

Welding of austenitic stainless steel - Part 2

Welding of austenitic stainless steel - Part 1, dealt with the metallurgy of austenitic stainless steels and some of the welding problems that may be encountered.

Austenitic stainless steels can be welded with all the commercially available welding processes. There are matching filler metals available for most of the austenitic range of alloys, the exceptions being that there is no type 304 filler metal available (this alloy is generally welded with type 308 filler metal) and no type 321 filler due to the problems of transferring titanium across the arc. Type 321 steels are usually welded with a type 347 filler.

Also mentioned in Part 1 was that the austenitic stainless steels are metallurgically simple alloys and room temperature mechanical properties are not significantly affected by variations in the welding procedure. However, increasing the oxygen and ferrite levels will reduce the toughness at cryogenic ( $\sim -196^{\circ}\text{C}$ ) temperatures.

Basic coated manual metal arc electrodes with a controlled short arc length and basic agglomerated submerged arc fluxes are required for best toughness if arc welding processes are used. The steel and filler metal

should be selected with as low a ferrite content as possible, say 1 to 3% for best Charpy-V test results.

Conversely, for best creep resistance an 'H' grade steel should be selected and rutile or acid/rutile electrodes and acid submerged arc fluxes should be used. These improve the creep strength by increasing the titanium and niobium content of the weld metal, forming a greater concentration of grain strengthening carbides.

TIG (GTAW) welding of the root pass must always be carried out with an inert gas back purge to prevent loss of chromium (and hence of corrosion resistance), argon being the gas generally used for this purpose. Nitrogen may be used but there is a risk of the weld deposit absorbing nitrogen, thereby becoming fully austenitic and hot crack sensitive.

Two characteristics of austenitic stainless steels that differentiate them from ferritic steels are the coefficients of thermal conductivity and expansion. Austenitic stainless steels have a low coefficient of thermal conductivity, approximately 1/3rd that of ferritic steel at room temperature and a coefficient of thermal expansion some 30% more than that of a ferritic steel.



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Higher expansions in a narrower HAZ result in higher residual stresses and more distortion. This is a particular problem with thin sheet fabrications where the achievement of the desired dimensional tolerances can be extremely difficult and costly to achieve. The use of accelerated cooling techniques such as copper chills or a freezing gas (the liquid CO<sub>2</sub> low stress-no distortion technique typifies this approach) have been used to reduce distortion to acceptable levels.

One of the main reasons for using an austenitic stainless steel is its corrosion resistance. Whilst this is primarily a function of the chromium content of the steel, carbon also has a major but adverse effect resulting in a form of corrosion known as intergranular or inter-crystalline corrosion (ICC) or weld decay, a localised effect confined to the HAZ.

Carbides present in the HAZ of an austenitic stainless steel dissolve on heating and reform on cooling during the welding heat cycle. Unfortunately, these new precipitates form preferentially as chromium carbides on the grain boundaries, depleting chromium from the region immediately adjacent to the boundary, resulting in a local loss of chromium and a reduction in corrosion resistance. If sufficient

chromium carbides are formed this results in a network of steel along the grain boundaries sensitive to corrosion; the steel has been sensitised. This sensitisation occurs in the HAZ region that has seen temperatures between 600 and 900°C and times that may be as short as 50 seconds.

There are several methods that may be used to overcome this difficulty. A solution heat treatment (1050°C followed by a water quench) will re-dissolve the carbides and these will be retained in solution on rapid cooling. Whilst this will eliminate the chromium depleted regions it is rarely practical to solution-treat complex welded structures.

The most obvious alternative technique is to reduce the carbon content. This has two beneficial effects:

The lower the carbon content, the longer the time required to form the carbides. At 0.08% carbon this time is around 50 seconds; at 0.03% carbon the time required is about eight hours, most unlikely to be achieved during welding!

The lower the carbon content then the fewer carbides there are to form a continuous chromium depleted network. Hence the 'L'



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grades, type 304L, or 316L, are preferred where best corrosion resistance is required.

One other method is the addition of alloying elements that will form carbides in preference to chromium; thus the stabilised type 321 and 347 grades containing titanium and niobium respectively were developed.

Titanium and niobium are very strong carbide formers that precipitate carbides at higher temperatures than those at which chromium carbides will form so there is no carbon available to react with the chromium. However, even these stabilised grades may corrode in a very narrow band close to the fusion line (the so-called knife-line attack) in the presence of hot acids. This is due to the higher and more restricted temperature range at which the niobium or titanium carbides dissolve. The solution, as above, is to limit the carbon to 0.03% maximum.

