

Understanding and controlling crevice corrosion in stainless steel

A troublesome problem with marine gear and equipment



Plastic and wood are the main construction materials for this Oregon oyster grower—but it was the stainless steel hooks that failed first (see the third example in the column on the right).

Corroded hardware like fittings, bolts, plates, and wires is a fact of life in any area near the sea. It is extremely common on boats and fishing gear. People often assume that a simple, though not always inexpensive, solution exists: make it out of stainless steel.

But under certain conditions, you might discover that after a short period of time, the piece of stainless steel has corroded and fallen apart, anyway.

Consider some Oregon examples:

- A lightweight Dungeness crab pot is constructed without the customary exposed iron ballast weights (figure 1a). Stainless steel 316 wire mesh covers the frame, made up of steel reinforcing rod tightly wrapped with rubber. After only a few months in the ocean, the stainless wire is corroded and broken at all those places where it was tightly fastened to the rubber-wrapped frame (figure 1b).
- A stainless steel pump has PVC plastic pipe threaded into its intake and discharge. After pumping seawater for about a year and a half, the housing under the gasket is badly corroded (figure 2). In addition, the pipe threads are virtually destroyed (figure 3).
- An oyster grower uses rubber thongs fastened to stainless wire hooks, to secure plastic shellfish trays to an intertidal wood frame (photo at left and figure 4a). After 6 months, the hooks begin to fail; the metal under each rubber band is corroded (figure 4b).
- A marine lab supporting biological research controls seawater temperature by pumping it through a plate heat exchanger. Warm water or cool glycol flows in the other passages of the heat exchanger, which is made up of a stack of corrugated 316 stainless plates

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Figure 1a.—This Dungeness crab pot has no bare iron bars—needed for cathodic protection.

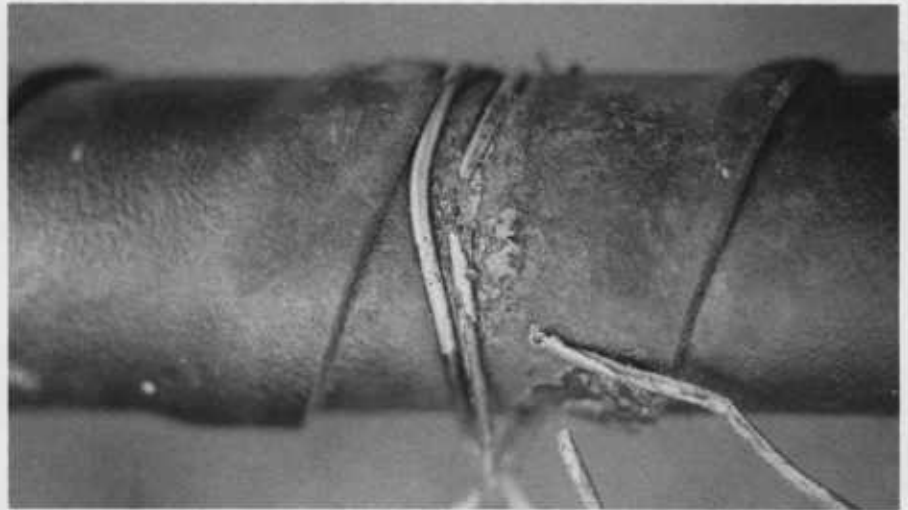


Figure 1b.—Stainless wire has corroded away, where it was imbedded in rubber on this Dungeness crab pot.

pressed together (figure 5a). They are sealed along the edges by a neoprene gasket (figure 5b). After 3 years of intermittent use, holes in the plates appear under the gasket in several areas (figure 5c). They must be completely replaced.

The corrosion in these stainless steel components has all occurred in cracks and crevices where seawater is essentially stagnant. It is called *crevice corrosion*.

Many of us can recall seeing other examples of stainless steel corrosion as well—pitting under an end-plate gasket on a seawater-cooled refrigeration condenser; rusty streaks in the crevices of a stainless wire rope, or around a stainless bolt and washer in the fishhold ceiling; rusting at the riveted joint of a stainless steel filleting table.

