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Tanks

Chapter 6.8
Categorization of austenitic-ferritic stainless steel grades

Transmitted by the Government of Sweden[1,2]

Summary

Explanatory summary:	This proposal proposes a separate category for austenitic-ferritic stainless steel grades in 6.8.2.1.19 and an amendment of the minimum allowed shell thicknesses for austenitic-ferritic stainless steel grades in 6.8.2.1.19.
Action to be taken:	Amendment of the text in 6.8.2.1.19 and introduction of a new provision for austenitic-ferritic stainless steel grades.
Related documents:	None.

[1] In accordance with the programme of work of the Inland Transport Committee for 2010–2014 (ECE/TRANS/208, para.106, ECE/TRANS/2010/8, programme activity 02.7 (c)).
[2] Circulated by the Intergovernmental Organisation for International Carriage by Rail (OTIF) under the symbol OTIF/RID/RC/2011/17.

Introduction

1. The minimum shell thickness for low pressure tanks is defined in ADR, sections 6.8.2.1.17 to 6.8.2.1.22.

2. The equivalent thickness can be reduced when protection of the tank against damage through lateral impact or overturning is provided. The table in 6.8.2.1.19 indicates the minimum shell thicknesses for the four existing material groups, when protection against damage is present. The four material groups with the respective minimum shell thicknesses are as shown in Table 1.

Table 1
Minimum thickness of shells according to 6.8.2.1.19

	Diameter of shell	*≤ 1.80 m*	*>1.80 m*
Minimum thickness of shells	Stainless austenitic steels	2.5 mm	3 mm
	Other steels	3 mm	4 mm
	Aluminium alloys	4 mm	5 mm
	Pure aluminium of 99.80 %	6 mm	8 mm

3. Austenitic-ferritic stainless steel grades (also commonly called Duplex stainless steels) belong to the second group "other steels" and are therefore also treated as mild steels.

4. The categorization however is imprecise and does not reflect the properties of austenitic-ferritic grades. Therefore the potential of austenitic-ferritic stainless steel grades cannot be used, which hinders tank manufacturers from finding cost efficient solutions.

5. Thus, it is suggested to add a fifth material group to the table which contains austenitic-ferritic stainless steel grades as defined by EN 10028-7. The minimum properties of those austenitic-ferritic steels are summarized in Table 2.

6. Furthermore, it is suggested to adopt the same minimum shell thicknesses of the austenitic stainless steels for the austenitic-ferritic stainless steels. This suggestion will be discussed in detail in the "Justification" below.

7. By means of the equation in 6.8.2.1.18 the minimum shell thicknesses can be calculated for tanks without protection against damage. In 6.8.2.1.19 it is elaborated how the formula can be adapted when protection against damage is provided leading to $e_0 = 4$ mm in the case of tanks with a diameter > 1.8 m, and $e_0 = 3$ mm in the case of tanks with a diameter ≤ 1.8 m.

$$e_1 = \frac{464 e_0}{\sqrt[3]{(R_{m1} A_1)^2}}$$ (Equation according to 6.8.2.1.18)

Where:

e_1 = minimum shell thickness for the metal chosen, in mm:

e_0 = minimum shell thickness for mild steel, in mm, according to 6.8.2.1.18 and 6.8.2.1.19;

R_{m1} = minimum tensile strength of the metal chosen, in N/mm^{2};

A_1 = minimum elongation at fracture of the metal chosen under tensile stress in %.

8. Calculations are done for both cases: tanks without protection against damage and tanks with protection against damage. The calculated values for all austenitic-ferritic stainless steels as listed in EN 10028-7 and the calculated values for in tank applications typically using austenitic stainless steels are shown in Table 3.

Table 2
Minimum values according to EN 10028-7

Grade	*R_m = Ultimate tensile strength [MPa]*	*Elongation [%]*	*Type of steel*
1.4362	650	20	Austenitic-ferritic
1.4462	700	20	Austenitic-ferritic
1.4507	690	20	Austenitic-ferritic
1.4410	750	30	Austenitic-ferritic
1.4501	730	25	Austenitic-ferritic
1.4404	530	40	Austenitic
1.4401	530	40	Austenitic
1.4307	520	45	Austenitic

Table 3
Calculation of shell thicknesses according to 6.8.2.1.18 and 6.8.2.1.19

Calculation according to equation in 6.8.2.1.18 without protection of the tank against damage

