WATER SERVICES ASSOCIATION
of Australia

An information fact sheet by the Water Services Association *of Australia*

SELECTION OF STAINLESS STEELS FOR USE IN THE WATER INDUSTRY

Introduction

Over the last two decades stainless steel has become a widely accepted material for use in the water industry, displacing both coated mild steel components and other less corrosion resistant materials. Whilst many of the components fabricated from stainless steel are giving good service, there have been significant and costly failures through poor selection of the stainless steel grade for the given environment. The WSAA Materials Network has prepared this information to help designers, specifiers, manufactures and users in selecting the correct grade of stainless steel for a particular application. It covers the principal grades that can be used in water and wastewater environments, and should be read in conjunction with Fact Sheet No 3 'Stainless Steel Fabrication'.

What Is Stainless Steel?

Stainless steels are steels that contain enough chromium to form a thin, protective chromium-rich oxide film on their surface when exposed to oxygen in air or water. The amount of chromium required to do this is about 11% and the oxide film that is formed gives a high degree of protection against corrosion. If the film is damaged through, for example, abrasion, the film rapidly reforms in an oxygen containing environment.

There are many different grades of stainless steel with varying amounts of alloying elements such as nickel and molybdenum and it is most important for success that an appropriate grade be chosen for the particular application.

Why Use Stainless Steel?

With the industry under increasing pressure to lower the cost of ongoing maintenance, such as painting, and a push for whole-of-life costing, stainless steel increasingly becomes a viable option. Its corrosion resistance reduces maintenance requirements and it has a long life expectancy.

Grades Of Stainless Steel

The variety of stainless steel grades includes ferritic, martensitic, austenitic and duplex. Features of these grades are outlined below.

- ***Ferritic***—The simple iron-chromium alloys, typically containing between 11 and 17% chromium, have the lowest general corrosion resistance which is generally better than painted or galvanised mild steels. They have very little application in the water industry, although suppliers sometimes propose proprietary brands such as '3CR12 'and '5CR12'. There is little information on their use in totally immersed conditions, and they are not recommended for this application. There is some potential for their use in lieu of galvanised steel in some non-immersed applications such as walkways.

- ***Martensitic***—These are basically ferritic stainless steels which have a higher carbon content and can thus be hardened through heat treatment. They have limited use in the water industry, but grades such as 431 are frequently used for spindles in valves, penstocks and pump shafts.

It is important to remember that neither the ferritic nor the martensitic grades can approach the austenitics in terms of general corrosion resistance.

- ***Austenitic***—These are by far the most widely used and important family of stainless steels: over 85% of total worldwide stainless steel production is either 304 or 316 grade and these are the workhorse stainless steels for the water industry. In the most commonly available annealed condition, these austenitic grades have similar strength to mild steel but with higher thermal expansion coefficients and lower thermal conductivity - aspects that may need to be considered in the design of stainless steel structures. The most important austenitic grades follow:

- ***304***—This is often referred to as '18/8' stainless steel because of the approximate composition–18% chromium and 8% nickel.

It is suitable for most drinking water immersed applications where chloride levels are below an arbitrary value of about 200mg/L. If the material is to be welded, a low carbon variant (304L) or a stabilised grade (such as 321) should be used (see Fact Sheet No 3).

- ***316***—This grade is similar to 304 except for the addition of about 2% molybdenum, which improves resistance to pitting and crevice corrosion in chloride containing waters. Because of this, it can be used in water up to a maximum of about 1000mg/L chloride ion. For welding, it is recommended that the low carbon version(316L) be used.

- ***303***—This is a free machining version of 304 that contains sulphur and is mainly used in the production of fasteners. In water or wastewater it rapidly corrodes and should be strenuously avoided. More recently, 'improved machinability' versions of 304 and 316 have been developed and these do not suffer from the poor corrosion properties of 303.

- ***Duplex***—As their name suggests, these are stainless steels with a mixed ferritic/austenitic structure. The most common grade of this type is 2205. This is more expensive than 316 but has the benefits of much higher strength, better resistance to chloride stress corrosion cracking and improved resistance to pitting and crevice corrosion. In more demanding applications, these can be useful benefits.

- ***Other grades of stainless steel***—There are various so-called 'super austenitic' grades such as the 6% Mo alloys and 'super duplex' grades such as 2507, as well as the exotic precipitation hardening stainless steels such as 17-4PH. These are invariably expensive and are seldom available 'off the shelf'. In the water industry, their use would be restricted to extremely corrosive conditions where superior corrosion resistance and/or strength is required, such as some critical off-shore ocean outfall components.

General comparison

The ferritic, martensitic and duplex grades of stainless steel are magnetic while the austenitic grades are not. This can be used in the field to differentiate the austenitic stainless steels although it should be noted that austenitic grades can develop detectable magnetism when deformed, such as at bends and cut edges.

