KNOWHOW

All the answers to the important questions

In extreme cases electrolytic corrosion can completely destroy aluminium sterndrives

THE SILENT BOAT KILLER

Galvanic and electrolytic corrosion can wreak havoc on your underwater metal fittings. But if you know how and why, it's easier to prevent the attacks

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Separate anodes may be needed on the leg and steering ram

Even shaftdrive GRP boats need annodes to protect their sterngear

What causes galvanic corrosion?
All metals and alloys boast a native voltage, as shown in the galvanic series (see Figure 1). When two dissimilar metals in direct electrical/physical contact with each other are immersed in an electrolyte (a liquid that conducts electricity, such as sea water) these elements form a galvanic couple, essentially an unwelcome underwater battery. Consequently, current flows from one metal electrode (the anode) through the electrolyte to the other electrode (the cathode) then continues around the loop (see Figure 2) using the connection between the two.

Why is this such a problem?
Unlike a domestic mains lead, which merely shuffles electrons to and fro, the anodic part of our battery experiences a loss of electrons, and the resulting metallic ions dissolve into the water – the process is called dissolution. So the anode corrodes because it suffers a physical loss of material.

The galvanic series has a cathodic or most noble end (see Figure 1) where the metals and alloys are the least active. Similarly, the anodic or least noble end is where the alloys with the greatest negative voltage lie. Aluminium, one of the main components of sterndrive legs, lies at the extreme negative end of the scale and is particularly vulnerable to galvanic corrosion if not properly protected, but so too are a number of other alloys used to make propellers, shafts, skin fittings and even hulls.

How does cathodic protection aim to reduce or prevent corrosion?
It renders all the potentially anodic underwater fittings cathodic, by supplying a more anodic electrical current from an alternative source. That source can either be sacrificial anodes, or an impressed current system which generates its own anodic current and feeds it into the water through an inert non-corroding anode.

What factors affect the rate of galvanic corrosion?
Voltage differential: in general, the greater the difference in voltage between the metals, the more potentially severe the corrosion. However, double the voltage does not necessarily mean double the corrosion. The initial current flow usually falls off due to an effect called polarisation, and some metals (notably stainless steel and aluminium which form an oxide skin) exhibit more polarisation than others.
Area ratio effect: as the surface area of the cathodic metal increases relative to the less noble parts, the anodic metals suffer more. For instance, say you had tiny aluminium rivets holding big steel hull plates together, the more anodic rivets would fade away faster than Charlie Sheen's TV career. Reverse the situation and fasten aluminium plates with small steel rivets, and the corrosion slows to a crawl. This is why sacrificial anodes cannot be left to waste away completely before they are replaced, because as their size diminishes, so does their effectiveness.
Salinity and pH: liquid conductivity is usually measured in µS/cm (micro siemens per centimetre). Fresh water usually lies in the 50 to 500µS/cm range, whereas salt water is significantly more conductive at around 50,000µS/cm. The alkalinity or acidity (pH) of water affects its conductivity too. So the type of water (fresh, brackish or salt) where you moor your boat can have a profound effect on the rate of corrosion.
Marine slime: some of the slimy bacterial films you find covering your precious underwater fittings may markedly increase the voltage of certain metals that lie at the cathodic end to around +0.3v to +0.4V, in particular the stainless steel family. This makes them more cathodic, but it also puts more strain on the anodes because of the increased voltage differential.

Why is aluminium alloy a special case?
Aluminium is so terrifyingly anodic compared with most metals that it is used to make sacrificial anodes. Yet for manufacturing reasons it's the material of choice for most sterndrive legs and outboard motor casings. However, like stainless steel, aluminium alloys quickly form a protective oxide coating that is self healing. That protective film is its saving grace, and by and large it ensures a poorer than expected electrical contact with neighbouring metal, and consequently less galvanic corrosion than its place in the table suggests.

