated in b) or P_{a2} calculated in c) shall be used for the maximum allowable external pressure P_a. Compare P_a with P. If P_a is smaller than P, select a larger value for s and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

A 1.2.4 Spherical shells

The minimum required thickness of a spherical shell under external pressure shall be determined by the procedure given in a) through f) as follows:

a) Assume a value for s and calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R / s)} \quad \text{(A 1-6)}$$

b) Using the value of A calculated in a) above, enter the applicable material chart in clause A 1.2.7 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values at A falling to the left of the material/temperature line, see e) below.

c) From the intersection obtained in b) above, move horizontally to the right and read the value of factor B.

d) Using the value of B calculate the value of the maximum allowable external pressure P_a using the following formula:

$$P_a = \frac{B}{(R / s)^2} \quad \text{(A 1-7)}$$

e) For values of A falling to the left of the applicable material/temperature line for the design temperature, the value of P_a can be calculated using the following formula:

$$P_a = \frac{0.0625 \cdot E}{(R / s)^2} \quad \text{(A 1-8)}$$

f) Compare P_a obtained in d) or e) P. If P_a is smaller than P, select a larger value for s and repeat the design procedure until a value for P_a is obtained that is equal to or greater than P.

A 1.2.5 Stiffening rings for cylindrical shells

(1) The required moment of inertia of the combined ring-shell section is given by the formula:

$$I_S = \frac{D_o^2 \cdot L_s \cdot (s + A_s / L_s) \cdot A}{10.9} \quad \text{(A 1-9)}$$

(2) The available moment of inertia I for a stiffening ring shall be determined by the procedure given in a) through f):

a) Assuming that the shell has been designed and D_o, L_s and s_n are known, select a member to be used for the stiffening ring and determine its area A_s and the value of I defined in clause A 1.2.2. Then calculate B by the formula:

$$B = \frac{3}{4} \cdot \left[\frac{P \cdot D_o}{s_n + A_s / L_s} \right] \quad \text{(A 1-10)}$$

b) Enter the right-hand side of the applicable material chart in clause A 1.2.7 for the material under consideration at the value of B determined in a) above. If different materials are used for the shell and stiffening ring, then use the material chart resulting in the larger value for factor A in d) or e) below.

c) Move horizontally to the left to the material/temperature line for the design metal temperature. For values of B falling below the left end of the material/temperature line, see e).

d) Move vertically to the bottom of the chart and read the value of A.

e) For values of B falling below the left end of the material/temperature line for the design temperature, the value of A can be calculated using the following formula:

$$A = 2 \cdot \frac{B}{E} \quad \text{(A 1-11)}$$

f) If the required I_s is greater than the computed moment of inertia I for the combined ring-shell section selected in a) above, a new section with a larger moment of inertia must be selected and a new I_s determined. If the required I_s is smaller than the computed I for the section selected in a) above, that section should be satisfactory.

(3) Stiffening rings may be attached to either the outside or the inside of the component by continuous welding.

A 1.2.6 Cylinders under axial compression

(1) The maximum allowable compressive stress to be used in the design of cylindrical shells and tubular products subjected to loadings that produce longitudinal compressive stresses in the shell or wall shall be the lesser of the values given in a) or b) below:

a) the S_m value for the applicable material at design temperature given in clause 6.2.4.2.2.3.

b) the value of the factor B determined from the applicable chart contained in clause A 1.2.7, using the following definitions for the symbols on the charts:

s minimum required thickness of the shell or tubular product, exclusive of the corrosion allowance

R inside radius of the cylindrical shell or tubular product

(2) The value of B shall be determined from the applicable chart contained in clause A 1.2.7 in the manner given in a) through e).

a) Using the selected values of s and R, calculate the value of factor A using the following formula:

$$A = \frac{0.125}{(R/s)} \qquad \text{(A 1-12)}$$

b) Using the value of A calculated in a) above, enter the applicable material chart in clause A 1.2.7 for the material under consideration. Move vertically to an intersection with the material/temperature line for the design temperature. Interpolation may be made between lines for intermediate temperatures. In cases where the value at A falls to the right of the end of the material/temperature line, assume an intersection with the horizontal projection of the upper end of the material/temperature line. For values of A falling to the left of the material/temperature line, see d) below.

c) From the intersection obtained in b), move horizontally to the right and read the value of factor B.

d) For values of A falling to the left of the applicable material/temperature line, the value of B shall be calculated using the following formula:

$$B = \frac{A \cdot E}{2} \qquad \text{(A 1-13)}$$

e) Compare the value of B determined in c) or d) above, with the computed longitudinal compressive stress in the cylindrical shell or tube, using the selected values of s and R.

If the value of B is smaller than the computed compressive stress, a greater value of s must be selected and the design procedure repeated until a value of B is obtained which is greater than the compressive stress computed for the loading on the cylindrical shell or tube.

A 1.2.7 Curves for determining the stresses

Figure A-1 to **A-4** show the curves for determining the stresses.

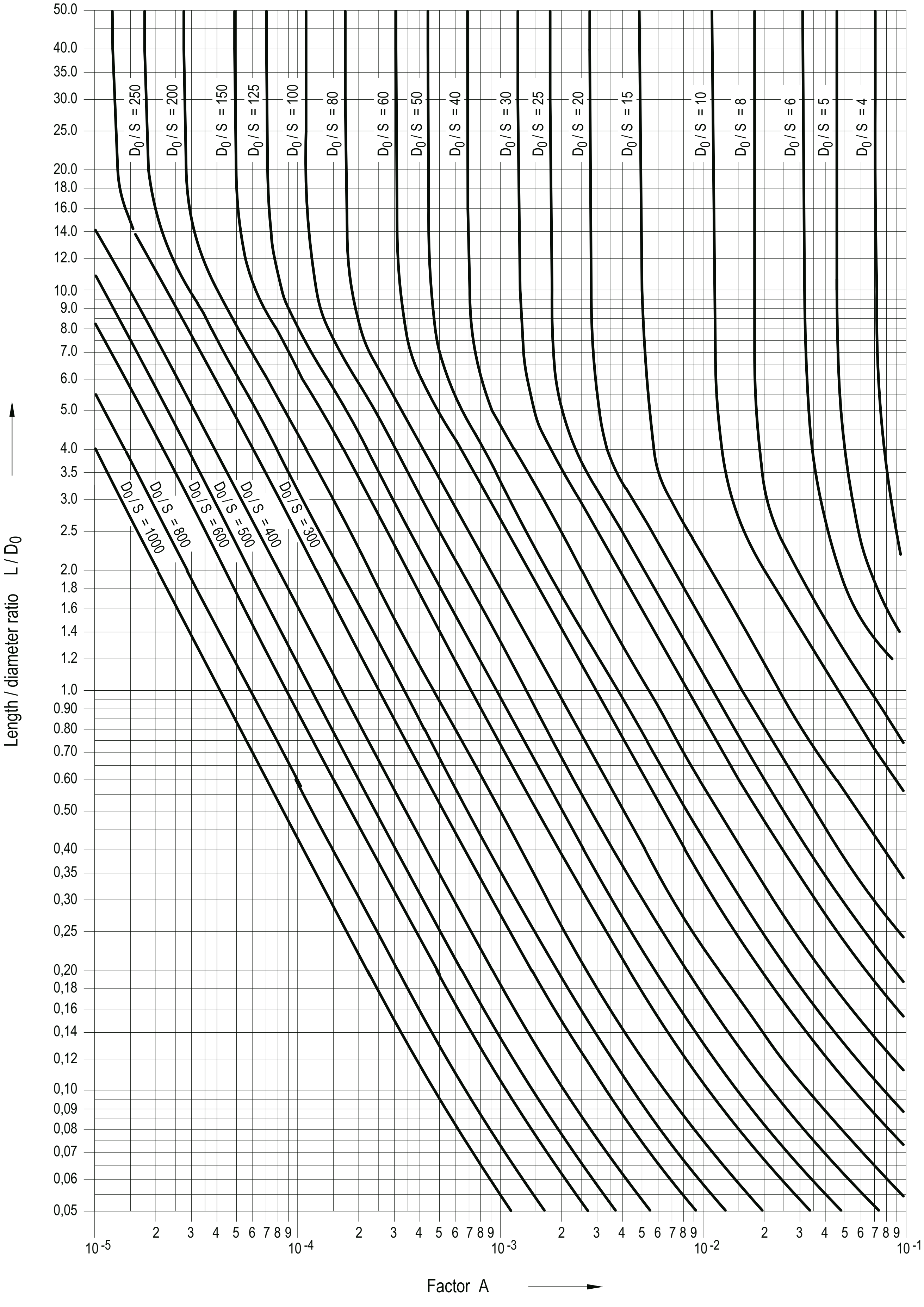


Figure A-1: Chart for cylinders under external pressure difference or pressure loading (for tabular values see **Table A-1**)

D_o/S	L/D_o	A
4	2.2	0.959 -01
	2.6	0.884
	3.0	0.839
	4.0	0.783
	5.0	0.759
	7.0	0.739
	10.0	0.729
	30.0	0.720
	50.0	0.720
5	1.4	0.929 -01
	1.6	0.802
	2.0	0.658
	2.4	0.586
	3.0	0.532
	4.0	0.494
	5.0	0.478
	7.0	0.465
	10.0	0.459
	30.0	0.454
	50.0	0.453
6	1.2	0.837 -01
	1.6	0.584
	2.0	0.469
	2.4	0.411
	3.0	0.369
	4.0	0.341
	5.0	0.329
	7.0	0.320
	10.0	0.316
	30.0	0.312
	50.0	0.312
8	0.74	0.968 -01
	0.8	0.875
	1.0	0.660
	1.6	0.372
	2.0	0.285
	2.4	0.242
	3.0	0.212
	4.0	0.192
	5.0	0.184
	7.0	0.179
	10.0	0.176
	20.0	0.174
	50.0	0.174
10	0.56	0.964 -01
	0.7	0.720
	1.0	0.463
	1.2	0.371
	2.0	0.201
	2.4	0.165
	3.0	0.139
	4.0	0.124
10	5.0	0.118 -01
	7.0	0.114
	10.0	0.112
	16.0	0.111
	50.0	0.111
15	0.34	0.968 -01
	0.4	0.770
	0.6	0.453
	1.0	0.244
	1.2	0.197
	2.0	0.109
	2.4	0.890 -02
	3.0	0.691
	4.0	0.573
	5.0	0.534
	6.0	0.516
	10.0	0.497
	40.0	0.490
	50.0	0.490
20	0.24	0.982 -01
	0.4	0.477
	0.6	0.286
	0.8	0.203
	1.0	0.156
	1.2	0.127
	2.0	0.127 -02
	3.0	0.446
	3.4	0.388
	4.0	0.342
	5.0	0.308
	7.0	0.287
	10.0	0.280
	40.0	0.275
	50.0	0.275
25	0.2	0.877 -01
	0.3	0.484
	0.5	0.250
	0.8	0.143
	1.0	0.111
	1.2	0.902 -02
	2.0	0.508
	3.0	0.323
	4.0	0.235
	5.0	0.204
	6.0	0.191
	7.0	0.186
	10.0	0.180
	30.0	0.176
	50.0	0.176
30	0.16	0.904 -01
	0.2	0.635
	0.3	0.357
30	0.4	0.246 -01
	0.6	0.150
	0.8	0.108
	1.0	0.838 -02
	1.2	0.683
	2.0	0.388
	3.0	0.246
	4.0	0.177
	4.4	0.161
	5.0	0.147
	6.0	0.136
	7.0	0.130
	10.0	0.125
	30.0	0.122
	50.0	0.122
40	0.12	0.864 -01
	0.2	0.385
	0.3	0.222
	0.4	0.155
	0.6	0.958 -02
	0.8	0.691
	1.0	0.539
	1.2	0.441
	2.0	0.252
	4.0	0.117
	5.0	0.912 -03
	6.0	0.804
	7.0	0.756
	8.0	0.731
	10.0	0.708
	16.0	0.692
	40.0	0.688
	50.0	0.688
50	0.088	0.984 -01
	0.1	0.782
	0.2	0.263
	0.3	0.154
	0.4	0.108
	0.6	0.677 -02
	0.8	0.490
	1.0	0.384
	2.0	0.181
	4.0	0.842 -03
	5.0	0.652
	6.0	0.548
	7.0	0.502
	8.0	0.478
	10.0	0.458
	12.0	0.449
	16.0	0.444
	40.0	0.440
	50.0	0.440
60	0.074	0.954 -01
	0.10	0.556
	0.14	0.323
	0.2	0.193
	0.4	0.812 -02
	0.6	0.510
	0.8	0.371
	1.0	0.291
	2.0	0.138
	3.0	0.886 -03
	4.0	0.645
	6.0	0.409
	7.0	0.364
	8.0	0.341
	10.0	0.322
	14.0	0.310
	40.0	0.306
	50.0	0.306
80	0.054	0.990 -01
	0.07	0.608
	0.09	0.391
	0.10	0.328
	0.14	0.196
	0.20	0.120
	0.24	0.950 -02
	0.4	0.516
	0.6	0.328
	0.8	0.239
	1.0	0.188
	2.0	0.895 -03
	4.0	0.424
	6.6	0.241
	8.0	0.205
	10.0	0.186
	14.0	0.176
	30.0	0.176
	50.0	0.172
100	0.05	0.741 -01
	0.07	0.338
	0.10	0.220
	0.14	0.133
	0.20	0.831 -02
	0.40	0.364
	0.5	0.283
	0.8	0.170
	1.0	0.134
	2.0	0.641 -03
	4.0	0.305
	6.0	0.195
	8.0	0.142
	10.0	0.124
	14.0	0.114
	25.0	0.110
	50.0	0.110

