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Economic Commission for Europe**Inland Transport Committee****Working Party on the Transport of Dangerous Goods****Joint Meeting of the RID Committee of Experts and the
Working Party on the Transport of Dangerous Goods**

Geneva, 13-23 September 2011

Item 2 of the provisional agenda

Tanks**Chapter 6.8****Differentiation of austenitic-ferritic stainless steel grades****Transmitted by the Government of Sweden^{1, 2}***Summary*

Explanatory summary: This document proposes a new footnote to be added for the austenitic-ferritic stainless steel grades 6.8.2.1.19, based on the minimum elongation values and a new second paragraph in subsection 6.8.2.1.10.

Related documents: ECE/TRANS/WP.15/AC.1/2011/17
Informal document INF.33 (Bern, March 2011)
INF.42 (Bern, March 2011)

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/2011/44.

I. 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 gives 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 with protection according to 6.8.2.1.19

		<i>Diameter of shell</i>	
		$\leq 1.80\text{ m}$	$> 1.80\text{ m}$
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. During the Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods, Working Group on Tanks on its Spring 2011 session, it was decided to introduce a new group of steels, namely the austenitic-ferritic stainless steels. Further, it was decided to adopt 3.0 mm shell thickness for shell diameters below or equal to 1.8 meters, and 3.5 mm for shell diameters above 1.8 meters, see Table 2. Documentation from the discussions can be found in document INF 42.

Table 2

Amendments in the table in 6.8.2.1.19, adopted by the Joint Meeting in Bern, March 21-23 2011 (INF 42)

		<i>Diameter of shell</i>	
		$\leq 1.80\text{ m}$	$> 1.80\text{ m}$
Minimum thickness of shells	Stainless austenitic steels	2.5 mm	3 mm
	Austenitic-ferritic stainless steels	3 mm	3.5 mm
	Other steels	3 mm	4 mm
	Aluminium alloys	4 mm	5 mm
	Pure aluminium of 99.80 %	6 mm	8 mm

4. Further on, at the Joint Meeting of the RID Committee of Experts and the Working Party on the Transport of Dangerous Goods, Working Group on Tanks on its Spring 2011 session, the impact strength at low temperatures, the energy absorption, the elongation after rupture and the behaviour of the welds of austenitic-ferritic stainless steel grades in comparison to austenitic standard steels were discussed and some questions still remained. These questions can be answered and demands fulfilled by introducing additional requirements and limitations on this group of steels.

II. Proposals

Proposal 1: Additional requirement on elongation

5. By specifying additional requirements on design temperature range, impact toughness and elongation on the austenitic-ferritic stainless steels it will be possible to further reduce thickness compared to Table 2. By introducing a demand for an elongation of minimum 30% in elongation A_5 , being the minimum elongation demand for austenitic stainless steels in pressure vessel standard EN 13445, the following footnote is proposed, see Table 3.

Table 3

	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*	3 mm	3.5 mm
	Other steels	3 mm	4 mm
	Aluminium alloys	4 mm	5 mm
	Pure aluminium of 99.80 %	6 mm	8 mm

* Austenitic-ferritic stainless steels with an elongation, A_5 , of minimum 30 % may have a minimum thickness of 2.5 mm if the diameter is ≤ 1.80 m or a minimum thickness of 3.0 mm if the diameter is > 1.80 m.

Proposal 2: Additional requirements on impact toughness and design temperature range

6. It is proposed to add additional requirements at the end of section 6.8.2.1.10 for the austenitic-ferritic stainless steels. The following text is proposed, based on EN 10028-7, Flat products made of steels for pressure purposes – Stainless steels and EN 13445-2, unfired pressure vessels – Part 2: Materials, Appendix B.

7. Proposed amendment as a new second paragraph in sub-section 6.8.2.1.10:

For the austenitic-ferritic stainless steels the two following general requirements must be fulfilled:

The permitted design temperature range must be within -40 °C to +250 °C.

