HANDBOOK OF OCEANOGRAPHIC ENGINEERING MATERIALS

STEPHEN C. DEXTER

College of Marine Studies
University of Delaware
Lewes, Delaware

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Chapter Six

STAINLESS STEEL

The class of materials commonly called stainless steels is probably the most misunderstood and misapplied of all the groups of metallic alloys. It consists of the iron based alloys to which 12% or more of chromium is added. The materials are resistant to uniform rusting, hence the name "stainless." As in the case with aluminum alloys, their corrosion resistance depends on a thin oxide film that isolates the material from the liquid environment. The film is quite resistant to fresh water and salt spray, but when fully immersed in seawater the film is attacked and disrupted at local sites by chloride ions. This makes the material susceptible to severe localized forms of corrosion such as pitting, and crevice and intergranular corrosion, which often result in holes all the way through the section thickness, while leaving the rest of the surface untouched.

Of the commonly available stainless steels, only the 300 series containing about 18 wt % chromium, 8 to 12% nickel, and up to 3% molybdenum are suitable for marine service—types 304 and 316 having the highest volume of usage. These alloys give excellent service above the waterline, but their lifetime is limited under fully immersed conditions by the tendency to undergo severe pitting and crevice corrosion. The misapplication of stainless steels (e.g., as hardware and fasteners) to situations requiring full immersion for long periods often leads to sudden, unexpected failures and disastrous results.

Table 6.1 lists several of the commonly available series 300 stainless steels in order of increasing corrosion resistance, along with their maximum recommended duration of continuous, fully immersed service. These recommended service times are based on more than 30 years of experience with stainless steels in seawater; 8 years of this period includes my personal experience with stainless steel hardware and fasteners on oceanographic instrumentation in the deep North Atlantic Ocean. The times represent maximum durations of continuous exposure over which the bare, unprotected alloy can be relied on. After exposure for these maximum times, a large percentage of hardware items will be sufficiently damaged by crevice corrosion to warrant their replacement before a subsequent deployment of the same piece of equipment. If the cross-sectional area of a load-bearing part is less than about 20 mm², the maximum exposure time should be shortened by 50%. The times can be extended by cathodic protection from a sacrificial anode, but bear in mind that each piece of hardware to be protected must be in electrical contact with the anode.

Less corrosion-resistant alloys such as the 400 series stainless steels and type 303 should not be used in fully submerged seawater applications. If there is some doubt about the identity of a particular piece of stainless, the 300 and 400 series can easily be distinguished by using a magnet. All members of the 400 series are magnetic, whereas all 300 series alloys are nonmagnetic. Type 303 stainless steel, the free machining grade usually used for manufacturing threaded fasteners, is very poor in seawater resistance. The reader should be warned that type 303 is sometimes substituted by the supplier even when type 304 or 316 has been ordered specifically.

Another pitfall to be avoided when ordering stainless steel hardware for seawater applications is the use of items manufactured by powder metal technology (sintering). In this manufacturing technique the metal is supplied to the fabricator in the form of a finely divided powder, which is then pressed into the final shape under high temperature and pressure, causing the individual particles of the powder to fuse together. The technique is economically attractive for making small complex shapes such as fasteners because there is no waste and no subsequent machining is needed. Such products, however, nearly always have some

TABLE 6.1 300 SERIES STAINLESS STEELS

Type	Nominal Composition (%)	Maximum Continuous Immersion (months)
303	18 Cr, 9 Ni, 0.15 S	Not recommended
302	18 Cr, 9 Ni	4
304	19 Cr, 10 Ni	4
316	18 Cr, 12 Ni, 2 Mo	6

