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Pressure vessel standards giving presumption of conformity with the PRESSURE EQUIPMENT DIRECTIVE Comparison between ASME Section VIII and EN 13445

Dr. Ing. Fernando Lidonnici
SANT'AMBROGIO SERVIZI INDUSTRIALI SRL
Piazza Carlo Donegani 8 – 20133 MILANO, Italy
Phone: +39.02.70603113 Fax: +39.02.2663546
E-mail: santambrogio@sant-ambrogio.it
www.sant-ambrogio.it

Abstract

According to the so called New Approach, all the European Technical Directives intended to the elimination of technical barriers to trade do not contain detailed prescriptions about design, materials, construction and testing of the products concerned: such detailed prescriptions are left to the "Harmonized Standards", that is, to the standards based on the "Essential Safety Requirements" of the directives. In other words, these requirements, not the standards themselves, are the only legal basis on which compliance of a given product with the European Law must be evaluated. This is the case of the **Pressure Equipment Directive** and its product standards: **EN 13445** for unfired pressure vessels, **EN 12952** and **12953** for steam generators, **EN 13480** for piping. However the experience of 16 years (2002-2018) has shown that the harmonized standards are not the only possible route to assure compliance with the Essential Safety Requirements: particularly for pressure vessels, many other national and international standards have been and are actually used, although, on a merely theoretical basis, compliance with such requirements of vessels fabricated and marketed according to non harmonized standards should be proven by the manufacturers. In reality all the national pressure vessel standards which existed in the various European countries before the Pressure Equipment Directive (**PD 5500** in UK, **AD Merkblätter** in Germany, **CODAP** in France and **Raccolte ISPESL** in Italy) have now been brought in compliance with it, and are still regularly updated and commonly used by national manufacturers and notified bodies, so that they have in practice the same degree of "presumption of conformity" of the harmonized pressure vessel standard EN 13445.

What is interesting is that also the American pressure vessel standard **ASME Section VIII** is one of the standards which are most frequently used in Europe, despite of the fact that the criteria on which this standard is based are in many aspects different from the criteria used by the directive.

Scope of this paper is to **compare the two standards** (**EN 13445** and **ASME Section VIII**) in order to clarify which are the main differences and which additional requirements must be fulfilled by the products made in accordance with ASME Section VIII in order to assure full conformity with the directive.

Legal and normative aspects in Pressure Vessel fabrication

- **USA:** the **ASME Code** (**Section VIII for Pressure Vessels**) is the safety standard generally accepted, but there are differences in the different States (in some of them it is imposed by law, in other it is required for insurance purposes only).

- **Europe:** the **PED** (**Pressure Equipment Directive**) is a law and therefore it is compulsory in all the European countries. It requires compliance with the **Essential Safety Requirements** (**ESR**s) only, not with a detailed set of rules. The use of a "**Harmonized Standard**" (**EN 13445 for Pressure Vessels**) assures "**Presumption of Conformity**" with the PED, but other standards are also acceptable, provided they take into account the ESRs.

Requirements and responsibilities

- **ASME:** requires strict compliance with the section of the ASME code concerning a given pressure component (there is a specific section for each type of component). The **ASME Stamp** (different for each section) assures **full compliance** with every detail contained in that section. The Manufacturer is responsible to take into account the requirements and loading conditions specified by the Purchaser.

- **PED:** the Manufacturer (not the Purchaser) is fully responsible for the safety of the equipment in all the possible conditions: normal operating, exceptional, testing, transport, erection, maintenance, etc. The **CE mark** means that **only the ESRs have been complied with**, not a specific code or standard. Design and fabrication must be made on the basis of a specific **Risk Analysis**, different for each component, under the responsibility of the Manufacturer.

Main differences among ASME VIII div.1, ASME VIII div. 2 and EN 13445

ASME VIII division 1:

- Use of this standard usually involves larger thicknesses and weights in comparison with other PV standards (see exceptions in the following slides).
- However for small vessels the increase in weights is generally compensated by the smaller amount of NDT and weld test coupons (in the case of formed ends it is very easily possible to avoid heat treatment of hot forming).
- The use of the standard is relatively simple even for those who do not have a technical culture at university level.
- All kind of metallic materials are considered.
- The design in the creep range for a number of hours greater than 100,000 is not possible.
- Design by analysis, fatigue calculations and calculation of stresses induced by loads on nozzles are not possible.
- Use of this standard in the context of the Pressure Equipment Directive involves a series of problems (Particular Material Appraisal for ASME material, test pressure not in accordance with the Directive, nominal design stresses in some particular cases less conservative than the stresses recommended in the PED)
- The standard is regularly updated every year. Every two years a complete new edition is published.

Main differences among ASME VIII div.1, ASME VIII div. 2 and EN 13445

ASME VIII division 2:

- For all vessels volumetric non-destructive tests (XR or UT) are needed.
- The standard is more modern than ASME VIII division 1 and more sophisticated design methods are used.
- The design requires the presence of an engineer with university degree.
- All kind of metallic materials are considered.
- The design in the creep range for a number of hours greater than 100,000 is not possible.
- Design by analysis can be used as an alternative to Design by Formulae.
- Fatigue calculations are possible, however only with a complete stress analysis of the vessel.
- For calculation of stresses induced by loads on nozzles there is a clear reference to specific publications of the Welding Research Council, that can be easily combined with the rules for opening reinforcement.
- Use of this standard in the context of the Pressure Equipment Directive is easier then division 1. However also in this case a Particular Material Appraisal is needed for all ASME (SA and SB) materials.
- Two different classes of vessels are provided, with different nominal design stresses (however the differences in thickness are relatively small except at room temperature).
- The standard is regularly updated every year. Every two years a complete new edition is published.

Main differences among ASME VIII div.1, ASME VIII div. 2 and EN 13445

EN 13445:

- For almost all vessels volumetric non-destructive tests (XR or UT) are needed: the construction of vessels without non-destructive tests (XR or UT) is possible, however only for carbon and austenitic steels with thicknesses not greater than 16 mm, pressures < 20 bar and product Pressure (bar) x Volume (litre) < 20000.
- The standard is more modern than ASME VIII division 1 and more sophisticated design methods are used.
- The presence of an engineer with university degree is recommended.
- Only steels, spheroidal cast iron, Aluminium alloys and Nickel alloys are considered. Specific parts for Titanium alloys and Copper alloys are in preparation. However many times it is necessary to use materials of different standardization systems, because there are not enough EN material specifications; in this case the guarantee of the material manufacturer for the characteristics used in design is always needed.
- The design in the creep range is possible for any number of hours, provided the specific material creep characteristics are available and guaranteed.
- Design by Analysis can be used as an alternative to Design by Formulae.
- Fatigue calculations are possible, either with a complete stress analysis of the vessel, or with a simplified method based on design by formulae.
- Calculation of stresses induced by loads on nozzles is possible (the method, based on limit analysis, has recently been completed with all the 6 possible load components).
- This standard is the harmonized Pressure Vessel standard for the PED, that is, it gives presumption of conformity with it.
- The standard is regularly updated every year. Every 5 years a complete new edition is published.

Different philosophy between ASME and PED about Materials

- **ASME:** Only material specifications explicitly considered in the applicable Section of the code may be used. This applies to the great majority of American material specifications (**ASME materials**, generally practically same as the corresponding **ASTM materials**). Also **some EN materials** (and other foreign materials) **have recently been included**. For all material specifications the allowable stresses (or nominal design stresses, using the EN terminology) and the hot yield and tensile characteristics to be used for design must be taken from **ASME Section II part D**. These characteristics are **recommended for design purposes**, but **the material manufacturers are not obliged to respect them**. Note that while for ASME materials hot tensile characteristics are generally not provided by the original specifications, **in the case of EN materials the values given by ASME Section II-D are sometimes higher than the corresponding values provided in the original EN specification**.

- **PED**: three possibilities are mentioned:

  1) use of **"harmonized" material standards** (that is, EN material standards which have been recognized to be in full compliance with the Directive, as provided in a specific list issued by the European Commission).

  2) Use of materials already examined with a procedure called **"European Material Approval"**.