Does that mean my sterndrive legs are safe?
Not necessarily. Aluminium sterndrive legs invariably have their own dedicated anodes, designed and installed by the manufacturers, who doubtless understand their products' galvanic needs. But if your usual anodes are defunct, then the aluminium sterndrive could become the anode for the rest of the boat. Sterndrives also need special attention because neglect or misunderstanding can have a significantly greater effect on their wellbeing than most other areas of the boat. Amongst myriad dangers are: leaving a partially raised leg with the lower casing immersed but the anodes clear of the water; water ingress resulting from failure of the rubber gaiter; overstretching the inbuilt anodes by replacing the alloy propellers with high-performance stainless ones, or

FIGURE 1: THE GALVANIC TABLE

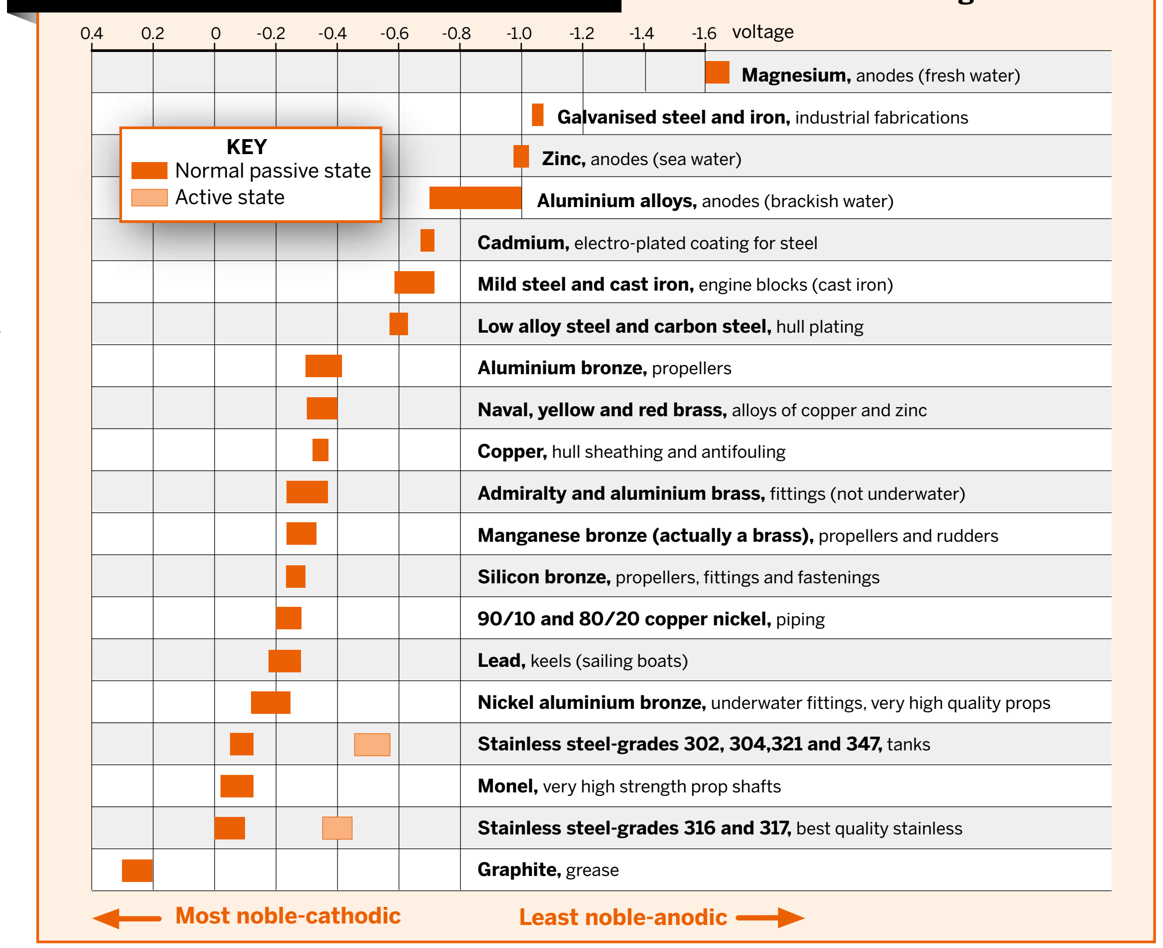
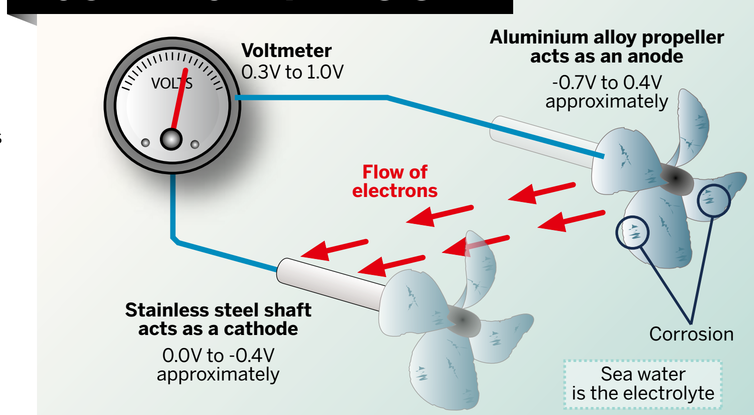


