Comparison between Stabilised and Low Carbon Austenitic Stainless Steels

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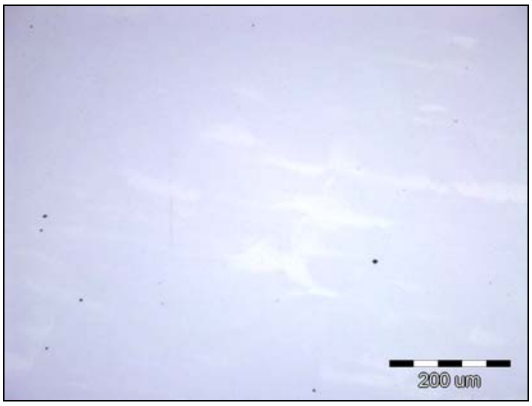
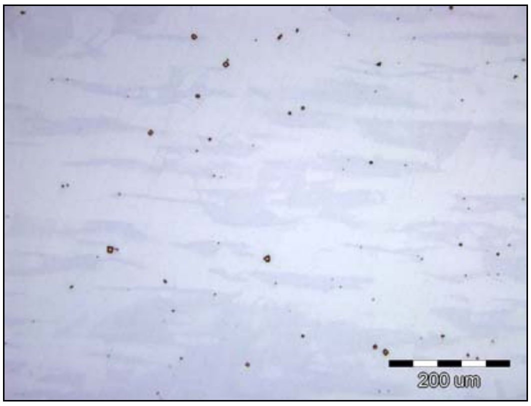
1 Introduction

When the austenitic grades of stainless steel were first developed, steel making technology was not as far advanced as it is today and carbon was difficult to remove from the molten steel. The resultant large amount of carbon in these steels led to the formation of chromium carbides of the type $Cr_{23}C_6$, primarily along the grain boundaries. During the formation of these precipitates a chromium-depleted zone forms around the precipitate since chromium is incorporated into the precipitate faster than it can diffuse from the remainder of the grain to maintain a constant chromium level. When these precipitates are located along the grain boundaries, as they usually are, then accelerated corrosion of the chromium depleted regions can occur, i.e. intergranular corrosion. This is due to the combined effect of

- an unfavourable small anode (chromium depleted region) and a large cathode (remainder of the grain and inert precipitate) area effect
- significantly reduced corrosion resistance of the chromium depleted region.

This carbide formation also known as sensitisation and subsequent intergranular corrosion when exposed to corrosive environments was primarily encountered after welding or high temperature forming processes. The solution consisted in adding another alloying element which would preferentially combine with the excess carbon in the steel, thereby leaving the chromium to perform its function of forming and maintaining a stable oxide layer (passive film). Research showed that strong carbide formers such as niobium and titanium were particularly suitable for this task and resulted in the development of the titanium stabilised types of stainless steel, for instance grades 1.4541 and 1.4571. In general, the "stabilised grades" require a titanium addition of at least 5 times the carbon content of the steel.





Microscopic view to the low carbon (left) and titanium stabilised steel (right). In the case of stabilised grades carbon reacts with titanium to form titanium carbonitrides.
Photos: Acroni, Jesenice (SI)

More recent developments in steel making technology have enabled more economical removal of carbon from the steel, primarily through the development of the argon oxygen decarburisation (AOD) and the vacuum oxygen decarburisation (VOD) processes. Both of these production methods make carbon levels below 0.03 % possible. At these low carbon levels, the steels are generally considered to be resistant to sensitisation, with problems only occurring after prolonged holding times in the critical temperature range, see Figure 1.

From this basic introduction the stabilised and low carbon austenitic stainless steels, it becomes possible to compare the various properties that can be expected from each grade. It must be noted that the same general trends in properties can be expected for other stabilised grades.