  3) Use of other materials for which the material manufacturer has supplied a **"Particular Material Appraisal"**, that is, for which he has guaranteed in a written certificate the values (generally hot tensile characteristics or low temperature impact values) required by the PED but not contained in the original specification. Note that **for all the above 3 cases the PED requirement is the guarantee of the material manufacturer about the values used in design.** Only with a PMA ASME/ASTM materials (for which these characteristics are missing) may be used in the context of the Directive

- **EN 13445**: A list of harmonized material standard is given in **EN 13445.2** for **steels**, in **EN 13445.6** for **spheroidal cast iron**, in **EN 13445.8** for **Aluminium alloys** and in **EN 13445.10** for **Nickel alloys.**

Validity of the tensile characteristics of materials given by ASME II-D

Note b) to table U: "*The tabulated values of tensile strength are those which the Committee believes are suitable for use in design calculations. At temperatures above room temperature, the values of tensile strength tend toward an average or expected value which may be as much as 10% above the tensile strength trend curve adjusted to the minimum specified room temperature tensile strength. The tensile strength values do not correspond exactly to "average" as this term is applied to a statistical treatment of a homogeneous set of data. Neither the ASME Material Specifications nor the rules of Sections I, III, or VIII require elevated temperature testing for tensile strengths of production material for use in Code components. It is not intended that results of such tests, if performed, be compared with these tabulated tensile strength values for ASME Code acceptance/rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means should be considered.*"

Note b) to table Y-1: "*The tabulated values of yield strength are those which the Committee believes are suitable for use in design calculations. At temperatures above room temperature, the yield strength values correspond to the yield strength trend curve adjusted to the minimum specified room temperature yield strength. The yield strength values do not correspond exactly to "minimum" or "average" as these terms are applied to a statistical treatment of a homogeneous set of data. Neither the ASME Material Specifications nor the rules of Section I, Section III, or Section VIII require elevated temperature testing for yield strengths of production material for use in Code components. It is not intended that results of such tests, if performed, be compared with these tabulated yield strength values for ASME Code acceptance/ rejection purposes for materials. If some elevated temperature test results on production material appear lower than the tabulated values by a large amount (more than the typical variability of material and suggesting the possibility of some error), further investigation by retest or other means should be considered.*"

Materials: requirements of the **P**ressure **E**quipment **D**irective

4.2 The pressure equipment manufacturer shall:

(a) define in an appropriate manner the values necessary for the design calculations referred to in point 2.2.3 and the essential characteristics of the materials and their treatment referred to in point 4.1;

(b) provide in his technical documentation elements relating to compliance with the materials specifications of this Directive in one of the following forms:

- *by using **materials which comply with harmonized standards**,*
- *by using **materials covered by a European approval of pressure equipment materials** in accordance with Article 15,*
- *by a **particular material appraisal**;*

(c) for pressure equipment in categories III and IV, a specific assessment of the particular material appraisal shall be performed by the notified body in charge of conformity assessment procedures for the pressure equipment.

*4.3 **The equipment manufacturer shall take appropriate measures to ensure that the material used conforms with the required specification. In particular, documentation prepared by the material manufacturer affirming compliance with a specification shall be obtained for all materials.***

For the main pressure-bearing parts of equipment in categories II, III and IV, this shall take the form of a certificate of specific product control.

Where a material manufacturer has an appropriate quality-assurance system, certified by a competent body established within the Union and having undergone a specific assessment for materials, certificates issued by the manufacturer are presumed to certify conformity with the relevant requirements of this point.

PARTICULAR MATERIAL APPRAISAL REPORT

Identification data

Vessel manufacturer: complete address		....	
Applicable construction standard		**EN 13445-3 Ed. 2014 Issue 4**	
Material specification	**ASTM/SA 516 gr 70**	Material standard	**ASTM/ASME II A Ed.2017**
Product form	**Plate**	Delivery condition	**Normalized, killed and produced to fine grain practice**
Welding group, if applicable (SAC, CR ISO 15608, etc.)		**P-No.1/Group No.2**	

PART I – Particular Material Appraisal (PMA)

Mechanical and technological properties for Design and Construction

All chemical, mechanical and technological characteristics and the specific limitations to use are the ones provided by the a.m. specifications/standards	Yes ☒	No ☐ (See characteristics in attachment 1)

Essential Safety Requirements *(specified by the manufacturer in his risk analysis)*

	Properties	Ref. Annex I PED	Compliance with the requirements		PED requirements
	Tracing	par. 4.1(a) / 7.5	✓		Procedure/Certif. identification/Stamping
	Characteristics	par. 4.1 (a) / 7.5	$Re_{0.2\%/20}$= 262 MPa $Re_{0.2\%/TD}$= 243 MPa $Rm_{/20}$= 483 MPa $Rm_{/TD}$= 483 MPa $E_{/TD}$= 199066 MPa		See relevant ASME/ASTM specification
	Ductility	par. 4.1 (a) / 7.5	A%min = 21%		A% ≥ 14%
	Toughness	par. 4.1 (a)	☐ Tmin≥20°C	Impact test ISO V (at T_{min} = 20°C)	≥ 27 J @ T≤MDMT
			☒ Tmin<20°C	Impact test ISO V (at T_{min} = -15°C)	≥ 27 J @ T≤MDMT
	Chemical resistance	par. 4.1 (b)	✓ An adequate corrosion allowance has been foreseen		Sufficient chemical resistance
	Aging properties	par. 4.1 (c)	✓		Not significant
	Workability	par. 4.1 (d)	✓		Suitable for processing procedures and treatments
	Weldability	par. 4.1 (d) / (e)	✓ See WPS-PQR		Compatible with all other adjoining materials
	Mechanical properties	par. 4.2 (a) / 7.1.2	✓ See calculation report		Calculation according to EN 13445-3
	Material certificate & Quality system	par. 4.3	✓ See material list in Drawing 90-RC-B-70365		Compliance with the material specification; certification according to EN 10204 type 3.1 (or 3.2 if the material manufacturer does not have an ISO 9000 certificate)

Deviations (if present) from the minimum required values specified by par.7, Annex I of PED Directive:
(specify the document certifying the equivalent safety level)..

PART II – Specific evaluation for the intended use

Vessel/component type and relevant operating conditions

Vessel/Component type	**Horizontal tank**	Drawing N° & Serial N°	**Dwg. .... SN. ....**	
Brief description and operation	**The vessel is a tank for hydrocarbons**			
Type of component object of the PMA	**Plate**			
Thickness	**See construction drawings**			
Allowable working Temperatures [°C]	Maximum (DT) **80**		Minimum (MDMT)	**-5**
Fluid content (or mixture of fluids)	**Hydrocarbons**			
Special operating conditions (if any)	**N.A.**			
Other conditions (pressure, wear, erosion, corrosion, heat treatment, etc.)	**Design Pressure:** 34 barg @ 80°C / F.V. @ 80 °C **Corrosion:** 3 mm (internal) **Heat Treatment:** Yes			

Note:

The material specified above is in compliance with the Essential Safety Requirements of the PED Directive and is suitable for the intended use and for the construction of the appliance in question.

Rev.	Date	Description	Issued	Checked	Approved	No.Bo. Stamp
0	26/01/2018	First Issue				

Nominal Design Stresses (= Allowable Stresses) for steels below the creep range according to different Pressure Vessel standards

	Carbon and Low-Alloy Steels	Austenitic Stainless Steels
ASME Section VIII div.1	$\min\left(\frac{R_m}{3{,}5}, \frac{R_t}{3{,}5}, \frac{R_{p\,0{,}2/t}}{1{,}5}\right)$	$\min\left(\frac{R_m}{3{,}5}, \frac{R_t}{3{,}5}, \frac{R_{p0{,}2}}{1{,}5}, 0.9R_{p0{,}2/t}\right)$ (2)
ASME Section VIII div.2 Class 1	$\min\left(\frac{R_m}{3}, \frac{R_{p0{,}2/t}}{1{,}5}\right)$	$\min\left(\frac{R_m}{3}, \frac{R_{p0{,}2}}{1{,}5}, 0{,}9R_{p0{,}2/t}\right)$ (2)
ASME Section VIII div.2 Class 2	$\min\left(\frac{R_m}{2{,}4}, \frac{R_{p\,0{,}2/t}}{1{,}5}\right)$	$\min\left(\frac{R_m}{2{,}4}, \frac{R_{p0{,}2}}{1{,}5}, 0.9R_{p0{,}2/t}\right)$ (2)
EN 13445.3 , CODAP (France) and VSR (Italy)	$\min\left(\frac{R_m}{2{,}4}, \frac{R_{p0{,}2/t}}{1{,}5}\right)$ (3) (4)	$\max\left[\frac{R_{p1/t}}{1{,}5}, \min\left(\frac{R_t}{3}, \frac{R_{p1/t}}{1{,}2}\right)\right]$ (1)
AD 2000 (Germany)	$\frac{R_{p0{,}2/t}}{1{,}5}$	$\frac{R_{p1/t}}{1{,}5}$
PD5500 (United Kingdom)	$\min\left(\frac{R_m}{2{,}35}, \frac{R_{p0{,}2/t}}{1{,}5}\right)$	(5) $\min\left(\frac{R_m}{2{,}5}, \frac{R_{p1/t}}{1{,}35}\right)$

