CRIMES AGAINST METAL

Understanding corrosion is the first step toward preventing it.

STORY AND PHOTOGRAPHY BY STEVE D'ANTONIO

When it comes to copper alloys, pink is indicative of a corrosion phenomenon known as dezincification. In this case it's a cutless bearing shell, which is less noble than the strut in which it's installed, making this event somewhat predictable.

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Bonding connections must offer a low resistance electrical path, which means they must be tight and free of corrosion.

All zincs are anodes, but not all anodes are zinc.

It's a truism. Electrical systems and electricity in general likely represent the greatest mystery for most vessel owners. It is by far the subject about which I field the greatest number of questions. Countless boat owners and skippers have shared with me their lack of understanding on this subject. I fully appreciate the mystery that surrounds this system. Electricity falls into the category of faith—you simply have to believe it's there, even though it remains essentially invisible.

When it comes to corrosion, you may unknowingly suffer the effects of faulty electrical systems in ways that are not immediately obvious, yet are nearly always costly to correct after the fact.

BONDING SYSTEMS

If electricity represents a mystery, then it seems that bonding and grounding and the role they play in corrosion prevention are, to paraphrase Winston Churchill, a riddle wrapped in a mystery inside an enigma. Many seemingly inexplicable corrosion problems are often chalked up, even by professionals, as "a bad ground." Strangely enough this assessment is often accurate; however, the folks making such proclamations frequently aren't sure why this is so.

Recently, while inspecting a vessel as it rested on blocks in a local boatyard, I noticed a sharp disparity in the consumption rate of the two transom anodes. One had been consumed by roughly 50 percent, a rate that I would consider consistent with the vessel's season afloat; the other, however, remained in a near-virgin condition. I'd seen this phenomenon before and knew something was amiss. Hold this thought, I'll return to that story later.

BONDING BASICS

While many folks understand that it's important and valuable to have a bonding system, few truly understand what it is or how it works. Little wonder because it can be complex and encompasses guidelines from at least two ABYC Standards, E-2 Cathodic Protection, and E-11 AC and DC Electrical Systems, which have different goals for corrosion mitigation and electrocution and fire prevention, respectively. In brief, while the terms are used interchangeably, there are differences between grounding and bonding systems and their requirements and goals. Just to keep it interesting, there's a considerable degree of overlap. For the sake of this discussion, however, I'll stick to corrosion mitigation and use the term bonding.

The bonding system is used to interconnect, among other things, underwater metals such as through-hull fittings and seacocks, rudders, and struts. Propeller shafts may be included in the system, but because they are connected to the engine by an oil-filled medium, the transmission, and because oil is an insulator, such a connection cannot be considered electrically sound. Therefore, in order for propeller shafts and propellers to be included in the bonding system they should incorporate a shaft brush, which is a device that ideally completes a low resistance connection with the bonding system.

Anodes should decay at roughly the same rate, especially those that are the same size and collocated, when one remains near pristine it's usually a sign of a poor bonding system connection.

Ideally, and particularly where larger vessels are concerned, rather than connecting each piece of hardware to the next in daisy chain fashion, with its potential for failure, bonding systems are often more reliable and present lower overall resistance when they rely on central bonding buses—copper strips that run the length of the vessel—to which various items are connected by shorter lengths of wire.

The way that bonding is achieved with the bonding strip is critically important. In no case should self-tapping, sheet-metal, or wood screws be used. If machine screws are used, the strip must be thick enough to be tapped and allow a minimum of four threads of engagement. Otherwise, through bolts and nuts may be used to connect a wire's ring terminal to the strip, which should have a minimum thickness of 1⁄32 of an inch and minimum width of 1⁄2-inch. If wiring ring terminals are connected to a bonding strip using self-tapping screws, which pass through the strip and into fiberglass, or worse, wood, then you can be assured of a poor connection. In almost every case, when I inspect vessels whose bonding systems are wired in this manner, I find universally loose connections. Such connections do not comply with ABYC guidelines.

Using tapping screws, screwed into wood or fiberglass virtually guarantees a poor connection; it's also a violation of ABYC guidelines.