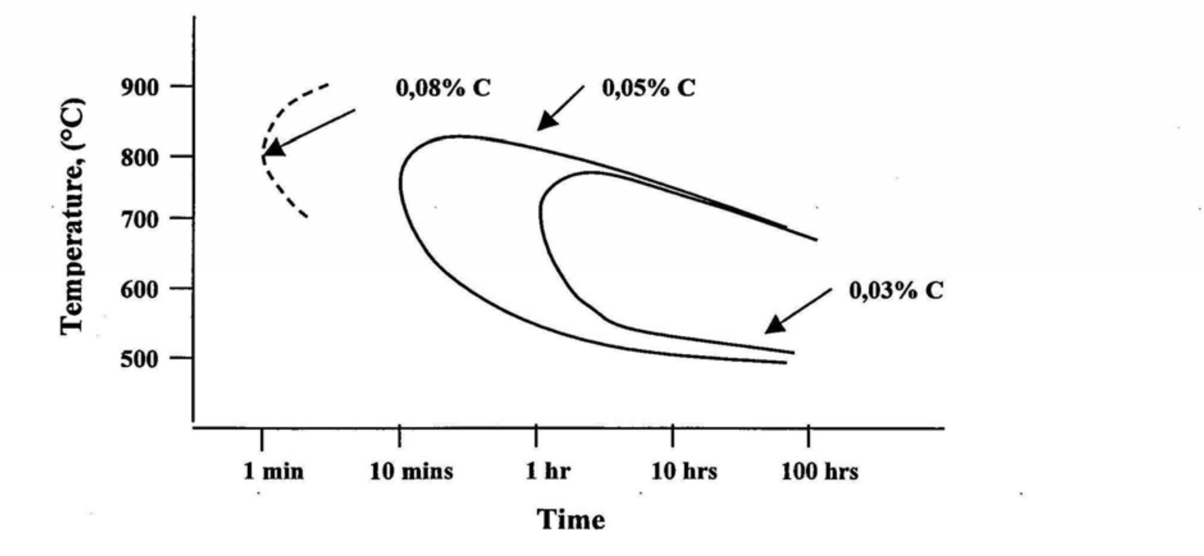


Figure 1: Schematic diagram showing the effect of carbon content on the time to sensitisation

2 Corrosion properties

2.1 Pitting corrosion resistance

Titanium has been found to have a detrimental effect on the pitting corrosion resistance of stainless steels.

2.2 Crevice corrosion resistance

Experimental results have shown that there is basically no difference between the crevice corrosion resistance of the low carbon and Ti-stabilised grades of stainless steel.

2.3 Stress corrosion cracking resistance

Titanium has a negative effect on the resistance of a stainless steel to chloride induced stress corrosion cracking. This finding is not surprising since the negative effect of titanium additions on the pitting corrosion resistance is known and because stress corrosion cracks usually initiate from the base of corrosion pits located in highly stressed regions.

2.4 Knife-line attack and stabilised steels

When stabilised steels, especially titanium stabilised steels are welded, stabilising carbides near the weld dissolve because of the heat input during welding. Subsequent heat input in this area, arising from another weld run or stress relieving treatments for instance, could result in the formation of chromium carbides. This is due to the fact that chromium carbides form more rapidly at temperatures below 850 °C than the titanium carbides are able to reform. The formation of these chromium carbides at some distance from each side of the weld bead gives rise to a narrow zone which is susceptible to intergranular corrosion. This form of corrosion is referred to as knife-line attack (KLA) and is only encountered with stabilised stainless steel grades.

Low carbon steels are preferred option when corrosion properties play a vital role
Photo: Niezgodka, Hamburg (D)

3 Mechanical properties

Due to the detrimental effect of titanium additions on e.g. surface finish, steel manufacturers have reduced the carbon and nitrogen contents of their stabilised grades to very low levels in order to reduce the amount of titanium required for full stabilisation.

3.1 Strength at elevated temperature

Stabilised steels are usually welded with consumables, which are alloyed with niobium. This is because titanium volatilises rapidly in the welding arc and will thus be lost i.e. will not enter the weld pool in sufficient quantities to affect adequate stabilisation. It must be noted that low carbon welding consumables can also be used to successfully weld the stabilised austenitic grades. Care must be taken however with low carbon filler metals. These are not recommended for high temperature conditions because their strength at higher temperatures is considerable lower than that of the stabilised steels.

3.2 Impact properties and toughness

Additions of titanium to steel result in the formation of large, cubic Ti (C, N) precipitates which decrease the impact toughness primarily because these precipitates act as crack initiators. This decrease in impact toughness may even occur at titanium contents below those required for stabilisation. In addition to this effect, excess titanium additions also adversely affect ductility due to the solid solution strengthening effect of titanium. This reduced ductility also results in reduced cold formability when compared with the low carbon grades. In stainless steel long products, the stabilised grades are inferior to the low carbon grades in cold heading applications since the steel is not just cold formed, but also subjected to impact during the forming operation. So it becomes clear that the low carbon grade will be far more suited for cold heading applications than the stabilised grades.

