High-Strength Marine Metals Part 1 - Stainless Steel

Why Stainless Steel is Not the Ideal Marine Metal

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Whether you're running a full-service yard or marina, surveying boats, or supervising new construction, these days–more than likely–if you think of fabricating or purchasing a piece of strong (high-strength) metal hardware for a boat, you'll think stainless. Stainless is, in fact, a superb alloy. It's is certainly strong and appears corrosion resistant. It's also widely available. As we'll see, however, stainless steels have some serious and not well understood drawbacks.

Stainless Anchor and Chafe Pads

The common stainless alloys for marine use are listed in the composition table below.

All these stainless steels contain about 2% manganese and 1% silicon. They also all have between 17% and 20% chromium. In fact, the steels in this group are often referred to as "18-8 stainless" because they're roughly based on adding 18% chromium and 8% nickel to steel to reduce corrosion and increase strength. You can see from the table, however, that more corrosion resistant alloys have higher nickel contents. Properly, only 302 and 304 are true 18-8 stainless. The better stuff (316, 317, 321) has more nickel, also molybdenum, and even titanium. (Well look at Aqualoy 22 later.) Engineers–always fond of catchy terms–refer to this whole group as "austenitic" stainless steels. This just means that they are alloyed with nickel and chromium and are thus non-magnetic and corrosion resistant. (The term is in honor of Sir William Chandler Roberts-Austen, a British metallurgist.) Whatever they're called, 302, 304, 316, and 317 stainless all have a tensile strength of about 75,000 psi and a tensile yield of 30,000 psi–a high average for structural metals.

Composition of Marine Stainless Steel Alloys

Type	C	Mn	P	S	Si	Cr	Ni	Mo	Ti
302	0.15 max	2.00 max	0.045 max	0.030 max	1.00 max	17.0 to 19.0	8.0 to 10.0	-	-
304	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	18.0 to 20.0	8.0 to 10.5	-	-
304L	0.03 max	2.00 max	0.045 max	0.030 max	1.00 max	18.0 to 20.0	8.0 to 12.0	-	-
316	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	16.0 to 18.0	10.0 to 14.0	2.0 to 3.0	-
316L	0.03 max	2.00 max	0.045 max	0.030 max	1.00 max	16.0 to 18.0	10.0 to 14.0	2.0 to 3.0	-
317	0.08 max	2.00 max	0.045 max	0.030 max	1.00 max	18.0 to 20.0	11.0 to 15.0	3.0 to 4.0	-
317L	0.03 max	2.00 max	0.045 max	0.030 max	0.75 max	18.0 to 20.0	11.0 to 15.0	3.0 to 4.0	-
321	0.08 max	2.00 max	0.040 max	0.030 max	1.00 max	17.0 to 19.0	9.0 to 12.0	0.75	6 x C%
Aqualoy 22	0.03 max	5.00	0.040 max	0.030 max	1.00 max	22.0	13.0	2.2	-

Values are percentages

302 and 304

Sadly, a large portion of the stainless fittings and hardware you buy will be made of either 302 or 304 (plain 18-8 stainless). These alloys work fine for interior hardware. They really have no other place on a boat, however. Both 302 and 304 stainless are subject to rust spotting. In fact, on two of my boats–a 42- and a 50-footer–custom bow and stern rails were made up from 302. The result was that–in mere days–they showed rust staining and spots–not exactly "stainless!"

Stainless Chainplates, Toggles & Turnbuckles

This brings us to another drawback with stainless steels: How can you tell which alloy of stainless you have? I've never found a good answer to this question. The builders of these boats had specifically ordered 316 for these rails per my instructions. Nevertheless, somehow, the fabricator had used 302. Of course, new all-316 rails arrived as replacement at no cost, but all this is unwanted hassle.

Still, rust spots are merely a cosmetic problem. 302 and 304 stainless also suffer from potential structural failures. Indeed, all stainless alloys can potentially suffer from pitting and crevice corrosion underwater–severe pitting and crevice corrosion.