Materials Selection—Choosing The Right Stainless For The Job

General Issues: It is imperative to consider basic issues before stainless steel is specified for any purpose in the water industry. The following points are crucial to choosing the right stainless steel for the job:

- Careful consideration of the local environment is fundamental. A grade of stainless steel that is suitable in one location may be a disaster in other regions.

- Good plant design is important—for example, crevices of all types should be eliminated as far as possible.

- High standards of fabrication are essential and it is particularly important that appropriate post-fabrication cleaning be carried out before the structure is put into service.

- Correct commissioning and operating procedures must be followed. The use of incorrect hydro-testing procedures, for instance, has been a source of expensive failures in the industry and this topic is extensively covered in NiDI publication No. 10085, *Microbio-logically influenced corrosion of stainless steels by water used for cooling and hydrostatic testing,*

Water and Wastewater Treatment Plant

On virtually all occasions either 304 or 316 stainless steel or their low carbon variants will be sufficient for submerged use at a water or wastewater treatment plant, particularly under free flowing non-stagnant conditions. Only on a few occasions will a more highly alloyed, and more expensive grade, be required, and this will necessitate specialist advice. Such advice will be needed if it is known, for example, that conditions will be anaerobic, or that the structure will be subject to microbiological attack, or have unavoidable crevices or be liable to elevated temperature or fouling through deposits.

When Should type 304 or 316 be used ?

The local environment is the key issue in material selection. In most water treatment plants with chlorides below 200 mg/L, 304 or 304L will be sufficient. The 200 mg/L figure should be based on maximum chloride levels rather than average values. Sewage is usually more critical, as chlorides are generally higher, therefore 316/316L is recommended. This is particularly relevant in coastal catchments subject to seawater infiltration and other adverse environmental conditions .

It is important to note that pitting and crevice corrosion can occur at lower chloride levels than those mentioned above. This may be due to local environments where the protective film is weakened (such as strongly anaerobic conditions) or where chloride levels can concentrate. A more conservative approach in such situations would be to use 304 up to 50 mg/L and 316 up to 250 mg/L chlorides.

Stainless steels are usually resistant to most chemicals used in water treatment, such as alum, but some conditions and chemicals, such as highly chlorinated water or ferric chloride should not be used with common grades of stainless steels.

Reticulation Systems

Stainless steel is becoming common in such items as repair clamps, valves, pump components and plumbing items.

Burying stainless steel

Where stainless steel is to be buried, 316 as a minimum is recommended. Performance of 316 can still vary greatly depending on the soil conditions. Well-drained soils with high resistivity (some sands) give far better results than waterlogged soil of low resistivity (such as wet clay or estuarine swamps where 316 is not recommended). Stainless steel should be buried in a drained trench that has been backfilled with sand or crushed aggregate. Additional corrosion protection is not normally recommended for buried stainless steel as a product such as petrolatum tape can induce crevice corrosion unless it is applied with great care. If there are situations where this is necessary, petrolatum tape systems (primer, mastic, tape and overwrap) are preferred. Following wrapping these should be spark tested to ensure the wrapping is complete.

Fasteners

Galling (micro welding) is sometimes a problem with stainless steel threaded components. The former belief that that this problem could be overcome by the use of a 316 bolt and a 304 nut, is a myth and in some cases can result in corrosion of the nut in high chloride environments. The problem can be minimised by the use of anti-seize treatments such as: PTFE coatings; rolled threads (as opposed to cut threads); a nut of significantly greater hardness than the bolt (eg a duplex stainless steel nut); and ensuring that fasteners are not over-torqued. Fasteners by their very design are prone to crevice corrosion but it has been shown that the application of a thread sealant such as a neutral cure silicone sealant will minimise this effect. If thread sealants are used, excess material should be removed after the completion of the joint.

Costs

In real terms, stainless steels are *one third* the cost they were in the late 1960's, which in part explains why they are increasingly used in the water industry. Using whole-of-life present value calculations, it can often be shown that the choice of low maintenance stainless steel has considerable cost savings over more conventional painted or galvanised mild steel alternatives.

The price of stainless steel can, however, fluctuate widely depending on the price of alloying additions and general supply/demand. Depending on section and order size, grade 304 usually varies between $4.00–$6.00 per kilo, with 316 being about 25% more expensive for a given section.

Stainless Steel Failures

Localised failure is the most common form of corrosion failure in stainless steel. The principal modes of failure, and their avoidance, are summarised below.