FIGURE 2: GALVANIC CELL



The stainless steel shaft is the cathode, the **most** noble metal
The aluminium propeller is the anode, the **least** noble metal

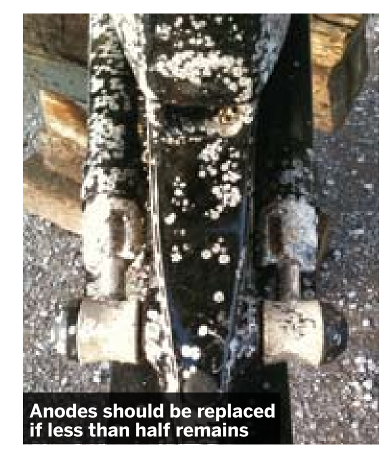
Trim tabs need separate anodes

Barnacles can exacerbate corrosion by exposing bare metal under paint

There is no better way to eliminate galvanic corrosion than to ensure total separation of all your dissimilar metals

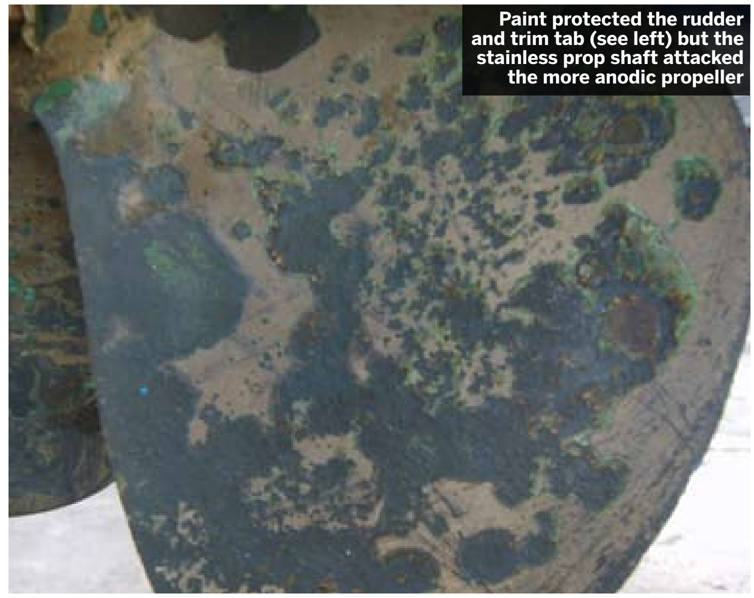
fitting aftermarket prop guards, rope-cutters or planing fins; a break in the crucial connecting wire between the casing and the transom plate; and unforeseen electrolytic corrosion which can wreck a sterndrive leg within weeks.

Why is stainless steel a special case?
Stainless steels achieve their stainless temperament because the chromium in the alloy reacts with oxygen to form a tough oxide film that renders it resistant to further corrosion – it changes from active to passive. And this layer obligingly reforms if it's damaged. Above the water the stainless can usually find a plentiful supply of oxygen in the air. But in slow moving or poorly aerated water the chromium can be starved of the necessary oxygen. When that happens,



Anodes should be replaced if less than half remains

Both steel and GRP boats are prone to galvanic corrosion of their sterngear if the correct precautions aren't taken



Paint protected the rudder and trim tab (see left) but the stainless prop shaft attacked the more anodic propeller

Crevice corrosion on stainless steel can trigger galvanic corrosion

the stainless not only corrodes and becomes active again, but its electrical potential can shift to around -0.5V. The normally passive stainless has become conspicuously anodic compared with, say, an adjoining manganese bronze propeller at around -0.3V.