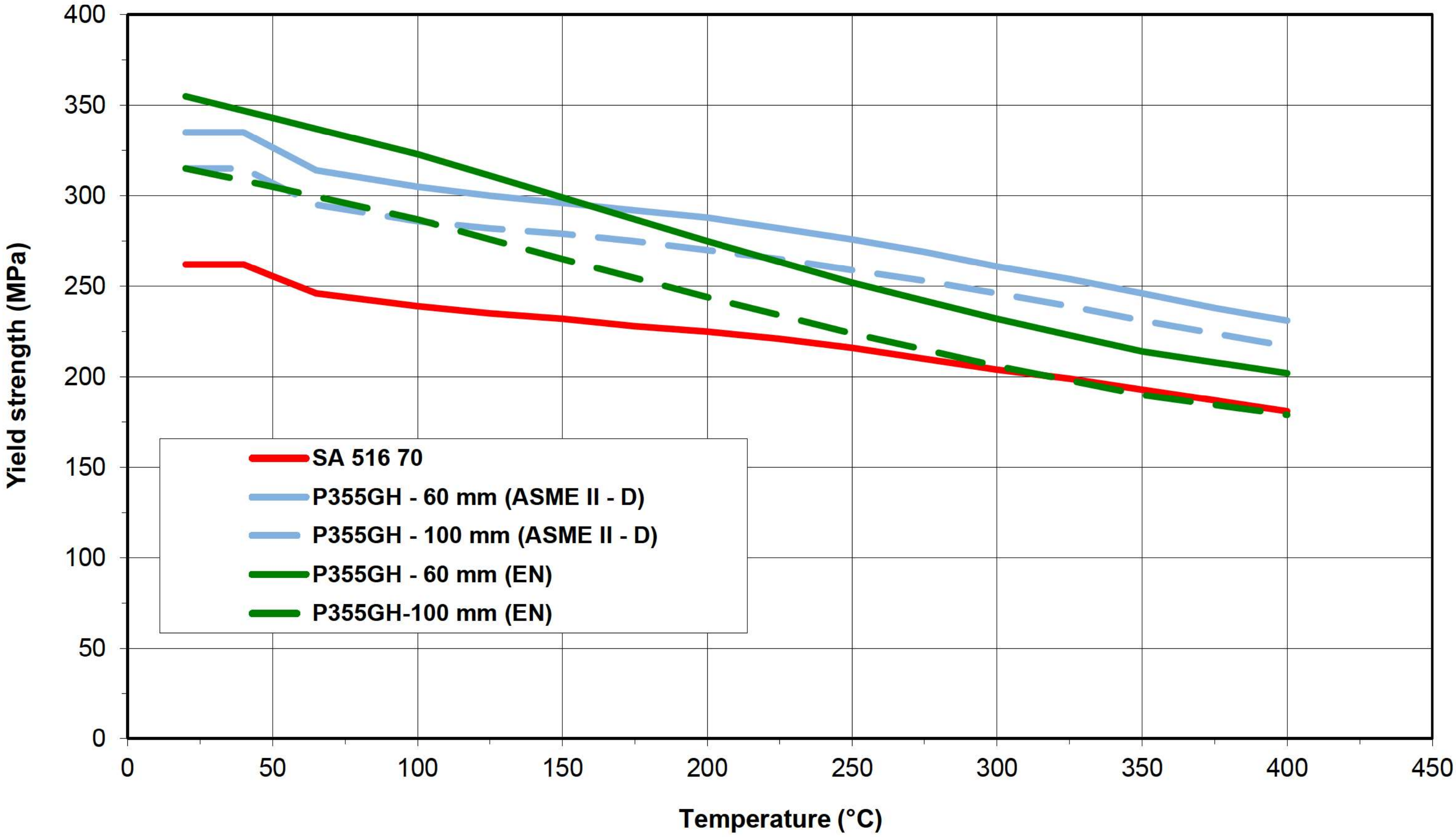
(1) For A ≥ 35%; for30≤ A <35% use $R_{p1/t}/1{,}5$
(2) For components where permanent strains are not acceptable use the same nominal design stresses of Carbon and Low-Alloy steels
(3) For EN 13 445.3: safety factor on room temperature tensile strength reduced to 1,875 with particular additional safety measures.
(4) For VSR: safety factor on room temperature tensile strength reduced to 2,0 with particular additional safety measures.
(5) At 150°C and above. At 50°C the safety factor on $R_{p1/t}$ is 1 ,5 (linear interpolation of nominal design stresses between 50°C and 150°C).

Nominal Design Stresses (= Allowable Stresses) for steels in the creep range according to different Pressure Vessel standards (f_{nc}= stress below the creep range)

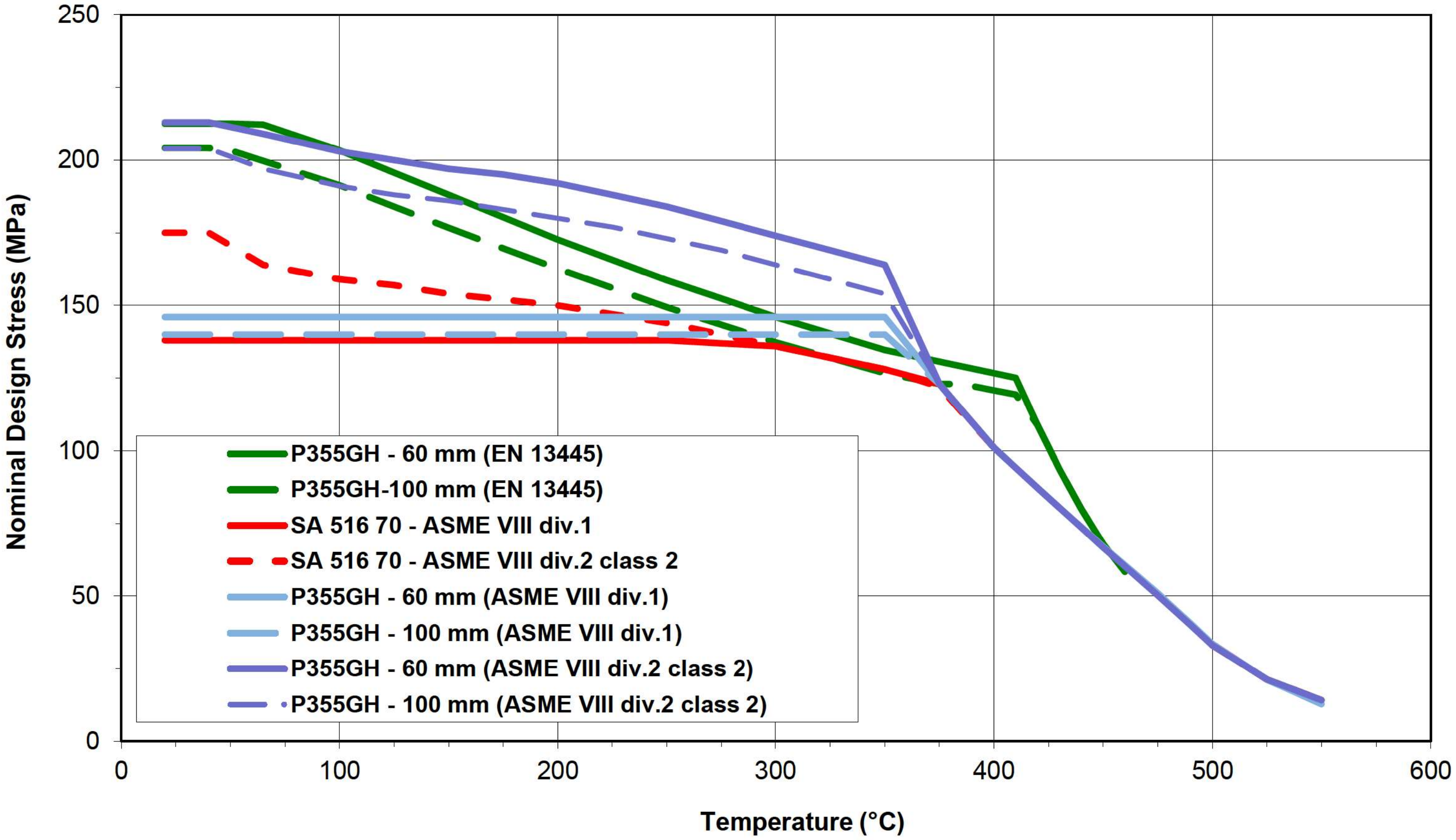
	Allowable Stresses at 100.000 hours	Allowable Stresses at 200.000 hours
ASME Section VIII div.1 and div.2	$\min\left(f_{nc}, 0.67\sigma_{R/T/100000}, \sigma_{0,01/T/1000}, 0.8\sigma_{RMIN/T/100000}\right)$	—
EN 13445.3	$\min\left(f_{nc}, \frac{\sigma_{R/T/100000}}{1.25}\right)$ (1)	$\min\left(f_{nc}, \frac{\sigma_{R/T/200000}}{1.25}\right)$ (1)
CODAP 2005	$\min\left(f_{nc}, \frac{\sigma_{R/T/100000}}{1.6}, \sigma_{1/T/100000}\right)$	$\min\left(f_{nc}, \frac{\sigma_{R/T/200000}}{1.6}, \sigma_{1/T/200000}\right)$
AD 2000	$\min\left(f_{nc}, \frac{\sigma_{R/T/100000}}{1,5}\right)$	$\min\left(f_{nc}, \frac{\sigma_{R/T/200000}}{1,25}, \frac{\sigma_{R/T/100000}}{1,5}\right)$
PD 5500	$\min\left(f_{nc}, \frac{\sigma_{R/T/100000}}{1,3}\right)$	$\min\left(f_{nc}, \frac{\sigma_{R/T/200000}}{1,3}\right)$
VSR	$\min\left(f_{nc}, \frac{\sigma_{R/T/100000}}{1,5}\right)$	$\min\left(f_{nc}, \frac{\sigma_{R/T/200000}}{1,25}, \frac{\sigma_{R/T/100000}}{1,5}\right)$