- ***Crevice Corrosion***—Intense localised corrosion frequently occurs within crevices and other shielded areas on metal surfaces exposed to a corrosive environment. This is the cause of most stainless steel failures in the water industry. Crevices can be present as a result of poor design, such as overlapping metal surfaces that have not been sealed, poor fabrication, such as undercuts during welding, or operating conditions, such as the formation of deposits on stainless steel surfaces. To minimise opportunities for crevice corrosion, all of these aspects need to be addressed. It is generally the chloride ion that drives crevice corrosion of stainless steel, therefore the correct grade specification is very important using the guidelines outlined in this Fact Sheet. Adhesive labels and coatings on stainless steel can also induce crevices and these should be removed or avoided.

- ***Pitting Corrosion***—Pitting is a form of extremely localised corrosion that results in perforation of the metal. Pitting usually requires an extended initiation period before visible pits appear. However, once started, a pit penetrates the metal at an ever-increasing rate. It can occur on stainless steel surfaces in high chloride conditions or with chemical additions such as ferric chloride. Correct grade selection and careful process operation will alleviate the problem

- ***Weld Decay***—The most common form of this problem is when chromium carbides form in the heat-affected zone during welding. The stainless steel is then said to be sensitised and can fail due to intergranular corrosion. The problem is easily overcome by selecting the low carbon (eg. 304L) or stabilised (eg. 321) variant of the grade.

- ***Stress Corrosion Cracking***—This is rarely found in the water industry, but can be a problem in items such as solar hot water systems when a combination of high chlorides, high temperatures and mechanical stresses are present with austenitic stainless steels. The problem can be solved through using more resistant grades such as the duplex series of stainless steels.

- ***Galvanic Corrosion–***A potential difference usually exists between two dissimilar metals placed in contact (or otherwise electrically connected) and immersed in a corrosive solution. Corrosion of the less corrosion-resistant metal (anode) is increased and attack of the more resistant metal (cathode) is decreased. The driving force for current and corrosion is the potential developed between the two metals. Stainless steel generally becomes cathodic to most other commonly used metals, and because of its protective oxide forming tendency a very inefficient cathode. Galvanic corrosion involving stainless steel is thus, in fact, rare. It is generally only a factor in submerged or buried service where it should be insulated from other less corrosion resistant metals such as mild steel or galvanised steel. However, for atmospheric exposure stainless fasteners in most cases can be used quite satisfactorily with aluminium alloy or galvanised steel structures such as handrails, as the surface area of the stainless steel cathode in such situations is very small and inefficient in providing a corrosion current. The exception is in marine coastal applications where some instances of galvanic corrosion have occurred on aluminium structures. In these situations the use of sealants or insulation is recommended. While sealants applied to the contacting surfaces do not normally provide electrical insulation, in severe atmospheric situations they will exclude water and salt from the joint and thereby prevent galvanic corrosion. Another important point to note is that there is *no* significant galvanic action between different grades of stainless steel, e.g. 304 and 316.

- ***Microbiological Influenced Corrosion (MIC)***—Bacteria is not capable of attacking stainless steel. However when present in biofilms and tubercles, the microbes (which can be anaerobic or aerobic) may form acids or concentrate chlorides that can attack the stainless steel substrate.

MIC is unlikely to be found in flowing, treated potable waters or on properly fabricated stainless steel components, free of crevices and heat tint. Conversely, stagnant, raw or untreated waters or where sludges can deposit may promote MIC so such conditions should be avoided. Where they cannot be avoided, select more highly alloyed stainless steels.

Maintenance

A major reason for using stainless steel is to avoid the periodic maintenance that is a feature of mild steel structures, and to reduce the risk of premature failure of key components in a water system. In most flowing, aerated systems minimal maintenance of stainless steel is needed, such as removing any build up of dirt and sludge in crevices. In marine atmospheric exposure, stainless steel will often show surface rusting that is unsightly but rarely fatal if the correct grade (such as 316) has been selected. Frequent wash down with fresh water or occasional chemical cleaning with pickling or passivating solutions will correct the appearance if this is desired.

References

This fact sheet gives only broad information. There are a host of references for more detailed reading on stainless steels, some of which are as follows:

- WSAA Fact Sheet No 3: *Stainless Steel Fabrication*, (2000).
- *Applications for Stainless Steel in the Water Industry* published by Steel Construction Institute in association with Avesta Sheffield and NIDI, (1999).
- *ASSDA Reference Manual*, (1998).
- *Metals Handbook. 9th Edition* Volume 13 'Corrosion' p547 onwards ASM, (1987).
- *Corrosion Tables*, published by JERNKONTORET, Sweden, (1979).
- *Microbiologically influenced corrosion of stainless steels by water used for cooling and hydrostatic testing*, NiDI publication No. 10085.

Useful Web Sites

www.assda.asn.au

www.nidi.org

www.bssa.org.uk

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