Crevice corrosion can occur in stainless steel in nooks and crannies, or when the metal is poorly set in a bedding compound, or inside a cutlass bearing, again, where there's oxygen starvation. Although the crevice corrosion itself is not galvanic, the metal's change in voltage can trigger galvanic corrosion. It's possible for a corroded stainless fastening to be anodic to an identical neighbour in good order.

Can neighbouring boats cause me problems?

Yep. As always, the electrical circuit must be complete for problems to arise. So in strictly galvanic terms, the risk is low in that it would take, for example, two poorly painted steel boats rubbing against each other to complete the circuit and link their separate underwater parts. The greater risk is from electrolytic corrosion.

How does electrolytic corrosion differ from galvanic?

If galvanic corrosion is a naughty boy, electrolytic corrosion is its evil twin. Electrolytic and galvanic corrosion trigger the same problem, that of an unwanted underwater battery eating away at the anodic side. So nearly all the information here applies to both.

There is almost no limit to the harm electrolytic corrosion can lead to, with a short circuit causing fast-acting, untold damage

However, electrolysis is the result of unsolicited stray currents from an external source flowing between metals.

There are several culprits such as poorly installed or damaged wiring, bad earthing on power tools, dodgy float switches, and even extremely damp salty conditions causing current leakage. Unfortunately, unlike our galvanic cell, there is almost no limit to the harmful current that can be generated, from a damp day trickle to the torrent of a full short circuit. So the damage that electrolytic problems can inflict can be far greater and faster acting.

The neighbourly aspect of electrolytic corrosion arises because many powerboats use shorepower leads, and your neighbour's connection will doubtless share a common AC grounding (earth) circuit that eventually leads to a big copper grounding rod buried in the marina. Even when both boats' shorepower circuits are perfectly installed, the common AC earth creates an electrical/physical connection between the boats. So your neighbour's faults, such as lack of anodes or faulty wiring, become yours. Your anodes could end up protecting your neighbour's huge cathodic bronze fittings, or even the marina's steel pilings which you may now be connected to. If the boats both have metal hulls, these too can function as a giant anode and cathode.

How do I stop shorepower problems?

Fit a simple galvanic isolator. This typically comprises two diodes which restrict current flow in the grounding (earth) wire when the applied voltage is low, but still allow full flow in case of an earth fault.

Far safer is to use a more expensive isolating transformer. Because windings transfer the power across, a transformer eliminates the metallic connection between the marina's shorepower and the boat, so the physical metallic link (i.e. the earth wire) is severed.

Bonding metallic fittings together: good or bad?

When it comes to preventing corrosion, this is the most crucial topic of all, yet it's not free of debate. Remember, dissimilar metals submerged in sea water do not complete the galvanic circuit on their own, they need that final electrical/physical connection. So there is no better way to eliminate galvanic corrosion than to ensure total separation of all your dissimilar metals. There again, any powerboat with an interconnected stainless steel prop shaft and a manganese bronze propeller will need to connect at least this duo to an anode.

An anode must be bonded to the parts it's intended to protect. This bonding circuit can take the form of a complete circuit where all underwater fittings are bonded together, and/or a number of more isolated connections, e.g. anode + trim tabs. With everything connected, and with the sacrificial anodes at the end of the chain, however unusual your mix of metal fittings and fastenings, they should all be protected. All-embracing bonding circuits assume greater importance on boats with shorepower and 240V systems where

TABLE 1: **WHAT TYPE OF ANODES CAN I FIT?**

Zinc: Most common and relatively cheap. It appears anodic to nigh on everything else except a few aluminium alloys. Zinc anodes should not be used in fresh or brackish water because over time they may become coated with a white oxide crust that prevents them working.

Magnesium: Normally only used in fresh water because their high negative voltage (around -1.6V) causes them to waste away too fast in more conductive salt water. Although the galvanic series remains largely unchanged in fresh water, because of its relatively poor conductivity, the currents can't travel as far, so corrosion is more localised. Magnesium anodes can damage timber, so avoid using on wooden boats and aluminium craft.

Aluminium alloy: Aluminium anodes are used in brackish, and possibly salt water environments. Like zinc, a white oxide crust develops in fresh water.