Welding consumables must also be selected with low carbon content if best corrosion resistance is required. Most arc welding consumables contain less than 0.03% carbon but there are filler metals available with carbon contents of up to 0.10%; these should only be used to weld the 'H' grades of steel where good creep resistance is required.

Although MAG (GMAW) welding is often used it should be remembered that carbon pick-up is possible when argon/CO<sub>2</sub> mixtures are used, particularly if the welding is carried out in the dip transfer mode. Argon/2% oxygen mixtures are therefore generally preferred where best corrosion resistance is required but argon/10% CO<sub>2</sub>/2% oxygen is a good compromise that can be used for a broad range of applications.

The other major service problem encountered with the austenitic stainless steels is that of stress corrosion cracking. This may be caused by strong alkali solutions but it is the halides (chlorides, fluorides and bromides) that are primarily responsible. Cracking takes place in areas of high stress, as the name suggests, and is not therefore confined solely to welds, but it is at and adjacent to welds that stresses approaching the yield point of the metal are found and these present a particular problem.

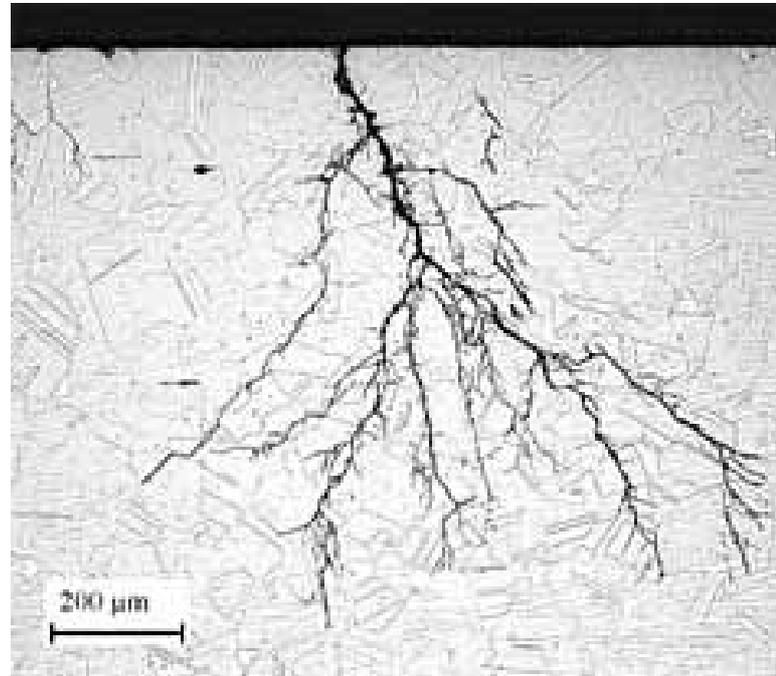
The cracking is transgranular and propagation rates can be extremely rapid given the ideal conditions. In hot concentrated chloride solutions, for example, penetration can occur in thin, sheet components within a few minutes. However, the lower the temperature and/or the acid concentration then the rate of crack propagation is correspondingly slower.

Austenitic stainless steels are therefore not generally used where halides are present. Even here, stress corrosion cracking (SCC) may occur due to contamination, either of the product in the pipe or vessel or externally from sea water, particularly where the liquid is able to concentrate in crevices.

To eliminate any chance of SCC, the only solution is to stress relieve the weld at a temperature of around 700 to 900°C. It should be remembered that:

this may sensitise the steel so only low carbon grades should be used and

the steel may embrittle due to sigma phase formation (see Part 1) at the lower heat treatment temperatures.



Stress corrosion cracking (SCC) in Type 316L stainless steel

Local stress relief should be approached with caution as the temperature gradients may result in stresses developing outside the heated band; wider heated bands and more stringent control of temperature gradients than required by specifications or codes may therefore be necessary. Solution treatment (1050°C soak followed by very rapid cooling, ideally a water quench) will eliminate all residual stresses whilst avoiding both sensitisation and embrittlement but is rarely practical on a welded assembly.



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The alternative is to select a steel that is more resistant; the molybdenum bearing grade type 316 is better than 304 or 321. The ferritic stainless steels are not susceptible to chloride SCC.

This article was written by *Gene Mathers*.