The impact toughness in the base material, weld metal and the heat affected zone at -40 °C, or at the lowest design temperature, must be minimum 40 J tested with ISO-V test specimens

III. Justification

8. As a result of the last Joint meeting of RID experts and the Working Party of the Transport of Dangerous Goods, austenitic-ferritic stainless steels were acknowledged as separate material group. The proposed changes to the table in 6.8.2.1.19 were adopted. The

justification of the previous change was based on stress-strain curve behaviour of austenitic-ferritic stainless steels in comparison to that of austenitic steels and on energy absorption capacities of both material groups.

9. Furthermore, calculations of shell thicknesses according to 6.8.2.1.18 and 6.8.2.1.19 have shown that thinner gauges than allowed by the table in 6.8.2.1.19, when designing tank shells with austenitic-ferritic stainless steels, are possible. Additional requirements, as they are presented in proposals 1 and 2 of this document, shall ensure adequate demands on the austenitic-ferritic stainless steels in order to account for safety.

10. The demand in Proposal 1 of an elongation, A_5 , of minimum 30 % ensures that the austenitic-ferritic stainless steels that fulfil this demand, also fulfil the same elongation demand as the austenitic stainless steels.

11. The proposed amendment in Proposal 2 will ensure that the permitted design temperature range is within the inner envelope of what has been internationally accepted in pressure vessel standards.

12. The proposed amendment in Proposal 2 will further ensure that the impact toughness in the base material, weld metal and the heat affected zone at $-40\text{ }^{\circ}\text{C}$, or at the lowest design temperature, fulfils what has been internationally accepted in pressure vessel standards.

13. The impact toughness of austenitic-ferritic stainless steels was a major concern during the last Working Group meeting. Annex 1 give additional information on impact toughness in general and on impact toughness of austenitic-ferritic stainless steels in particular, as well as on impact toughness of welds.

14. Annex 2 gives additional information on the weldability of austenitic-ferritic stainless steels, since the weldability was discussed during the last Working Group meeting.

15. The possibility to further reduce shell thicknesses and hence the dead weight of the tank shell will, in the long run, have a positive effect in reducing emissions and making tank transport more environmentally friendly.

Annex 1

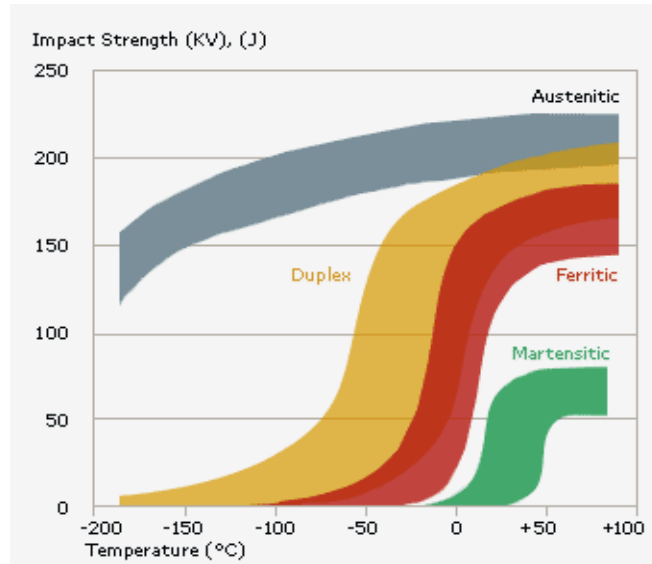
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Impact toughness of Stainless Steels

