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Advance

Enhanced structural efficiency with duplex stainless steel in pressure vessels

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Abstract

The American ASME Section VIII is the most commonly used code for design and fabrication of pressure vessels. It consists of two divisions. Division 1 is a well-proven but also conservative design standard. Several types of duplex stainless steel (as well as austenitic) grades are covered by the material specification standard ASME Section II Part A: SA-240 or Code Cases, and can be applied according to ASME Section VIII Division 1. The higher strength of duplex grades can be utilized to reduce the shell thickness of a pressure vessel under certain conditions, and hence improve the structural efficiency compared to lower strength alloys such as austenitic stainless steel (e.g. type 316) or conventional pressure vessel (mild) steel. High alloy (high nitrogen) austenitic stainless steel may also be an interesting alternative to duplex grades with comparable allowable design stresses.

Nevertheless, more recently developed pressure vessel codes, with more advanced design criteria, such as the European standard EN 13445, the Chinese standard GB 150, or the alternative rules by division 2 of ASME Section VIII, allow even higher design stresses, and consequently higher weight and cost saving potentials. However, ASME Section VIII Division 2 permits fewer duplex grades than Division 1, and the Chinese standard GB 150 is only applicable to duplex type 2205 (S22053/ S22253) according to the material standard GB 24511. The European standard EN 13445 with the material standard 10028-7 has good coverage of duplex grades.

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1. Introduction

The inclusion of modern 22Cr duplex stainless steel (e.g. type 2205) in pressure vessel standards in the late 1970's made it possible to use duplex stainless steel in pressurized systems such as pulp digesters with a commercial break-through in the late 1980's, see Figure 1.

Figure 1. Kraft pulp digester (design pressure 15 bar at 200°C) in duplex type 2205 with shell thicknesses of 20-25 mm, which replaced a carbon steel vessel with shell thickness of 42 mm, i.e. weight savings of about 50%. In service 1989 [1].

The key benefits of using duplex stainless steel in pressure vessels are: the great combination of high strength, which potentially provides higher structural efficiency, i.e., enables thinner shell thicknesses compared to austenitic stainless steel (e.g. type 316) or mild steel, and higher durability (e.g. corrosion resistance) compared to conventional pressure vessel steel grades. Protective coatings can therefore often be excluded, which potentially reduces maintenance needs and increases service life. Moreover, by the development of modern nitrogen alloyed 22Cr duplex stainless steels their weldability were significantly improved as well, which is a crucial factor in the design and manufacturing of pressure vessels.
Thus, the beneficial properties of duplex stainless steel made it economically feasible to manufacture solid duplex vessels instead of the same in carbon steel with an austenitic stainless steel lining or with an advanced protective coating system.

The material cost per unit weight for a duplex stainless steel is several times higher than a pressure vessel steel, but with more efficient material utilization, utilizing higher strength, or by excluding any corrosion allowance the shell thickness can be reduced, which results in lower material consumption. Thinner gauges means less welding, and without coating application, the fabrication time of the vessel is reduced substantially, which generate savings in both time and money.

A peroxide reactor under construction is shown in Figure 2.

Figure 2. Hydrogen peroxide reactor in Forta LDX 2101 under construction, Smurfit Kappa, Piteå, Sweden. The reactor is 32 m high and 4 m in diameter

Thus, if we consider the total initial investment cost of a vessel, duplex can be cost competitive, especially for large vessels. However, the real advantage becomes clear when the total life cycle cost is calculated; where the cost of maintenance and production loss during maintenance shutdowns are taken into account, see Figure 3.

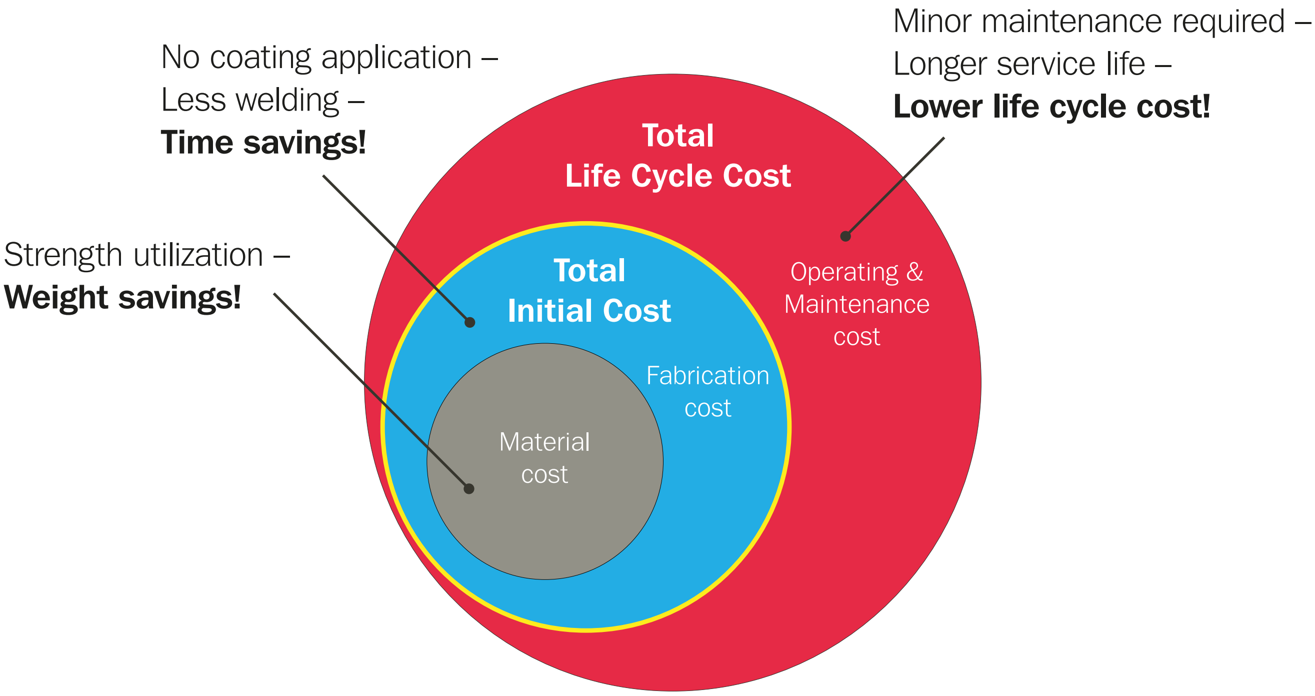


Figure 3. Different aspects of cost: materials vs. fabrication vs. life cycle cost.