Table A-1: Tabular values for Figure A-1

D_o/S	L/D_o	A
125	0.05	0.480 -01
	0.06	0.344
	0.08	0.210
	0.10	0.148
	0.14	0.917 -02
	0.2	0.578
	0.4	0.257
	0.6	0.165
	0.8	0.121
	1.0	0.955 -03
	2.0	0.459
	4.0	0.220
	6.0	0.141
	9.0	0.904 -04
	10.0	0.837
	12.0	0.770
	14.0	0.740
	20.0	0.713
	40.0	0.704
	50.0	0.704
150	0.05	0.338 -01
	0.06	0.244
	0.08	0.151
	0.10	0.108
	0.12	0.833 -02
	0.16	0.569
	0.2	0.431
	0.4	0.194
	0.6	0.125
	1.0	0.726 -03
	2.0	0.349
	4.0	0.168
	6.0	0.108
	8.0	0.787 -04
	10.0	0.619
	12.0	0.553
	16.0	0.510
	20.0	0.498
	40.0	0.489
	50.0	0.489
200	0.05	0.196 -01
	0.06	0.143
	0.08	0.909 -02
	0.10	0.659
	0.14	0.421
	0.2	0.272
	0.3	0.171
	0.5	0.976 -03
	0.8	0.592
	1.0	0.969
	2.0	0.227
	4.0	0.110
	6.0	0.711 -04
	8.0	0.520
	10.0	0.403
	12.0	0.338
200	14.0	0.309 -04
	16.0	0.295
	20.0	0.283
	40.0	0.275
	50.0	0.275
250	0.05	0.129 -01
	0.06	0.955 -02
	0.08	0.617
	0.10	0.452
	0.14	0.293
	0.2	0.191
	0.4	0.881 -03
	0.6	0.572
	0.8	0.422
	1.0	0.335
	2.0	0.163
	4.0	0.789 -04
	6.0	0.513
	8.0	0.377
	10.0	0.293
	12.0	0.238
	14.0	0.210
	16.0	0.196
	20.0	0.184
	40.0	0.176
	50.0	0.176
300	0.05	0.923 -02
	0.06	0.690
	0.08	0.452
	0.10	0.334
	0.12	0.264
	0.2	0.143
	0.4	0.666 -03
	0.6	0.433
	0.8	0.321
	1.0	0.254
	2.0	0.124
	4.0	0.602 -04
	6.0	0.393
	8.0	0.287
	10.0	0.225
	14.0	0.156
	16.0	0.142
	20.0	0.130
	40.0	0.123
	50.0	0.122
400	0.05	0.549 -02
	0.06	0.417
	0.08	0.278
	0.10	0.208
	0.12	0.166
	0.16	0.118
	0.2	0.914 -03
	0.4	0.429
400	0.6	0.288 -03
	0.8	0.207
	1.0	0.165
	2.0	0.808 -04
	4.0	0.393
	6.0	0.257
	8.0	0.189
	10.0	0.148
	14.0	0.102
	16.0	0.882 -05
500	0.05	0.370 -02
	0.06	0.284
	0.08	0.192
	0.10	0.145
	0.12	0.116
	0.16	0.830 -03
	0.2	0.645
	0.4	0.305
	0.6	0.199
	0.8	0.148
	1.0	0.118
	2.0	0.579 -04
	4.0	0.282
	6.0	0.185
	8.0	0.137
	10.0	0.107
	12.0	0.880 -05
600	0.05	0.270 -02
	0.06	0.208
	0.08	0.142
	0.10	0.108
	0.12	0.868 -03
	0.16	0.624
	0.2	0.486
	0.4	0.231
	0.6	0.151
	0.8	0.112
	1.0	0.894 -04
	2.0	0.439
	4.0	0.216
	6.0	0.141
	8.0	0.104
	8.4	0.988 -05
800	0.05	0.165 -02
	0.06	0.129
	0.08	0.892 -03
	0.10	0.682
	0.12	0.551
	0.16	0.398
	0.2	0.312
	0.4	0.149
	0.6	0.980 -04
	0.8	0.728
	1.0	0.580
800	2.0	0.286 -04
	4.0	0.140
	5.0	0.112
	5.6	0.992 -05
1000	0.05	0.113 -02
	0.06	0.891 -03
	0.07	0.733
	0.09	0.541
	0.12	0.388
	0.16	0.282
	0.2	0.221
	0.4	0.106
	0.7	0.596 -04
	1.0	0.414
	2.0	0.204
	4.0	0.101
	4.2	0.957 -05

Table A-1: Tabular values for Figure A-1 (continued)

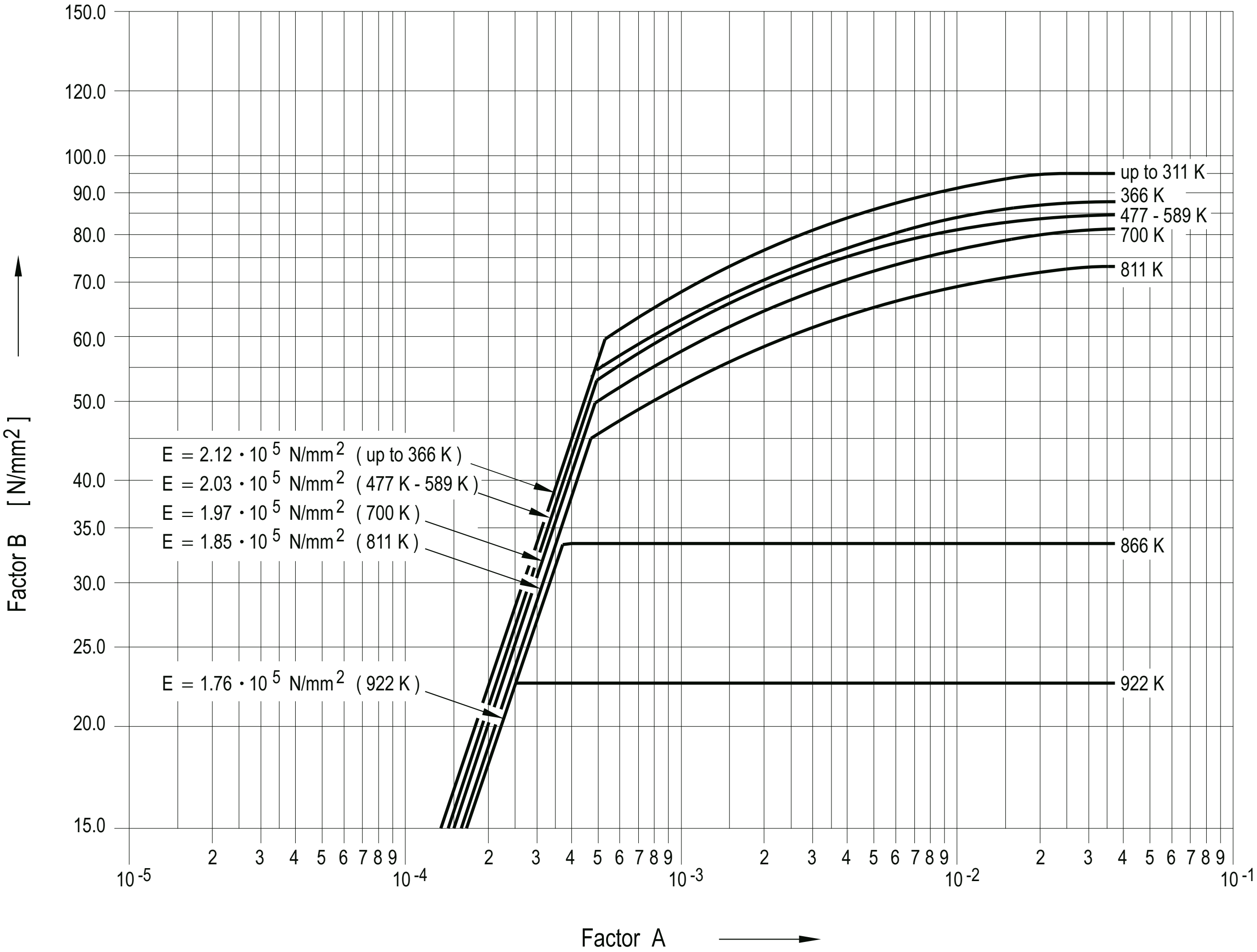


Figure A-2: Chart for determining the thickness of cylindrical and spherical shells made of quenched and tempered Ni-Cr-Fe alloys under external pressure loading (for tabular values see **Table A-2**)

Temperature K	A	B N/mm^2	Temperature K	A	B N/mm^2	Temperature K	A	B N/mm^2
311	$0.100 \cdot 10^{-4}$	1.1	477	$0.200 \cdot 10^{-2}$	67.9	700	$0.150 \cdot 10^{-1}$	78.6
	$0.531 \cdot 10^{-2}$	59.6		$0.400 \cdot 10^{-2}$	74.5		$0.300 \cdot 10^{-1}$	81.4
	$0.100 \cdot 10^{-2}$	67.8		$0.500 \cdot 10^{-2}$	76.5		0.100	81.4
	$0.300 \cdot 10^{-2}$	80.7		$0.100 \cdot 10^{-1}$	80.7	811	$0.100 \cdot 10^{-4}$	0.9
	$0.400 \cdot 10^{-2}$	84.1		$0.300 \cdot 10^{-1}$	84.4		$0.471 \cdot 10^{-3}$	45.0
	$0.100 \cdot 10^{-1}$	91.7		0.100	84.4		$0.100 \cdot 10^{-2}$	52.4
	$0.200 \cdot 10^{-1}$	95.1	589	$0.100 \cdot 10^{-4}$	1.0		$0.200 \cdot 10^{-2}$	58.2
	0.100	95.1		$0.500 \cdot 10^{-3}$	53.0		$0.500 \cdot 10^{-2}$	64.9
366	$0.100 \cdot 10^{-4}$	1.1		$0.100 \cdot 10^{-2}$	60.9		$0.100 \cdot 10^{-1}$	68.5
	$0.494 \cdot 10^{-3}$	54.6		$0.200 \cdot 10^{-2}$	67.9		$0.300 \cdot 10^{-1}$	73.1
	$0.100 \cdot 10^{-2}$	62.5		$0.400 \cdot 10^{-2}$	74.5		0.100	73.1
	$0.200 \cdot 10^{-2}$	70.3		$0.500 \cdot 10^{-2}$	76.5	866	$0.100 \cdot 10^{-4}$	0.9
	$0.300 \cdot 10^{-2}$	74.4		$0.100 \cdot 10^{-1}$	80.7		$0.372 \cdot 10^{-3}$	33.4
	$0.900 \cdot 10^{-2}$	83.4		$0.300 \cdot 10^{-1}$	84.8		$0.400 \cdot 10^{-3}$	33.5
	$0.200 \cdot 10^{-1}$	86.9		0.100	84.8		0.100	33.5
	0.100	88.3	700	$0.100 \cdot 10^{-4}$	1.0	922	$0.100 \cdot 10^{-4}$	0.9
477	$0.100 \cdot 10^{-4}$	1.0		$0.487 \cdot 10^{-3}$	49.8		$0.250 \cdot 10^{-3}$	22.6
	$0.500 \cdot 10^{-3}$	53.0		$0.100 \cdot 10^{-2}$	57.5		0.100	22.6
	$0.100 \cdot 10^{-2}$	60.9		$0.400 \cdot 10^{-2}$	70.3			

Table A-2: Tabular values for Figure A-2

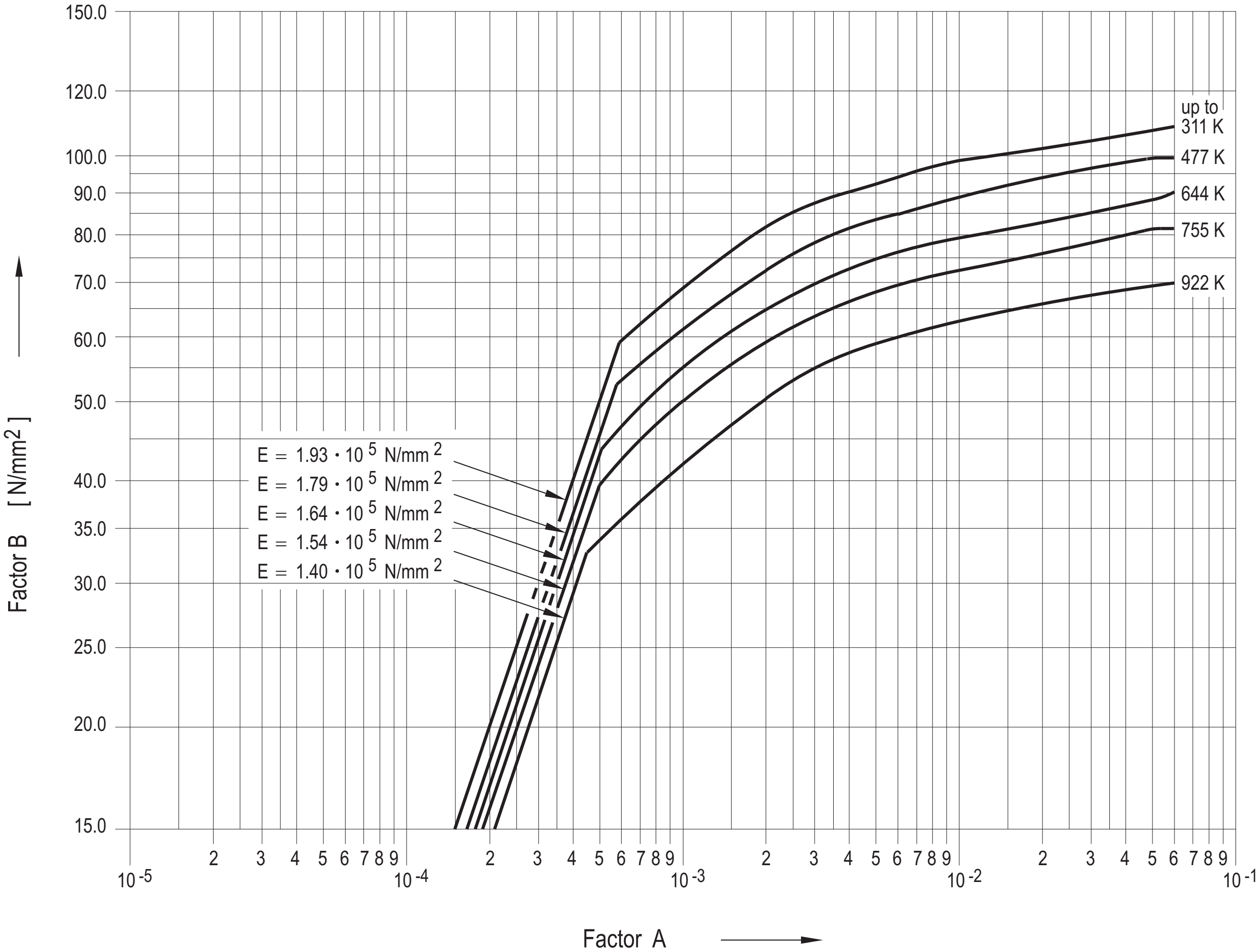


Figure A-3: Chart for determining the thickness of cylindrical and spherical shells made of austenitic steel (for tabular values see **Table A-3**)

Temperature K	A	B N/mm²	Temperature K	A	B N/mm²	Temperature K	A	B N/mm²
311	$0.100 \cdot 10^{-4}$	1.0	477	$0.300 \cdot 10^{-2}$	77.9	644	$0.498 \cdot 10^{-3}$	39.5
	$0.588 \cdot 10^{-3}$	59.0		$0.400 \cdot 10^{-2}$	81.4		$0.600 \cdot 10^{-3}$	42.5
	$0.150 \cdot 10^{-2}$	76.5		$0.500 \cdot 10^{-2}$	83.4		$0.100 \cdot 10^{-2}$	50.1
	$0.200 \cdot 10^{-2}$	82.0		$0.600 \cdot 10^{-2}$	84.8		$0.300 \cdot 10^{-2}$	63.2
	$0.250 \cdot 10^{-2}$	84.8		$0.100 \cdot 10^{-1}$	88.9		$0.400 \cdot 10^{-2}$	66.3
	$0.300 \cdot 10^{-2}$	87.6		$0.500 \cdot 10^{-1}$	99.3		$0.100 \cdot 10^{-1}$	72.4
	$0.400 \cdot 10^{-2}$	90.3		0.100	99.3		$0.500 \cdot 10^{-1}$	81.4
	$0.500 \cdot 10^{-2}$	92.4	644	$0.100 \cdot 10^{-4}$	0.8		0.100	81.4
	$0.700 \cdot 10^{-2}$	95.8		$0.507 \cdot 10^{-3}$	43.4	922	$0.100 \cdot 10^{-4}$	0.7
	$0.100 \cdot 10^{-1}$	98.6		$0.700 \cdot 10^{-3}$	48.8		$0.450 \cdot 10^{-3}$	32.7
	$0.200 \cdot 10^{-1}$	102.0		$0.100 \cdot 10^{-2}$	54.9		$0.100 \cdot 10^{-2}$	41.9
	$0.700 \cdot 10^{-1}$	109.6		$0.300 \cdot 10^{-2}$	69.6		$0.200 \cdot 10^{-2}$	50.4
	0.100	109.6		$0.400 \cdot 10^{-2}$	72.4		$0.300 \cdot 10^{-2}$	54.8
477	$0.100 \cdot 10^{-4}$	0.9		$0.100 \cdot 10^{-1}$	79.3		$0.400 \cdot 10^{-2}$	57.4
	$0.575 \cdot 10^{-3}$	52.5		$0.500 \cdot 10^{-1}$	88.3		$0.500 \cdot 10^{-2}$	58.9
	$0.100 \cdot 10^{-2}$	61.1		$0.600 \cdot 10^{-1}$	90.3		$0.100 \cdot 10^{-1}$	62.7
	$0.150 \cdot 10^{-2}$	67.8		0.100	90.3		$0.700 \cdot 10^{-1}$	70.3
	$0.200 \cdot 10^{-2}$	72.4						