Grade	*Diameter of shell: > 1.8m*	*Diameter of shell: ≤1.8m*
	Min. shell thickness for the metal chosen in mm, with e_0 = 6 mm	*Min. shell thickness for the metal chosen in mm, with e_0 = 5 mm*
Austenitic-ferritic		
1.4362	5.04	4.2
1.4462	4.8	3.99
1.4507	4.84	4.03
1.4410	4.58	3.81
1.4501	4.02	3.35
Austenitic		
1.4404	3.63	3.03
1.4401	3.63	3.03
1.4301	3.32	2.77

Calculation according to equation in 6.8.2.1.18 with protection of the tank against damage

Grade	*Diameter of shell: > 1.8 m*		*Diameter of shell: ≤1.8 m*	
	Min. shell thickness for the metal chosen in mm, with e_0 = 4 mm	*Min allowed thickness according to ADR 6.8.2.1.19 in mm*	*Min. shell thickness for the metal chosen in mm, with e_0 = 3 mm*	*Min allowed thickness according to ADR 6.8.2.1.19 in mm*
Austenitic-ferritic				
1.4362	3.36	4	2.52	3
1.4462	3.2	4	2.4	3
1.4507	3.23	4	2.42	3
1.4410	3.05	4	2.29	3
1.4501	2.68	4	2.01	3
Austenitic				
1.4404	2.42	3	1.82	2.5
1.4401	2.42	3	1.82	2.5
1.4301	2.21	3	1.66	2.5

9. Table 3 shows that the austenitic-ferritic stainless steels obtain (slightly) higher minimum thickness values in comparison to the austenitic grades when calculations are made according to 6.8.2.1.18. The same applies when calculations are made according to 6.8.2.1.19. However, the minimum shell thicknesses for austenitic-ferritic steels calculated according to 6.8.2.1.19 are smaller than the required minimum thicknesses of 3 mm and 4 mm for shell diameters ≤ 1.8 m and > 1.8 m respectively. Accordingly, the minimum required shell thickness for austenitic-ferritic steels can be designed to thinner dimensions, i.e. the calculated values, or the two proposed minimum allowed thicknesses of 3 mm and 2.5 mm for diameters > 1.8 and ≤ 1.8 respectively.

Proposal

10. It is proposed to add a fifth category to the table in 6.8.2.1.19 and adopt the values of the austenitic stainless steels for austenitic-ferritic stainless steel grades, as shown in Table 4 below.

Table 4
Proposed amendments of the table in 6.8.2.1.19

	Diameter of shell	*≤ 1.80 m*	*>1.80 m*
Minimum thickness of shells	Stainless austenitic steels	2.5 mm	3 mm
	Austenitic-ferritic stainless steels	**2.5 mm**	**3 mm**
	Other steels	3 mm	4 mm
	Aluminium alloys	4 mm	5 mm
	Pure aluminium of 99.80 %	6 mm	8 mm

11. These proposals do not apply to high pressure vessels. The thickness of high pressure vessels is given by the classical pressure vessel formula and austenitic-ferritic steels are to be treated as "other steels", which is in accordance with the pressure vessel codes, such as standard EN 13445 and section VIII of the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers.

Justification

1. Reasoning for the proposed changes regarding the minimum thicknesses of austenitic-ferritic stainless steels

Stress-strain curve behaviour

12. Any collision causes damage to a structure, whereas the extent of damage depends on different factors. One factor that influences the impact of a collision is the energy absorption capability of a material. Generally, a material with high energy absorption can provide greater safety.

13. In order to visualize and deduce the energy absorption capability of a material, stress-strain curves can be used. Figure 1 shows the stress-strain curve of the austenitic grade 1.4404 and Figure 2 shows a general stress-strain curve that represents the austenitic-ferritic stainless steel grades. The calculation of the energy absorption will be discussed below.

14. The formula for calculating the minimum shell thickness as given in 6.8.2.1.18 takes into account the energy absorption capability of a material. Rm_1 A_1 is the part of the formula which factors in the energy absorption of a material.

$$e_1 = \frac{464 e_0}{\sqrt[3]{(R_{m1} A_1)^2}}$$ (Equation according to 6.8.2.1.18)

15. The area in the rectangle in Figure 1 (red and green part) indicates an energy absorption of 1.4404 as calculated by Rm_1 A_1. The same applies to austenitic-ferritic steels in Figure 2. The energy absorption, as included in the formula in 6.8.2.1.18, is however not the real energy absorption capability of a material. The real energy absorption is composed of the area below the curve hence the green and yellow part in the Figure.