2. Codes and standards for pressure vessels

ASME section VIII division 1 (VIII-1) is the most commonly used code worldwide for design and fabrication of pressure vessels [2]. The code is based on experience and using a traditional design-by-formula philosophy. More than ten different types of the duplex grades are permitted for use according to ASME VIII-1. These grades are listed in ASME Section II Part D (II-D) 'Properties' [3] together with material data such as yield and tensile strength, maximum allowable design stress at different temperatures, maximum use temperature, and with reference to applicable material specification, which for stainless steel is SA-240. This specification is included in ASME Section II Part A (II-A) 'Material specifications' [4].

In addition to the American ASME code, the European design standard for pressure vessels EN 13445 is also commonly used together with its affiliated material standard EN 10028-7, which currently includes five duplex grades (revision is pending and the next edition will include four additional duplex grades)[5][6]. EN 13445 fulfils the European pressure vessel directive (PED) and originates from several national pressure vessel design codes of the member states.

The design rules of the European standard EN 13445 is generally more advanced than ASME VIII-1, which results in higher strength utilization and structural efficiency when applied to high strength steel. To meet the development of the European standard, ASME updated their Section VIII Division 2 (VIII-2) 'Alternative rules' in 2007, which provided more engineered design rules and allowing higher design stresses [2]. However, ASME VIII-2 is applicable for fewer duplex grades than ASME VIII-1.

The regulation for stationary pressure vessels in China is given in TSG R0004-2009. The specific design rules are provided in the Chinese standard GB 150 [7], with its affiliated material specification standard GB 24511 [8]. Unfortunately, a very limited number of duplex grades are included in the latter, where only two versions of type 2205 (S22053/S22253) are of interest in comparison with ASME and EN. However, steel grades not listed in above standard can be approved by an assessment procedure specified in TSG R0004-2009.

2.1 ASME Section II and VIII

A selected number of duplex grades included in the material specification ASME SA-240 are listed with their chemical composition range in Table 1 together with some austenitic grades as references.

The localized corrosion resistance of the grades listed in Table 1 are indicated by both the pitting resistance equivalent (PRE), based on the chemical composition range for Cr, Mo and N in SA-240, and the critical pitting temperature (CPT), which are experimentally tested values according to ASTM G 150 [9]. The PRE value or better the CPT value can be used to rank the corrosion resistance of the grades starting from the low nickel, lean duplex grades

S32101 (comparable with the austenitic grade 316L) up to the super duplex grades S32760 and S32750 (comparable with the 6Mo austenitic grade S31254). Note that duplex type 2205 is available as both S31803 and S32205, where the alloying range for the latter is limited to the upper end considering Cr, Mo and N.

Table 1. Chemical compositions, %, PRE-numbers and CPT-values of selected duplex and austenitic stainless steels according to ASME II-A: SA-240.

UNS no.	Outokumpu steel names	Grade familiy[1]	C	Cr	Ni	Mo	N	Other	PRE[2]	CPT, ASTM G 150 (°C)
S32101	Forta LDX 2101	D	0.04	21.0–22.0	1.35–1.70	0.10–0.80	0.20–0.25	Mn	25–29	17±3
S32304	Forta DX 2304	D	0.03	21.5–24.5	3.0–5.5	0.05–0.60	0.05–0.20	–	22–30	24±3
S82441	Forta LDX 2404	D	0.03	23.0–25.0	3.0–4.5	1.00–2.00	0.20–0.30	–	30–36	43±3
S31803	Forta DX 2205	D	0.03	21.0–23.0	4.5–6.5	2.5–3.5	0.08–0.20	–	31–38	52±33
S32205	Forta DX 2205	D	0.03	22.0–23.0	4.5–6.5	3.0–3.5	0.14–0.20	–	34–38	52±33
S32760	Forta SDX 100	D	0.03	24.0–26.0	6.0–8.0	3.0–4.0	0.20–0.30	W	37–44	–
S32750	Forta SDX 2507	D	0.03	24.0–26.0	6.0–8.0	3.0–5.0	0.24–0.32	–	38–48	84±3
S31603	Supra 316L	A	0.02	16.0–18.0	10.0–14.0	2.0–3.0	–0.10	–	23–30	20±3
N08904	Ultra 904L	A	0.02	19.0–23.0	23.0–28.0	4.0–5.0	–0.10–	Cu	32–41	62±3
S31254	Ultra 254 SMO	A	0.02	19.5–20.5	17.5–18.5	6.0–6.5	0.18–0.25–	Cu	42–46	87±3
S32654	Ultra 654 SMO	A	0.02	24.0–25.0	21.0–23.0	7.0–8.0	0.45.0.55	Mn Cu	54–60	>90

1) D = Duplex, A = Austenitic.
2) PRE (Pitting Resistance Equivalent) = %Cr + 3.3x%Mo + 16x%N.
3) The material tested is EN 1.4462 in accordance with EN 10028-7: 21-23Cr, 2.5-3.5Mo and 0.10-0.22N.

Proof and tensile strength, fracture elongation and the allowable design stress values at room temperature (RT) based on design criteria for both ASME VIII-1 and VIII-2 are listed in Table 2. For new steel grades not yet included in SA-240 or when additional or extended design rules has been prepared for already included grades, so called Code Cases are published annually by ASME, which specify permitted use in accordance to applicable ASME code (Code Case for a specific steel grade is listed in Table 2).

Table 2. Mechanical data at RT (20°C) of selected duplex and austenitic grades according to ASME II-D or applicable Code Case.