Table A-3: Tabular values for Figure A-3

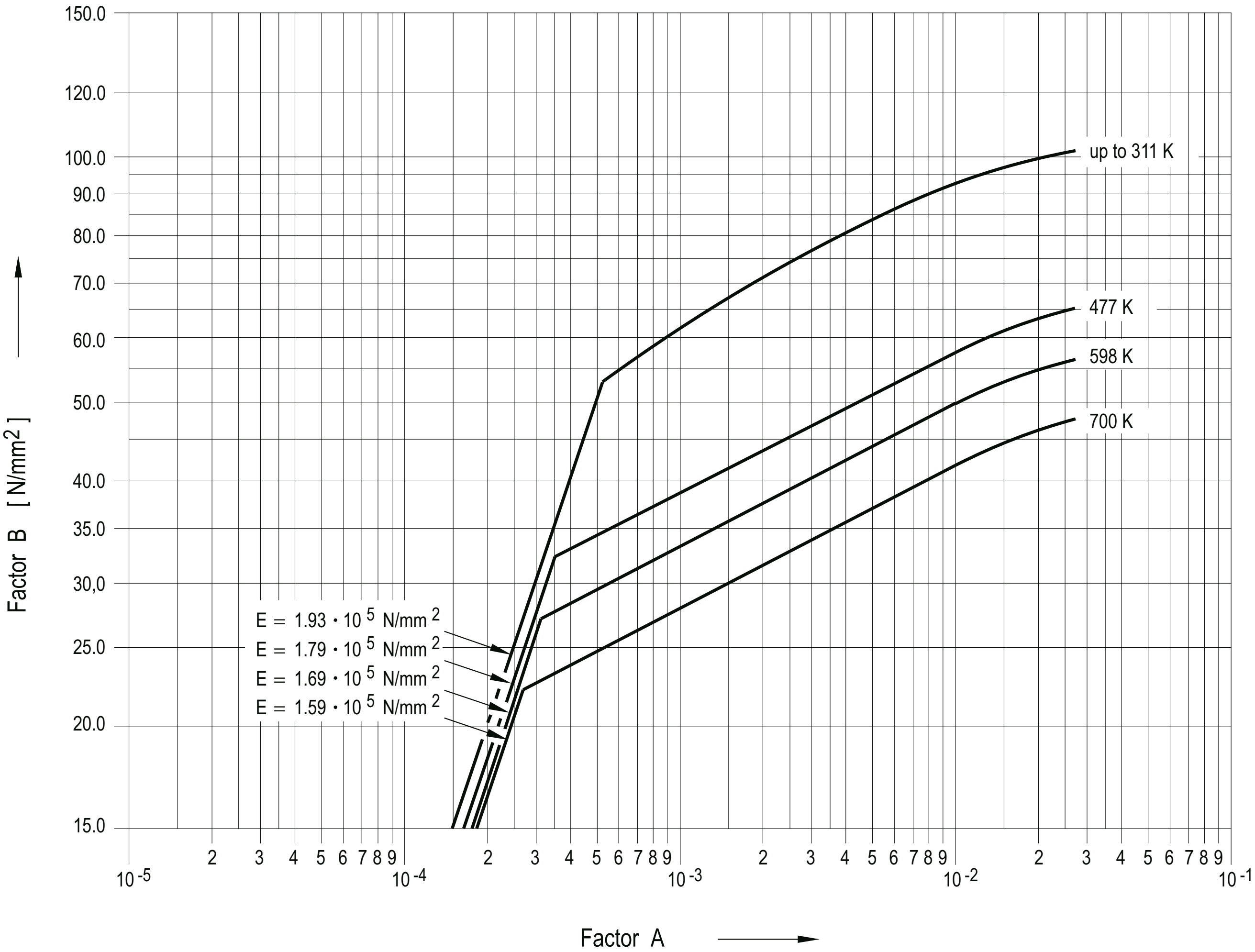


Figure A-4: Chart for determining the thickness of cylindrical and spherical shells (18/8 CrNi; max. 0.035 C, material no. 1.4603) under external pressure loading (for tabular values see **Table A-4**)

Temperature K	A	B N/mm²	Temperature K	A	B N/mm²
311	$0.100 \cdot 10^{-4}$	1.0	598	$0.100 \cdot 10^{-4}$	0.8
	$0.524 \cdot 10^{-3}$	52.9		$0.313 \cdot 10^{-3}$	27.1
	$0.200 \cdot 10^{-2}$	71.0		$0.100 \cdot 10^{-2}$	33.4
	$0.600 \cdot 10^{-2}$	86.2		$0.100 \cdot 10^{-1}$	49.8
	$0.200 \cdot 10^{-1}$	99.3		0.100	59.0
	0.100	105.5			
477	$0.100 \cdot 10^{-4}$	0.9	700	$0.100 \cdot 10^{-4}$	0.8
	$0.352 \cdot 10^{-3}$	32.3		$0.270 \cdot 10^{-3}$	22.2
	$0.100 \cdot 10^{-2}$	38.7		$0.150 \cdot 10^{-2}$	30.0
	$0.100 \cdot 10^{-1}$	57.5		$0.100 \cdot 10^{-1}$	41.8
	0.100	68.1		0.100	50.8

Table A-4: Tabular values for Figure A-4

A 2 Structural analysis for loading level C

(1) The analysis shall be made according to the methods of verification given in Section A 1.1 or A 1.2.

(2) The static or equivalent static external pressure difference loading shall be limited to 150 % of the values given in Section A 1.2. Where dynamic pressure differences occur, the aforementioned limit value applies or the allowable external pressure difference loading is limited to one-half the value of the dynamic buckling pressure.

A 3 Structural analysis for loading level D

(1) The analysis shall be made according to the methods of verification given in Section A 1.1 or A 1.2.

(2) The static or equivalent static external pressure difference loading shall be limited to 150 % of the values given in Section A1.2. At an out-of-roundness equal to or less than 1 % the allowable external pressure difference shall be 250 % of the values given in Section A 1.2.

Where dynamic pressure differences or loadings occur, a dynamic instability analysis can be made. In such a case, the external pressure difference loading or pressure loading shall be limited to 75 % of the dynamic buckling pressure or dynamic buckling load.

(3) A plastic analysis may be made to determine the plastic instability load for a given combination of loading on a structure. The plastic instability load is a load at which unbound plastic deformation occurs or where the ratio of force and deformation shows a horizontal tangent line. This plastic instability load is designated as P_I.

See **Table 6-6** for limit values.

(4) A plastic analysis may be made to determine the collapse load for a given combination of loading on a structure. A collapse load is that load at which the deformation reaches twice the value calculated for the first deviation from linear behaviour. In evaluating the analysis the calculations shall be interpreted such that it corresponds to the evaluation of the experiment (**Annex D**). If the interpretation is made in such a way the collapse load obtained from plastic analysis shall be limited to satisfy the rules of the limit analysis (**Annex B**). The symbol used for the collapse load is P_c.

Annex B
Limit analysis

B 1 General requirements

(1) The limits on primary membrane stress intensity and primary membrane plus primary bending stress intensity need not be satisfied at a specific location of the structure if it can be shown by means of limit analysis that the specified loadings do not exceed the lower bound collapse load as per Section B 2.

(2) The lower bound collapse load is that maximum load or load combination (see clause 6.2.1 (20)), where the deformations increase without bound, without the load being increased significantly.

(3) This collapse load shall be determined in accordance with the method of Tresca or von Mises.

(4) Since reaching of the collapse load may be bound to large deformations, the structure shall be checked for the occurrence of instabilities (e.g. buckling) in each individual case.

B 2 Evaluation criteria

The lower bound collapse load shall be fixed for the various loading levels as follows, in which case the S_m value shall be determined in accordance with clause 6.2.4.2.2.3:

a) Loading levels A and B

The allowable lower bound collapse load shall be $0.67 \cdot G_u$, where G_u is the lower bound collapse load determined for a fictitious yield strength of $1.5 \cdot S_m$.

For materials where the yield strength is fixed by the 0.2 % proof stress, the S_m values may reach 90 % of the 0.2 % proof stress. This corresponds to a permanent strain of 0.1 %. Where permanent strain is not permitted, the S_m value shall be multiplied with the applicable strain limiting factor according to **Table B-1**.

b) Loading level C

The allowable lower bound collapse load shall be $1.0 \cdot G_u$, except for threaded structural fasteners with R_{mRT} exceeding 700 N/mm^2. In this case, the allowable lower bound collapse load shall be determined as for the loading levels A and B.

c) Loading level D

The allowable lower bound collapse load shall be $0.9 \cdot G_u$, where G_u is the lower bound collapse load determined for a fictitious yield strength of $2.3 \cdot S_m$, except for threaded structural fasteners with R_{mRT} exceeding 700 N/mm^2. In this case, the allowable lower bound collapse load shall be $1.33 \cdot G_u$, where the value of K equal to or less than 1.5 shall be used for the shape factor in the calculation and G_u shall be determined in accordance with a) above.

Permanent strain	Factor
0.10	0.90
0.09	0.89
0.08	0.88
0.07	0.86
0.06	0.83
0.05	0.80
0.04	0.77
0.03	0.73
0.02	0.69
0.01	0.63

Table B-1: Strain limiting factors

Annex C
Stress ratio method

C 1 General requirements

C 1.1 Evaluation criteria

(1) In lieu of an elastic analysis the stress ratio/interaction curve method may be used for evaluating stresses in components provided for loading levels C and D.

(2) For threaded structural fasteners with R_{mRT} exceeding 700 N/mm^2 the stress ratio method shall not be used.

(3) The stress ratio method is only applicable if the mechanical loadings on a component are determined by an elastic or a plastic system analysis and the resulting stresses are determined by an elastic analysis of the component.

C 1.2 Nomenclature

Symbol	Variable	Unit
A	Cross-sectional area	mm^2
c	Distance from neutral axis to outermost fibre	mm
e	Strain	—
F_z	Tensile force	N
F_d	Pressure force	N
f_{zulK}	Linearized allowable bending stress for section factor K	N/mm^2
f_{mK}	Linearized ultimate bending stress for section factor K	N/mm^2
f_{pK}	Linearized yield (0.2% proof) bending stress for section factor K	N/mm^2
I	Moment of inertia	mm^4
K	Section factor	—
m	Applied moment	N/mm^2
M	Allowable bending moment	N/mm^2
n	Interaction exponent (tensile load)	—
Q	Static moment $Q = \int_o^c y \cdot dA$	mm^3
σ_b	Applied bending stress	N/mm^2
τ	Applied shear stress	N/mm^2
σ_z	Applied tensile stress	N/mm^2
σ_{bez}	Reference stress	N/mm^2
R_{mT}	Tensile strength	N/mm^2
$R_{p0.2T}$	0.2% proof stress	N/mm^2
R_{pg}	Proportional limit stress	N/mm^2
R_o	Trapezoidal intercept stress	N/mm^2
R_{om}	Trapezoidal intercept stress at tensile strength	N/mm^2
R_{op}	Trapezoidal intercept stress at 0.2% proof stress	N/mm^2
S_b	Stress ratio for bending	—
S_d	Stress ratio for compression	—
S_s	Stress ratio for shear	—
S_z	Stress ratio for tension	—
S_{bd}	Stress ratio for bending and compression	—
S_{bs}	Stress ratio for bending and shear	—
S_{bz}	Stress ratio for bending and tension	—
S_{bzs}	Stress ratio for bending, tension and shear	—
S_{bds}	Stress ratio for bending, compression and yield	—
x	Centroidal axis, x direction	—
y	Centroidal axis, y direction	—
x´	Principal axis, x' direction	—
y´	Principal axis, y' direction	—
φ	Circle between centroidal and principal axis	degrees
γ	Plasticity factor	—

Indices used:
- z : tension
- d : compression
- b : bending
- s : shear
- K : section factor
- p : strain
- m : ultimate tensile strength

C 2 Interaction of uni-axial and multi-axial loads

C 2.1 General requirements

(1) This paragraph contains interaction equations for determining the combination of the various loadings in a component cross-section (bending, tension, compression, shear). Structural instability is not considered here. For the structural analysis clause 6.2.4.2.5 and **Annex A** apply.

(2) Interaction equations other than those specified hereinafter may be used for other types of cross-sections or shapes if they have been substantiated by the following:

a) common appearance in appropriate technical literature, industry codes or standards,

b) experimental development which includes a variation of all types of loads or stresses that appear in the interaction equations,

c) theoretical development which includes experiments and tests to verify the interaction equations developed.

C 2.2 Interaction equations for beam shapes

(1) The interaction equations hereinafter apply to common beam shapes and not to thin-walled cylinders or thin-walled tubes or pipes. **Table C-1** lists the interaction equations for beam shapes.

Note:

An approach for circular cross-sections can be found, e.g., in [10].

(2) The methods provided herein may also be used for beam shapes with cut-outs or notches, provided that the geo-

metric properties are based on the net area of the cut-out or notch.

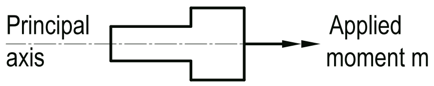
Note:

For related literature [11], [12] see Annex H.

See also DIN EN 13345-3 and the publications [13] and [14].

C 2.2.1 Simple bending - Symmetrical sections

(1) The methods given in (2), (3) and (4) below shall be used when the applied moment vector is parallel to a principal axis which is also an axis of symmetry.



(2) The section factor K is given by

$$K = \text{Min}\left\{2 \cdot Q/(I/c);\ 2\right\} \qquad \text{(C 2-1)}$$

(3) The allowable bending stress at the outermost fibre shall be calculated by determination of the

a) applied moment m,

b) reference stress σ_{bez} according to Section C 3,

c) section factor K either according to paragraph (2) or for common shapes according to **Figure C-1**,

d) allowable bending stress f_{zulK} for section factor K according to Section C 4.1.

(4) The bending stress ratio S_b shall be determined using those bending moments where the stress is no more proportional to the moment.

a) The allowable moment is obtained from

$$M = f_{zulk} \cdot I/c \qquad \text{(C 2-2)}$$

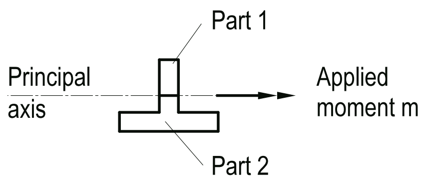
with f_{zulK} according to (2) d).

b) For the bending stress ratio the following applies

$$S_b = \frac{m}{M} \leq 1.0\ . \qquad \text{(C 2-3)}$$

C 2.2.2 Simple bending - Unsymmetrical sections

(1) The method given in (2) and (3) hereinafter shall be used when the resultant moment vector is parallel to a principal axis which is not an axis of symmetry.



(2) Break down the section into the two parts on either side of the principal axis. For each part, compute Q and I/c about the principal axis of the original complete section. Compute the section factor K = Q/(I/c) for each part. In using the K value for each part, computed as above, it will be the same as for a symmetrical section composed of the given part and its reflection about the principal axis of the original section.

