Corrosion Evasion: Part 2

Corrosion risks in stainless steel and aluminum.

TEXT AND PHOTOGRAPHS BY STEVE D'ANTONIO

Installing hardware on an aluminum spar requires careful measures to seal out water that can promote corrosion of aluminum and stainless if it becomes stagnant and oxygen starved, or set up galvanic action between the dissimilar metals.

We continue our primer on corrosion vulnerabilities of common marine metals from Part 1 in *Professional BoatBuilder* No. 212.

Stainless Steel

Since its accidental discovery nearly 100 years ago, stainless steel has become a fixture in everything from automobile and household appliance manufacturing to skyscraper trim and turbine blades. Of course, it's also well known to boat builders, yards, and owners. The average vessel is simply riddled with a range of stainless-steel alloys that support everything from propellers (stainless-alloy propeller shafts) to headliners (stainless-steel staples).

The primary alloy in stainless steel is humble and familiar iron. To this mundane and plentiful element, more exotic alloys such as chromium and nickel are added, giving stainless steel its corrosion-resistant properties. The chrome enables the metal to form a tough oxide film as soon as, and for as long as, it's exposed to oxygen. This film exists even while submerged as long as the water contains oxygen. Adding nickel increases the steel's resistance to acid. Depending on the role it will be called upon to fill—architectural trim, cutlery, or bow rails, for instance—differing primary elements in varying amounts are added, along with traces of more exotic materials such as columbium and tantalum.

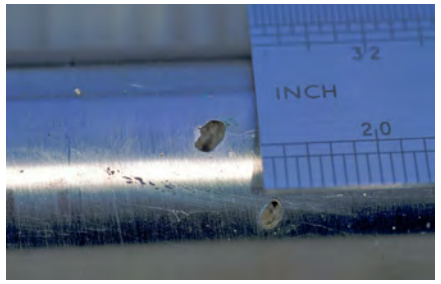
Essentially, there are three subgroups of stainless steel: martensitic, which is often used for cutlery, many fasteners, and turbine blades; ferritic, used for automotive trim applications; and austenitic, which is best suited to the marine environment. Of the three, high nickel content (6% or more) is exclusive to austenitic or marine-grade stainless, which is further categorized into two popular alloys, designated by the American Iron and Steel Institute as 300 series. For recreational marine applications, the most common of these are 304 and 316. The alloy ratio used in 304 stainless steel consists of 18%-20% chromium and 8%-12% nickel, which is added to conventional carbon steel. For this reason, 304 stainless steel is often referred to as 18-8. The alloy ratios for 316 stainless steel, on the other hand, are 16%-18% chromium and 8%-12% nickel, as well as 2%-3% molybdenum. The final ingredient aids 316's ability to resist a phenomenon referred to as crevice or pitting corrosion.

The most common variety of marine-grade stainless steel is 304. Its popularity is largely a function of expense; the alloying elements make 304 less costly to manufacture than 316. Nearly all commonly available stainless fasteners, from the smallest tapping screw to large nuts and bolts, are manufactured from 304 alloys. Fasteners, machine screws, nuts, and bolts manufactured from 316 are available, but must nearly always be special ordered, which reflects their price.

To prevent carbide precipitation, and the corrosion it can facilitate, stainless steel that is to be welded must be of the low-carbon variety, typically identified by an L suffix, such as 304L or 316L.

One of stainless steel's other primary weakness, crevice or pitting corrosion (while the distinction isn't relevant for this discussion, there is a scientific distinction between the two. See **"The Power and Peril of Stainless Steel"** in *Professional BoatBuilder* No. 146, page 48), occurs when the material is used in an oxygen-depleted environment. The tough, nearly impenetrable oxide film that forms as soon as stainless steel is exposed to air only remains intact as long as the metal is exposed to oxygen. If stainless steel is placed in an environment where it is starved of oxygen and it is exposed to water—fresh or salt—it becomes susceptible to crevice corrosion, which typically manifests ~~itself~~ as roughness, valleys, pitting, or even worm-like holes.