Stainless and Oxygen

The reason for this is stainless protects itself from corrosion by interaction with the oxygen dissolved in seawater. This forms a protective oxide film. By comparison, bronze, Monel, copper, and copper-nickel corrode very slightly faster if they loose this film, but will still remain extremely corrosion resistant.

Stainless steels, on the other hand, rely almost entirely on this oxide film to protect them from corrosion. When stainless is in clean flowing water containing plenty of oxygen, it has no difficulty generating and retaining its protective oxide film. In this condition, it's highly cathodic (noble)–a state that's also called passive–and is highly corrosion resistant. If you deprive stainless of a regular supply of oxygen, however–for instance, pressed against a rudder bearing; smothered by barnacles; or enclosed in a stern tube–it looses its protective oxide film. In these conditions, without the protective oxide film, it becomes "active," and can suffer badly from pitting and crevice corrosion.

Stainless Anchor Chain Failure At Welds
Photo Connie McBride/Sail Magazine

Stainless Welding Concerns

Another problem with stainless occurs during welding. Most of 300-series steels have a moderately high carbon content–from 0.08% to as high as 0.25%. The trouble with this–for marine use–is that, when the steel is heated in welding, the carbon mixes with the chromium to form a chromium carbide. (Sounds like we're getting deep into chemistry here, but hang on for a moment.) The result is you end up with a welded metal fitting with two sub-alloys formed inside: chromium carbide and chromium depleted stainless right next to it. These alloys are different enough to corrode each other (they form a galvanic couple in seawater).

This is why you should not "strengthen" a stainless steel rudder stock by welding a pipe sleeve round the outside to make it thicker. Visually, the increased outside diameter makes such a rudder stock appear much beefier and more robust. In reality, the welds are all too likely to suffer from pitting corrosion due to the internal chromium carbide formation. Such pitting corrosion has lead to some truly spectacular failures.

Further, most stainless rudder stocks have steel plates or fingers welded to them and embedded in the rudder-blade's core. The purpose of these structures is to transmit the torque from the rudder stock into the blade itself. Of course–as long as the weld is sealed away from seawater inside the stock it's fine. If any water seeps in, though—and this happens more often than

The Galvanic Series

A galvanic couple forms when two metals are electrically connected to each other in the boat or internally, while immersed in an electrolyte, in our case, seawater. When a galvanic couple forms, corrosion problems will soon follow. It's critical that all metals used below the waterline on a boat be no more than 200 millivolts apart on the galvanic table or galvanic series. Refer to the galvanic series on page 3.

The Galvanic Series

ANODIC OR LEAST NOBLE END (Active)	Millivolts (mV)
Magnesium (Mg)	-1730
Magnesium (2% Manganese (Mn))	-1670
Magnesium (9%Aluminum (Al), 1% Mn,1.5% Zinc (An))	-1580
Galvanized Iron (hot dipped)	-1140
Zinc Electroplating	-1130
Cadmium (Cd) Zinc Solder (71%/29%)	-1120
Zinc (Zn)	-1050
Cadmium (Cd)	-860
Cadmium Plated Steel (Cd 0.001 in.)	-860
Aluminum (Marine Alloys 5086, 5083, 6061)	-820
Mild or Structural Steel(A36)	-790
Alloy Steel	-740
Aluminum (forged alloy)	-730
Stainless Steel (316,317,321,347,302,304 — active, oxygen starved)	-550
Tin (Sn)	-500
Manganese Bronze, CA-464 Naval Brass (58%Cu,39%Zn,1%Alum,0.25%Mg)	-450
Naval Brass (60% Copper, 39% Zinc)	-450
Yellow Brass	-450
Admiralty Brass (70% Copper, 29% Zinc)	-360
Copper CA-110 (Cu)	-340
Brass (60% copper, 40% zinc)	-330
Gunmetal (88% Copper, +Tin)	-310
Silicon Bronze (96% Copper, 1.5% Silicon)	-260
Tin Bronze	-260
Lead (Pb)	-240
Copper/Nickel (CA-715 - 70% Cu, 30%Ni)	-200
Aluminum Bronze (90% Copper, 10% aluminum)	-150
Stainless Steel (316,317,321,347,302,304 — passive, oxygenated)	-150
Monel 400 & 500	-110
Titanium (Ti)	-100
Silver (Ag)	-80
Graphite and Carbon Fiber (C)	(+250)
Platinum (Pt)	(+260)
CATHODIC OR MOST NOBLE END (Passive)	Millivolts (mV)