(3) The bending stress ratio S_b shall be computed by determination of the

a) applied moment m,

b) reference stress $\sigma_{bez\ 1}$ according to Section C 3,

c) allowable bending stress f_{zulK1} according to Section C 4.1 using the reference stress $\sigma_{bez\ 1}$ and the section factor K_1 for that part of the section with the greater distance c_1 to the outer fibre,

d) strain e_1 corresponding to the reference stress $\sigma_{bez\ 1}$ of the related stress-strain curve and strain e_2 for that part of the section with the smaller distance c_2 to the outermost fibre:

$$e_2 = \frac{c_2}{c_1} \cdot e_1 \qquad \text{(C 2-4)}$$

Enter this stress-strain curve to obtain the reference stress $\sigma_{bez\ 2}$ corresponding to the strain e_2 and then the allowable bending stress f_{zulK2} according to Section C 4.1 using the reference stress $\sigma_{bez\ 2}$ and the section factor K_2 for that part of the section with the smaller distance c_2 to the outermost fibre.

e) The total allowable bending moment M shall be obtained by adding the two moments of parts 1 and 2 to obtain:

$$M = \left(f_{zulk} \cdot I/c\right)_1 + \left(f_{zulk} \cdot I/c\right)_2 \qquad \text{(C 2-5)}$$

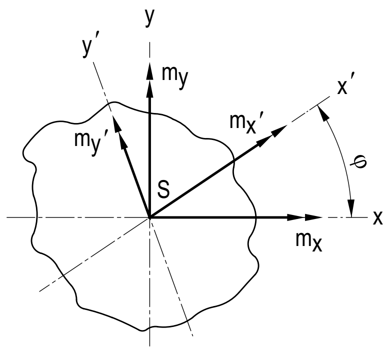
f) For the bending stress ratio the following applies

$$S_b = \frac{m}{M} \leq 1.0. \qquad \text{(C 2-6)}$$

C 2.2.3 Complex bending - Symmetrical and unsymmetrical sections

(1) General

The method given in (2) and (3) below shall be used if the resultant applied moment vector is not parallel to a principal axis



Note:

In this sketch x and y are the centroidal axis and x´ and y´ the principal axes. Moment vectors are designated by double-headed arrows.

(2) Resolution of complex bending into simple bending

Any case of complex bending may be resolved into two cases of simple bending about the principal axes of the section. If the principal axes x´ and y´ cannot be determined, obtain I_x, I_y and I_{xy} about any arbitrary pair of centroidal axes x and y. The angle φ then determines the two principal axes:

$$\tan 2\varphi = \frac{2 \cdot I_{xy}}{I_y - I_x} \qquad \text{(C 2-7)}$$

(3) Determination of the stress ratio for bending S_b

a) The allowable moments about the main axes $M_{x'}$ and $M_{y'}$ shall be determined in accordance with clause C 2.2.1 or C 2.2.2.

b) the applied moments about the principal axes $m_{x'}$ and $m_{y'}$ are obtained using the following relationships:

$$m_{x'} = m_x \cdot \cos\varphi + m_y \cdot \sin\varphi \qquad \text{(C 2-8)}$$

$$m_{y'} = -m_x \cdot \sin\varphi + m_y \cdot \cos\varphi \qquad \text{(C 2-9)}$$

c) the bending stress ratios $S_{bx'}$ and $S_{by'}$ are obtained from

$$S_{bx'} = \frac{m_{x'}}{M_{x'}}\ ; \qquad \text{(C 2-10)}$$

$$S_{by'} = \frac{m_{y'}}{M_{y'}} \qquad \text{(C 2-11)}$$

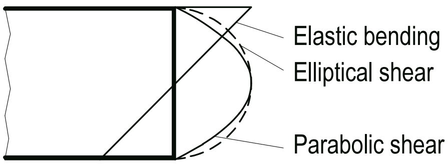
e) For the bending stress ratio the following applies:

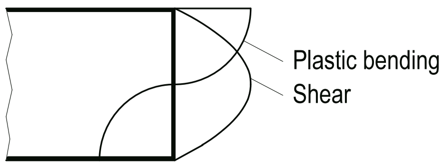
$S_b = (S_{bx'} + S_{by'}) \leq 1.0.$ (C 2-12)

C 2.2.4 Interaction - Simple or complex bending and shear

(1) General

The maximum shear stress in a beam usually occurs at the neutral fibre (principal axis) where the bending stress is zero. The maximum bending stress occurs at an extreme fibre where the shear stress is zero. If the shear stress distribution is elliptical and the bending stress distribution linear, than the total cross-section shall be checked.





Note:

In the elastic range, the distribution of shear and bending stresses is usually such that the most critical point in the section is at either the principal axis or the extreme fiber. This is true on a rectangular section since the shear distribution across the section is parabolic and the bending distribution is linear. If the shear distribution has been elliptical, every point in the cross section will be equally critical in combined stress based on circular interaction.

In the plastic range, however, the distribution of the shear stress as well as the bending stress differs from that in the elastic range. This results in intermediate points which frequently become more critical in combined stress than either the shear stress at the principal axis or the bending stress at the extreme fibre. To find the most critical point would require the calculation of combined stresses at a series of points across the section.

(2) Determination of bending and shear stress ratio S_{bs}

The bending and shear stress ratio S_{bs} shall be determined as follows:

a) For simple bending the bending stress ratio S_b = m/M shall be determined in accordance with C 2.2.1 or C 2.2.2 and for complex bending from $S_b = S_{bx'} + S_{by'}$ in accordance with C 2.2.3.

b) The shear stress ratio for simple bending shall be determined from

$$S_s = \frac{\tau}{\tau_{zul}} \qquad \text{(C 2-13)}$$

For complex bending the shear stress ratio will be

$$S_s = \sqrt{S_{sx'}^2 + S_{sy'}^2} \qquad \text{(C 2-14)}$$

with

$$S_{sx'} = \tau_{x'}/\tau_{zul} \qquad \text{(C 2-15)}$$

$$S_{sy'} = \tau_{y'}/\tau_{zul} \qquad \text{(C 2-16)}$$

$\tau_{x'}$ and $\tau_{y'}$ are the maximum shear stresses in the direction of the principal axes x´ and y´. The allowable bending stress for simple or complex bending is

$$\tau_{zul} = 0.6 \cdot \sigma_{bez}. \qquad \text{(C 2-17)}$$

For the shear stress ratio $S_s \leq 1.0$ applies.

c) The total stress ratio S_{bs} from simple or complex bending S_b and shear S_s shall be computed from

$$S_{bs} = \sqrt{S_b^2 + S_s^2} \leq 1.0 \qquad \text{(C 2-18)}$$

The acceptability of S_{bs} may also be reviewed by means of **Figure C-3**. The intersection of S_b and S_s shall then lie on the curve drawn.

C 2.2.5 Interaction - Simple or complex bending and tension

(1) General

The method given hereinafter shall be used if bending and tension occur simultaneously.

(2) Determination of the bending stress ratio S_b and tensile stress ratio S_z

a) The bending stress ratio S_b for simple bending shall be determined in accordance with C 2.2.1 or C 2.2.2 and for complex bending in accordance with C 2.2.3.

b) The tensile stress ratio S_z shall be computed by means of the following formula

$$S_z = \frac{F_z}{A \cdot \sigma_{bez}} \qquad \text{(C 2-19)}$$

(3) Determination of the interaction exponent n

a) The material plasticity factor for use in obtaining the interaction exponent is $\gamma = 0.9$ for all materials.

b) Determine $A \cdot c/(2 \cdot Q)$ for use in obtaining the interaction exponent n in conformance with **Figure C-2**. If the section is unsymmetrical, take c for the side for which bending and tensile stresses are of opposite sign.

For complex bending obtain both $A \cdot c/(2 \cdot c_{x'})$ and $A \cdot c/(2 \cdot c_{y'})$. If the section is unsymmetrical about the x´ axis and y´ axis, take c for the side for which bending and tensile stress are of opposite sign. Then obtain the interaction exponents $n_{x'}$ and $n_{y'}$ as per **Figure C-2** and calculate the combined exponent n as follows:

$$n = \frac{(n_{x'} \cdot S_{bx'}) + (n_{y'} \cdot S_{by'})}{S_b} \qquad \text{(C 2-20)}$$

(4) Determination of the combined bending and shear stress ratio S_{bz}

The combined bending and shear stress ratio shall be obtained from

$$S_{bz} = S_b + S_z^n \leq 1.0 \qquad \text{(C 2-21)}$$

The acceptability of S_{bz} may be reviewed by means of **Figure C-4**. The intersection of S_b and S_z then shall lie on the curve with the interaction exponents n determined as per (2).

C 2.2.6 Interaction - Simple or complex bending and compression

(1) General

The method given hereafter shall be used if bending and compression occur simultaneously. Additional bending moments caused by the compressive load shall be taken into account and instabilities, if any, be examined separately.

(2) Determination of the bending stress ratio S_b and compressive stress ratio S_d

a) For simple bending the bending stress ratio S_b shall be determined in accordance with C 2.2.1 or C 2.2.2 and for complex bending in accordance with C 2.2.3.

b) The compressive stress ratio S_d shall be computed by the following formula

$$S_d = \frac{F_z}{A \cdot \sigma_{bez}} \qquad \text{(C 2-22)}$$

(3) For the combined bending and compressive stress ratio the following applies

$$S_{bd} = S_b + S_d \leq 1.0 \qquad \text{(C 2-23)}$$

C 2.2.7 Interaction - Simple or complex bending, tension and shear

The method given hereafter shall be used if bending, tension and shear occur simultaneously.

a) The combined bending and shear stress ratio S_{bs} shall be determined in accordance with C 2.2.4.

b) The combined bending and tensile stress ratio S_{bz} shall be determined in accordance with C 2.2.5.

c) The total stress ratio S_{bzs} shall basically be determined using the bending and tensile stress ratio S_{bz} and the shear stress ratio S_s as follows:

$$S_{bzs} = \sqrt{S_{bz}^2 + S_s^2} \leq 1.0 \qquad \text{(C 2-24)}$$

The acceptability of S_{bzs} may also be reviewed by means of **Figure C-3**. The intersection of S_{bz} and S_s then shall lie on the curve drawn. Here, S_{bz} may be determined in accordance with **Figure C-4** calculating the ratio of the projections AB´/AC´.

C 2.2.8 Simple or complex bending, compression and shear

The method given hereafter shall be used if bending, compression and shear occur simultaneously.

a) The combined bending and shear stress ratio S_{bs} shall be determined in accordance with C 2.2.4.

b) The combined stress ratio S_{bd} shall be determined in accordance with C 2.2.6.

c) The total stress ratio S_{bds} shall be determined using the combined bending and compression stress ratio S_{bd} and the shear stress ratio S_s to obtain:

$$S_{bds} = \sqrt{S_{bd}^2 + S_s^2} \leq 1.0 \qquad \text{(C 2-25)}$$

The acceptability of S_{bds} may also be reviewed by means of **Figure C-3**. The intersection of S_{bd} and S_s then shall lie on the curve drawn.

C 3 Stress intensity limits

The stress intensity limits to be used in the application of the stress ratio method are laid down in Sections C 3.1 and C 3.2, and the S_m value shall be determined as per clause 6.2.4.2.2.3.

C 3.1 Loading level C

The primary membrane stress P_m shall be limited with a reference stress of

$$\sigma_{bez} = 2.0 \cdot S_m \qquad \text{(C 3-1)}$$

The primary membrane plus bending stress shall be limited by using the interaction equations with $K \cdot \sigma_{bez}$ for the types of stress mentioned in Section C 2.

C 3.2 Loading level D

The primary membrane stress P_m shall be limited with a reference stress of

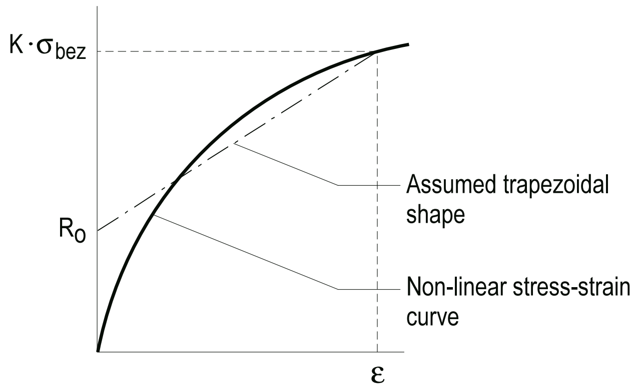
$$\sigma_{bez} = \text{Min}\left\{3 \cdot S_m ; 0.7 \cdot R_{mT}\right\} \qquad \text{(C 3-2)}$$

The primary membrane plus bending stress shall be limited by using the interaction equations with $K \cdot \sigma_{bez}$ for the types of stress mentioned in Section C 2.

C 4 Bending strength in the plastic region

C 4.1 Determination of allowable bending stress f_{zulK}

(1) A fictitious bending stress, called the linearized allowable bending stress f_{zulK}, max be used for establishing the bending strength of a material. This method assumes that in the plastic region the non-linear-stress-strain relationship for a particular section and material can be approximated by a trapezoidal shape as shown in the following sketch:



(2) The stress R_o is a fictitious stress which is assumed to exist at the neutral axis or at zero strain. The value of R_o is determined by requiring that the internal moment of the non-linear stress-strain curve must be equal to the inertial moment of the assumed trapezoidal shape.

(3) Thus the total moment capacity of a symmetrical section may be expressed as follows:

$$\begin{aligned} M &= 2 \cdot R_o \int_o^c y \cdot da + (\sigma_{bez} - R_o) \cdot (I/c) \qquad \text{(C 4-1)} \\ &= 2 \cdot R_o \cdot Q + (\sigma_{bez} - R_o) \cdot (I/c) \\ &= (I/c) \cdot [\sigma_{bez} + R_o \cdot (2 \cdot Q/(I/c) - 1)] \\ &= (I/c) \cdot [\sigma_{bez} + R_o \cdot (K - 1)] \end{aligned}$$

Thus the allowable bending stress for any section factor K becomes:

$$f_{zulK} = \frac{M}{I/c} \cdot \sigma_{bez} + (K - 1) \cdot R_o \qquad \text{(C 4-2)}$$

(4) The allowable bending stress f_{zulK} at a given cross-section shall be computed as follows: At first the intercept stress R_o or the allowable moment M shall be determined that corresponds to a given section (with a section factor K) and the reference stress σ_{bez}.

Note:

The allowable moment may be determined either by test or an exact stress analysis. This procedure, however, would strongly limit the applicability of the stress ratio method.

(5) The values for R_{om} and R_{op} have been calculated for about 50 materials and are shown in **Figure C-6**. These curves may be utilized for low-carbon and high-alloy steels (e.g. austenite).

Note:

For related literature [15] see Annex H.

(6) Using the proportional limit stress R_{pg} from **Figure C-5** and the trapezoidal intercept stresses R_{op} and R_{om} from **Figure C-6** the allowable bending stress f_{zulK} can be determined with the following equations:

a) For $\sigma_{bez} \leq R_{pg}$

$$f_{zulK} = \sigma_{bez} \qquad \text{(C 4-3)}$$

b) For $R_{pg} < \sigma_{bez} \leq R_{p0.2T}$

$$f_{zulK} = R_{pg} + \frac{(f_{pK} - R_{pg}) \cdot (\sigma_{bez} - R_{pg})}{R_{p0.2T} - R_{pg}} \qquad \text{(C 4-4)}$$

where

$$f_{pK} = R_{p0.2T} + (K - 1) \cdot R_{op} \qquad \text{(C 4-5)}$$

c) For $R_{p0.2T} < \sigma_{bez} \leq R_{mT}$

$$f_{zulk} = R_{pK} + \frac{(f_{mK} - f_{pK}) \cdot (\sigma_{bez} - R_{p0.2T})}{R_{mt} - R_{p0.2T}} \qquad \text{(C 4-6)}$$

where

$$f_{pK} = R_{p0.2T} + (K - 1) \cdot R_{op} \qquad \text{(C 4-7)}$$

and

$$f_{mK} = R_{mT} + (K - 1) \cdot R_{om} \qquad \text{(C 4-8)}$$

C 4.2 Example illustrating the derivation of the allowable bending stress f_{zulK}

(1) Given:

Material No. 1.4550 according to DIN EN 10222-5

$R_{p0.2T}$ = 130 N/mm² at 350 °C

R_{mT} = 350 N/mm² at 350 °C

(2) Determine:

Allowable bending stress for rectangular cross section (K = 1.5) at a reference stress of

$$\sigma_{bez} = 0.7 \cdot R_{mT} = 0.7 \cdot 350 = 245 \text{ N/mm}^2$$

(3) Solution:

Since $R_{p0.2T} < \sigma_{bez} \leq R_{mT}$, equation (C 4-6) shall be used.