CHRISTMAS LIGHT SCENARIO

If a bonding strip is not used, and components are wired one to the other, avoid making connections through hardware. That is, if two bonding wires—"in" and "out" connections—are connected to a single component, a seacock or strainer for instance, install the wire's ring terminals on the same fastener and stud rather than separately. This will prevent the bonding system's low voltage and current from relying on the potentially and comparatively high resistance of the hardware component as a conductive medium. Or worse, should one connection fail completely, everything downstream is disconnected from the bonding system à la the old-fashioned Christmas light scenario.

An alternative to the stem-to-stern copper bus bar or strip, one that is especially useful in after-build installations, employs a series of purpose-made, tin-plated bonding bus bars, installed in various locations around the vessel's machinery and bilge spaces, each of which is interconnected. These are easily installed and offer reliable bonding points.

It's important to note that the soundness of the connections in a bonding system will bear heavily on its effectiveness. Because the voltage and current that such a system is called on to transport are often quite low, the resistance must be equally low. Therefore, the resistance between any two points in the system must not exceed one ohm, a high standard for conductivity indeed, and often a tall order considering the location in which so many bonding connections are located—the bilge.

Bonding system connections should be periodically inspected for corrosion and fastener tension; using a conductant paste when making connections, and then coating those with a corrosion inhibitor when complete will improve long-term reliability.

The reason for interconnection of this seemingly disparate gear is twofold. One, bonding provides a low current path to ground for stray current. Stray current corrosion, which is nearly always DC, is especially destructive and rapid; it can consume a propeller or turn a shaft into useless mass riddled with

Left: Underwater hardware should bond in such a way as to avoid using the fittings as the current path. The fittings in this image are incorrectly wired. Right: Galvanic isolators are an inexpensive means of preventing shore-ground wire-induced corrosion. Units should be fail-safe and comply with the latest ABYC standards.

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holes in a matter of days. Its source is typically a positive DC wire that comes into contact with bilge water; it's often associated with bilge pump wiring. In the presence of a sound bonding system, the likelihood of severe stray current corrosion damage is reduced, although not eliminated.

Second and relevant to the aforementioned vessel I inspected, when the bonding system is connected to a sacrificial anode as it typically is, then that anode will afford protection against galvanic corrosion, to *all* metals that are interconnected and immersed in the same body of water. The definition of the phrase "the same body of water" essentially is the water in which these components are immersed without the benefit of interconnecting hoses. Such an arrangement makes it considerably easier to protect multiple metals by maintaining just a few anodes.

If the metals are not located in the same body of water (i.e., the engine and generator contain seawater; however, for all intents and purposes it is not the same water as that in which the vessel floats), then hull anodes will do nothing to prevent corrosion within the engine and generator even if they are connected to the bonding system. It is for this reason that engines and generators are equipped with their own sacrificial anodes.

Similarly, regardless of their connection to the bonding system, metallic raw water plumbing components used deep within many vessels are often afforded little if any protection from hull or engine anodes.

NOT ONLY ZINC

While there are many types of corrosion, two forms are especially prevalent in marine applications. *Stray current corrosion* is nearly always the result of DC current that is "leaking" into bilge water or underwater metals. It's especially destructive in that it typically causes severe damage very rapidly, sometimes in a matter of hours, but often in a matter of days or weeks.

Galvanic corrosion, on the other hand, while also DC in nature, is much slower and more insidious, taking months or years to do its dirty work. It's the result of a cell being set up between dissimilar metals that are typically far apart on the galvanic series (a voltage potential scale of metals that's used to assess corrosion resistance and potential), aluminum and copper for instance, immersed in an electrolyte, which may be any water but especially seawater.

In either case, a sound bonding system and anodic protection (installing and maintaining anodes) are key elements in the defense against stray current and galvanic corrosion, respectively. In the former case, the bonding system may prevent, reduce, or delay corrosion by affording stray current a return path to ground that excludes immersed metals.

Remember, anodes are any of several sacrificial metals—they may be zinc, aluminum, or magnesium—and for that reason they are properly referred to as anodes rather than zincs, although the vast majority of anodes are in fact zinc. All zincs are anodes, but not all anodes are zinc.