16. Comparing each curve, it can be ascertained that the red part over the curve of 1.4404 is considerably larger than that of austenitic-ferritic steels. When calculating e_1 with the equation in 6.8.2.1.18 the red part is fully factored in, but this part virtually does not contribute to the real energy absorption of the material. Taking Figures 1 and 2 into account it becomes obvious that the equation in 6.8.2.1.18 is much more conservative for austenitic-ferritic steels than for austenitic stainless steels. Hence, it is suggested to adopt the minimum thickness of shells required for austenitic also for austenitic-ferritic grades (Tables 1 and 4).

17. Table 3 shows the calculated values for the minimum shell thicknesses of some stainless steel grades. The calculated minimum shell thicknesses for austenitic-ferritic grades are higher in some cases (see Introduction). This depends to some extent on how the energy absorption capability of a material is calculated according to the formula in 6.8.2.1.18 as already mentioned earlier in this section. Even though the minimum shell thicknesses of some austenitic-ferritic steels exceeds for 3 mm for diameters > 1.8 m and 2.5 mm for diameters ≤ 1.8 m, there are also some grades that can be designed for 3 mm and 2.5 mm respectively. Thus, it seems reasonable to provide the opportunity for tank builders to design for the minimum thicknesses of 3 mm and 2.5 mm, depending on which austenitic-ferritic grade they choose.

18. Moreover, due to the conservative treatment of austenitic-ferritic steels by the formula, the amendment to the table in 6.8.2.1.19 seems justified.

Figure 1
Energy absorption of 1.4404

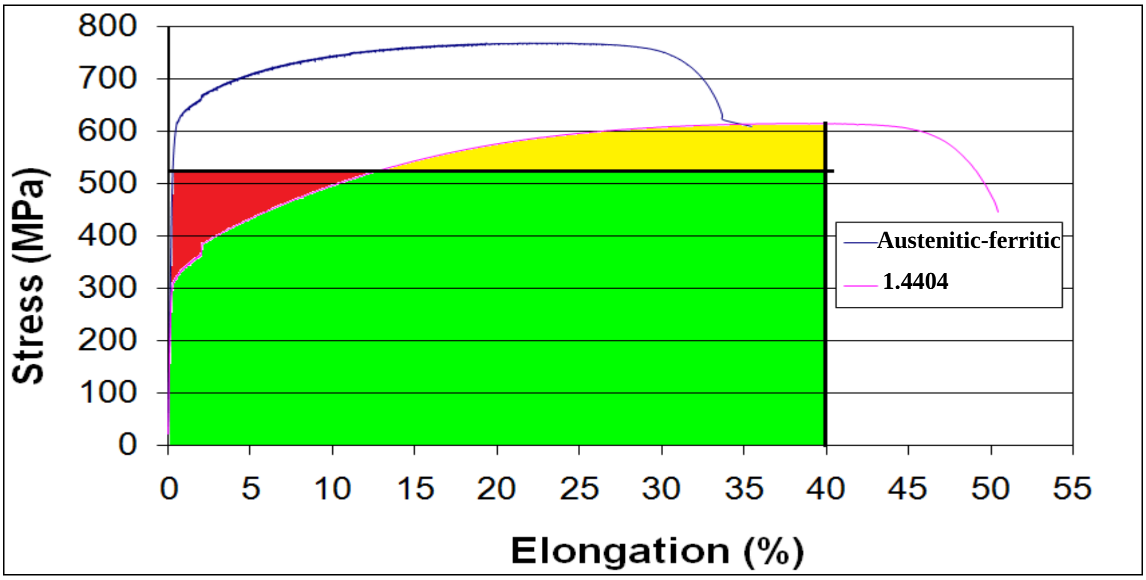
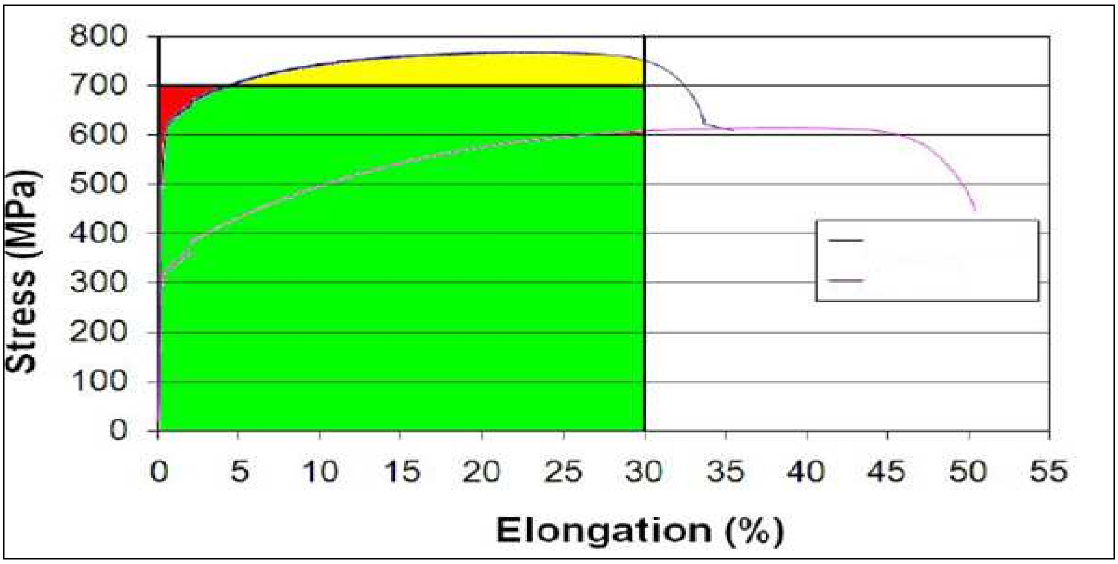