Trapezoidal intercept stress at tensile strength and 0.2 proof stress (**Figure C-6**):

a) R_{om} = 310 N/mm²

b) R_{op} = 85 N/mm²

c) $R_{p0.2T}$ = 130 N/mm²

d) R_{mT} = 350 N/mm²

The allowable bending stress for the rectangular section as per equation (C 4-6) is:

$$f_{zul\,1.5} = f_{p\,1.5} + \frac{(f_{m\,1.5} - f_{p\,1.5}) \cdot (\sigma_{bez} - R_{p0.2T})}{R_{mT} - R_{p0.2T}}$$

$$f_{p\,1.5} = R_{p0.2T} + (1.5 - 1) \cdot R_{op}$$

$$f_{p\,1.5} = 130 + (1.5 - 1) \cdot 85 = 172.5 \text{ N/mm}^2$$

$$f_{m\,1.5} = R_{mT} + (1.5 - 1) \cdot R_{om}$$

$$f_{m\,1.5} = 350 + (1.5 - 1) \cdot 310 = 505 \text{ N/mm}^2$$

$$f_{zul\,1.5} = 172.5 + \frac{(505 - 172.5) \cdot (245 - 130)}{350 - 130}$$

$$f_{zul\,1.5} = 346 \text{ N/mm}^2$$

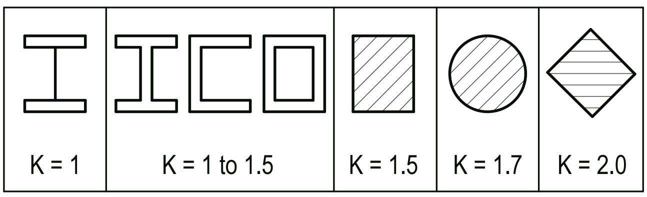


Figure C-1: Section factors (see clause C 2.2.1)

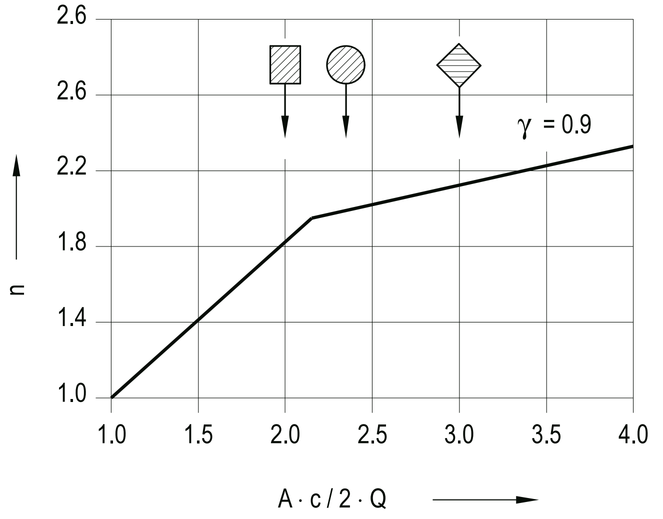


Figure C-2: Interaction exponent (see clause C 2.2.5)

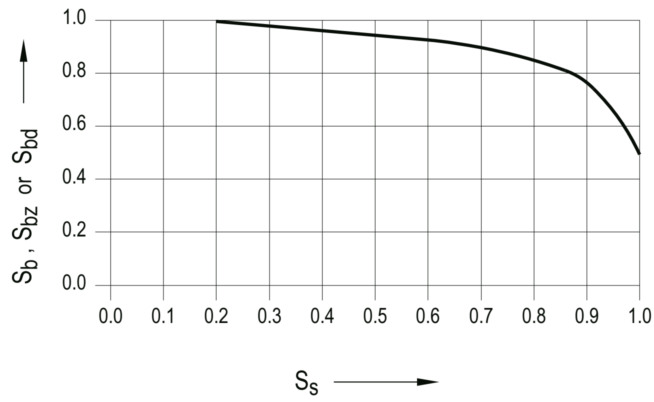


Figure C-3: Interaction curve for bending and shear (see clause C 2.2.7)

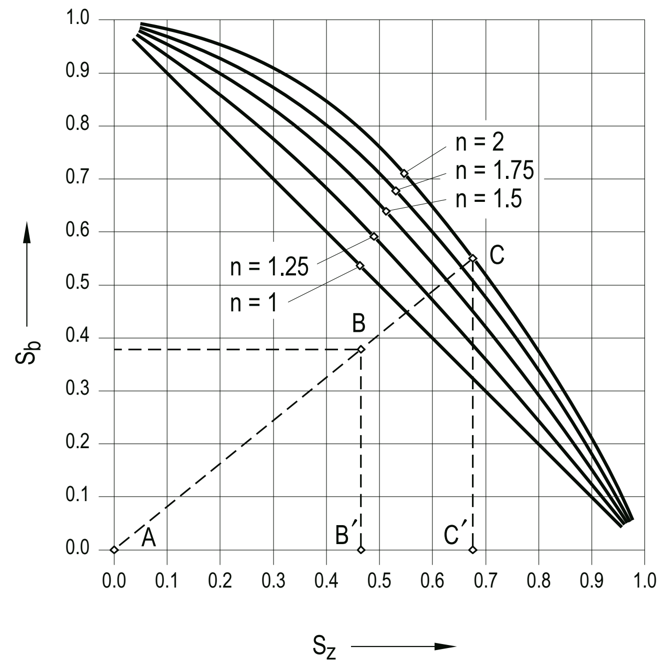


Figure C-4: Interaction curve for bending and tension (see clause C 2.2.7)

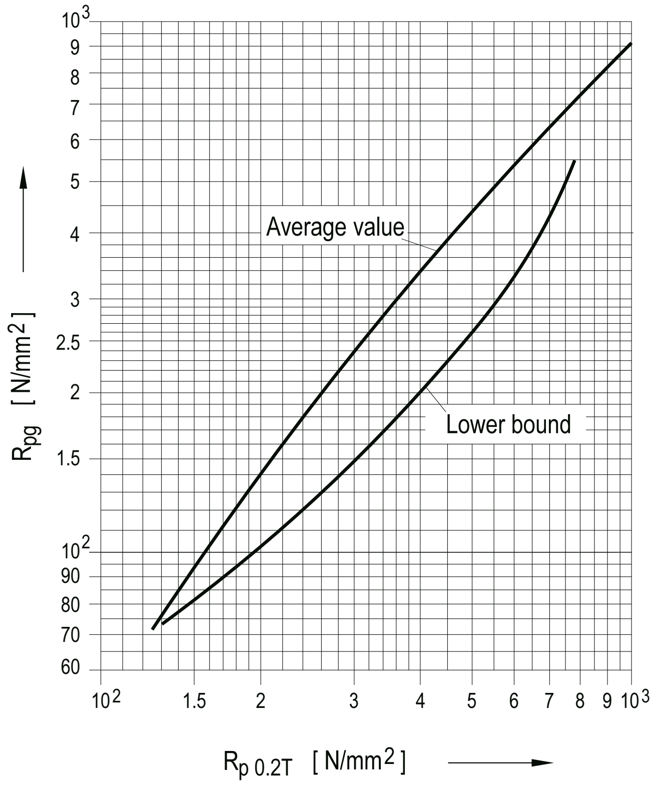


Figure C-5: Proportional limit as a function of 0.2 proof stress (see Section C 4.1)

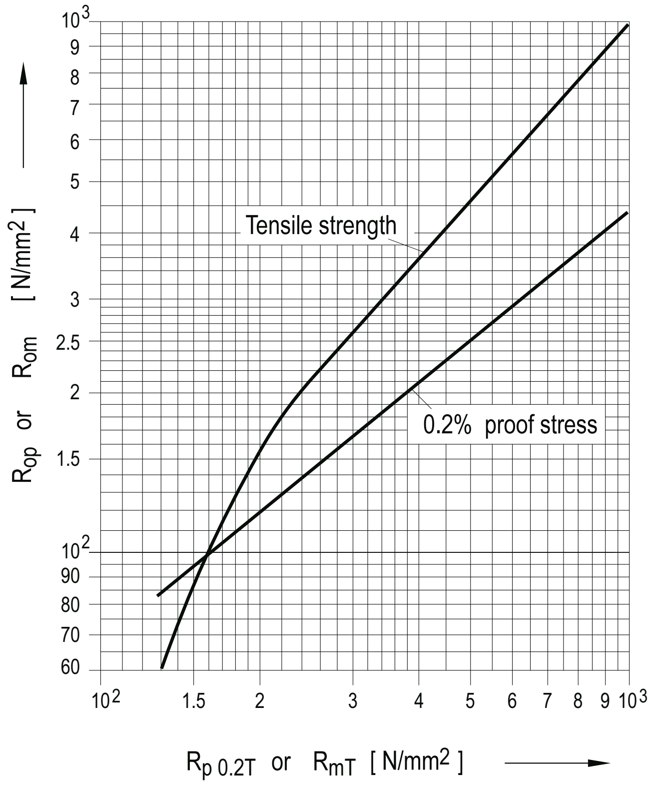


Figure C-6: Trapezoidal intercept stress (see Section C 4.1)

Type of load	Interaction equation 5)	See clause
Simple bending	$S_b \leq 1.0$	C 2.2.1 and C 2.2.2
Complex bending	$S_b = S_{bx'} + S_{by'} \leq 1.0$	C 2.2.3
Simple or complex bending plus shear	$S_{bs} = \sqrt{S_b^2 + S_s^2} \leq 1.0$ 1)	C 2.2.4
Simple or complex bending plus tension	$S_{bz} = S_b + S_z^n \leq 1.0$ 2)	C 2.2.5
Simple or complex bending and compression	$S_{bd} = S_b + S_d \leq 1.0$ 4)	C 2.2.6
Simple or complex bending plus tension and shear	$S_{bzs} = \sqrt{\left(S_b + S_z^n\right)^2 + S_s^2} \leq 1.0$ 3)	C 2.2.7
Simple or complex bending plus compression and shear	$S_{bds} = \sqrt{\left(S_b + S_d\right)^2 + S_s^2} \leq 1.0$ 1) 4)	C 2.2.8

1) As an alternate to the given equation the curve of **Figure C-3** may be used.
2) As an alternate to the given equation the curve of **Figure C-4** may be used.
3) As an alternate to the equation the curve of **Figure C-3** in conjunction with the curve of **Figure C-4** may be used.
4) Amplification of bending moment by axial load (compression) shall be taken into account.
5) All interaction ratios S_i are positive by definition.

Table C-1: Interaction equations for common beam shapes (see Section C 2.2)

Annex D

Experimental stress analysis

D 1 General requirements

D 1.1 Scope

(1) The critical or governing stresses in components for which theoretical stress analysis is inadequate or for which suitable design rules are unavailable, shall be substantiated by experimental stress analysis.

(2) Reevaluation is not required for configurations for which there are available detailed experimental results that are consistent with the requirements of this Annex.

Note:
See also clause 6.2.4.1.

D 1.2 Wall thickness allowances

The test procedures followed and the interpretation of the results shall be such as to discount the effects of material added to the thickness of members (such as corrosion allowance, claddings) which cannot be considered as contributing to the strength of the part.

D 1.3 Tests and reports

For the experimental tests a test program in accordance with clause 6.2.5 and a test report shall be established.

D 2 Tests under static loading

D 2.1 Types of test

D 2.1.1 Test for determination of governing stresses

Permissible types of tests for the determination of governing stresses are strain measurement tests and photo-elastic tests. Brittle coating tests may be used only for the purpose described in clause D 2.3.1.

D 2.1.2 Test for determination of collapse load P_c

Strain measurement tests may be used for the determination of collapse load P_c. Distortion measurement tests may be used for the determination of collapse load if it can be clearly shown that the test set-up and the instrumentation used will give valid results for the configuration on which the measurements are made.

D 2.1.3 Destructive tests

The use of results obtained from destructive tests is not permitted for an experimental stress analysis acc. to this Annex.

D 2.2 Test procedures

D 2.2.1 Strain or distortion measurement test procedure

(1) Except in tests made for the measurement of collapse load, strain gauge data may be obtained from the actual component or from a model component of any scale. The model material need not be the same as the component material but shall have an elastic modulus which is either known or has been measured at the test conditions. The requirements of dimensional similitude shall be met as possible.

(2) In the case of collapse load tests, only full scale models, prototypical in all respects, are permitted unless the experimenter can clearly demonstrate the validity of the scaling laws used.

D 2.2.2 Photoelastic test procedure

Either two-dimensional or three-dimensional techniques may be used as long as the model represents the structural effects of the loading.

D 2.3 Test procedures

D 2.3.1 Sensor arrangement

(1) In tests for determination of governing stresses, sufficient locations on the vessel shall be investigated to ensure that measurements are taken at the most critical areas to cover all stress components, if possible. If the location of the critical areas is not known, the orientation of test gauges may be determined by a brittle coating test.

(2) In tests made for the measurement of collapse load, sufficient measurements must be taken so that all areas which have any reasonable probability of indicating a minimum collapse load are adequately covered. If strain gauges are used to determine the collapse load, particular care should be given to assuring that strains (either membrane, bending, or a combination) are being measured which are actually indicative of the load carrying capacity of the structure. If distortion measurement devices are used, care should be given to assure that it is the change in cardinal dimensions or deflections which are measured, such as diameter or length extension, or beam or plate deflections that are indicative of the tendency of the structure to actually collapse.

D 2.3.2 Application of mechanical load

(1) In tests for determining governing stresses, the mechanical loads shall be applied in such increments that the variation of strain with load can be plotted so as to establish the ratio of stress to load in the elastic range. If the first loading results in strains which are not linearly proportional to the load, it is permissible to unload and reload successively until the linear proportionality has been established. When frozen stress photo-elastic techniques are used, only one load value can be applied, in which case the load shall not be so high as to result in deformations that invalidate the test results.

(2) In tests made for the measurement of collapse load, the proportional load shall be applied in sufficiently small increments so that an adequate number of data points for each gauge are available for statistical analysis in the linear elastic range of behaviour. All gauges should be evaluated prior to increasing the load beyond this value. A least square fit (regression) analysis shall be used to obtain the best fit straight line G_1 (see **Figure D-1**) , and the confidence interval shall be compared to preset values for acceptance or rejection of the strain gauge or other instrumentation. Unacceptable instrumentation will be replaced and the replacement instrumentation tested in the same manner.

(3) After all instrumentation has been deemed acceptable, the test should be continued on a strain or displacement controlled basis with adequate time permitted between load changes for all metal flow to be completed.

D 2.4 Interpretation of results

D 2.4.1 Calculation of stresses

Clause 6.2.4.2.2.7 (5) contains a modified Poisson's ratio to be used only in the case of local thermal stresses. This modified value may also be used for any calculation where stress intensities occur exceeding a stress intensity of 2.0 · $R_{p0.2T}$. If the allowable stress intensity limit is not satisfied at a specific location (e.g. in case of a fatigue analysis) the modified Poisson's ratio shall be considered in determining the stress intensity range.