ASTM UNS no.	Outokumpu steel names	$R_{p0.2}$ min MPa	R_m min MPa	A_{50} %	Allowable design stress, ASME VIII-1	Allowable design stress, ASME VIII-2	Material spec., ASME II-A SA 240	Code Case
S32101	Forta LDX 2101	450/530[1]	650/700[1]	30	186/200[1]	–	Yes	–
S32304	Forta DX 2304	400	600	25	172	250	Yes	–
S82441	Forta LDX 2404	480/540[2]	680/740[2]	25	194/211[2]	–	Yes	2780
S31803	Forta DX 2205	450	620	25	177	253	Yes	2727
S32205	Forta DX 2205	450	655	25	187	273	Yes	–
S32760	Forta SDX 100	550	750	25	214	–	Yes	–
S32750	Forta SDX 2507	550	795	15	228	333	Yes	2740
S31600	Supra 316	205	515	40	138	138	Yes	–
S31603	Supra 316L	170	485	40	115	115	Yes	–
N08904	Ultra 904L	220	490	35	140	140	Yes	2808
S31254	Ultra 254 SMO	310	655/690[3]	35	187/197[3]	187/197[3]	Yes	2808
S32654	Ultra 654 SMO	430	750	40	214	–	Yes	2195

1) First value corresponds to t > 5 mm, second value to t ≤ 5 mm.
2) First value corresponds to t ≥ 10 mm, second value to t < 10 mm.
3) First value corresponds to t > 5 mm, second value to t ≤ 5 mm.

2.2 EN 10028-7/EN 13445 and GB 24511/GB 150

Mechanical properties and maximum allowable stresses at RT of selected duplex and austenitic grades according to European and Chinese standards are listed in Table 3 and 4 respectively.

Table 3. **Mechanical properties at RT (20°C) of selected duplex and austenitic grades according to EN 10028-7 and maximum allowable design stresses at RT calculated according to EN 13445.**

EN no.	Outokumpu steel names	$R_{p0.2}$ min MPa	$R_{p1.0}$ min MPa	R_m min MPa	A_5 %	Allowable design stress, EN 13445	Material spec. EN 10028–7
1.4162	Forta LDX 2101	450	–	650	30	271[1]	No[1]
1.4362	Forta DX 2304	400	–	630	25	263	Yes
1.4662	Forta LDX 2404	480	–	680	25	283[2]	No[2]
1.4462	Forta DX 2205	460	–	640	25	267	Yes
1.4501	Forta SDX 100	530	–	730	25	304	Yes
1.4410	Forta SDX 2507	530	–	730	25	304	Yes
1.4401 / 1.4404	Supra 316/316L	220	260	520	45	173	Yes
1.4539	Ultra 904L	220	260	520	35	173	Yes
1.4547	Ultra 254 SMO	300	340	650	40	227	Yes
1.4652	Ultra 654 SMO	430	750	750	40	313[2]	No[2]

1) Approved material specification according to EAM-0045-01:2012/01 for t ≤ 10 mm. Particular material appraisal (PMA) route for t > 10 mm. Inclusion EN 10028-7 is pending.
2) Material specification approval through the PMA route. Inclusion EN 10028-7 is pending for EN 1.4662.

Table 4. **Mechanical properties at RT (20°C) of selected duplex and austenitic grades according to GB 24511 and maximum allowable design stress at RT calculated according to EN GB 150.**

GB no.	Conform to ASTM UNS	$R_{p0.2}$ min MPa	$R_{p1.0}$ min MPa	R_m min MPa	A_5 %	Allowable design stress, GB150	Material spec. GB 24511
S22253/ 022Cr22Ni5Mo3N	S31803	450	–	620	25	230	Yes
S22053/ 022Cr23Ni5Mo3N	S32205	450	–	620	25	230	Yes
S31603/ 022Cr17Ni12Mo2	S31603	180	260	490	40	120	Yes

3. Pressure vessel design

3.1 Design criteria for allowable stresses

The design criteria for maximum allowable design stresses in accordance with ASME VIII-1 and VIII-2 as well as EN 13445 and GB 150 are shown in Table 5. The allowable design stresses at room temperature included in Tables 2-4 are calculated based on these criteria.

3.2 Maximum allowable design stresses

Allowable design stresses for 22Cr duplex stainless steels (i.e. S32205, S31803, 1.4462 and S22053) according to ASME VIII-1 and VIII-2 , EN 13445 and GB 150 in comparison with the austenitic grades type 316/316L are depicted in Figure 4 as function of the design metal temperature. It is clearly visible that significantly higher design stresses are allowed for duplex stainless steels than the austenitic type 316 in the permitted temperature range considering all design standards.

Table 5. Design criteria for maximum allowable design stress. 'T' indicates design temperature and 'RT' room temperature.

	ASME VIII-1	ASME VIII-2	EN 13445	GB 150
Duplex	$\min\left[\frac{R_{p0.2}RT}{1.5};\frac{R_mRT}{3.5}\right]$ or $\min\left[\frac{R_{p0.2}T}{1.5};\frac{R_mT}{3.5}\right]$	$\min\left[\frac{R_{p0.2}RT}{1.5};\frac{R_mRT}{2.4}\right]$ or $\min\left[\frac{R_{p0.2}T}{1.5};\frac{R_mT}{2.4}\right]$	$\min\left[\frac{R_{p0.2}T}{1.5};\frac{R_mRT}{2.4}\right]$	$\min\left[\frac{R_{p0.2}RT}{1.5};\frac{R_mRT}{2.7}\right]$ or $\min\left[\frac{R_{p0.2}T}{1.5}\right]$
Austenitic A > 30%	$\min\left[\frac{R_{p0.2}RT}{1.5};\frac{R_mRT}{3.5}\right]$ or $\min\left[\frac{R_{p0.2}T}{1.1};\frac{R_mT}{3.5}\right]$	$\min\left[\frac{R_{p0.2}RT}{1.5};\frac{R_mRT}{2.4}\right]$ or $\min\left[\frac{R_{p0.2}T}{1.1};\frac{R_mT}{2.4}\right]$	$\min\left[\frac{R_{p1.0}T}{1.5}\right]$	$\min\left[\frac{R_{p0.2}RT}{1.5};\frac{R_mRT}{2.7}\right]$ or $\min\left[\frac{R_{p0.2}T}{1.5}\right]$ Note: $R_{p1.0}$ can be used if permitted in a reference standard e.g. EN 13445.
Austenitic A > 35%			$\min\left[\frac{R_{p1.0}T}{1.2};\frac{R_mRT}{3.0}\right]$ or $\min\left[\frac{R_{p1.0}T}{1.5}\right]$	

Note that both EN 13445 and GB 150 allow use of 1.0% proof strength for austenitic stainless steels, which result in higher allowable design stresses than using 0.2% proof strength. EN 13445 also permits higher design stresses for austenitic grades with fracture elongation values over 35%.