- All measurements taken relative to a silver:silver chloride (Ag/AgCl) electrode, at 77˚ F.
- The sign of potential applies with the negative (black) probe of the voltmeter connected to the reference electrode, and positive (red) terminal connected to the fitting being tested
- If using a zinc reference electrode, add 100 mV to the potential. For instance, silicon bronze is - 260mV, then + 100 mV = -160 mV.
- Average variability of potential is ±40 mV for alloys with iron and/or nickel. ±20 mV for copper-based alloys without nickel.
- Readings 200 to 400 mV more negative (more anodic) than given indicate the material is protected.
- Readings at or near those given, up to 200 mV above those given, indicate the material is unprotected and freely corroding.
- Readings over 400 mV more negative than given indicate overprotection.
- Stray current corrosion is indicated by metals reading more cathodic (more positive) than indicated on the table.

not—you have exactly the worst possible situation in terms of stainless corrosion—stainless in stagnant seawater with little oxygen. The welds can suffer from amazing pitting and fail.


Stainless Steel Cleat Showing Corrosion Cracking
Photo Connie McBride

Low-Carbon Stainless

One solution is to reduce the amount of carbon in the alloy. This is what the "L" stands for in 304L and 316L stainless—for "low carbon." You can see from the composition table (page 3) that these alloys have 0.03% carbon content or less, thus higher resistance to corrosion after welding. Another slightly more exotic approach is 321 stainless. 321 has titanium added. The titanium mixes with the carbon more readily than the chromium, which prevents the formation of chromium carbide.

If you have to use stainless underwater–especially a welded fitting–be very sure to use only 316L or 317L. Though you may hear otherwise, none of the other 300 series (18-8) stainless is up to the job. Stainless steel fuel tanks must be of only 316L or 317L, and welded with the TIG process, per ABYC. An even better alloy (not ABYC approved) is 321 stainless. ABYC has now approved stainless steel for diesel, not for gasoline fuel tanks. The one exception is that ABYC does permit stainless gasoline tanks if they are less than 20 gallons (75 l), are of cylindrical construction, and have domed ends. I personally can't see any reason to use such small stainless gas tanks. Polyethylene tanks are available in many shapes in this size range and are much superior for this application.

Special Stainless Steels

There are marine stainless alloys that don't fit in the standard 300 series. Probably the best known of these is known as Aquamet 22, Aqualoy 22, or as Nitronic 50 (nearly all the same composition). These are proprietary steel alloys. They are steel alloyed with about 21% chromium, 12% nickel, and 2% molybdenum. Aquamet 22 or Aqualoy 22 have almost become the "standard" prop shaft material for top-quality installations. They are very corrosion resistant and have a tensile strengths of over 100,000 psi. I have a slight preference for Monel shafts–especially–with a bronze or NiBrAl propeller, but Aquamet or Aqualoy is darn good stuff, and I'm happy to see it installed on any boat. Under the Nitronic 50 name, this basic alloy is the standard material for much of the rod rigging installed on performance sailboats. Aquamet-22 also make a reliable rudder-stock material as well as excellent keel bolts.

Other special stainless–usually used in high strength rigging components–are alloy 17-4 and 17-7. These are stainless with 17% chromium and 4% to 7% nickel. With tensile strengths over 170,000 pounds, these are high-strength alloys indeed. Nitronic 50 and the 17-4 or 17-7 stainless in a fitting are a sign of the utmost in high-tech engineering.


42-foot, ocean-going, beachable, tunnel-drive motorcruiser *Belle Marie,* designed by Dave Gerr