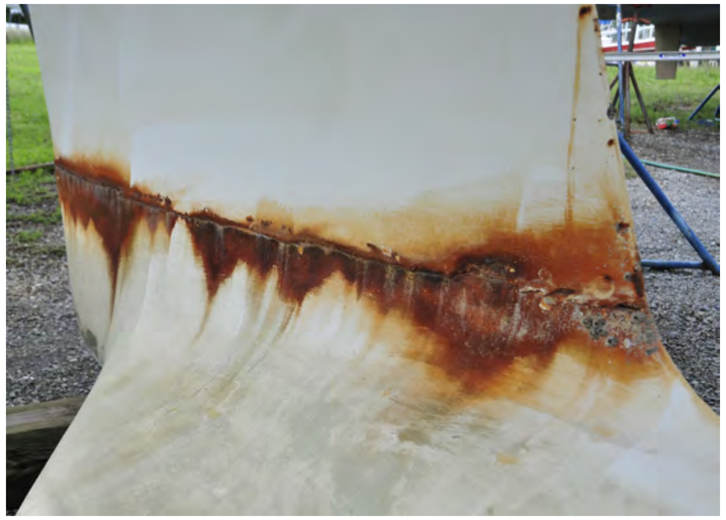
Thus, it's preferable to avoid using stainless steel in applications where it is regularly exposed to stagnant or still water for extended periods. Ideally, high-quality silicon bronze, cupronickel, Inconel, or nonmetallic alternatives should be used, particularly for fasteners and raw-water plumbing. The fasteners used to secure struts, strainers, and other underwater hardware, for instance, should be bronze rather than stainless steel. If stainless steel must be used in such an application—a custom strut, shaft log, or their related fasteners, for instance—they should be fabricated



***Top**—Where stagnant water is in persistent contact with a stainless fastener, pitting and crevice corrosion will set in. **Bottom**—Crevice corrosion can manifest as "worm holes" even in shaft-grade stainless steel where bearings and stuffing boxes keep oxygenated water from circulating.*

from the most corrosion resistant marine alloy available, 316L or 317L.

Propeller shafts fall into a special category. Because they require exceptional strength and corrosion resistance, and are often unused for long periods while exposed to stagnant water in shaft logs, shaft bearings, and stuffing boxes, propeller shafts are typically fabricated from a proprietary stainless alloy that includes a host of other trace elements. These mixtures yield the ideal combination for the environment in which shafts operate. Trade names such as Aquamet, Aquatech, and Aqualoy, among others, are available in several strength and corrosion resistance grades. The most corrosion resistant of which, and therefore the most desirable, particularly for recreational applications where use and oxygen exposure are often limited, is designated as AQ22. Shafts made of this alloy and grade are as close as a boatbuilder can get to corrosion-proof where steel-based alloys are concerned. Shafts manufactured from ordinary stainless steel, on the other hand, even 316 alloy, frequently suffer from crevice corrosion attacks, occasionally within less than a year of being placed in service beneath shaft bearings and stuffing box packing, where the damage cannot be easily observed.



Stainless bolts buried in a keel structure reveal that they are corroding with a weep of rust at the bulb and keel juncture.

Rust stains running across a deck or hull are unsightly, but in many cases are ignored or begrudgingly accepted as part of modern boat ownership. In some instances, they are a message about corrosion. If the staining is adjacent to stainless-steel hardware, it's likely from crevice corrosion, whereby normally passive, corrosion-resistant stainless steel becomes active (the equivalent of rusting in mild steel) and is compromised. Insidiously, active stainless lacks the telltale flaking and scale associated with rusting mild steel. So, it's wise to pay attention to staining and to eliminate its source.

Propeller shafts are vulnerable to corrosion where they are exposed to stagnant water in shaft logs, shaft bearings, and stuffing boxes.

To prevent such staining, sometimes referred to as "tea staining," it's important to understand the process by which it occurs. For stainless steel to remain rust free, it must be continuously exposed to oxygen, which allows it to replenish and maintain the tough oxide layer that resists rusting. Stainless steel used on deck is exposed to air, which has ample oxygen to maintain the protective layer. Even when used below the waterline, provided the water moves freely and regularly, stainless steel may be exposed to enough dissolved oxygen to remain passive. But if it is exposed to an oxygen-starved environment such as stagnant water, it's likely to enter an active state.

Where deck and above-the-waterline hull fittings are concerned, brown staining is usually from low corrosion resistance 304 stainless alloy and/or exposure of any stainless hardware to stagnant water. In the first case, short of replacing the hardware, there's not much that can be done. In the latter case, there is a solution. If you look closely, you'll see that the staining often emanates from the perimeter of, or under, the offending hardware where stagnant water is trapped and becomes oxygen depleted. This leads to "activation" of the stainless steel, and it begins to corrode.

Deck hardware and fittings in 304 stainless steel are particularly vulnerable to "tea staining," where water can stagnate around fasteners and flanges. Cleaning and rebedding hardware is the best solution.

This phenomenon extends to fasteners as well; if the holes through which they penetrate decks, cabins, and hulls are filled with stagnant water, they will become active.

The solution for this problem involves hardware removal, thorough cleaning, dewaxing/degreasing with solvent, and fully bedding the reinstalled hardware in sealant. That means applying bedding compound not only to the areas where fasteners pass through the hardware but to the entire faying surface of a cleat, port light trim ring, grab rail flange, chock, or any other hardware. The bedding compound should squeeze out around the entire perimeter to create a watertight seal and exclude water that could migrate beneath the hardware base. Water exclusion is the key to preventing staining.