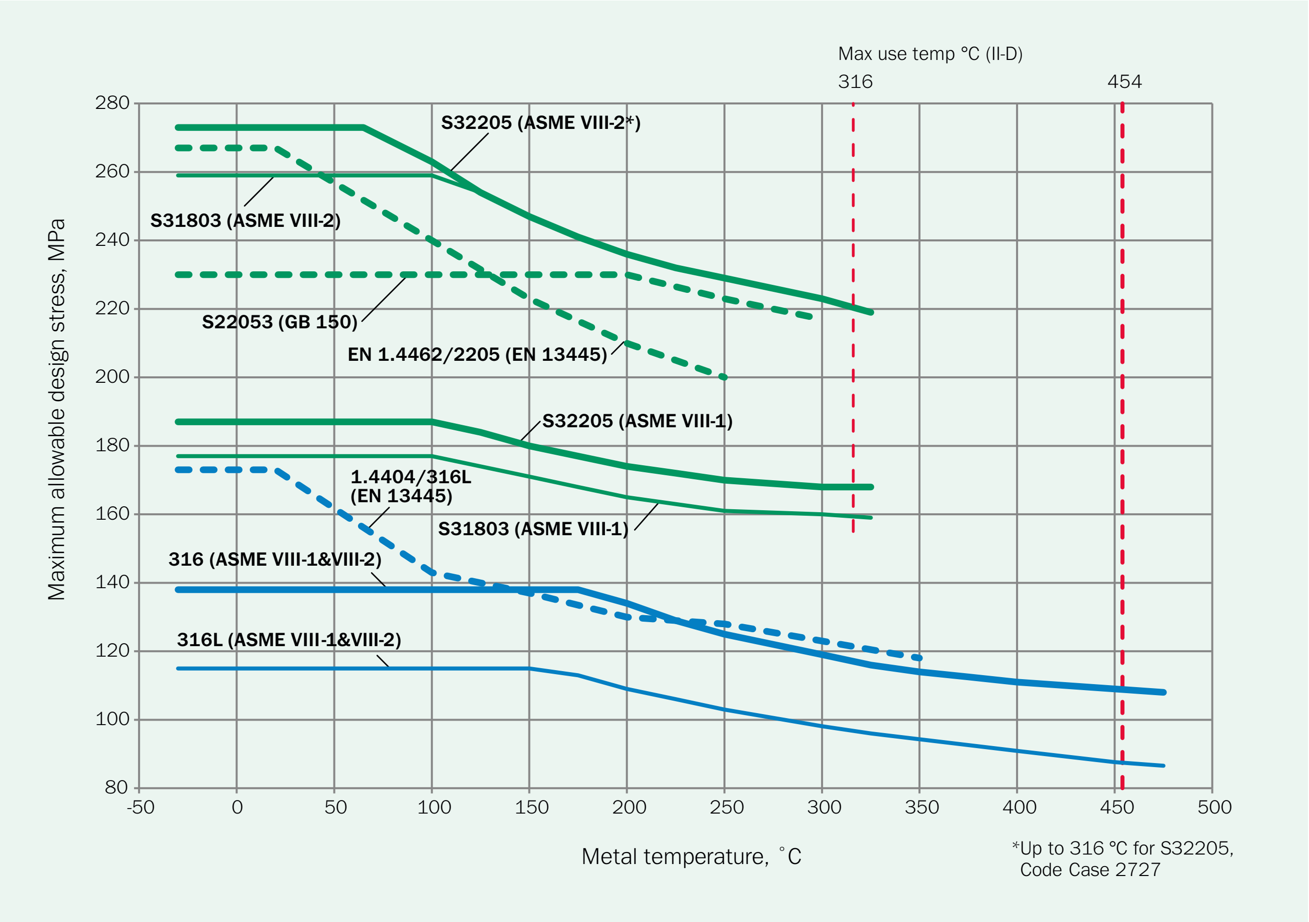


Figure 4. Maximum allowable design stresses vs. design metal temperature in accordance with ASME, EN and GB for type 2205 in comparison with type 316/316L.

Design data are available from -30°C up to the maximum use temperature of 316°C for duplex grades according to the ASME standard, and up to 250°C for European EN 10028/13445. Duplex grades can be used at lower design temperatures than -30°C (using the same design stress) if applicable toughness assessment criteria in ASME VIII are fulfilled. This is also applicable for EN 13445 with its design requirements. The Chinese standard GB 150 allows duplex grades in the temperature range from -30°C to 300°C.

However, for cryogenic use austenitic stainless steels would be the obvious choice due to their excellent toughness behavior at low temperatures. Also at design temperatures above 300°C austenitic grades are preferable to duplex stainless steels, which might exhibit embrittlement at elevated temperatures.

It is also notable in Figure 4 that the ASME VIII-2 permits about 45% higher design stresses at room temperature than ASME VIII-1 for S 32205 and S31803. Moreover, the allowable design stresses for S32205 is about 5% higher than S31803 up to 100°C for VIII-2, and above 100°C they are on the same level, whereas the 5% advantage is kept up to 316°C when using VIII-1.

The tensile strength based design criterion typically dictates the allowable design stress for duplex grades according to ASME VIII. Whereas the 0.2% proof strength based design criterion governs austenitic grades. Except at room temperature, the 0.2% proof strength based design criterion governs the design stresses for duplex grades (and 1.0% proof strength for austenitic grades) according to EN 13445. For G 150 the tensile strength based design criterion dictates the allowable design stresses up to about 200°C for duplex grades.

Moreover, the allowable design stress for S32205 according to ASME VIII-2 drops by 14% from RT to 200°C (from 276 to 236 MPa), whereas S32205 (VIII-1) drops only by 7% from RT to 200°C (from 187 to 174 MPa).