(1) For vessels monitored in service ; for vessels not monitored in service, the coefficient 1,25 is increased to1,5, however the nominal design stress cannot be greater of $\sigma_{1/T/XXXXX}$

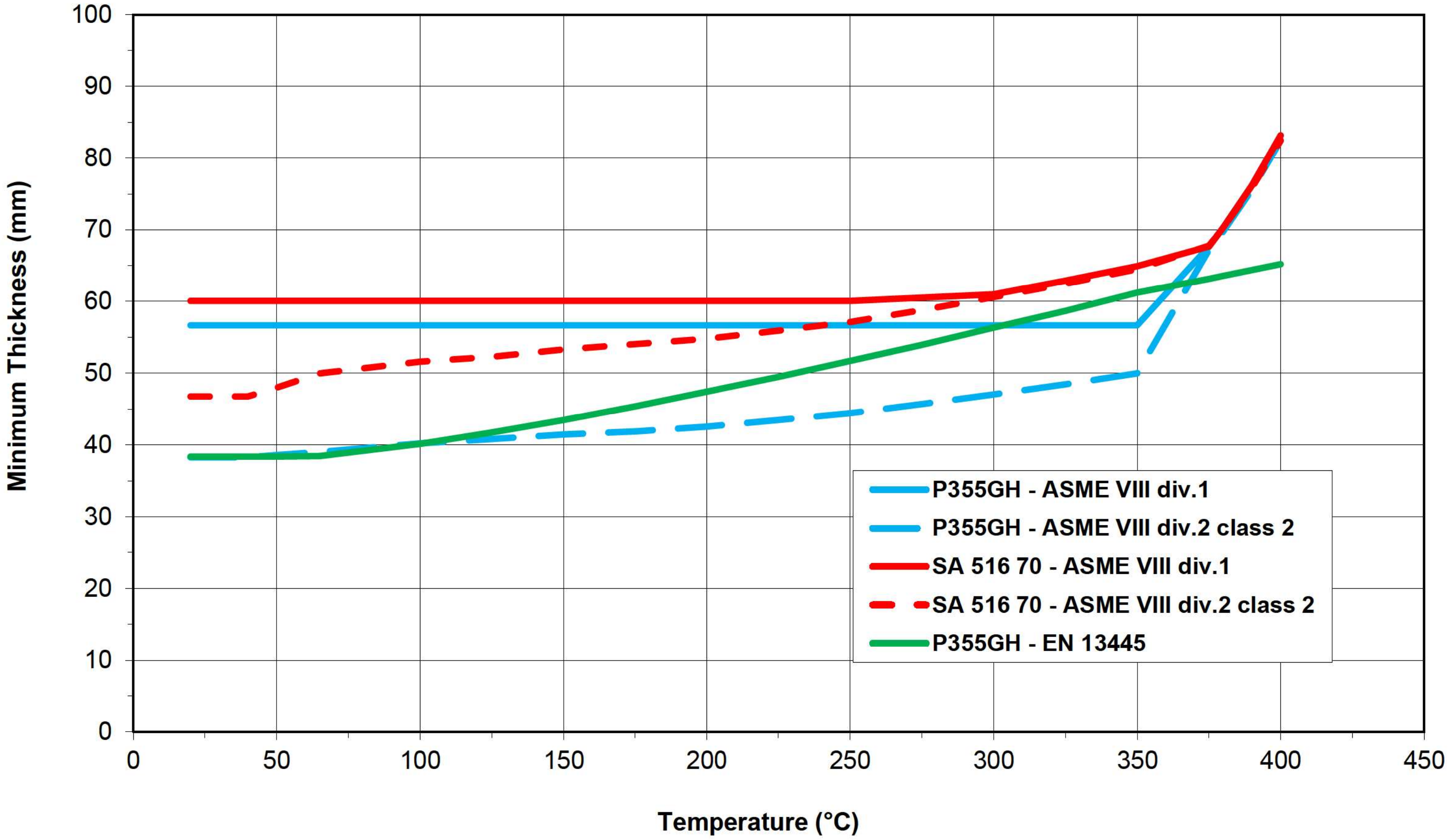
American vs. European Carbon Steel materials: values of $R_{p0,2t}$ for SA 516 70 and P355 GH (according to EN 10028.2 and to ASME section II – D)



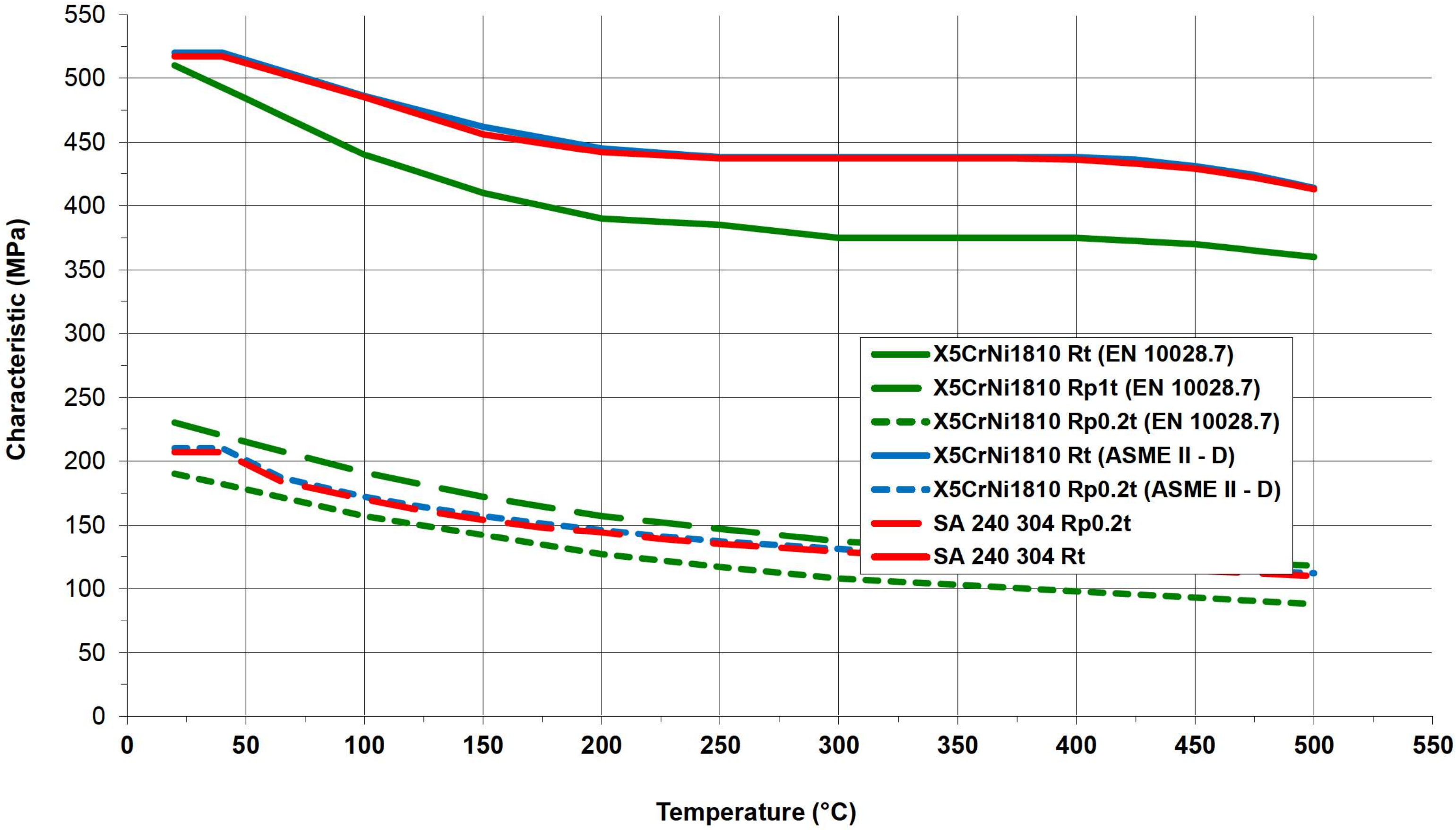
Nominal Design Stresses for Carbon Steel materials SA 516 70 and P355GH (according to EN 10028.2 and to ASME VIII - Creep values based on a lifetime of 100000 hours)