The aforementioned uneven anode consumption case is often indicative of a problem in the vessel's bonding system or the installation of the anodes themselves. Or, it may be a function of the anodes themselves. Simply put, some are made of higher-quality alloy and some are designed to be more effective than others. In this case, the problem turned out to be poor contact between the anode and the mounting stud. This scenario is exceptionally common and its symptoms, uneven or no consumption of anodes, should not be ignored.

INSPECT AND CLEAN

For anodes mounted to the hull, carefully inspect the studs themselves as well as the wiring that is attached to them inside the vessel, the latter is often immersed in bilge water and therefore subject to corrosion. The external portion should be clean and free of any scale or marine growth. The stud should remain captive to the hull regardless of whether an anode is installed or not. When installed, the anode should stand off the hull; there should be a gap between the back of the anode and the hull.

If necessary, remove the anodes and clean the hardware using a stainless steel or bronze. Make certain the fasteners used to hold anodes in place are secure and complete. Ensure that lock washers and washers, if necessary, are used and be certain they are installed in the correct order. The lock washer should always rest directly under the nut.

Hull anodes that are attached to studs of this sort should rely on an embedded contact plate that will maintain contact with the mounting stud as the anode's active material corrodes away. If the anode has no such plate, contact with the stud is often quickly lost as the anode begins to erode. In some cases the anode may loosen or even fall off. Once it's loose, it's no longer working. For anodes installed over other hardware, such as rudders, propeller shafts, and trim tabs, make certain the surface has been thoroughly cleaned before installing a new anode.

Emery cloth or bronze wool will often do the trick. If the anode is installed over a surface that is contaminated with scale, paint, or other debris, then the protection the anode provides will be compromised. Remember, the voltage and current associated with anodes and the bonding system is extremely low, so anything that gets in its way will quickly compromise the effectiveness of the system.

It's important to note as well that anodes that last an unusually long time are suspect. When an anode is consumed, it's doing its job. It's providing protection to the metal or metals to which it's connected.

In suspect installations on a boat that's hauled out use an ohmmeter to check the soundness of the bonding system by connecting one lead to the anode and the other to a bonded underwater metal, a through-hull fitting, strut, or rudder for instance (you may need to make extra long leads to perform this test). Remember, the resistance between any two bonded underwater metals and between any metals and an anode should not exceed one ohm. If it does, then the hull anode is either not making good contact with its mounting studs or the bonding system wiring is compromised by corrosion or a loose connection, etc.

While walking the floor of the Marine Equipment Trade Show (METS) in Amsterdam last November, I was reminded of the differences between anode alloys. I stopped and chatted with representatives from two anode manufacturers, Performance Metals, www.performancemetals.com, and Canada Metal, www.martyranodes.com, manufacturer of Martyr brand anodes.

Both of these companies offer aluminum anodes, in the case of Performance Metals, it's the only alloy anode they offer. As mentioned above, anodes come in different alloys, aluminum, magnesium, and, of course zinc. Traditionally, fiberglass vessels operating in seawater have used zinc because it provides more

Left: Studs used to support anodes must be installed in such a way as to avoid relying on the anode to maintain tension.
Below: Aluminum anodes, like the one shown here, offer a variety of advantages, including increased amp hour capacity and functionality in fresh, salt and brackish water.

Top: Bonding system integrity should be checked periodically, especially if anodes are not being consumed or if they are being consumed unevenly. Above: When anodes are working properly, they should not become encrusted with marine growth.

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BILGE WIRING PRECAUTIONS

Because of the potential for disaster it possesses, wiring should be routed above "normal" bilgewater levels and in cases where this cannot be avoided—bilge pumps and switches for instance—careful attention must be paid to wire routing and connection methods. My own rule of thumb for bilge pump and related component wiring calls for connections to be made 18 inches above the top of the pump, using a tin-plated, insulated terminal strip which, upon completion of the assembly, is sprayed with corrosion inhibitor. As an alternative, or if the 18-inch elevation is not possible, waterproof heat shrink butt splices should be used. Still, in my experience, the source of stray current corrosion is often damaged float switch wiring insulation and should be routed out of harm's way and inspected regularly for any signs of failure or corrosion.