Figure 2
Energy absorption of austenitic-ferritic grades



2. Observation

Energy absorption at different strain levels

19. Experiences from tests in the automotive industry show that a material only deforms up to 10 % in a crash and not up to 20 %, 30 % or higher values. Figure 3 illustrates the real energy absorption of 1.4404 and for austenitic-ferritic steels at 10 %, 15 % and 20 % elongation, respectively.

20. Until fracture, austenitic-ferritic steels have a much better real energy absorption capability than 1.4404. For a simple illustration, energy absorption was computed by R_{px} A_1

at an elongation of x. The results are presented in Table 5 below. It should be emphasized that the results do not reflect the real energy absorption for the reasons discussed (see Justification, 1.).

Table 5
Energy absorption of austenitic ferritic steels in comparison to 1.4404

Elongation	Energy absorption ([3]R_{px} A_1) of austenitic-ferritic steels	Energy absorption ([3]R_{px} A_1) of 1.4404	Energy absorption of austenitic-ferritic steels in comparison to 1.4404
10 %	7400	5000	+ ~50 %
15 %	11400	8100	+ ~40 %
20 %	15600	11600	+ ~35 %
30 %	22500	18300	+ ~23 %

21. Table 5 also indicates that for an energy absorption corresponding to that of austenitic-ferritic steels, an austenitic grade will deform (elongate) much more. For example, the energy absorption (EA-number) of a austenitic-ferritic grade is 11400 at an elongation of 15 %. In a crash situation, 1.4404 would need to elongate to 21.5 % in order to absorb the same amount of energy that austenitic-ferritic absorbs at 15 % (see Figure 4). Further comparisons have been made for the elongation values of 10 %, 20 %, 25 % and 30 %. The results are listed in Table 6.

Table 6
Elongation of 1.4404 to a given energy absorption value

Energy absorption of austenitic-ferritic steels	*Elongation of austenitic-ferritic steels*	*Elongation of 1.4404 to obtain the same energy absorption as for austenitic-ferritic steels*
7400	10%	15%
11400	15%	22%
15600	20%	27%
22500	30%	37%

[3] R_{px} = Stress at respective elongation.

Figure 3

Energy absorption at 10%, 15%, 20% and 30% elongation for austenitic-ferritic and 1.4404