In addition to bedding, polishing otherwise rough or irregular stainless steel will minimize surface staining by removing micro-pits where corrosion gets its start. Avoiding water traps, in recesses where (often undersized) fasteners are installed, will also prevent crevice corrosion and staining. Fastener heads should fill the hole and countersink in any hardware. To that end, always use the largest screw shank that will fit, and fully bed it with sealer so water is less likely to be trapped between the head and hardware. Even then, fastener recesses can form water traps that lead to staining.

Insisting on 316 stainless alloy fasteners and polishing fastener heads will help reduce the incidence of staining.

Aluminum

It comes as a surprise to many that aluminum is among the most corrosion-prone metals. This may seem counterintuitive as it's a common boatbuilding material, used for everything from spars and outboards, to deck hardware, and of course complete hull and deck structures. It's also frequently applied as a sacrificial anode, which speaks to its vulnerable place on the galvanic series. In short, aluminum is a metal of many alloys and contradictions.

Aluminum most commonly falls prey to two types of corrosion, galvanic and poultice. The former occurs when aluminum is placed in contact with another metal either directly or via an electrical connection, with both being immersed in an electrolyte to establish a galvanic cell

While the metal sits on the vulnerable extreme of the galvanic series, raw aluminum, especially in the 500 or 600 series, is naturally corrosion resistant and used extensively for workboat hulls.

Aluminum and copper-based alloys don't mix. Where they must be part of an onboard system or structure, it's vital that they be isolated from one another by a nonmetallic bushing or sleeve.

At breaches in the paint, water held against the underlying aluminum causes corrosion-forming aluminum hydroxide, a white byproduct.

(see "**Corrosion Evasion: Part 1**" in *Professional BoatBuilder* No. 212, page 30).

That's straightforward enough, but there are a host of other details essential to understanding how this works.

Perhaps most importantly, virtually all other metals, save two—zinc and magnesium—are nobler than aluminum, which means they all will cause aluminum to corrode when the two are in contact and exposed to moisture. The further the connected metal is from aluminum on the galvanic series, the faster the aluminum will corrode. Consequently, while stainless steel will cause aluminum to corrode under these conditions, the rate is not especially quick, and as such the two are considered moderately compatible.

Copper and copper alloys, including brass and bronze, are located further from aluminum in the series, and are therefore far more harmful; they are considered entirely incompatible with aluminum. A bronze pump, for instance, mounted directly to an aluminum base plate, is a serious corrosion faux pas.

The connecting conductive electrolyte is typically seawater, but freshwater will also facilitate the galvanic reaction, albeit it at a slower pace. Furthermore, while immersion in the electrolyte completes the galvanic cell, it's not essential; simple atmospheric humidity, spray, or rain will suffice. You can prevent galvanic corrosion in two ways: by isolating aluminum from incompatible metals and/or using sacrificial anodes to protect submerged metals.

Aluminum is also susceptible to poultice corrosion, sometimes referred to as "simple corrosion" because no other metals are involved. Here's how it works. When exposed to air, aluminum almost instantly develops a tough transparent coating that serves as a corrosion inhibitor. Even underwater, provided it's not stagnant, aluminum is exposed to enough dissolved oxygen for this coating to form. But where aluminum is starved of oxygen and remains exposed to moisture, the environment is ripe for poultice corrosion. Because the protective oxide coating cannot form without oxygen, the aluminum becomes active and corrodes, in the process forming aluminum hydroxide, a white byproduct resembling freezer-burned ice cream.

The most common instances of poultice corrosion occur when stagnant water is trapped against aluminum beneath blistered paint, under a gasket or insulator, beneath spreader boots, or even where it's in contact with wood, which by its porous nature retains water. You can prevent it by ensuring aluminum is either continuously exposed to oxygen, or fully encapsulated, with the latter being practically

Aluminum sailing rig hardware kept in a moist environment under the rubber spreader boots is particularly vulnerable to corrosion.

Minute flaws in coatings around fastener penetrations are common initiation points for corrosion of painted aluminum components.

Left—*Corners of metal structures are often subject to excessive abrasion and frequently suffer from thin paint coverage making them particularly vulnerable to corrosion.* ***Right***—*Especially on aluminum spars, paint failures tend to propagate from hardware installations.*

impossible. For instance, if an aluminum surface is painted, all that's required for poultice corrosion to start is a single nick or scratch that breaches the coating. It's particularly common around hardware installations where antennas, brackets, pad eyes, or even a single screw head or canvas snap is enough to compromise the paint.