Stabilised steels are suitable for higher temperatures, because of higher strength
Photo: Schubert & Salzer, Ingolstadt (D)

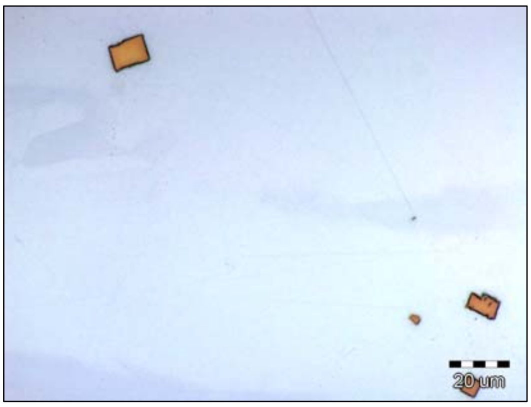
4 Processing properties

4.1 Machinability

The formation of titanium carbonitrides in stabilised grades alters the machinability of the stainless steel compared with the low carbon titanium free variants because these hard particles increase tool wear and reduce the optimal cutting / machining rates.

4.2 Polishability

The presence of the hard titanium carbonitrides, which form in the stabilised grades of stainless steels make these steels unsuitable for polishing, due to the comet trails that form during polishing when these hard particles are removed from the matrix and dragged across the surface being polished. Since the low carbon grades do not contain titanium, no titanium carbides and nitrides can form making these grades readily polishable.



Hard titanium carbonitrides in the stabilised steel
Photo: Acroni, Jesenice (SI)

4.3 Non-metallic inclusion content

Due to the presence of titanium carbides and nitrides in the stabilised grades of stainless steel, their inclusion content will be higher than those of the low carbon stainless steel grades – all else being equal. In most instances the difference in inclusion content is not critical, but in some applications this difference might be noted.

4.4 Weldability

A common misconception exists that the stabilised stainless steel grades are easier to weld than the low carbon grades. This is not correct however and both the stabilised and low carbon grades can be readily welded using all common techniques.

5 Conclusions

Due to improvements in the production of stainless steels, low carbon variants (such as **grade 1.4404**) have replaced the titanium stabilised grades of stainless steel (such as **grade 1.4571**). In addition to minimising the possibility of sensitisation during welding or high temperature processing, the low carbon (≤ 0.03 %C) grades have overcome the surface problems commonly experienced with the titanium stabilised grades. Despite this and the other benefits that the low carbon grades offer, **grade 1.4571** continues to be used as a "traditional" stainless steel grade. This is primarily true within the chemical industry in some European countries, where the cost of changing the specifications on design drawings are keeping the steel grade alive.

As a conclusion, it can be stated that the use of **grade 1.4571** over **1.4404 and 1.4541 over 1.4307** is only technically justified when high temperature strength is a consideration. A summarised comparison between the Ti-stabilised and low carbon stainless steels is presented in the table.

Summarised comparison between titanium-stabilised and low carbon stainless steels[1]

	Cr-Ni grades	Cr-Ni-Mo grades
Property	**Low carbon grade 1.4307 compared to stabilised grade 1.4541**	**Low carbon grade 1.4404 compared to stabilised grade 1.4571**
	Corrosion properties	
General corrosion resistance	=	=
Pitting corrosion resistance	↗	↗
Crevice corrosion resistance	=	=
Resistance against stress corrosion cracking	↗	↗
Resistance against intergranular corrosion and knife-line attack	↗	↗
	Mechanical properties	
Strength at elevated temperature	↘	↘
Impact properties	↗	↗
Cold formability	↗	↗
Cold heading	↗	↗
	Processing properties	
Machinability	↗	↗
Polishability	↗	↗
Surface finish	↗	↗
Steel cleanliness	↗	↗
Weldability	=	=

[1] The table provides an indicative comparison only.

↗ higher rank

↘ lower rank

= equal

6 References

PECKNER, D., BERNSTEIN, I.M., *Handbook of Stainless Steels*, New York: McGraw-Hill, 1977
LULA, R.A., *Stainless Steel,* American Society for Metals, 1986
SEDRICKS, A.J., *Corrosion of Stainless Steels*, John Wiley and Sons, 1979
ASM Specialty Handbook, Stainless Steels, Davis, J. R. (ed.), ASM International, 1996