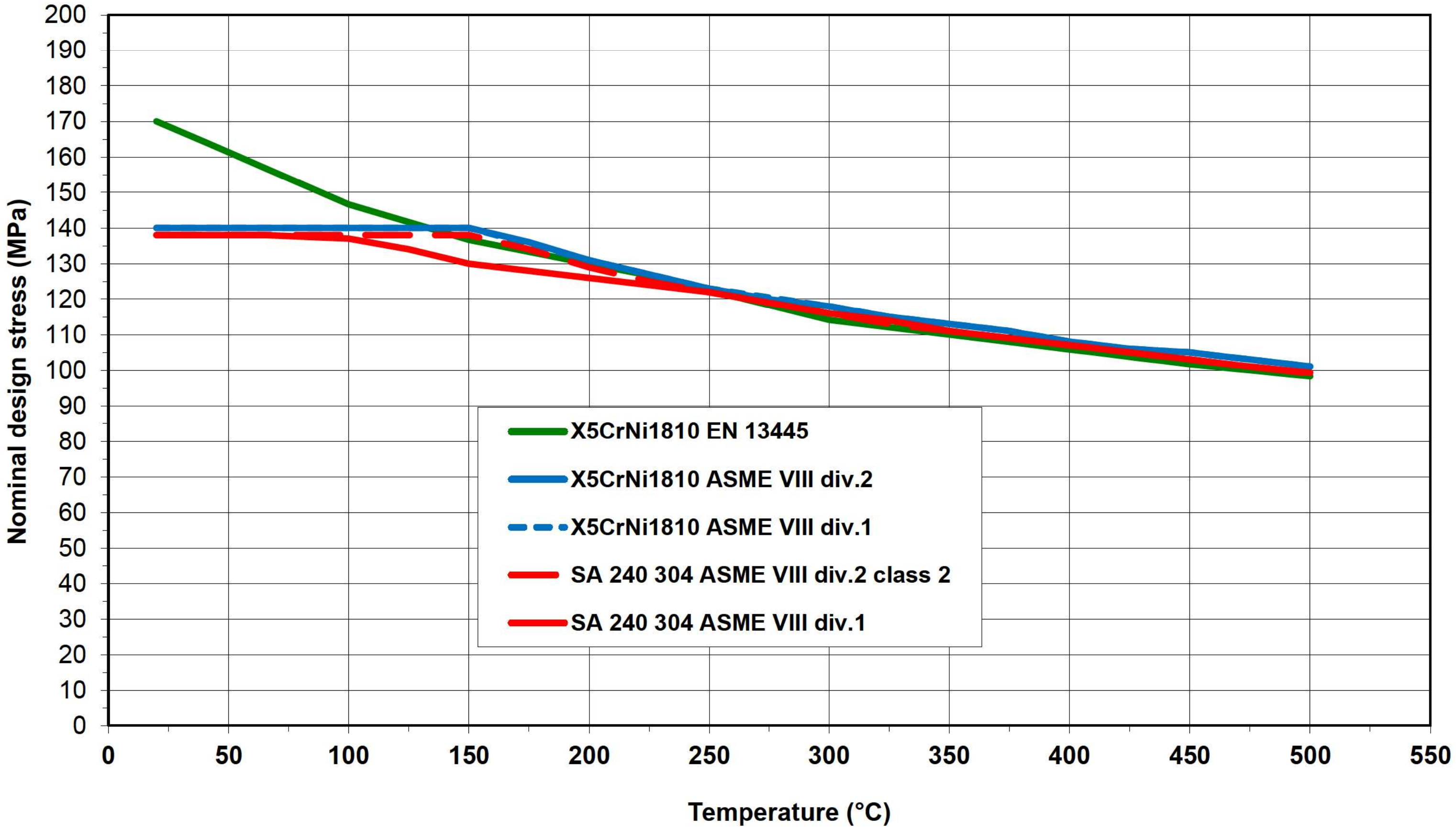
Minimum thickness of a cylindrical shell (ID=2000 mm, PS=80 bar) made of SA 516 70 and P355GH (according to EN 10028.2 and to ASME VIII - Creep values based on a lifetime of 100000 hours)



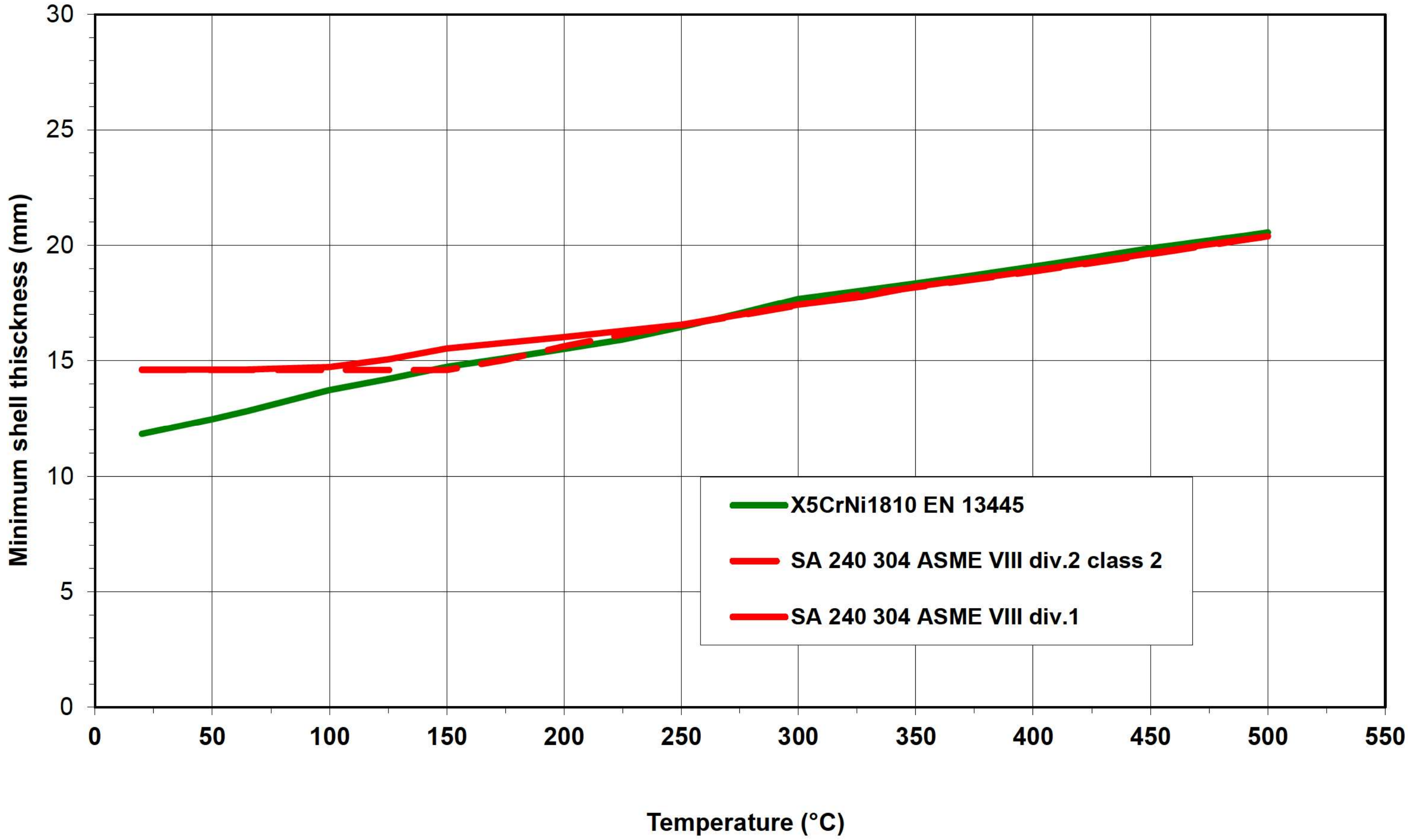
Tensile Characteristics of Austenitic Stainless Steels SA 240 304 and X5CrNi1810 (according to ASME sect.II part D and to EN 10028.7)