D 2.4.2 Interpretation to be on elastic basis

The experimental results obtained shall be interpreted on an elastic basis to determine the stresses corresponding to the design loads; that is, in the evaluation of stresses from strain gauge data, the calculations shall be performed under the assumption that the material is elastic. The elastic constants used in the evaluation of experimental data shall be those applicable to the test material at the test temperature.

D 2.4.3 Required extent of stress analysis

The extent of experimental stress analysis performed shall be sufficient to determine the governing stresses. When possible, combined analytical and experimental methods shall be used to distinguish between primary, secondary, and peak stresses so that each combination of categories can be controlled by the applicable stress limit.

D 2.4.4 Criterion of collapse load P_c

(1) For distortion measurement tests, the loads are plotted as the ordinate and the measured deflections are plotted as the abscissa. For strain gauge tests, the loads are plotted as the ordinate and the maximum principal strains on the surface as the abscissa.

(2) The least square fit (regression) line as determined from the data in the linear elastic range is drawn on each plot considered. The angle that the regression line G_1 makes with the ordinate is called Θ. A second straight line G_2, hereafter called the collapse limit line, is drawn through the intersection of the regression line with the abscissa so that it makes an angle φ = arctan (2 tan Θ) with the ordinate (see **Figure D-1**).

(3) The test collapse load is determined from the maximum principal strain or deflection value of the first data point for which there are three successive data points that lie outside of the collapse limit line. This first data point is called the collapse load point. The test collapse load is taken as the load on the collapse limit line G_2 which has the maximum principal strain or deflection of the collapse load point. The collapse load used for design or evaluation purposes shall be the test collapse load multiplied by the ratio of the material elevated temperature proof stress $R_{p0.2T}$ to the test material proof stress at the test temperature.

D 3 Tests with components subject to cyclic loading

D 3.1 General requirements

Fatigue test may be performed to demonstrate the adequacy of a component or portion thereof to withstand cyclic loading.

D 3.2 Requirements for load cycle tests

Note:

In this Section "component" means that parts or sub-units are also covered.

Experimental methods constitute a reliable means of evaluating the capability of a structural component to withstand cyclic loading. In addition, when it is necessary to prove that higher peak stresses are acceptable than can be justified by the methods of Sections D 2.1 and D 2.2 and the fatigue curves of the materials used, the adequacy of a component to withstand cyclic loading may be demonstrated by means of a fatigue test. The fatigue test shall not be used, however, as justification for exceeding the allowable values of primary or primary plus secondary stresses.

D 3.3 Requirements for fatigue tests on the component

(1) The test components shall be constructed of material having the same material properties as the material of the prototype component.

Geometrical similarity must be maintained, at least in those portions whose ability to withstand cyclic loading is being investigated and in those adjacent areas which affect the stresses in the portion under test.

(2) The test component or portion thereof shall withstand the number of cycles as set forth in (3) below before failure occurs.

Note:

Failure is herein defined as a propagation of a crack through the entire thickness, such as would produce a measurable leak in a pressure retaining member.

(3) The minimum number of cycles (hereinafter referred to as test cycles) which the component must withstand, and the magnitude of the loading (hereinafter referred to as the test loading) to be applied to the component during test, shall be determined by multiplying the design service cycles by a specified factor K_{TN} and the design service loads by K_{TS}.

Values of these factors shall be determined by means of the test parameter ratio diagram, the construction of which is described under a) through e) in the following and is illustrated in **Figure D-2**. This is based on the design fatigue curve of **Figure 6-3**.

a) Project a vertical line from the design service cycles N_D on the abscissa to intersect the fatigue design curve at point D to an ordinate value of K_s [see (7) below] times S_{aD}. Label this point A.

b) Extend a horizontal line through the point D until its length corresponds to an abscissa value of K_n [see (7) below] times N_D. Label this point B.

c) Connect the points A and B. The segments AB embrace all the allowable combinations of K_{TS} and K_{TN} [see (4) for accelerated testing with reduced test cycle number]. Any point C on this segment may be chosen at the convenience of the tester. Referring to **Figure D-2**, the factors K_{TS} and K_{TN} are defined by:

$$K_{TS} = \frac{\text{Value of the ordinate at point C}}{\text{Value of the ordinate at point D}}$$

$$K_{TN} = \frac{\text{Value of abscissa at point C}}{\text{Value of abscissa at point D}}$$

Thus

P_T (test loading) = K_{TS} multiplied by design service loading

and

N_T (number of test cycles) = K_{TN} multiplied by design service cycles.

d) If the test article is not a full size component but a geometrically similar model, the test cycle loading P_T shall be adjusted by the appropriate scale factor, to be determined from structural similitude principles, if the loading is other than pressure. The number of cycles that the component must withstand during this test, under the test cycle loading P_T, without failure must not be less than N_T.

e) If in the performance of the test only the loading or the number of cycles is to be increased, the requirements of (5) and (6) shall be met.

(4) Accelerated fatigue testing with reduced number of test load cycles (test cycles N_T are less than design cycles N_D) may be conducted if the design cycles N_D are greater than 10^4 and the testing conditions are determined by the procedures in a) through c) in the following (see **Figure D-3**). In this Figure, the points A, B, and D correspond to similar labelled points in **Figure D-2**.

a) The minimum number of test cycles N_{Tmin} shall be:

$$N_{Tmin} = 10^2 \cdot \sqrt{N_D} \quad \text{(D 2-1)}$$

Project a vertical line through N_{Tmin} on the abscissa of the diagram such that it intersects and extends beyond the fatigue design curve.

b) Construct a curve through the point A and intersect the vertical projection of N_T [see (4) a)] by multiplying every point on the fatigue design curve by the factor K_s [see (7)]. Label the intersection of this curve and the vertical projection of N_{Tmin} as A´.

c) Any point C on the segment A´, A, B determines the allowable combinations of K_{TS} and K_{TN}. The factors K_{TS} and K_{TN} are obtained in the same manner as in (3).

(5) **Case 1** (Factor applied to cycles only)

In this case K_{TS} = 1 and

$$K_{TN} = \frac{\text{Value of abscissa at point B}}{\text{Value of abscissa at point D}}$$

The number of test cycles that the component must withstand during this test must, therefore, not be less than $N_T = K_{TN}$ multiplied by design service cycles, while subjected to the cyclic design service loading, adjusted as required, if a model is used [see also (3) d)].

(6) **Case 2** (Factor applied to loading only)

In this case K_{TN} = 1 and

$$K_{TS} = \frac{\text{Value of the ordinate at point A}}{\text{Value of the ordinate at point D}}$$

The component must, therefore, withstand a number of cycles at least equal to the number of design service cycles, while subjected to a cyclic test loading $P_N = K_{TS}$ multiplied by design service loading, again adjusted as required, if a model is used [see also (3) d)].

(7) The values of K_s and K_n are the multiples of factors which account for the effects of size, surface finish, cyclic rate, temperature, and the number of replicate tests performed. They shall be determined as follows:

$$K_s = K_{sl} \cdot K_{sf} \cdot K_{st} \cdot K_{ss} \cdot K_{sc} \quad \text{(D 2-2)}$$

$$K_n = (K_s)^{4.3} \quad \text{(D 2-3)}$$

K_s shall never be allowed to be less than 1.25.

The factors are defined as follows:

K_{sl} : factor for the effect of size on fatigue life

K_{sl} = 1.5 – 0.5 LM/LK, where LM/LK is the ratio of the linear model size to prototype size

K_{sf} : factor for the effect of surface finish

K_{sf} = 1.175 – 0.175 OGM/OGK, where OGM/OGK is the ratio of model surface finish to prototype surface finish expressed as arithmetical average (AM).

K_{st} : factor for the effect of test temperature

$$K_{st} = \frac{S_s \text{ at test temperature}}{S_s(N) \text{ at design temperature of the fatigue curve}}$$

where S_a (N) refers to the applicable fatigue curve at N cycles (**Figures 6-3** and **6-4**).

K_{ss} : factor for the statistical variation in test results

K_{ss} = 1.470 – 0.044 times number of tests performed.

K_{sc} : factor for differences of S_a values of the design fatigue curve to S_a value at test temperature (Temperature correction factor as shown in **Figures 6-3** and **6-4**).

No value of K_{sl}, K_{sf}, K_{st}, K_{ss} or K_{sc} less than 1.0 may be used in calculating K_s.

D 3.4 Determination of fatigue strength reduction factors

Experimental determination of fatigue strength reduction factors shall be in accordance with the following procedures:

a) The test part shall be fabricated from a material equivalent to that of the component and shall be subjected to the same heat treatment as the component.

b) The stress level in the specimen shall be such that the stress intensity does not exceed the limit for primary and secondary stresses prescribed by **Table 6-5** and so that failure does not occur in less than 1000 cycles.

c) The configuration, surface finish, and stress state of the specimen shall closely simulate those expected in the components. In particular, the stress gradient shall not be more abrupt than that expected in the component.

d) The cyclic rate shall be such that appreciable heating of the specimen does not occur.

e) The fatigue strength reduction factor shall preferably be determined by performing tests on “notched” and “unnotched” specimens and calculated as the ratio of the “unnotched” stress to the “notched” stress for failure.

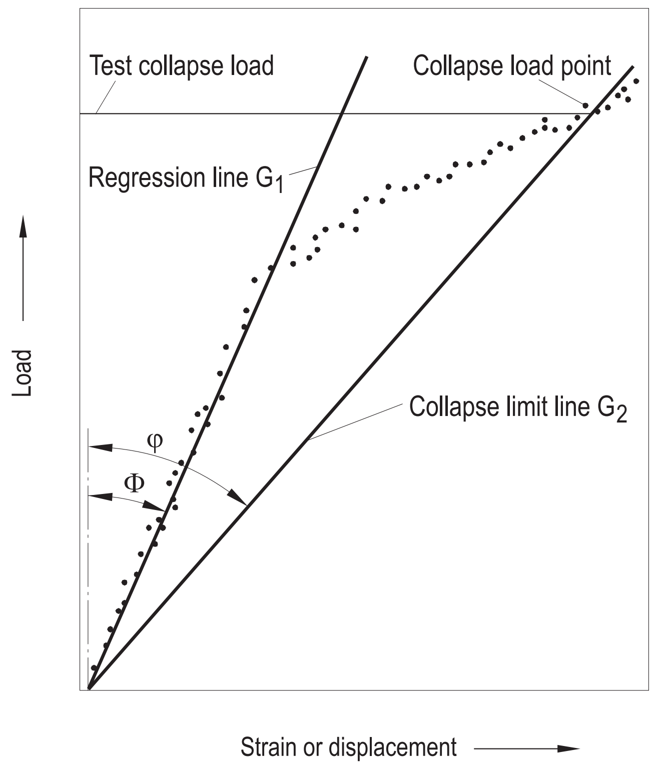


Figure D-1: Construction curve to determine collapse load according to D 2.4.4

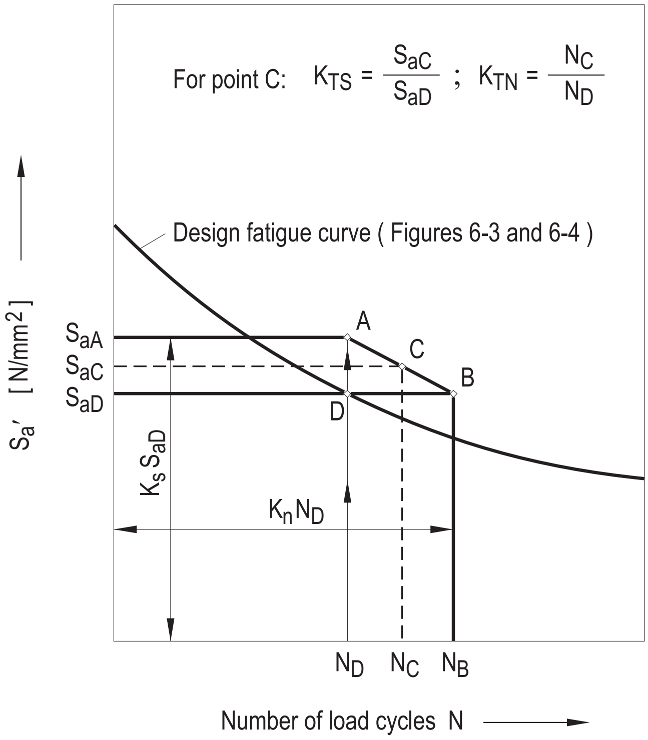


Figure D-2: Construction of the testing parameter ratio diagram [see clause D 3.3 (3)]

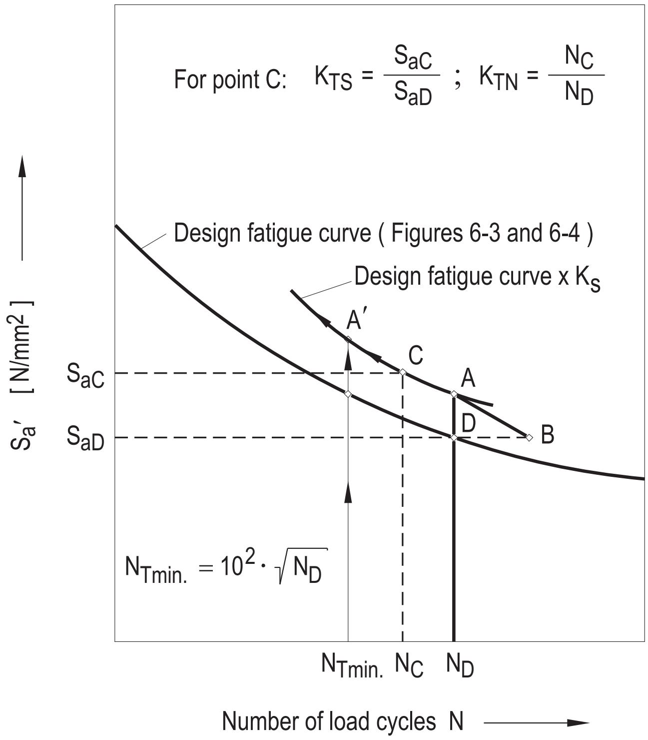


Figure D-3: Diagram for determining the test parameters in case of tests with reduced number of load cycles (see clause D 3.3 (4))

Annex E

Testing for susceptibility to hot cracking (ring segment test coupon)

E 1 General

(1) This testing method applies to austenitic weld filler metals with a delta ferrite content of 5 % or less as well as to weld filler metals of nickel alloys.

(2) The test applies to metal arc welding with rod electrodes as well as to metal and tungsten inert gas welding.

E 2 Test coupon

E 2.1 Test coupon form

The test coupon shall consist of four square segments of equal size into which, on one-side, an annular groove is machined after tack welding is completed on both sides (**Figure E-1**).

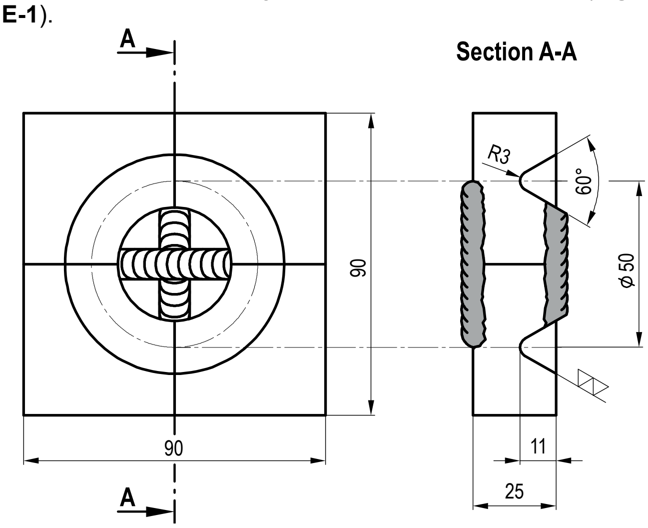


Figure E-1: Test coupon form

E 2.2 Base metals

(1) For the test coupon the base metal X6 CrNiNb 18 10, material number 1.4550 acc. to DIN EN 10088-2, shall be used unless another material is specified in the purchase specification.