Impressed current anodes: If your boating involves switching between fresh water and salt water environments, consider using impressed current anodes. There are various systems available: most are integrated into the boat's hull, others hang over the bow and stern. If you're considering one of these systems, it's best to talk directly with the relevant manufacturer. Their notable advantages are that the current can (in theory) be precisely regulated to provide complete and uninterrupted protection, and once fitted there are no anodes to replace.

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Despite its position on the galvanic scale, copper usually attacks aluminium far more fiercely than more noble materials such as stainless


Severe corrosion can occur unexpectedly; for instance, after moving to a new marina

earthing is required for safety, and possibly lightning protection too.

The corollary is that, were your anodes to waste away unexpectedly (from unavoidable neglect say, or a severe electrolytic attack beyond your control), then a complete circuit would put everything at risk. What might otherwise have been happily isolated metallic parts would all become part of your unwanted underwater battery, susceptible to attack from everything more cathodic. Choosing to isolate parts as much as possible is generally more appropriate on boats without 240V or shorepower.

What else can be done to minimise galvanic & electrolytic corrosion?

1. Use non-metallic, non-absorbent insulators such as tufnol or neoprene between dissimilar metals (especially fastenings and their hosts) to prevent current flow and help reduce corrosion. It's easy to check for lack of conductivity with a voltmeter.
2. Use the most cathodic metal possible for very small parts, especially fastenings. This reduces the chances of attack from much larger, more cathodic parts. But beware of too great a galvanic difference between fastenings and their hosts as this can cause bolt holes to corrode and enlarge.
3. Consider using plastic alternatives. There is some 'silicon bronze is best' snobbery when it comes to things like seacocks, but there are high quality plastic and composite options available.
4. Painting is one of the easiest ways to minimise galvanic corrosion. But great care is needed with parts that are not part of a bonded circuit. Beware painting just the anodic side of a mixed metal assembly (say, a silicon bronze fitting held with 316 stainless bolts) because if the silicon fitting is scratched and therefore exposed slightly, it can result in a dangerously high cathode (the bolts) to anode (the fitting) ratio.
5. Beware mixing copper and aluminium. Despite its position in the galvanic scale, copper usually attacks aluminium far more fiercely than more noble materials such as stainless steel. Copper sheathing a boat with aluminium sterndrives is risky, and copper antifouling should always be kept well clear of sterndrives. Beware using graphite grease on bearings or threads as graphite is extremely noble and will attack almost any metal it's in contact with. Zinc-coated fastenings can rapidly lose their anodic coating underwater. And avoid using brass (a copper-zinc alloy) fittings below the waterline as they will invariably suffer from dezincification.
7. Always disconnect your batteries when the boat is idle to reduce stray electrolytic currents.
8. Using a multimeter, regularly check the connection (resistance) between your anodes and the parts they're supposedly protecting. You should have a reading of one ohm or less.
9. Turn everything off and disconnect your positive battery lead. Measure the resistance between the terminal and the lead. Between ten & 1,000 ohms indicates a serious leak, more than 1,000 ohms indicates a minor one. If an electrolytic leak is present, you then need to trace the fault by checking individual circuits.

With thanks MGDUFF


Manufacturing (shown here inside MGDUFF's factory) is remarkably straightforward


The critical thing is getting the right alloy composition

MGDUFF anodes

TABLE 2: HOW SHOULD ANODES BE INSTALLED?

Wiring and bonding: any resistance will reduce the anode's effectiveness, so interconnecting wire should be generously sized: at least 4mm2 PVC insulated multi-stranded copper.

Line of sight: it's better if the anode maintains line-of-sight contact with the parts it's protecting.

Fixings: make sure the fixing studs passing through the anode, and any exposed wiring, are kept dry and clean and clear of any bilge water.

Trim tabs and steel rudders: these should be protected separately with their own surface mount anodes.

Propeller shafts: external hull anodes require a brush gear or slip ring arrangement inside to create a connection with the shaft/propeller. Shafts and props can be protected with their own shaft anodes, but it's harder to attach sufficient anodic metal to cope with the demands of the shaft and propeller. If this is your only option, dual or multiple shaft anodes can be the answer.

Number and size: given the limitless permutations, it's impossible to give rule of thumb guidelines. The best starting point we found was an online mix-n-match selector which takes into account: type of water, hull material, single/twin/sterndrive installations, prop diameter and so on. Go to www.anodeoutlet.co.uk and hit 'find your anode'.