General

1. The toughness of the different types of stainless steels shows considerable variation, ranging from excellent toughness at all temperatures for austenitic steels to the relatively brittle behaviour of martensitic steels. Toughness is dependent on temperature and generally improves with increasing temperature.
2. One measure of toughness is the impact toughness, i.e. the toughness measured on rapid loading. Figure 1 shows categories of stainless steel at temperatures from -200 °C to +100 °C. It is apparent from the Figure 1 that there is a fundamental difference at low temperatures between austenitic stainless steels on the one hand and martensitic, ferritic and austenitic-ferritic stainless steels on the other.
3. Martensitic, ferritic and austenitic-ferritic stainless steels are characterised by a transition in toughness, from tough to brittle behaviour. Transition in toughness occurs at a certain temperature, the transition temperature.
4. For ferritic steel the transition temperature increases with increasing carbon and nitrogen content. Even though carbon and nitrogen increase toughness, a high content facilitates brittleness of the material at higher temperatures. As the austenitic-ferritic stainless steels contain 40 to 60 % austenite, they are generally a little tougher than the ferritic stainless steels. Yet, the higher the ferrite content, the higher the transition temperature, i.e. more brittle behaviour.
5. Martensitic stainless steels have transition temperatures around or slightly below room temperature, while those for ferritic and austenitic-ferritic stainless steels are in the range 0 to -50 °C, with ferritic steels in the upper part of this range.
6. Austenitic stainless steels do not exhibit a toughness transition as do the other stainless steel types, but have excellent toughness at all temperatures, although the toughness decreases slightly with decreasing temperature.

Figure 1
Categories of stainless steels at temperatures from -200 °C to + 100 °C

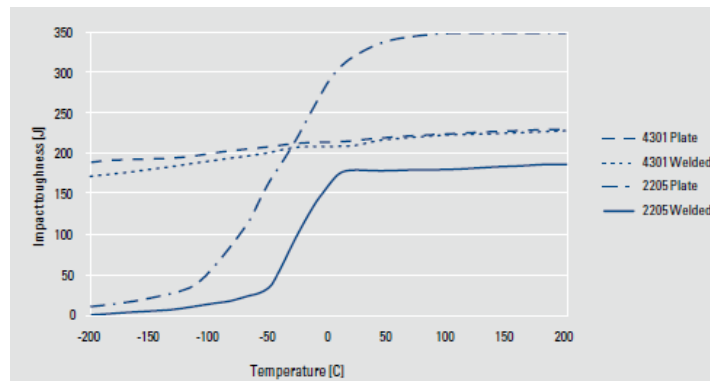


Impact toughness of welds

7. Impact toughness is commonly tested by a Charpy-V test in order to determine the suitability of a material for use at different temperatures. It is common to test both the base material and the weld, sometimes also the heat affected zone, HAZ. The impact toughness of austenitic stainless steel grades welded with standard fillers and welding methods is very high, even down to very low (cryogenic) temperatures. Most common austenitic stainless steels can be used down to -196 °C without any special measures and some grades, like EN 1.4311, can be used down to -270 °C.

8. The ferritic and martensitic grades, on the other hand, become brittle and show low impact toughness values in the base material when reaching temperatures of -20 °C to -40 °C. In the weld, the toughness may be even lower, depending on the welding method. Increased toughness in the weld can be achieved by using a nickel-based filler metal that makes the weld metal more ductile, but the properties of the HAZ might still be poor. Ferritic and martensitic grades are not at all suitable for cryogenic applications.

Figure 2
Typical impact toughness vs. temperatures for base and weld metal (From Outokumpu Welding Handbook, Ed. 1, 2010)



9. The austenitic-ferritic stainless steels have toughness somewhere between austenitic and ferritic steels. The austenitic-ferritic base material is more ductile than the ferritic and martensitic grades and they are ductile down to about -100 °C, but the welds in this type of steel set the temperature limit. The welding method used must give the proper level of toughness depending on the requirements of the construction. If there are high requirements on toughness at sub-zero temperatures, TIG welding gives the best results.

10. In Figure 2, the influence of welding on the impact toughness is shown for a standard austenitic grade that is very little affected by the welding and a duplex grade where the weld has pronounced effect on the toughness of welded structures at low temperatures.