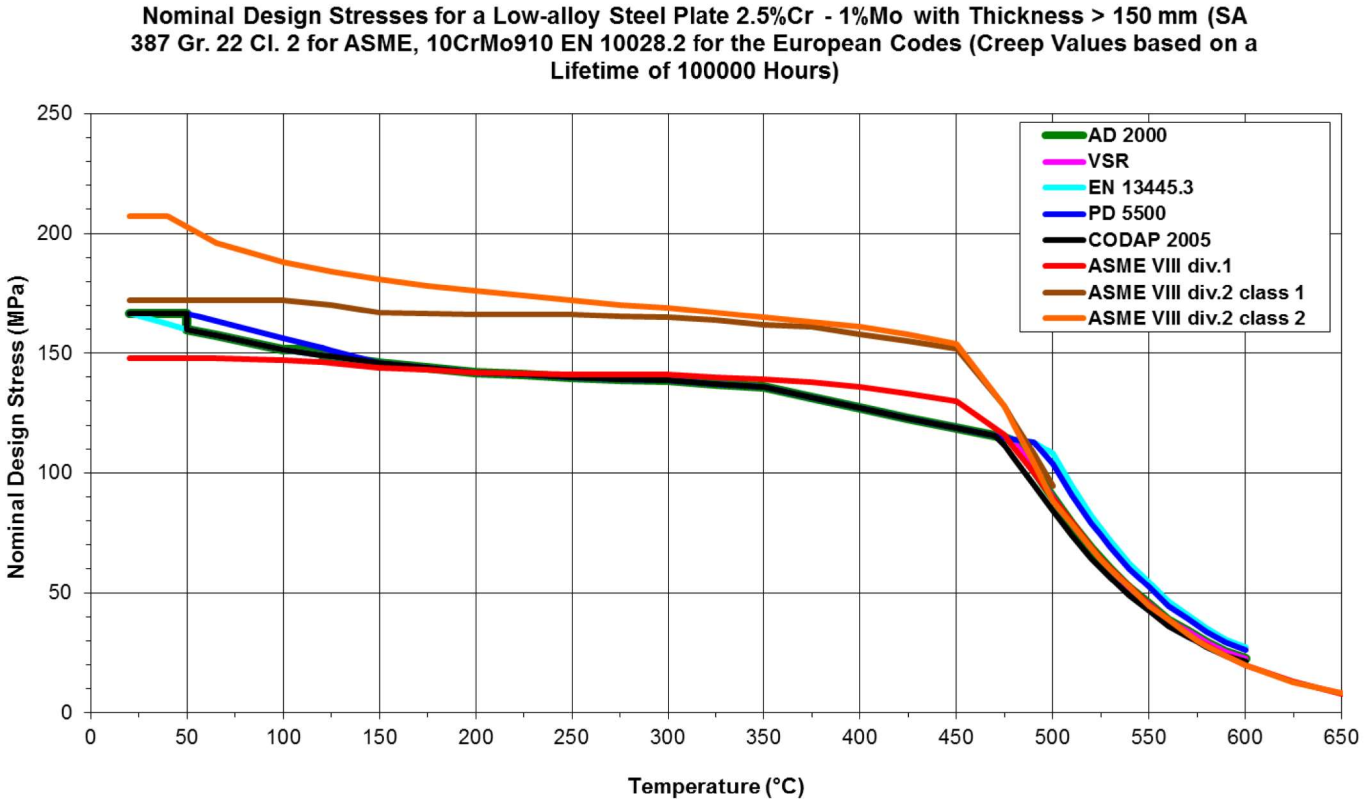
Nominal Design Stresses of Austenitic Stainless Steels SA 240 304 and X5CrNi1810 EN 10028.7 according to ASME sect.VIII div.1, ASME VIII div.2 and EN 13445)



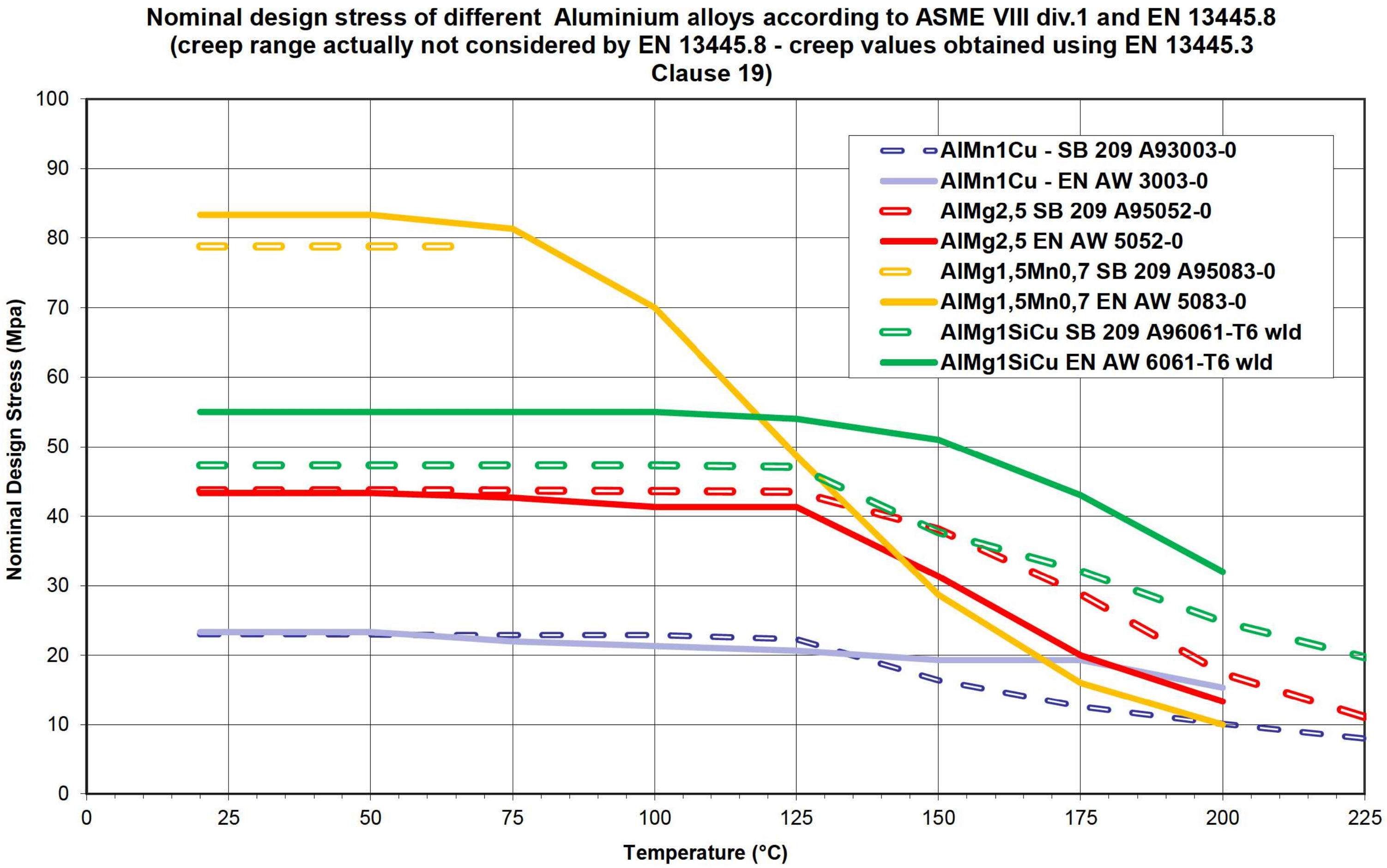
Minimum thickness of a cylindrical shell (ID=2000 mm, PS=20 bar) made of austenitic SS (SA 240 304 for ASME, X5CrNi1810 EN 10028.7 for EN) according to ASME sect.VIII div.1, ASME VIII div.2 and EN 13445