Basically, the base metal no. 1.4550 acc. to DIN EN 10088-3 shall be used for the test coupon. If the base metal no. 1.4306 is used for the component weld, this material may also be used for the test coupon.

(2) Weld filler metals are considered to be “not susceptible to hot cracking” if the test demonstrates that the welds are free from cracks.

E 2.3 Preparation

(1) Four square parts each with a thickness of 25 mm and an edge length of 45 mm shall be prepared such that they can be used to produce the test coupon (**Figure E-1**) by means of tack welding. Rolling scale needs not be removed. The contact surfaces shall be face-ground prior to tack welding.

(2) In the case of combination of different base metals, segments A and C as well as segments B and D shall consist of the same base metal.

E 2.4 Work sequence (Figure E-2)

a) Grind surfaces 1-0 of parts A and B as well as surfaces 3-0 of parts C and D.
b) Clamp parts A and B as well as C and D together.
c) Join parts A and B as well as C and D by tack welds on both sides (25 mm long).
d) Grind surfaces 4-0-2 of tack-welded parts A-B and C-D.
e) Clamp tack-welded parts A-B and C-D together.
f) Join tack-welded parts A-B and C-D by tack welds on both sides (50 mm long).

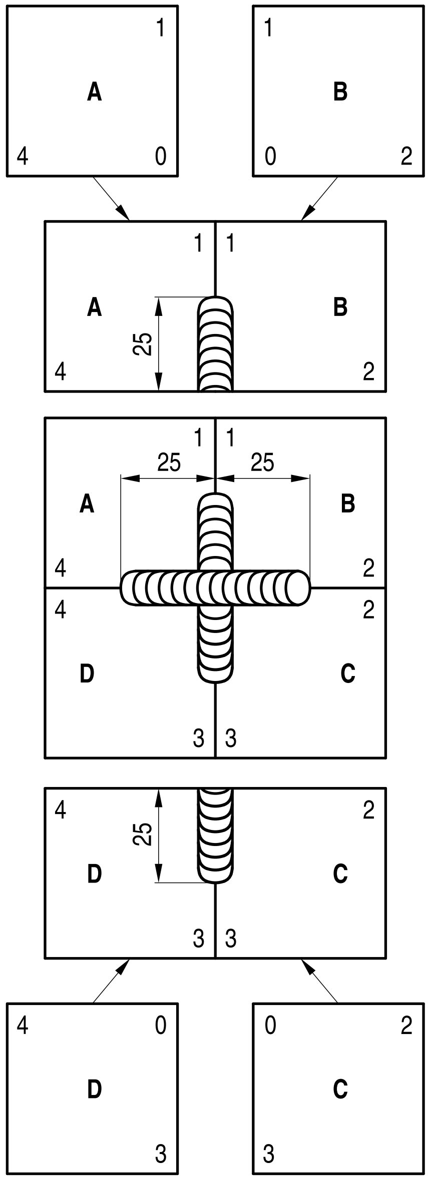


Figure E-2: Preparation of test coupon

E 2.5 Annular groove

After tack welding, an annular groove shall be machined into one side of the test coupon; the dimensions of the groove shall be as indicated in **Figure E-1**. The use of cooling liquids during mechanical processing is not permitted.

E 3 Production of test coupons

E 3.1 Welding conditions

Type of current, polarity and type of inert gas shall be in compliance with the welding conditions under which the weld filler metals to be tested are required to be non-susceptible to hot cracking.

E 3.2 Diameter of the weld filler metal

For the production of the test coupons, the diameters of the weld filler metals to be used for the component weld shall be used.

E 3.3 Welding position

The test coupon shall be welded in flat position (PA).

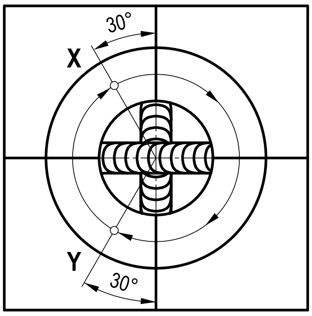


Figure E-3: Welding of test coupon

E 3.4 Welding

Welding shall be carried out clockwise from Point X (**Figure E-3**) to Point Y, without weaving and in an uninterrupted process. After the specimen has cooled down to approximately room temperature and the weld surface and groove have been cleaned, welding shall be restarted clockwise from Point Y to Point X, again without weaving and in an uninterrupted process. The welding speeds for distances X-Y and Y-X shall be specified by the manufacturer depending on the weld filler metal and the welding process.

E 4 Evaluation

(1) After the test coupon has cooled to room temperature, the cleaned annular weld shall be examined for surface cracks by penetrant testing using sensitivity class 4 according to section 4.2.2 of DIN EN ISO 3452-2.

(2) After the surface inspection, the test coupon shall be broken at the four separation points in order to be able to verify fusion at the root.

E 5 Test report

The test report shall contain the following information:

a) weld filler metals (trade name and DIN designation, production unit),

b) welding consumables (e.g. inert gas),

c) base metal or combinations of base metals,

d) welding process,

e) amount of inert gas,

f) current source, amperage, current type, polarity,

g) average weld thickness, measured from base of groove at three points and rounded to 0.1 mm,

h) test results

   ha) If no crack was found - “not susceptible to hot cracking”;

   hb) If cracks were found, information on position, direction, number and length of the cracks as well as details of the evaluation;

i) deviations, if any, from the specifications of this Annex;

k) identification of tester and date of testing.

Annex F

Testing for susceptibility to hot cracking (cylindrical test coupon)

F 1 General

(1) This testing method applies to austenitic weld filler metals with a delta ferrite content of 5 % or less as well as to weld filler metals of nickel alloys.

(2) The test applies to wire-flux welding. Here, the test condition is stricter than the double fillet weld test specimens type B or type C according to DIN EN ISO 17641-2.

F 2 Test coupon

F 2.1 Test coupon form

The test coupon shall consist of two cylindrical rod segments of equal size (**Figure F-1**).

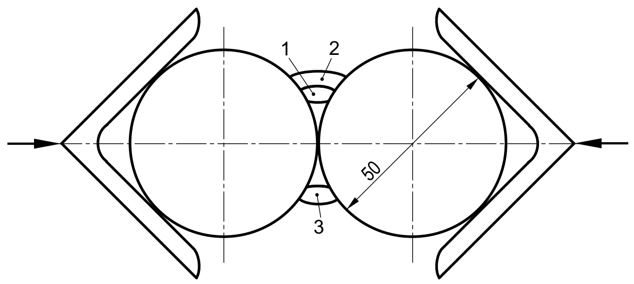


Figure F-1: Test coupon form

F 2.2 Base metals

(1) Basically, the base metal no. 1.4550 according to DIN EN 10088-3 shall be used for the test coupon. If the base metal no. 1.4306 is used for the component weld, this material may also be used for the test coupon.

(2) Weld filler metals are considered to be “not susceptible to hot cracking” if the test demonstrates that the welds are free from cracks.

F 2.3 Preparation

Two scale-free cylindrical rods both of at least 300 mm in length shall be compressed against each other using low contact pressure and be welded (see **Figure F-1**). The digits 1 to 3 indicate the order of the welding passes (beads).

F 3 Production of test coupons

F 3.1 Welding conditions

Type of current, polarity and type of inert gas shall be in compliance with the welding conditions under which the weld filler metals to be tested are required to be non-susceptible to hot cracking.

F 3.2 Diameter of the weld filler metal

For the production of the test coupons, the diameters of the weld filler metals to be used for the component weld shall be used.

F 3.3 Welding position

The test coupon shall be welded in flat position (PA).

F 3.4 Welding

The 3 welding passes (beads) shall be welded using only one welding wire, without interruption in welding of each bead and such that the welding directions of the beads are opposite each other. The time period between the completion of one bead and the welding of the next bead shall not exceed 20 seconds.

(2) The test weld shall have a thickness a = 4 +0.3/-0.5 mm but must be at least 20 percent thinner than the sum of the thicknesses of weld 1 and 2.

(3) If the requirements regarding dimensions of the welding beads are not complied with, the test must be declared null and void.

(4) The welding speed shall be specified by the manufacturer depending on the weld filler metal and the welding process.

F 4 Evaluation

After the test coupon has cooled to room temperature, the cleaned weld no. 3 (test weld) shall be examined for surface cracks by visual testing using a magnifying glass (approximately 6 times magnification) as well as by penetrant testing using sensitivity class 4 acc. to section 4.2.2 of DIN EN ISO 3452-2.

F 5 Test report

The test report shall contain the following information:

a) weld filler metals (trade name and DIN designation, production unit),
b) welding consumables (e.g. flux),
c) base metal,
d) welding process,
e) current source, amperage, current type, polarity,
f) average weld thickness, measured at three points and rounded to 0.1 mm,
g) test results
   ga) If no crack was found - “not susceptible to hot cracking”;
   gb) If cracks were found, information on position, direction, number and length of the cracks as well as details of the evaluation;
h) deviations, if any, from the specifications of this Annex;
i) identification of tester and date of testing.

Annex G

Regulations referred to in this Safety Standard

(The references exclusively refer to the version given in this annex. Quotations of regulations referred to therein refer to the version available when the individual reference below was established or issued.)

AtG		Act on the Peaceful Utilization of Atomic Energy and the Protection against its Hazards (Atomic Energy Act) of December 23, 1959 (BGbl. I, p. 814) as Amended and Promulgated on July 15, 1985 (BGBl. I, p. 1565), last amended by article 2 (2) of the law dated 20th July 2017 (BGBl. I 2017, no. 52, p. 2808)
StrlSchV		Ordinance on the Protection against Damage and Injuries Caused by Ionizing Radiation (Radiation Protection Ordinance) dated 20th July 2001 (BGBl. I p. 1714; 2002 I p. 1459), last amended in accordance with article 10 by article 6 of the law dated 27th January 2017 (BGBl. I p. 114, 1222)
SiAnf	(2015-03)	Safety Requirements for Nuclear Power Plants (SiAnf) as Amended and Promulgated on March 3rd 2015 (BAnz. AT 30.03.2015 B2)
Interpretations on the SiAnf	(2015-03)	Interpretations on the Safety Requirements for Nuclear Power Plants of November 22nd 2012, as Amended on March 3rd 2015 (BAnz. AT 30.03.2015 B3)
KTA 1202	(2017-11)	Requirements for the Operating Manual
KTA 1401	(2017-11)	General Requirements Regarding Quality Assurance
KTA 1404	(2013-11)	Documentation during the Construction and Operation of Nuclear Power Plants
KTA 2201.4	(2012-11)	Design of Nuclear Power Plants against Seismic Events. Part 4: Components
KTA 2502	(2011-11)	Mechanical Design of Fuel Assembly Storage Pools in Nuclear Power Plants with Light Water Reactors
KTA 3201.2	(2017-11)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 2: Design and Analysis
KTA 3201.3	(2017-11)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 3: Manufacture
KTA 3201.4	(2016-11)	Components of the Reactor Coolant Pressure Boundary of Light Water Reactors; Part 4: Inservice Inspections and Operational Monitoring
KTA 3205.1	(2002-06)	Component Support Structures with Non-integral Connections; Part 1: Component Support Structures with Non-integral Connections for Components of the Reactor Coolant Pressure Boundary of Light Water Reactors
KTA 3902	(2012-11)	Design of Lifting Equipment in Nuclear Power Plants
KTA 3903	(2012-11)	Inspection, Testing and Operation of Lifting Equipment in Nuclear Power Plants
DIN EN ISO 148-1	(2017-05)	Metallic materials - Charpy pendulum impact test - Part 1: Test method (ISO 148-1:2016); German version EN ISO 148-1:2016
DIN EN ISO 643	(2013-05)	Steels - Micrographic determination of the apparent grain size (ISO 643:2012); German version EN ISO 643:2012
DIN EN ISO 898-1	(2013-05)	Mechanical properties of fasteners made of carbon steel and alloy steel - Part 1: Bolts, screws and studs with specified property classes - Coarse thread and fine pitch thread (ISO 898-1:2013); German version EN ISO 898-1:2013
DIN EN ISO 1101	(2014-04)	Geometrical product specifications (GPS) - Geometrical tolerancing - Tolerances of form, orientation, location and run-out (ISO 1101:2012 + Cor. 1:2013); German version EN ISO 1101:2013
DIN EN ISO 1302	(2002-06)	Geometrical product specifications (GPS). Indication of surface texture in technical product documentation; German version EN ISO 1302:2002 / Corrigendum 2008-08
DIN EN 1370	(2012-03)	Founding - Examination of surface condition; German version EN 1370:2011
DIN EN 1371-2	(2015-04)	Founding - Liquid penetrant testing - Part 2: Investment castings; German version EN 1371-2:2015
DIN EN 1559-1	(2011-05)	Founding. Technical conditions of delivery. Part 1: General; German version EN 1559-1:2011
DIN EN 1559-2	(2014-12)	Founding. Technical conditions of delivery. Part 2: Additional requirements for steel castings; German version EN 1559-2:2014