The allowable design stresses for EN 1.4462 according to EN 13445 is in between S32205 and S31803 (ASME VIII-2) at room temperature. EN 1.4462 gives about 10% lower values at 200°C, however still about 20% above the design values for S32205 according to ASME VIII-1.

Finally, the allowable design stress for S22053 according to GB 150 is in between the values for S32205 VIII-1 and VIII-2 at room temperature. However, at 200°C the value for S22053 is only a few percent below S32205 according to ASME VIII-2.

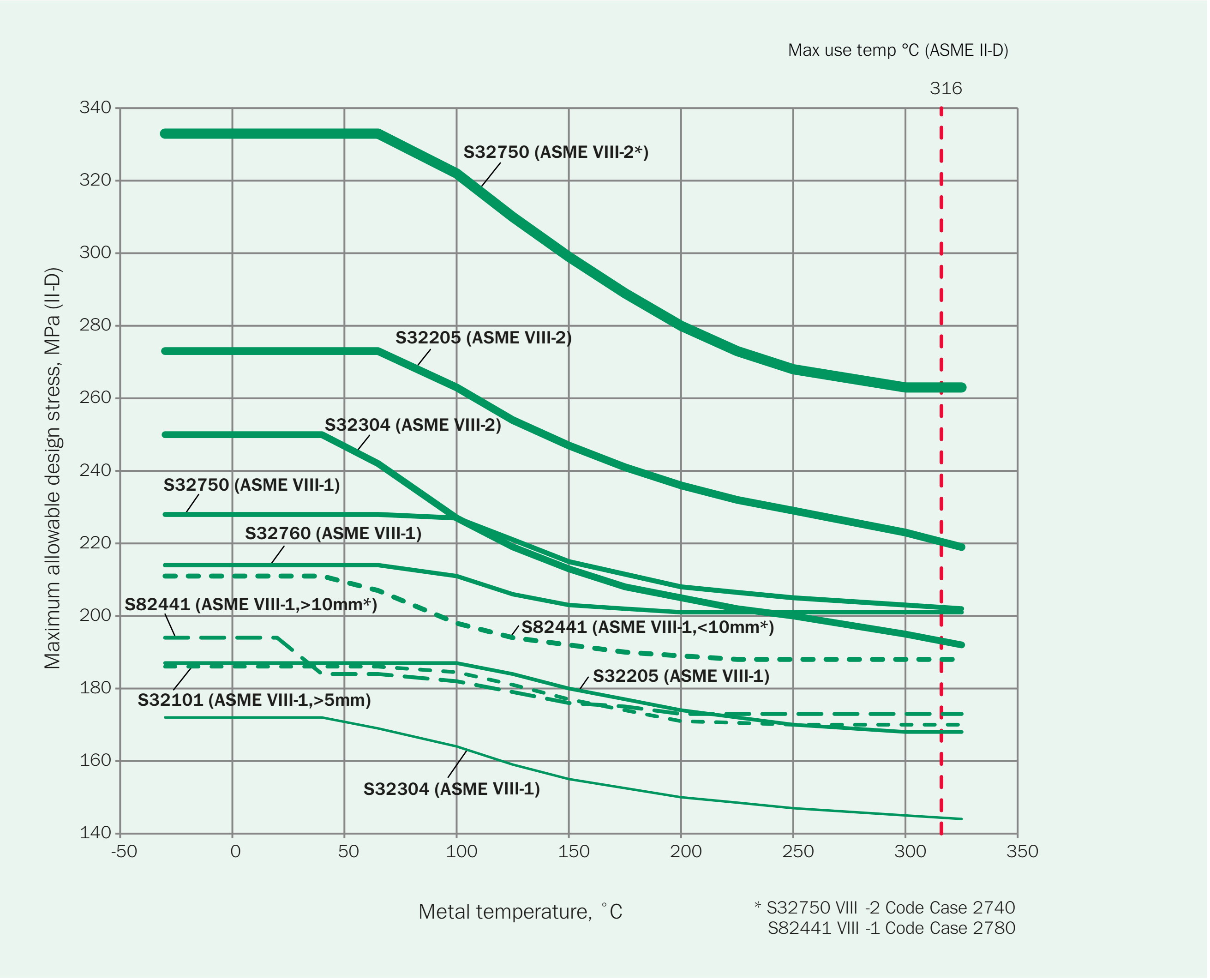


Figure 5. **Maximum allowable design stresses vs. design metal temperature in accordance with ASME VIII-1 and VIII-2 for a selected number of duplex grades.**

In Figure 5 the allowable design stresses for a selected range of duplex grades are depicted according to ASME VIII-1 and VIII-2. The advantage of using VIII-2 is significant. However, its design requirements are more challenging than VIII-1 and fewer grades are applicable for VIII-2.

S82441, up to 10 mm, stands out with roughly 10% higher design stresses compared to S32205 (and up to 20% higher than S31803) according VIII-1. S32304 has obviously the lowest allowable design stress among the duplex grades.

When comparing the higher nitrogen alloyed austenitic grades (S31254 and S32654) with duplex S32205 according ASME VIII-1 it is evident in Figure 6 that they provide a similar design stress level or higher in a wider temperature range than S32205. Whereas the austenitic grades with very low nitrogen content such as S31600 and N08904 have considerably lower allowable design stresses than S32205. Note that austenitic grades cannot benefit from the design stress criteria of ASME VIII-2 to provide higher allowable design stresses.