Bus bars are an effective, low resistance means of connecting multiple bonding system wiring runs.

than adequate protection for common underwater metals such as stainless steel and bronze. Zinc anodes are, however, less effective in fresh water or brackish water, and they pack less of a protective punch in any water when compared to other alloys. The relative energy capacity of zinc is 368Ah per lb. and their voltage is minus 1050 millivolts (in corrosion-speak, the more negative the voltage the better). Remember those numbers.

ALUMINUM'S ADVANTAGES

Aluminum anodes, on the other hand, have several advantages. They are well suited for use in seawater as well as brackish and fresh water. Thus, if you intend to transit these water types, then aluminum anodes make the most sense for that reason alone. Where I live, on the lower Chesapeake Bay, the salinity of the countless creeks, inlets, and harbors can be affected by rainfall, and as such, one week they may be salt, while the following they may be brackish or even fresh. Thus, especially in cases such as this, it's desirable to use an anode that will work in both fresh and salt water.

Furthermore, when zinc anodes are exposed to fresh water, they develop a white and sometimes brownish calcareous coating, which effectively puts them to sleep electrically. The coating can be removed, with a non-metallic brush or scuff pad; however, until it is removed, the anode will not erode and will do little to prevent corrosion. Calcareous coatings are often the reason behind anodes that appear to last forever.

Aluminum anodes offer more corrosion prevention energy. They last longer than zinc anodes of the same weight and they are impervious to the calcareous coating phenomenon. Their relative energy capacity is, at 1108Ah per lb., significantly greater than zinc, with a voltage of minus 1100 millivolts, *more* negative than zinc's minus 1050 millivolts. If you opt for aluminum anodes, ideally the change should be universal, for all anodes used within the same bonding system. It's not harmful to mix aluminum and zinc anodes, however, the former will "protect" the latter, which serves no purpose. Surprisingly, aluminum anodes are often no more costly than their zinc brethren, offering a free lunch of sorts.

When I asked the folks from Performance Metals and Martyr why, based on aluminum anodes' clear advantages, more folks don't use them the responses were similar, "We're not sure", which wasn't so surprising. I have my own theory, professionals and boat owners either don't know about them (aluminum anodes) and their advantages, or they are reluctant to change something associated with the perceived black art of corrosion protection and prevention. Rest assured, there are many good reasons to use aluminum anodes and no reasons to avoid them.

Magnesium, on the other hand is an alloy that is reserved exclusively for use in fresh water. If that's the only place a vessel is operated, then consider using this as the anode material.

Whichever anode material you select, be certain it carries a military specification approval. Doing so will ensure, among other things, that it is free of an excessive amount of other trace metals that offer no corrosion protection.

For more on anode use and selection see www.performancemetals.com/anodes/AnodeFAQs.shtml

Inspect anodes regularly, look for signs of uneven, or unusually rapid or slow consumption, particularly in those that are the same size. The rate at which they are consumed is a function of how much metal they are protecting and the size of the anode. If the anodes' appearance remains unchanged and they seem to last indefinitely, this is undesirable. It's an indication something's probably wrong and that their underwater metals may not be properly protected.

If, on the other hand, they are consumed very rapidly or the rate at which they are being consumed increases, do not ignore this symptom, it's probably telling you something is wrong with the system or, worse, that stray current corrosion is at work. Once the anodes' protection voltage is diminished beyond that of the metals it is protecting, the next least noble metal—often the propeller or stern drive—will take its place by corroding.

Bonding systems and their associated anodes play a vital role in protecting a vessel's underwater hardware against corrosion, however, they will only function as designed if properly installed and maintained.

The web extras on shorepower cables and shaft brushes expand on this article. Go to www.passagemaker.com and click the Magazine tab.

Steve owns and operates Steve D'Antonio Marine Consulting (www.stevedmarine.com), providing consulting services to boat buyers, owners, and the marine industry.

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