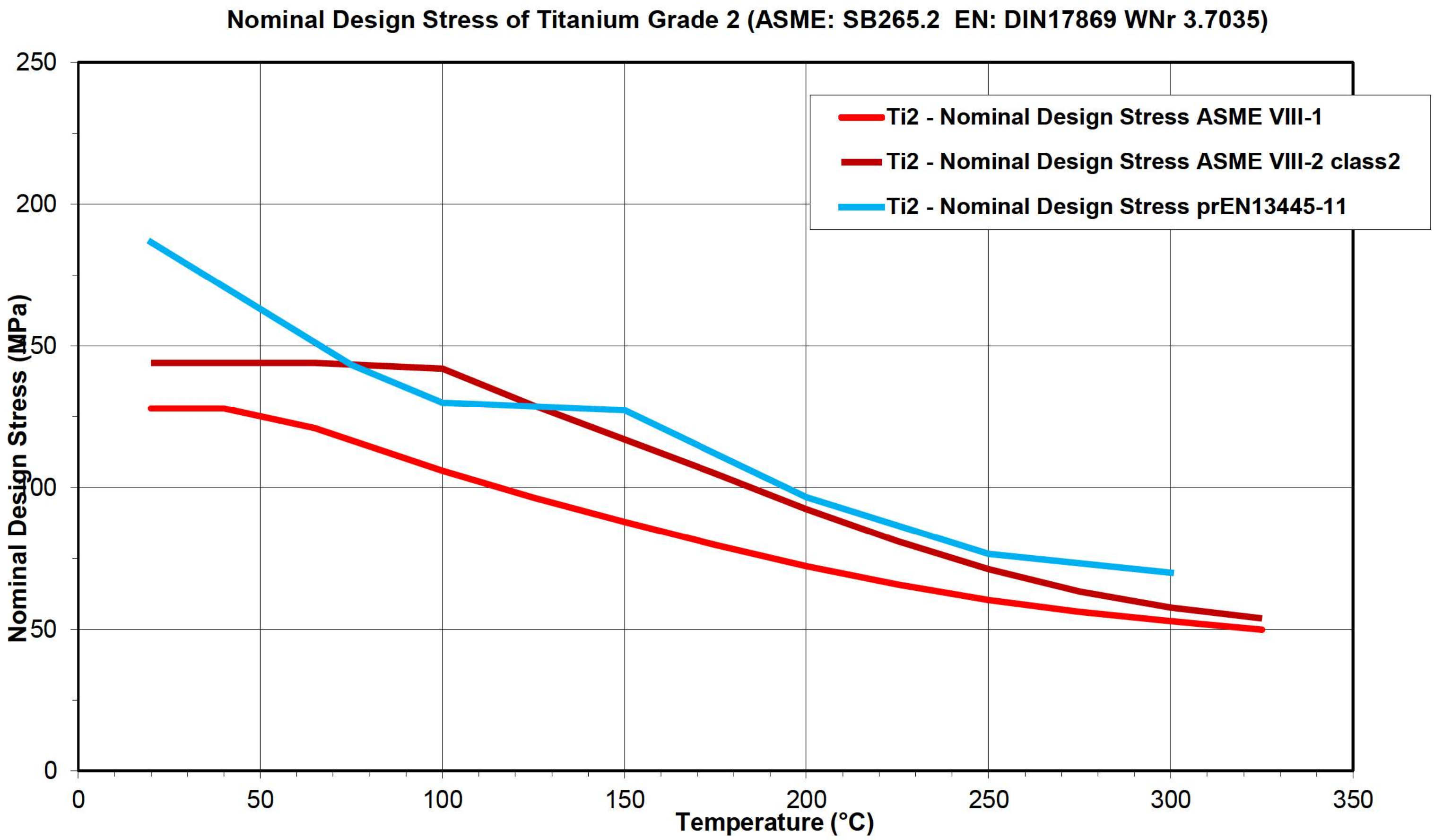
Nominal Design Stresses for a Low-alloy Steel plate 2.5%Cr - 1%Mo with thickness > 150 mm (SA 387 Gr. 22 Cl. 2 for ASME, 10CrMo910 EN 10028.2 for the European standards (Creep values based on a lifetime of 100000 hours)



Nominal design stress of different Aluminium alloys according to ASME VIII div. 1 and EN 13445.8



Nominal design stresses of Titanium gr.2 according to ASME VIII and prEN 13445.11



Formulae for fiber elongation of dished ends

ASME VIII division 1:

$$s = \frac{75e}{r + \frac{e}{2}} \qquad (1)$$

Note: in the other standards this formula is recommended for spheres or spherical segments only

ASME VIII division 2 and EN 13445.4:

$$s = 100 \ln\left(\frac{D_b}{D}\right) \qquad (2)$$

Note: D_b is the diameter of the "blank plate", that is the diameter of the flat plate before forming. D may be either the average or the inside diameter. Since $D_b \approx$ 1,21-1,23 D, the result is generally around 20%

Need for heat treatment of cold formed domed ends with high fibre elongation

- Using formula (1) of preceding slide, domed ends with small thicknesses will have low fibre elongations, however **with formula (2) the fibre elongation becomes much higher (≈ 20% in all cases) and regardless of the thickness**. Formula (2) gives a better picture of the real material behaviour, considering that the material which before forming was on the circumference of diameter D_b, after forming will find itself on the circumference of diameter *D (Db* ≈ 1,21-1,23 *D)*.

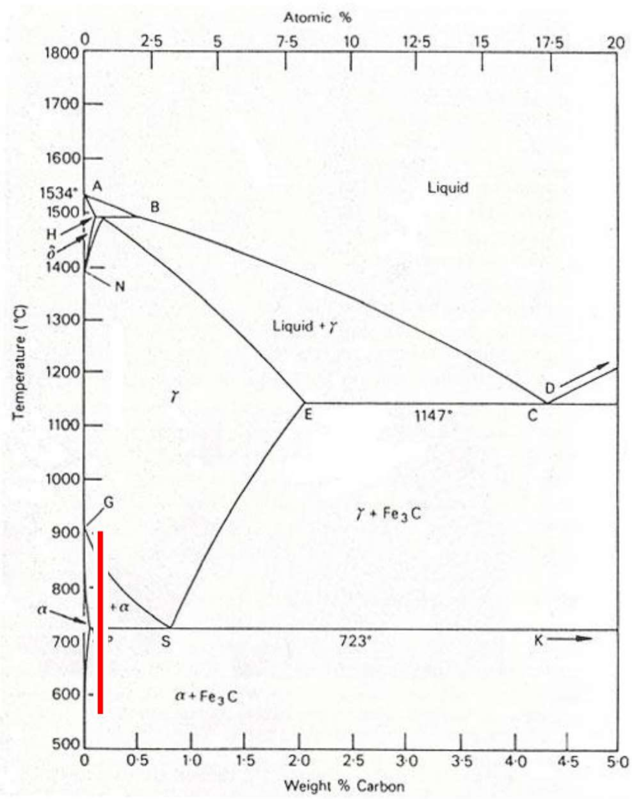
- Thick domed ends are generally hot formed, while thin domed ends are cold formed either by stamping or by spinning. **Cold forming with high fibre elongation will always cause a change in material properties** (generally speaking an increase in tensile characteristics and a decrease in the elongation at rupture). Original material properties can be restored with a suitable **heat treatment.**

- However the situation of ends made of Carbon and Low-alloy steels is different from the one of ends made of Austenitic Stainless steels: in **Carbon and Low-alloy** hot forming at around 900°C with subsequent cooling in air (= **Normalization**) will cause a **phase change**, that is a transition from a specific crystalline structure (***Fe γ* = Austenite**) stable at high temperatures to another one (***Fe α* = Ferrite**), stable at lower temperatures. In the phase change **the material will lose the memory of any important deformation due to a possible preceding cold forming**, and the original characteristics will be restored. The treatment may be different depending on the Cr content, because with more Cr instead of the Ferrite we can get a much harder phase called **Martensite**, therefore a further treatment at 550°C-700°C (**Tempering**) may be necessary.

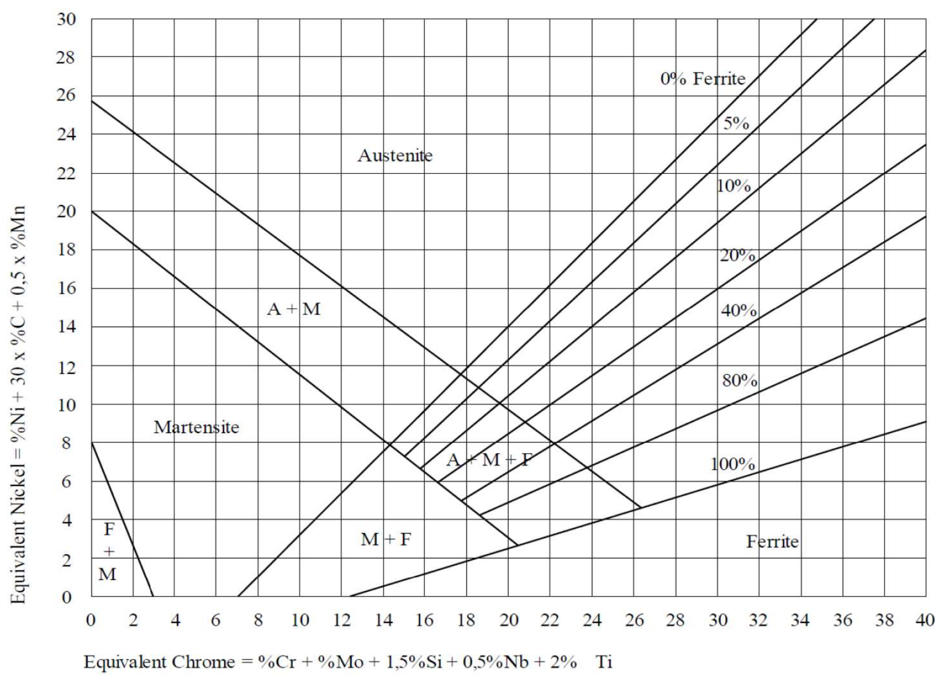
- In Austenitic steels the presence of Cr and Ni will cause a change in the diagram, so that ***Fe γ* remains stable up to room temperature, with a very limited amount of material transformed into *Fe α*** (which may be **Ferrite** or even **Martensite** – see Schäffler's diagram). **This amount tends to increase during cold forming**, thus giving raise to much harder structures, which can only be eliminated with a **solution heat treatment** (heating up to 1100-1200°C followed by rapid cooling in water). This kind of treatment may cause **sensible distortions**, particularly for thin ends of large dimensions.