Avoiding paint entirely is another approach, and aluminum alloys in the 5000 and 6000 series are naturally corrosion resistant, which suits them for a host of marine applications in their naked, unpainted form, including raw aluminum hull and deck structures. As noted earlier, when exposed to air, or oxygenated sea or fresh water, aluminum quickly develops a tough and corrosion-resistant oxide film. But there's an aesthetic price to be paid for this durability. Raw aluminum weathers to a low-maintenance dull gray, and eventually dusty, gritty finish; fine for commercial, agency, or other utilitarian vessels but not attractive to many recreational users. To meet the market's aesthetic standards, builders often turn to strong two-part paints and attempt to keep the water out.

Corrosion of Painted Aluminum

When it comes to painted aluminum structures, everyone loves the way it looks initially, however, it's often a short-lived affair as the paint and aluminum rarely remain together for long.

It's common to encounter unsightly blistered paint on aluminum hatches, spars, doors, cranes, hulls, cabins, and decks of boats only a few years in service. Early in my career I worked for a dealership that sold production powerboats equipped with painted aluminum arches. Invariably, the paint would blister, in some cases before the vessels were offloaded from delivery trailers, and warranty claims were dutifully submitted, which the builder, to its credit, promptly paid. To stem the outflow of cash, they earnestly focused on the preparation and paint application processes, yet the problem persisted.

When a few years later I found myself managing a boatyard where painting aluminum spars was common, I was leery of experiencing the same sort of failure. To determine the cause of paint failure in the hopes of avoiding it, I reviewed old spars and other painted aluminum hardware and noted a revealing trend: Nearly all of the failures occurred adjacent to a hardware installation, a fastener, spreader, step, winch, track, or some other type of fitting where the paint coating had necessarily been damaged or breached, in some cases microscopically. I observed repeatedly that once this occurs, water enters the flaw, reacting with the aluminum. Initially the wound seems to be self-healing, with the oxide coating forming in the exposed gap, however small. But as the oxide forms, it lifts the edge of the paint, allowing water to migrate and stagnate further under the coating.

At this point, the chemical equation changes, and the moisture and aluminum in the absence of air promote poultice corrosion. The aluminum pits and produces copious amounts of aluminum oxide powder—or when wet, aluminum hydroxide. This further lifts the paint, causing familiar and unsightly blistering. The lifted paint flake eventually falls off, exposing raw, pitted aluminum, but deterioration doesn't stop there. It begins anew at the perimeter interface between the paint and exposed aluminum. While it progresses slowly, once this process begins, it's difficult to impossible to stop it without removing all the blistered paint, thoroughly cleaning, priming, and repainting the surface.

I concluded that corrosion on painted aluminum spars was the result of breaches in the paint's otherwise contiguous coating, frequently caused by hardware installations or impacts. In virtually

After cleaning painted spar and mounted component surfaces, bedding hardware and fasteners in durable sealant minimizes the risk of paint failure and metal corrosion.

every case, the blisters formed around hardware, fasteners, or damage, scratches, dings, etc. Paint failures were particularly common around sharp or un-radiused edges where paint tends to run off when applied and to suffer from abrasion and impact during vessel use.

Other professionals have come to similar conclusions, and taken preventive measures, which in most cases involve the insertion of a plastic or other nonmetallic bushing or insulator between the hardware and the painted aluminum. While this can be helpful, it's far from ideal for several reasons. On heavily loaded structures such as cleats and winches, loads will often split or crush such insulators. Additionally, if water makes its way between the insulator and the painted surface, as it invariably will, the likelihood of poultice corrosion rises again.

I've concluded that it's virtually impossible to prevent paint from being damaged or breached at hardware installations. Therefore, instead of attempting to prevent the damage, it's more practical to assume it will occur and establish protocols to mitigate its effects.

Service yards and boat operators must be vigilant, and any paint abrasion, compromise, or failure should be coated with a resilient, pliable sealant to prevent water intrusion. Specifically, around hardware installations, after both surfaces are dewaxed/degreased using a solvent such as mineral spirits, all hardware should be liberally bedded using a sealant. These measures render the paint "wound" inert by keeping water out.

Fastener threads should be similarly treated, to prevent water entry leading to poultice, and dissimilar-metal corrosion, as well as seizing. If insulators are used, the surface between the insulator and the paint should also be bedded in sealant. Sharp edges that are to be painted should be gently rounded or radiused. That alone will prevent the thin-paint phenomenon, coating failure, and ~~the~~ resultant poultice corrosion.

All paint applications benefit from proper surface preparation, priming, and best industry paint application practices; aluminum is no exception. Add these to liberal hardware bedding technique, and quick repair of any damage and you can expect paint over aluminum to last for a decade or more. PBB

About the Author: *For many years a full-service yard manager, Steve D'Antonio now works with boatbuilders and owners and others in the industry as Steve D'Antonio Marine Consulting. He is an ABYC-certified Master Technician and sits on that organization's Engine and Powertrain, Electrical, and Hull Piping Project Technical Committees. He is also technical editor of* Professional BoatBuilder.