11. It is advisable to contact the material supplier when welding austenitic-ferritic stainless steels with high requirements on toughness at sub-zero temperatures.

Welding of Austenitic-Ferritic Stainless Steels

General characteristics

1. Austenitic-ferritic stainless steels combine many of the best properties of austenitic and ferritic stainless steels. They are readily weldable and the weldability is better than that of ferritic stainless steels, but not as good as the austenitic stainless steels. They can be joined with most welding methods used for austenitic stainless steels. For optimum weldment properties, however, the welding parameters may have to be modified. Austenitic-ferritic stainless steels are designed to have approximately equal amounts of ferrite and austenite in the solution annealed condition. The welding process involves thermal cycles that can change the phase balance to a more ferritic one in both the weld metal and adjacent areas of the base metal. This may in some cases have a detrimental effect on weldment properties.
2. The typical level of heat input used for austenitic-ferritic stainless steels is 0.5-2.5 kJ/mm. For lower and high alloyed austenitic-ferritic stainless steels the levels is however somewhat lower and more narrow (0.2-1.5 kJ/mm). Austenitic-ferritic stainless steels commonly solidify with a fully ferritic structure with austenite nucleation and growth during cooling. Rapid cooling from high temperatures may still result in high ferrite levels in the weld metal and adjacent base metal. Therefore filler metals are specially designed with higher nickel contents to produce a phase balance similar to that of the base material.
3. The general approach, if optimum weldment properties are required, is to use designed fillers and a joint design that allows the use of filler. All austenitic-ferritic stainless steel fillers are over-alloyed with respect to nickel to ensure good austenite formation. Modern austenitic-ferritic stainless steels also contain sufficient nitrogen to improve the austenite reformation in the HAZ. However, extremely high cooling rates (e.g. low heat input with thick gauges) can still result in an almost completely ferritic structure in the welds and this should be avoided. If designed fillers are used, typical ferrite levels in the weld metal will be 25-55 %. The ferrite level in the HAZ will be somewhat higher, 55-70 %.
4. Autogenous welding (e.g. TIG without filler, resistance and laser welding) will result in high ferrite levels, typically 60-95 % dependent on cooling rate. For such welds, subsequent annealing will restore the phase balance in the weldment. Nitrogen addition to the shielding gas is used with autogenous welding in order to preserve the corrosion resistance and strength of the weld. If subsequent annealing is not possible, TIG-welding must – for most cases - be made with a filler.
5. Exposure of austenitic-ferritic stainless steels at 700-900 °C can precipitate intermetallic phases, which impair toughness and corrosion resistance. This has to be considered when welding of high-alloyed austenitic-ferritic stainless steel grades, in particular with multipass welding. For standard and lean austenitic-ferritic stainless steels this is seldom an issue.
6. Austenitic-ferritic stainless steels may show lower penetration and fluidity than standard austenitic steels (1.4304/1.4404 or 304/316-series) during welding. This can result in lower welding speeds for automatic TIG and plasma arc welding. To improve penetration and fluidity, addition of helium or hydrogen to the argon shielding gas is commonly used. The reduced penetration will require the joint angle to be somewhat wider

(+10°) and the land to be smaller than for austenitic steels. Due to high strength of the parent material, the tacks should be somewhat longer compared to standard austenitic grades (≥ 25 mm).

7. Weld defects that can occur with austenitic-ferritic stainless steels are often a result of too high welding speed (cracking), too narrow joints (porosity, slag inclusions) or too high heat input (reduced ductility). Excessively thick weld beads may cause porosity due to entrapped nitrogen from the base metal.

8. Austenitic-ferritic stainless steels are less susceptible to hot cracking than austenitic steels with primary austenitic solidification. The risk of hydrogen cracking is also low provided that the austenite formation in the weld area is sufficient. As with all types of stainless steel weldments, the properties of austenitic-ferritic stainless steel welds differ to some extent from those of the base material.