- There are **important differences** among the different standards, due either to the **formulae** or to the **allowable fibre elongation limits**: therefore a **careful check of the prescriptions of the standard** is always needed, in order to avoid (particularly in the case of Austenitic steels) unnecessary heat treatments.

Carbon-Iron equilibrium diagram
(red line = normalization heat treatment for CS)



Schäffler's diagram



Maximum fibre elongations given by ASME VIII and EN 13445 in order to avoid heat treatment of cold formed domed ends

	Carbon Steel Ends	Low Alloy Steel Ends	Austenitic SS Ends
ASME VIII division 1 (2)	40% (1)	5%	15-20% (3)
ASME VIII division 2 (2)	40% (1)	5%	15-20% (3)
EN 13445	5% (4)	5%	5% (5)

(1) For P-No 1, groups 1 and 2 only, provided none of the following situations applies (in which case the value is reduced to 5%):
- Vessels in Lethal Service (Division 1 only)
- Minimum Design Metal Temperature involves impact testing
- Reduction in thickness greater than 10%
- Forming temperature between 120°C and 480°C

(2) Note that the formula of the fiber elongation in div. 2 is much more conservative than the formula of div.1!

(3) According to the Steel Quality (20% for 304 and 316, 15% for 321 and 347). All values reduced to 10% for design temperature above 675°C.

(4) For CS with thickness ≤ 8 mm, skirt height ≤ 40 mm, design temperature between -10°C and 120°C, no heat treatment is necessary

(5) No heat treatment necessary in the following situations:
- Residual elongation at fracture after forming ≥ 15%
- Elongation at fracture of material before forming (from material certificate) ≥ 40%, thickness ≤ 15 mm, design temperature ≥ -196°C
- Elongation at fracture of material before forming (from material certificate) ≥ 45%, thickness > 15 mm, design temperature ≥ -196°C
- Elongation at fracture of material before forming (from material certificate) ≥ 50%

Testing groups for steel pressure vessels (reprinted from Table 6.6.1-1 of EN 13445.5). This table is substantially equal to table 7.1 of ASME Section VIII division 2, except for category 4 (vessels without NDT), not permitted by division 2

Table 6.6.1-1 — Testing groups for steel pressure vessels

Requirements	Testing group [a]						
	1		2		3		4 [b,j]
	1a	1b	2a	2b	3a	3b	
Permitted materials [g]	1 to 10	1.1, 1.2, 8.1	8.2, 9.1, 9.2, 9.3, 10	1.1, 1.2, 8.1	8.2, 9.1, 9.2, 10	1.1, 1.2, 8.1	1.1, 8.1
Extent of NDT for governing welded joints [e,h]	100 %	100 %	100 % - 10% [d]	100 % - 10 % [d]	25 %	10 %	0 % [k]
NDT of other welds	Defined for each type of weld in Table 6.6.2-1						
Joint coefficient	1	1	1	1	0,85	0,85	0,7
Maximum thickness for which specific materials are permitted	Unlimited [f]	Unlimited [f]	30 mm for groups 9.1, 9.2 16 mm for groups 9.3, 8.2[i], 10	50 mm for groups 1.1, 8.1 35 mm for group 1.2	30 mm for groups 9.2, 9.1 16 mm for groups 8.2, 10	50 mm for groups 1.1, 8.1 30 mm for group 1.2	16 mm for groups 1.1, 8.1
Welding process	Unlimited [f]	Unlimited [f]	Fully mechanised welding only [c]		Unlimited [f]	Unlimited [f]	Unlimited [f]
Service temperature range	Unlimited [f]	Unlimited [f]	Unlimited [f]	Unlimited [f]	Unlimited [f]		Limited to (-10 to +300) °C for group 1.1, (-105 to +300) °C for group 8.1

Notes to Table 6.6.1-1 of EN 13445.5

[a] All testing groups shall require 100 % visual inspection
[b] Testing group 4 shall be applicable only for:
- Group 2 fluids; and
- $P_S \leq 20$ bar; and
- $P_S V \leq 20\,000$ bar·L above 100 °C; or $P_S V \leq 50\,000$ bar·L if temperature is equal or less than 100 °C; and
- maximum number of full pressure cycles less than 500.

If this testing group 4 is chosen, then a higher pressure test (see clause 10) and a lower nominal design stress (See EN 13445-3:2014) shall be used
[c] Fully mechanised and/or automatic welding process (See EN ISO 14732:2013).
[d] First figure: initially, second figure: after satisfactory experience. For definition of “satisfactory experience", see 6.6.1.2.4
[e] Testing details are given in Table 6.6.2-1
[f] Unlimited means no additional restriction due to testing. The limitations mentioned in the table are limitations imposed by testing. Other limitations given in the various clauses of the standard (such as design, or material limitations, etc.) shall also be taken into account.
[g] See EN 13445-2:2014 for permitted materials.
[h] The percentage relates to the percentage of welds of each individual vessel
[i] 30 mm for group 8.2 material is allowed if delta ferrite containing welding consumables are used for depositing filling passes up to but not including the capping run.
[j] Limited to single compartment vessels and single material group.
[k] except for assembly of a conical shell to a cylindrical shell without knuckle (large end of the cone) for which MT or PT shall be 100 %

Criteria to establish the exemption from Fatigue Analysis (EN 13445.3)

$$n_{eq} = \Sigma \, n_i \cdot \left(\frac{\Delta P_i}{P_{max}} \right)^3 \leq 500$$

(Valid for pressure fluctuations only)

Criteria to establish the exemption from Fatigue Analysis (ASME VIII Div.2)

- Two different groups of conditions may be used (**screening criteria**)
- For each one of the groups all the conditions must be verified at the same time
- To apply the screening criteria it is necessary to know all the details of the pressure and temperature changes in the vessel
- The temperature distribution and the relevant changes must be known at every point of the vessel
- Many times this distribution and relevant changes are not known in the detail required by the rules concerning the screening criteria

Hydrostatic test pressures required by the main P.V. standards

	Test Pressure	Components to be considered	Ratio f_0 / f	Notes
ASME VIII division 1	$1{,}3 \frac{f_0}{f} MAWP$	All, except Bolting	smaller	(1)(4)
ASME VIII division 2	$\max\left(1{,}43\, MAWP\,,\quad 1{,}25 \frac{f_0}{f} MAWP\right)$	All, except Bolting	smaller	(1)
EN 13445	$\max\left(1{,}43\, P_S\,,\quad 1{,}25 \frac{f_0}{f} P_S\right)$	Main Components, including Bolting of Main Flanges	smaller	(3)
CODAP 2005	$\max\left(1{,}43\, P_S\,,\quad 1{,}25 \frac{f_0}{f} P_S\right)$	All	greater	(5)
PD 5500	$1{,}25 \frac{f_0}{f} \frac{e}{e-c} P_S$	Main Components subject to membrane stress	See note (6)	(6)
ISPESL	$\max\left(1{,}43\, P_S\,,\quad 1{,}25 \frac{f_0}{f} P_S\right)$	Main Components, including Bolting of Main Flanges	greater	(2)
AD 2000	$\max\left(1{,}43\, P_S\,,\quad 1{,}25 \frac{f_0}{f} P_S\right)$	All	smaller	

Notes:

(1) *MAWP* can be replaced by P_s.
(2) With joint efficiency 0,85 or 1, test pressure may be limited to the maximum allowable test pressure compatible with the weaker main component.
(3) The formula is valid for Testing Groups 1 to 3 only, a higher test pressure is required for testing group 4. For temperatures in the creep range, f may be replaced by f_{nc} (the nominal design stress for non-creep conditions).
(4) The stress ratio of bolting has to be considered only in the case that the bolt stress in test pressure condition would overcome 90% of the elastic limit.
(5) Test pressure may be limited to the maximum allowable test pressure compatible with the weaker main component.
(6) Symbols: e = thickness, c = corrosion allowance. If there are different test pressures for different main components. use greater value of test pressure if it is lower than $1{,}35\ P_s$; if greater value of test pressure is higher than $1{,}35\ P_s$, use smaller value of test pressure or $1{,}35\ P_s$, whichever is greater. For vessels subject to the PED, minimum test pressure shall be $1{,}43\ P_s$.

THANK YOU VERY MUCH FOR YOUR ATTENTION!