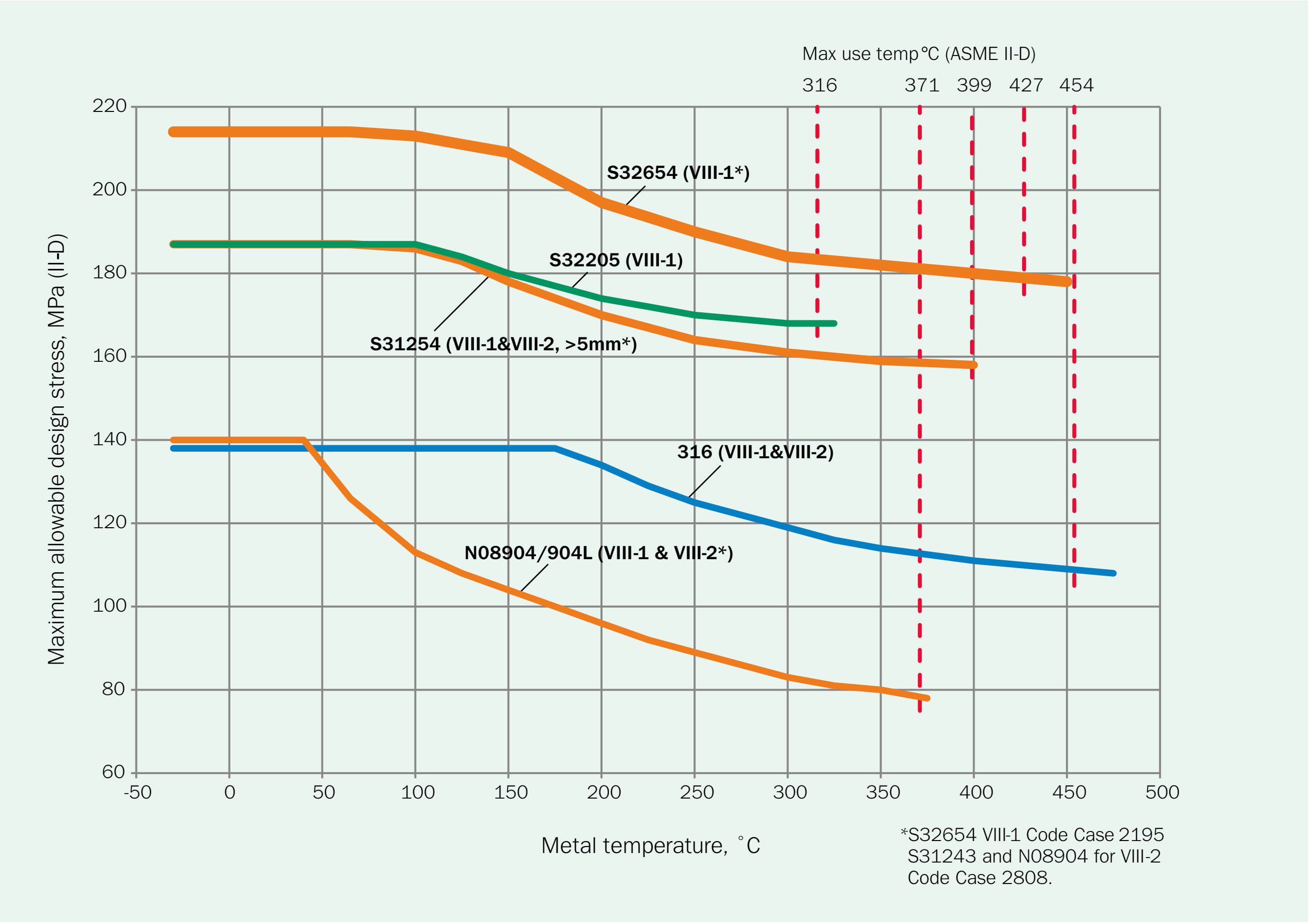


Figure 6. Maximum allowable design stresses of duplex S32205 vs. a selected number of austenitic grades in accordance with ASME VIII-1.

3.3 Strength utilization in pressure vessel shell

The maximum allowable design stresses at room temperature for both duplex and austenitic grades according to ASME VIII-1 and VIII-2 are summarized in Figure 7. By considering only membrane stresses as the critical design criterion for a pressure vessel shell, the material weight saving potential for the different steel grades with type 316 as reference are illustrated in Figure 8.

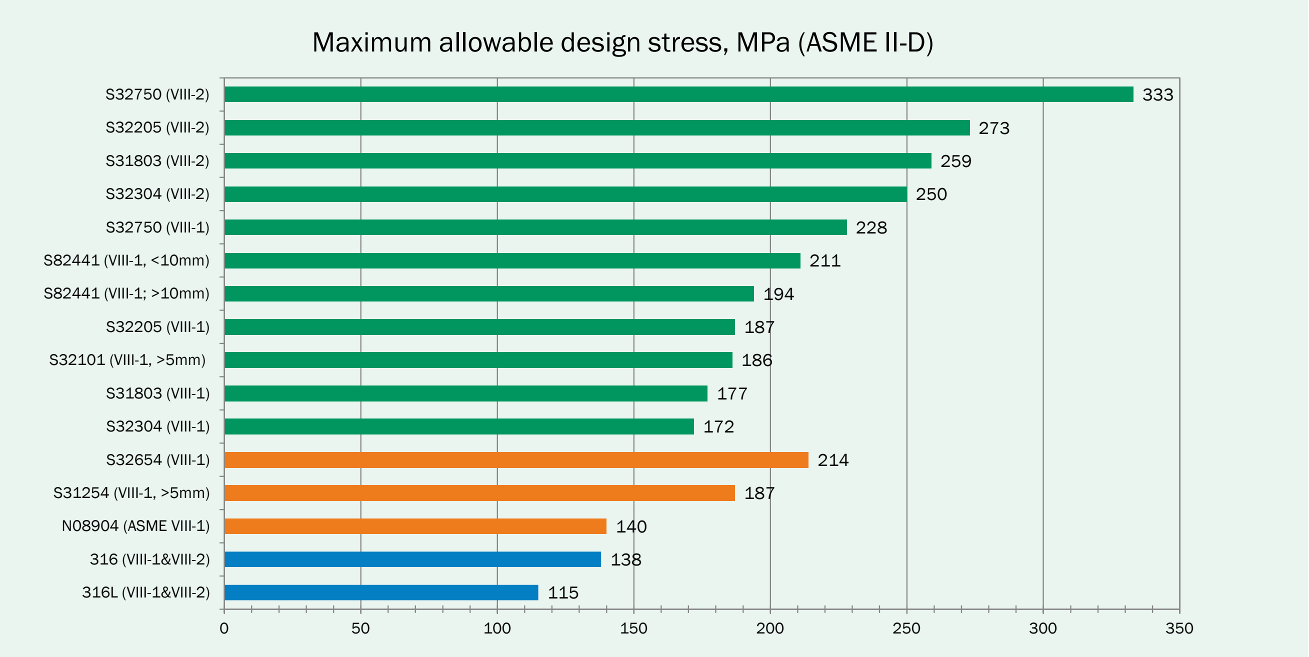


Figure 7. Maximum allowable design stresses at RT for duplex and austenitic grades according to ASME VIII-1 and VIII-2.