9. To counteract possible nitrogen loss in the weld metal when TIG or plasma welded, some percent of nitrogen addition to the shielding gas is often used. This will improve pitting corrosion resistance, ductility and strength. Backing/purging gases containing nitrogen (e.g. 90 % N₂ + 10 % H₂) are also beneficial for the corrosion resistance of TIG and plasma welds.

10. The lower fluidity and arc stability in MAG welding compared to standard austenitic steels can be solved by adopting a pulse technique and the use of special shielding gases containing Ar + He + O₂/CO₂. For this welding method, addition of nitrogen to the shielding gas may cause porosity and should be avoided. When welding with SAW, the flux should be of basic type to secure sufficient impact strength.

11. When austenitic-ferritic stainless steels are welded to carbon steels, a filler metal should be chosen with sufficient alloying content to produce an austenitic-ferritic or austenitic weld. The filler can be of austenitic-ferritic stainless steel type or of austenitic 23Cr13Ni2Mo type. In most cases austenitic-ferritic stainless steel fillers are used to provide sufficient strength.

12. When joining different austenitic-ferritic stainless steel grades, the filler that is designed for the higher alloyed grade should be used.

13. Joining austenitic-ferritic stainless steels to austenitic, super austenitic steels and nickel based alloys is also possible. When welding high strength steels to steels with lower yield strength, filler giving at least as high yield strength as the strongest steel should be chosen. Otherwise there is a risk that the strength level in the weld metal is exceeded and fracture may occur in the weld metal at tensile or bend testing.

14. Certain fillers as they are typically used for TIG/MIG welding are presented in Table 1. The selection of the right filler material depends on welding method and grade, as well as environment (for instance low temperature or very corrosive environments).

Table 1

Fillers used for TIG/MIG welding of some common austenitic-ferritic stainless steels.

<i>Grade EN 10028-7</i>	<i>Filler(s) EN ISO 14343</i>
1.4362	23 7 NL or 22 9 3 NL
1.4462	22 9 3 NL
1.4501	25 9 4 NL
1.4410	25 9 4 NL
1.4162*	23 7 NL or 22 9 3 NL

* Not yet in EN 10028-7. EAM-process to be ready during 2011.

Welding of austenitic-ferritic stainless steel, standard grades, 1.4362 and 1.4462

15. The most widely used austenitic-ferritic stainless steel today is 1.4462. The best results can be obtained with the use of designed fillers. Both grades can be welded with high productivity methods (kg/h). For heavy gauge thickness, the use of heat input up to 3 kJ/mm can often be used without impairing weld metal properties.

Less alloyed, “Lean” austenitic-ferritic stainless steel grade(s) like 1.4162

16. This steel is one of the lowest alloyed steel in this group. Members of this group can be TIG welded with or, in certain cases, without filler material. The high strength of the parent material means that the use of filler and/or nitrogen addition in the shielding gas when TIG welded may be necessary.

If high impact strength is required at sub-zero temperatures, slag-forming welding methods giving a large degree of fusion of parent metal (low Ni-content) should be avoided. This is for example the case when SAW is carried out with high input giving a high degree of fusion.

A typically used heat input interval for this steel is 0.3-1.5 kJ/mm. The level is strongly dependent of welding method and material thickness.

High alloyed austenitic-ferritic stainless steel grades like 1.4501 and 1.4410

17. These highly alloyed grades are more prone to intermetallic precipitation in the weld metal. For this reason the heat input should be below 1-1.5 kJ/mm and the interpass temperature should not exceed +100 °C. If welding is done from only one side and the root side will be exposed to corrosive media, it is important to make the root thick and following beads thin with low heat input. This minimizes the amount of detrimental sigma phase in the root. For SAW, the wire should not exceed Ø2.4 mm to facilitate low heat input welding.

Ref: Outokumpu Welding Handbook, pages 88-90.