DIN EN ISO 2560	(2010-03)	Welding consumables. Covered electrodes for manual metal arc welding of non-alloy and fine grain steels. Classification (ISO 2560:2009); German version EN ISO 2560:2009
DIN ISO 2768-1	(1991-06)	General tolerances; Tolerances for linear and angular dimensions without individual tolerance indications; Identical with ISO 2768-1:1989
DIN ISO 2768-2	(1991-04)	General tolerances; Geometrical tolerances for features without individual tolerances indications; Identical with ISO 2768-2:1989
DIN EN ISO 3269	(2000-11)	Fasteners. Acceptance inspection (ISO 3269:2000); German version EN ISO 3269:2000
DIN EN ISO 3452-1	(2014-09)	Non-destructive testing - Penetrant testing - Part 1: General principles (ISO 3452-1:2013, Corrected version 2014-05-01); German version EN ISO 3452-1:2013
DIN EN ISO 3452-2	(2014-03)	Non-destructive testing - Penetrant testing - Part 2: Testing of penetrant materials (ISO 3452-2:2013); German version EN ISO 3452-2:2013
DIN EN ISO 3452-3	(2014-03)	Non-destructive testing - Penetrant testing - Part 3: Reference test blocks (ISO 3452-3:2013); German version EN ISO 3452-3:2013
DIN EN ISO 3506-1	(2010-04)	Mechanical properties of corrosion-resistant stainless steel fasteners - Part 1: Bolts, screws and studs (ISO 3506-1:2009); German version EN ISO 3506-1:2009
DIN EN ISO 3506-2	(2010-04)	Mechanical properties of corrosion-resistant stainless steel fasteners - Part 2: Nuts (ISO 3506-2:2009); German version EN ISO 3506-2:2009
DIN EN ISO 3581	(2016-12)	Welding consumables - Covered electrodes for manual metal arc welding of stainless and heat-resisting steels - Classification (ISO 3581:2016); German version EN ISO 3581:2016
DIN EN ISO 3651-2	(1998-08)	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); German version EN ISO 3651-2:1998
DIN EN ISO 3834-1	(2006-03)	Quality requirements for fusion welding of metallic materials. Part 1: Criteria for the selection of the appropriate level of quality requirements (ISO 3834-1:2005); German version EN ISO 3834-1:2005
DIN EN ISO 3834-2	(2006-03)	Quality requirements for fusion welding of metallic materials Part 2: Comprehensive quality requirements (ISO 3834-2:2005); German version EN ISO 3834-2:2005
DIN EN ISO 4136	(2013-02)	Destructive tests on welds in metallic materials - Transverse tensile test (ISO 4136:2012); German version EN ISO 4136:2012
DIN EN ISO 4287	(2010-07)	Geometrical Product Specifications (GPS) - Surface texture: Profile method - Terms, definitions and surface texture parameters (ISO 4287:1997 + Cor 1:1998 + Cor 2:2005 + Amd 1:2009); German version EN ISO 4287:1998 + AC:2008 + A1:2009
DIN EN ISO 4759-1	(2001-04)	Tolerances for fasteners - Part 1: Bolts, screws, studs and nuts; Product grades A, B and C (ISO 4759-1:2000); German version EN ISO 4759-1:2000
DIN EN ISO 5173	(2012-02)	Destructive tests on welds in metallic materials - Bend tests (ISO 5173:2009 + Amd 1:2011); German version EN ISO 5173:2010 + A1:2011
DIN EN ISO 5579	(2014-04)	Non-destructive testing - Radiographic testing of metallic materials using film and X- or gamma rays - Basic rules (ISO 5579:2013); German version EN ISO 5579:2013
DIN EN ISO 5817	(2014-06)	Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections (ISO 5817:2014); German version EN ISO 5817:2014
DIN EN ISO 6506-1	(2015-02)	Metallic materials - Brinell hardness test - Part 1: Test method (ISO 6506-1:2014); German version EN ISO 6506-1:2014
DIN EN ISO 6508-1	(2016-12)	Metallic materials - Rockwell hardness test - Part 1: Test method (ISO 6508-1:2016); German version EN ISO 6508-1:2016
DIN EN ISO 6847	(2013-11)	Welding consumables - Deposition of a weld metal pad for chemical analysis (ISO 6847:2013); German version EN ISO 6847:2013
DIN EN ISO 6892-1	(2017-02)	Metallic materials - Tensile testing - Part 1: Method of test at room temperature (ISO 6892-1:2016); German version EN ISO 6892-1:2016
DIN EN ISO 6892-2	(2011-05)	Metallic materials - Tensile testing - Part 2: Method of test at elevated temperature (ISO 6892-2:2011); German version EN ISO 6892-2:2011
DIN ISO 7802	(2014-11)	Metallic materials - Wire - Wrapping test (ISO 7802:2013)
DIN 8201-7	(1985-07)	Synthetic mineral abrasives; Glass beads
DIN EN ISO 8249	(2000-10)	Welding - Determination of Ferrite Number (FN) in Austenitic and Duplex Ferritic-Austentic Cr-Ni Stainless Steel Weld Metals (ISO 8249:2000); German version EN ISO 8249:2000

DIN EN ISO 9017	(2013-12)	Destructive tests on welds in metallic materials - Fracture test (ISO 9017:2001); German version EN ISO 9017:2013
DIN EN ISO 9606-1	(2013-12)	Qualification testing of welders - Fusion welding - Part 1: Steels (ISO 9606-1:2012, including Cor. 1:2012); German version EN ISO 9606-1:2013
DIN EN ISO 9606-4	(1999-06)	Approval testing of welders. Fusion welding. Nickel and nickel alloys (IS) 9606-4); German version EN ISO 9606-4:1999
DIN EN ISO 9692-1	(2013-12)	Welding and allied processes - Types of joint preparation - Part 1: Manual metal-arc welding, gas-shielded metal-arc welding, gas welding, TIG welding and beam welding of steels (ISO 9692-1:2013); German version EN ISO 9692-1:2013
DIN EN ISO 9692-2	(1999-09)	Welding and allied processes. Recommendations for joint preparation. Part 2: Submerged arc welding of steels (ISO 9692-2:1998, incl. Corrigendum AC:1999); German version EN ISO 9692-2:1998 + AC:1999
DIN EN ISO 9712	(2012-12)	Non-destructive testing - Qualification and certification of NDT personnel (ISO 9712:2012); German version EN ISO 9712:2012
DIN EN 10025-2	(2005-04)	Hot rolled products of non-alloy structural steels. Part 2: Technical delivery conditions for flat products; German version EN 10025-2:2004
DIN EN 10028-7	(2016-10)	Flat products made of steels for pressure purposes - Part 7: Stainless steels; German version EN 10028-7:2016
DIN EN 10049	(2014-03)	Measurement of roughness average Ra and peak count RPc on metallic flat products; German version EN 10049:2013
DIN EN 10083-2	(2006-10)	Steels for quenching and tempering. Part 2: Technical delivery conditions for non alloy steels; German version EN 10083-2:2006
DIN EN 10084	(2008-06)	Case hardening steels. Technical delivery conditions; German version EN 10084:2008
DIN EN 10088-1	(2014-12)	Stainless steels. Part 1: List of stainless steels; German version EN 10088-1:2014
DIN EN 10088-2	(2014-12))	Stainless steels. Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes; German version EN 10088-2:2014
DIN EN 10088-3	(2014-12))	Stainless steels. Part 3: Technical delivery conditions for semi-finished products, bars, rods wire, sections and bright products of corrosion resisting steels for general purposes; German version EN 10088-3:2014
DIN EN 10204	(2005-01)	Metallic products; Types of inspection documents; German version EN 10204:2004
DIN EN 10213	(2016-10)	Steel castings for pressure purposes; German version EN 10213:2007+A1:2016
DIN EN 10216-5	(2014-03)	Seamless steel tubes for pressure purposes - Technical delivery conditions - Part 5: Stainless steel tubes; German version EN 10216-5:2013 (Corrigendum 2015-01)
DIN EN 10217-7	(2015-01)	Welded steel tubes for pressure purposes - Technical delivery conditions - Part 7: Stainless steel tubes; German version EN 10217-7:2014
DIN EN 10222-1	(2017-06)	Steel forgings for pressure purposes - Part 1: General requirements for open die forgings; German version EN 10222-1:2017
DIN EN 10222-5	(2017-06)	Steel forgings for pressure purposes - Part 5: Martensitic, austenitic and austenitic-ferritic stainless steels; German version EN 10222-5:2017
DIN EN 10250-1	(1999-12)	Open die steel forgings for general engineering purposes. Part 1: General requirements; German version EN 10250-1:1999
DIN EN 10250-4	(2000-02)	Open die steel forgings for general engineering purposes. Part 4: Stainless steels; German version EN 10250-4:1999
DIN EN 10272	(2016-10)	Stainless steel bars for pressure purposes; German version EN 10272:2016
DIN EN 10283	(2010-06)	Corrosion resistant steel castings; German version EN 10283:2010
DIN EN 10302	(2008-06)	Creep resisting steels, nickel and cobalt alloys; German version EN 10302:2008
DIN EN ISO 10893-6	(2011-07)	Non-destructive testing of steel tubes - Part 6: Radiographic testing of the weld seam of welded steel tubes for the detection of imperfections (ISO 10893-6:2011); German version EN ISO 10893-6:2011
DIN EN ISO 10893-7	(2011-07)	Non-destructive testing of steel tubes - Part 7: Digital radiographic testing of the weld seam of welded steel tubes for the detection of imperfections (ISO 10893-7:2011); German version EN ISO 10893-7:2011
DIN EN ISO 10893-10	(2011-07)	Non-destructive testing of steel tubes - Part 10: Automated full peripheral ultrasonic testing of seamless and welded (except submerged arc-welded) steel tubes for the detection of longitudinal and/or transverse imperfections (ISO 10893-10:2011); German version EN ISO 10893-10:2011

DIN EN ISO 11126-7	(1999-10)	Preparation of steel substrates before application of paints and related products. Specifications for non-metallic blast-cleaning abrasives. Part 7: Specification for fused aluminium oxide; German version EN ISO 11126-7:1999
DIN EN 12668-1	(2010-05)	Non-destructive testing - Characterization and verification of ultrasonic examination equipment - Part 1: Instruments; German version EN 12668-1:2010
DIN EN 12668-2	(2010-06)	Non-destructive testing - Characterization and verification of ultrasonic examination equipment - Part 2: Probes; German version EN 12668-2:2010
DIN EN 12668-3	(2014-02)	Non-destructive testing - Characterization and verification of ultrasonic examination equipment - Part 3: Combined equipment; German version EN 12668-3:2013
DIN EN 12681	(2003-06)	Founding. Radiographic examination; German version EN 12681:2003
DIN EN 13018	(2016-06)	Non-destructive testing - Visual testing - General principles; German version EN 13018:2016
DIN EN 13445-3	(2016-12)	Unfired pressure vessels - Part 3: Design; German version EN 13445-3:2014
DIN EN 13480-3	(2014-12)	Metallic industrial piping - Part 3: Design and calculation; German version EN 13480-3:2012 / Corrigendum 2015-12 and 2016-10
DIN EN ISO 13920	(1996-11)	Welding - General tolerances for welded constructions - Dimensions for lengths and angles; shape and position (ISO 13920:1996); German version EN ISO 13920:1996
DIN EN ISO 14172	(2016-02)	Welding consumables - Covered electrodes for manual metal arc welding of nickel and nickel alloys - Classification (ISO 14172:2015); German version EN ISO 14172:2015
DIN EN ISO 14175	(2008-06)	Welding consumables - Gases and gas mixtures for fusion welding and allied processes (ISO 14175:2008); German version EN ISO 14175:2008
DIN EN ISO 14343	(2017-08)	Welding consumables - Wire electrodes, strip electrodes, wires and rods for arc welding of stainless and heat resisting steels - Classification (ISO 14343:2017); German version EN ISO 14343:2017
DIN EN ISO 14732	(2013-12)	Welding personnel - Qualification testing of welding operators and weld setters for mechanized and automatic welding of metallic materials (ISO 14732:2013); German version EN ISO 14732:2013
DIN EN ISO 15792-1	(2012-01)	Welding consumables - Test methods - Part 1: Test methods for all-weld metal test specimens in steel, nickel and nickel alloys (ISO 15792-1:2000 + Amd 1:2011); German version EN ISO 15792-1:2008 + A1:2011
DIN EN 15800	(2009-03)	Cylindrical helical springs made of round wire - Quality specifications for cold coiled compression springs; German version EN 15800:2008
DIN EN 16983	(2017-09)	Disc springs - Quality specifications - Dimensions; German version EN 16983:2016
DIN EN ISO 17633	(2011-03)	Welding consumables - Tubular cored electrodes and rods for gas shielded and non-gas shielded metal arc welding of stainless and heat-resisting steels - Classification (ISO 17633:2010); German version EN ISO 17633:2010
DIN EN ISO 17636-1	(2013-05)	Non-destructive testing of welds - Radiographic testing - Part 1: X- and gamma-ray techniques with film (ISO 17636-1:2013); German version EN ISO 17636-1:2013
DIN EN ISO 17636-2	(2013-05)	Non-destructive testing of welds - Radiographic testing - Part 2: X- and gamma-ray techniques with digital detectors (ISO 17636-2:2013); German version EN ISO 17636-2:2013
DIN EN ISO 17637	(2017-04)	Non-destructive testing of welds - Visual testing of fusion-welded joints (ISO 17637:2016); German version EN ISO 17637:2016
DIN EN ISO 17641-2	(2016-03)	Destructive tests on welds in metallic materials - Hot cracking tests for weldments - Arc welding processes - Part 2: Self-restraint tests (ISO 17641-2:2015); German version EN ISO 17641-2:2015
DIN EN ISO 18274	(2011-04)	Welding consumables - Solid wire electrodes, solid strip electrodes, solid wires and solid rods for fusion welding of nickel and nickel alloys - Classification (ISO 18274:2010); German version EN ISO 18274:2010
DIN EN ISO 19232-1	(2013-12)	Non-destructive testing - Image quality of radiographs - Part 1: Determination of the image quality value using wire-type image quality indicators (ISO 19232-1:2013); German version EN ISO 19232-1:2013
DIN EN ISO 19232-3	(2014-02)	Non-destructive testing - Image quality of radiographs - Part 3: Image quality classes (ISO 19232-3:2013); German version EN ISO 19232-3:2013
DIN 25410	(2012-07)	Nuclear facilities - Surface cleanliness of components
DIN 25435-4	(2014-01)	In-service inspections for primary collant circuit components of light water reactors - Part 4: Visual testing
DIN 25475-1	(2013-01)	Nuclear facilities - Operational monitoring - Part 1: Monitoring of structure-borne sound for loose parts detection

DIN 25475-2	(2009-05)	Nuclear facilities - Operational monitoring - Part 2: Vibration monitoring for early detection of changes in the vibrational behavior of the primary coolant circuit in pressurized water reactors
DIN 50125	(2016-12)	Testing of metallic materials - Tensile test pieces
DIN CEN ISO/ TR 15608	(2013-08)	Welding - Guidelines for a metallic materials grouping system (ISO/TR 15608:2013); German version CEN ISO/TR 15608:2013
AD 2000-Merk-blatt B0	(2014-11)	Design of pressure vessels
AD 2000-Merk-blatt B 1	(2000-10)	Cylindrical and spherical shells subjected to internal overpressure
AD 2000-Merk-blatt B3	(2011-05)	Domed ends subject to internal or external pressure
AD 2000-Merk-blatt B 6	(2006-10)	Cylindrical shells subjected to external overpressure
AD 2000-Merk-blatt HP 0	(2013-02)	General principles of design, manufacture and associated tests
AD 2000-Merk-blatt HP 3	(2014-11)	Welding supervisors, welder
AD 2000-Merk-blatt W 2	(2016-09)	Austenitic and austenitic-ferritic steels

Annex H

Literature

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Annex I (informative)

Changes with respect to the edition 2015-11 and explanations

(1) In section 2 “Definitions” the term “Room temperature” was added based on the stipulations in DIN EN ISO 6892-1.

(2) The rules for applying inspection certificates according to DIN EN 10204, edition 1995-08, contained up to now in section 7.3.1, were deleted since for new fabrications only DIN EN 10204, edition 2005-01, is applicable. Despite this fact, the following is recognized upon individual checking if stored material is used:

a) instead of inspection certificate 3.1 according to DIN EN 10204 (2005-01) also inspection certificate 3.1 B according to DIN EN 10204 (1995-08),

b) instead of inspection certificate 3.2 according to DIN EN 10204 (2005-01) also inspection certificate 3.1 C according to DIN EN 10204 (1995-08).

(3) In Table 7-4 the product form „forgings“ was deleted since mechanical machining is generally intended for this product form and the abbreviations are not used in any standard. In addition, the column “Type of treatment” was adapted to the current standards.

(4) In Material Annex W 2 the designation NiCr19Fe19NbMo for material no. 2.4668 was replaced by NiCr19Fe19Nb5Mo3 since this is the official designation according to the European steel register.

(5) In Tables W 2-4 and W 2-5 the product form „strip“ was added which up to now was mentioned only in Table W 2-3.

(6) In materials test sheet W 2.5.1 the inspection certificates required under no. 8 and 9 were adapted to the stipulations under numbers 4, 5 and 7.

(7) In Materials Annex W 5 „Machine elements“, the following changes were made:

a) In the materials test sheets W 5.3.1 and W 5.3.2 the requirements regarding the check of dimensions and tolerances of fasteners were specified based on the current standards. In this context, the reference to DIN EN ISO 3269 was deleted in the title of Table W 5-2 since it is no longer appropriate for the current edition of this standard.

b) The requirements regarding disc springs in materials test sheet W 5.3.3 were adapted to DIN EN 16983 which has replaced DIN 2093 based on which the requirements were specified up to now.

(8) The normative references to regulations referred to in this Safety Standard in Annex G were updated.