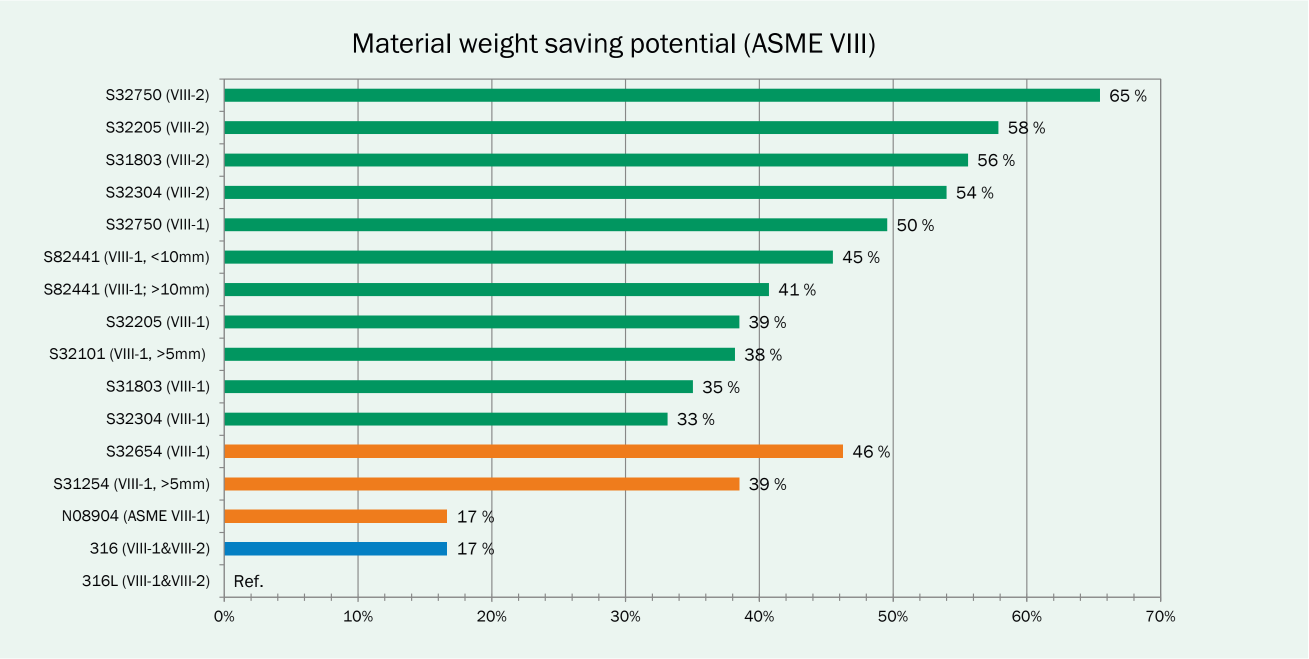


Figure 8. Potential material weight savings using high strength duplex and austenitic grades for a pressure vessel shell in comparison with 316L according to ASME VIII-1 and VIII-2.

Weight savings of about 40% is possible by using duplex grades according to ASME VIII-1, and up to 60% using ASME VIII-2. It is apparent that the high nitrogen alloyed austenitic grades have a similar weight saving potential as the duplex grades according to ASME VIII-1, and they can also be used in a wider temperature range than the duplex grades. Their ductility and toughness is also superior to duplex grades, which simplifies cold forming and enables cryogenic use.

However, from an economic perspective, the material cost per unit weight for the higher nickel and molybdenum alloyed austenitic grades are significantly higher than corresponding corrosion resistant duplex grade, which will affect the material cost as well as welding consumable cost.

Thus, if no excessive forming is needed, or not too high or too low design temperatures are specified, the duplex grades have the greatest potential to provide cost effective solutions for pressure vessels under the condition that their higher strength can be utilized to reduce the shell thickness compared to conventional austenitic stainless steel such as type 316 or other pressure vessel steels. The latter normally require advanced coating systems to protect their surfaces and also thicker shells when a corrosion allowance is added to the shell thickness, which lower the structural utilization of the material, with the consequence of additional welding, which affects both fabrication time and cost. In a life cycle perspective, the duplex solution is potentially more durable, providing longer service life with less maintenance work required, which generates higher operating efficiency of the vessel. Hence, the life cycle cost of a duplex vessel could in many cases be very cost competitive to a lined or coated carbon steel solution.

4. Typical pressure equipment in duplex stainless steel

The most common applications for duplex stainless steel in pressure equipment are pressure piping systems for seawater, chemicals or oil and gas transportation, which have their own specific standards often with great similarities to the standards for pressure vessels covered in this paper. If we consider pressure vessels, the most common applications are digesters within the pulp and paper industry, evaporators and distillation columns in the chemical industry, heat exchangers in the petro-chemical industry, chemical storage and transportation in road tankers and tank containers, fermenters in food and drink processing, autoclaves in the hydrometallurgical industry, and finally water heaters for domestic and industrial use.

High strength is a key characteristic of duplex grades. However, it is important to note that it is not always possible to utilize it fully in a pressure vessel application. The maximum allowable design stress is one important factor to consider, which has been scrutinized in this paper. Another crucial factor is the internal pressure versus external pressure, where the latter is caused by e.g. vacuum, wind and seismic loading on the vessel.

The potential weight savings illustrated in Figure 8 are only limited by the maximum allowable design stresses, i.e. allowable membrane stresses in the shell induced by the internal pressure. However, the external pressure may cause instability (buckling) becomes the critical design criterion which dictates required shell thickness. This can be illustrated by two application cases: evaporator and kraft pulp digester [10].