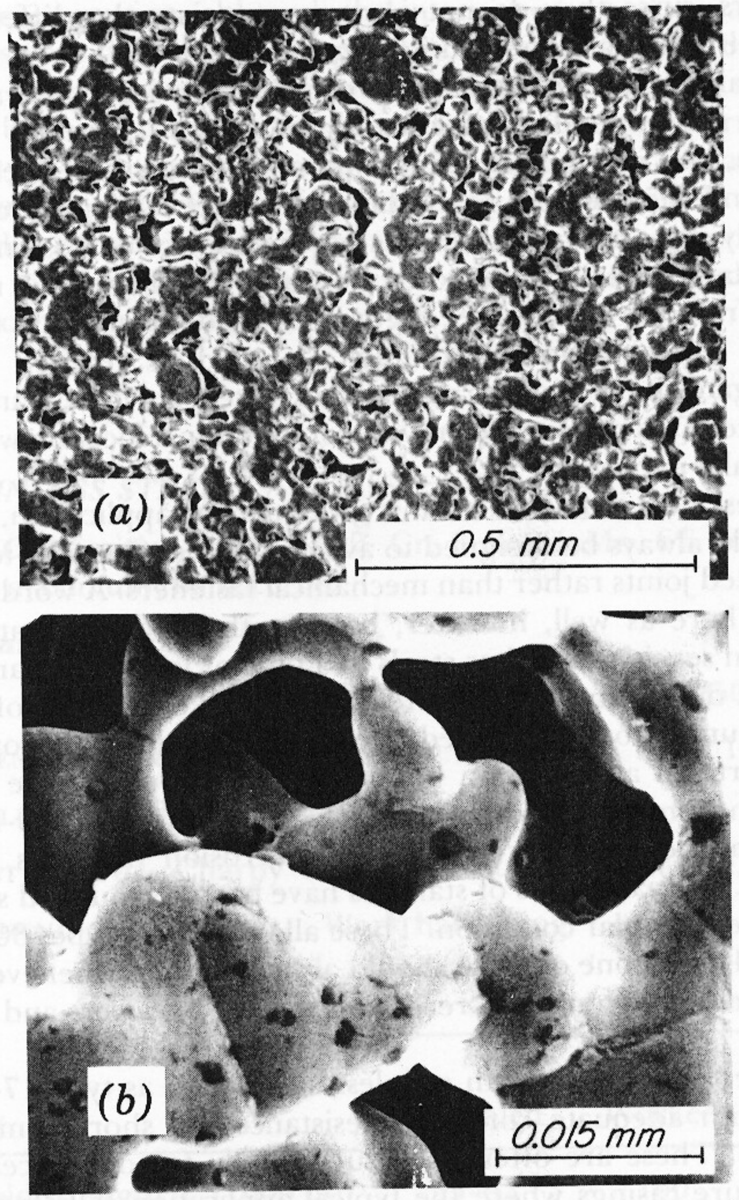

Figure 6.1 Scanning electron micrograph of the surface of a type 316 stainless steel part manufactured by sintering. (*a*) Low magnification view showing the porosity that often results from this manufacturing technique. (*b*) Higher magnification view within a single pore. Such sites are ideal locations for crevice corrosion to initiate.

porosity as shown in Figure 6.1, and this makes then highly susceptible to severe crevice corrosion.

The solution to both the problems just outlined is to make sure the supplier understands that you must have a wrought rather than a sintered product, and that you will not accept any alloy other than the one specified on the order. It is often wise not to buy from small local distributors, since they do not always appreciate the differences that such seemingly minor substitutions can make.

Small stainless steel parts can give excellent service in seawater if their maximum recommended exposure times are not exceeded in any one immersion, and if the equipment can be taken apart frequently for inspection and replacement of all damaged parts. Complete disassembly is especially important when inspecting for crevice corrosion, since this type of attack starts at inside surfaces, and the damage is not usually apparent from the outside (see Figure 1.2). If deployment is to be made in shallow waters prone to fouling, it should be realized that hard-shelled organisms such as barnacles can create a crevice on an otherwise free surface. This can lead to crevice corrosion in a location where it was not originally expected.

If stainless steel must be used in a given marine application, the equipment should always be designed to avoid crevices. One way to do this is to use welded joints rather than mechanical fasteners. A word of caution is needed here as well, however, because the heat generated during welding can sensitize stainless steels to a type of intergranular corrosion called weld decay. In the heat affected zone on either side of the weld, the chromium becomes depleted due to precipitation of chromium-rich carbide particles at the grain boundaries. The bulk of the alloy in a narrow band on either side of the weld is not stainless any longer because of the depleted chromium, and corrosion proceeds rapidly in these areas. Special grades of stainless have been formulated specifically to resist intergranular corrosion. These alloys include types 304L, 316L, 321, and 347, and one of these should always be used whenever welding is anticipated. They are less readily available, however, and more expensive.

A number of high strength stainless steels such as type 17-4 PH are available with adequate corrosion resistance for short-term seawater immersions. These are often used successfully for deep ocean instrument pressure casings where the typical application calls for repeated exposures of 2 to 6 hr with ample time for inspection and maintenance in between. For these short exposures, no corrosion protection is necessary, and the metal is left bare. The 400 series stainless steels, even though they may have adequate strength for pressure casings, have insufficient seawater corrosion resistance even for short immersions and should not be used.

Several stainless steels, some of them recently developed, are claimed to have increased corrosion resistance as compared to conventional types 304 and 316. Among these are type 216, type 22-13-5 (Nitronic 50), A-286, alloy 20, type 26-1, and type 6X. All these are subject to pitting and crevice corrosion, although the intensity of attack on alloy 20 and type 6X is considerably less. Types 216, 22-13-5, and A-286 should be about the same as type 316 in corrosion resistance, but they are stronger and may be more cost effective in situations where the corrosion resistance of type 316 would be adequate. Type 26-1 has the advantage of being immune to stress corrosion cracking in hot clorides but is magnetic, and is no more resistant to pitting and crevice corrosion than is type 316. All these alloys are more expensive and less readily available than the common grades.

216 STAINLESS STEEL. Austenitic; nonmagnetic.

Nominal Composition. 19 to 20% Cr, 8 to 9% Mn, 6% Ni, 2.5% Mo, 0.08% C maximum, balance Fe.

Physical and Mechanical Properties

DENSITY. In air, $\rho = 0.287$ lb/in^3; in seawater, $\rho_{sw} = 0.250$ lb/in^3.

COEFFICIENT OF THERMAL EXPANSION (20 TO 100°C). 8.5×10^{-6} in/in·°F.

FATIGUE LIMITS. 62,500 psi at 10^7 cycles in dry air.

IMPACT STRENGTH. Charpy V-notch at room temperature, 223 ft·lb.

STRENGTHENING MECHANISM. Work hardening.

	Condition		
Property	Annealed	25% Cold Worked	60% Cold Worked
0.2% Yield strength σ_y (1000 psi)	55–62	160	226
Tensile strength σ_u (1000 psi)	100–108	180	247
Elongation (% in 2 in.)	30–53	15	0.5–3
Hardness (Rockwell)	B92	nav	nav

Behavior in Natural Seawater

ELECTRODE POTENTIAL. −0.007 to −0.440 V, with a mean potential of −0.136 V (Ag-AgCl scale).[38]

TYPES OF CORROSION SUFFERED. Same as types 304 and 316 stainless steel.