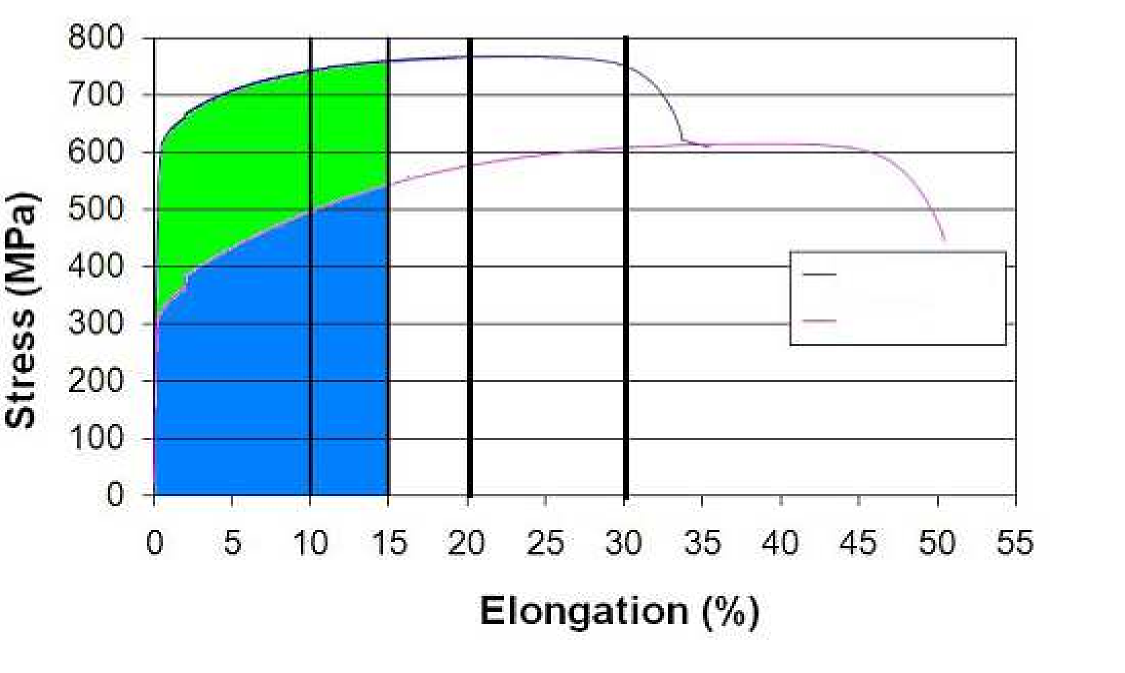
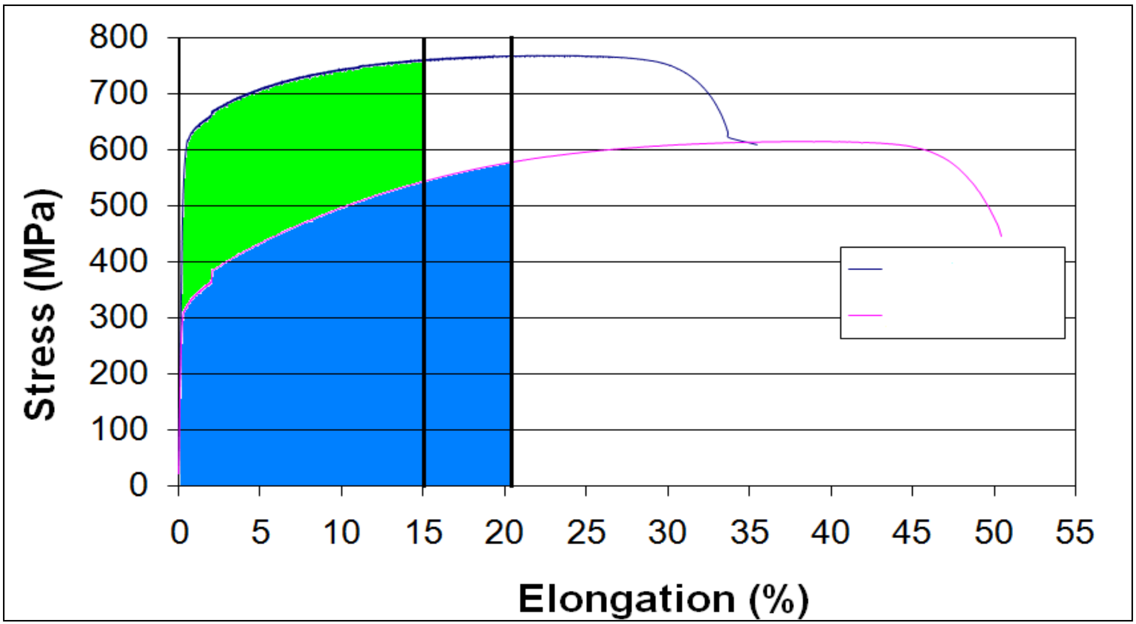


Figure 4

Elongation of 1.4404 and austenitic-ferritic when the energy absorption equals 11400



3. Additional information

22. In January 2011 a static and dynamic test is planned for some austenitic-ferritic and austenitic grades. The test will be carried out by BAM, the Federal Institute for Material Research and Testing in Germany. These test results will be presented and used for further discussion during the Joint Meeting in March 2011.