Kraft pulp digester
Diameter: 12.5 m
Total height: 54 m
Media density: 1100 kg/m3
Design temperature: 185°C
Internal pressure: 9 bar
External pressure: 1 bar

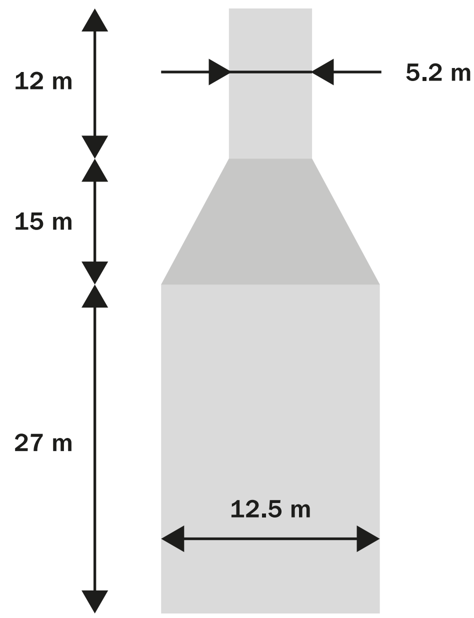


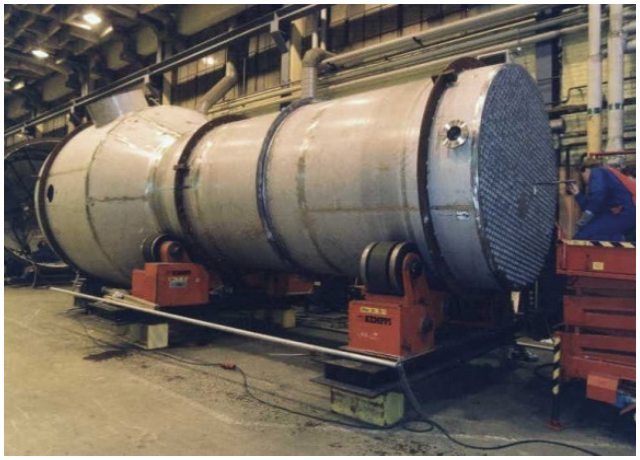
Figure 9. Application case: Kraft pulp digester. Courtesy of Kvaerner.

Table 6. Potential weight savings of using duplex in pressure vessel shell.

Grade	Allowable design stress ASME VIII-1 (185°C)	Required shell thickness (top down)	Total shell weight	Weight savings
S31603	112 MPa	26 – 96 mm	985 metric tons	Ref.
S32101	173 MPa	18 – 62 mm	653 metric tons	~33%

Evaporator

Diameter: 2.7 – 3.3 m
Total height: 16.6 m
Media density: 1100 kg/m3
Design temperature: 165°C
Internal pressure: 3.5 bar
External pressure: 1.0 bar



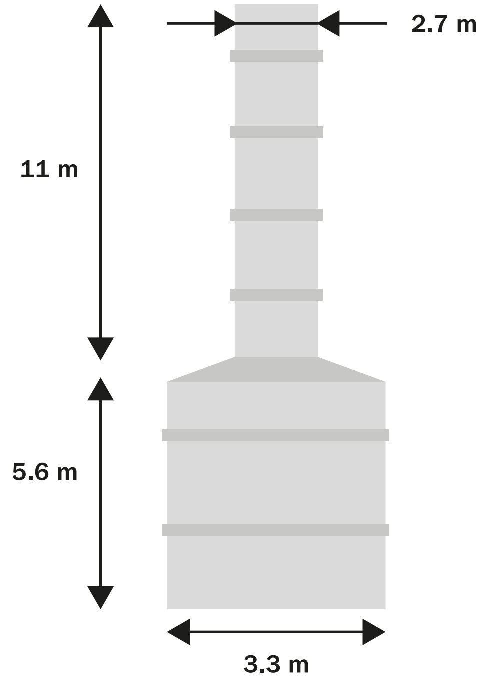


Figure 10. **Application case: Evaporator.**

Table 7. **Potential weight savings of using duplex in evaporator shell.**

Grade	Allowable design stress ASME VIII-1 (165°C)	Required shell thickness (top down)	Total shell weight	Weight savings
S31603	114 MPa	8 – 10 mm	11 metric tons	Ref.
S32101	175 MPa	8 – 10 mm	11 metric tons	~0%

Note from the two cases presented in Figure 9 and 10 that the ratio internal vs. external pressure is less for the evaporator than the digester. The latter is also much larger in size and the hydrostatic pressure induced by its content will be on the same level as the internal pressure, which will raise the membrane stresses further, and the higher strength of a duplex stainless steel can almost be fully utilized (potential weight savings of ~33%). Whereas the conditions for the evaporator implies that the thickness reduction is very limited due to the fact that the vacuum pressure is the critical design criterion, and stiffening rings (illustrated in Figure 10) have to be added to the shell to provide sufficient stiffness (i.e. by reducing thickness further would only result in denser spacing between the stiffening rings) and thus, the potential weight savings is nil. Moreover, external loading and specifically wind loading could be critical also for tall and slender vessels like distillation columns.

5. Conclusions

- Duplex stainless steel are well covered in the American pressure vessel code ASME Section VIII from low nickel lean duplex to higher alloyed super duplex grades.
- The coverage of duplex stainless steel is very limited in the Chinese pressure vessel code GB 150.
- The strength utilization and possible thickness and weight savings of using duplex stainless steel in the shell of a pressure vessel is considerable compared to conventional austenitic stainless steel (e.g. type 316).
- The more technically advanced division 2 of ASME section VIII allows much higher design stresses for duplex stainless steel than the basic rules provided by division 1. The European EN 13445 comes second to the ASME section VIII division 2, followed by the Chinese GB 150 considering allowable design stresses.
- Fewer duplex grades can benefit from ASME section VIII division 2 than division 1.
- High alloy (high nitrogen) austenitic stainless steels could be an interesting alternative to duplex grades, if highest possible corrosion resistance is required, or if exposed to high or low design temperatures, or if advanced cold forming operations are involved.
- Duplex grades can be a cost effective material solution to lined or coated carbon steel for large vessels with high internal pressure particularly in a life cycle cost perspective.

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