Why crevice corrosion occurs

For many reasons relating to cost, safety, and appearance, crevice corrosion is something to avoid. But before addressing some approaches that will eliminate or at least minimize the problem, it is necessary to understand something about *why* crevice corrosion occurs.



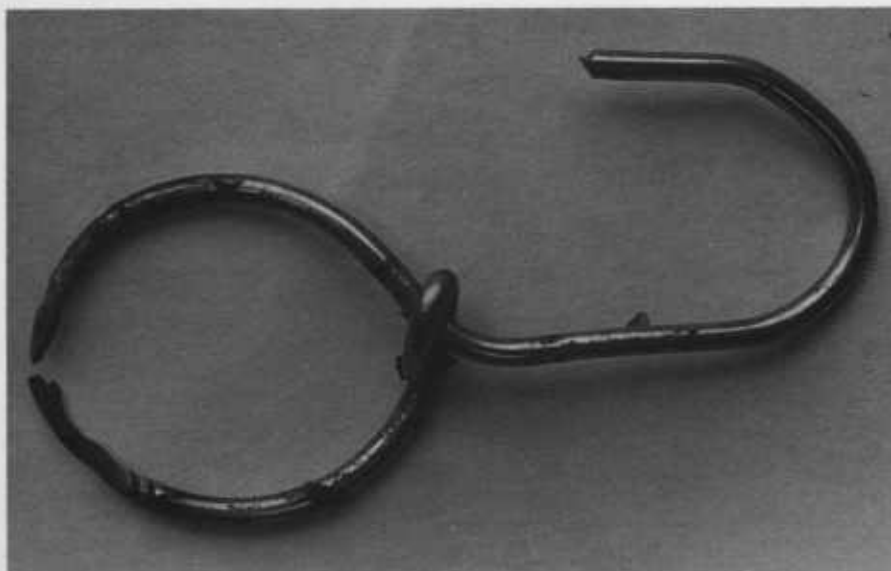
Figure 2.—Pitting has appeared under the gasket on this 316 stainless pump housing.



Figure 3.—The 1/4-inch stainless threads of this pump housing are badly corroded where a crevice was left between the housing and the threaded PVC pipe.



Figure 4a.—Hooks attached to a rubber thong hold down oyster trays in an intertidal area.



All metals corrode in seawater, but each has a different tendency to corrode. This relative tendency is described by a table sometimes known as the *galvanic series*, included in several of the publications listed under “Additional Reading” (page 6).

For each of the common metals, this table or series lists the voltage between that metal and a standard electrode, when each is immersed in seawater.

At one end of this series, metals with high voltages—like magnesium, zinc, and aluminum—are referred to as *active* metals, ones that corrode easily.

Those at the other end of the series with low voltages—titanium and stainless steel alloys, for example—are called *passive* metals.

If you immersed two separate metals in the ocean, you could measure a voltage difference between them. For example, zinc (active) and mild steel (less active) have a voltage difference of around 0.4 volt.

If you then bolted the two immersed metals together, an electrical circuit would be formed, and a current would begin to flow. The electrical circuit consists of the two-metal junction (which acts as a battery), the two pieces of metal (which act as electrical wire), and the seawater in contact with the two metals.

The seawater acts as an electrical resistor in the circuit. While this current is flowing, the more active metal begins to *ionize* or dissolve into the seawater, while the more passive one does not.

This dissolving is sometimes called *galvanic corrosion* and occurs when zinc is bolted or welded to a steel boat. The active metal—zinc—serves as a “sacrificial anode” that dissolves and in the process keeps the more passive steel hull or rudder or fitting from corroding.

The *rate* of corrosion depends on several factors: the environment, the materials that are corroding, and the relative amount of exposed area of the active and passive metals—sometimes referred to as *the area effect*.

In the case of the zinc that protects steel fittings, the smaller the exposed area of active zinc relative to that of the steel, the faster the zinc will corrode or ionize.

Figure 4b.—Stainless hooks covered with a rubber thong were destroyed in 6 months.

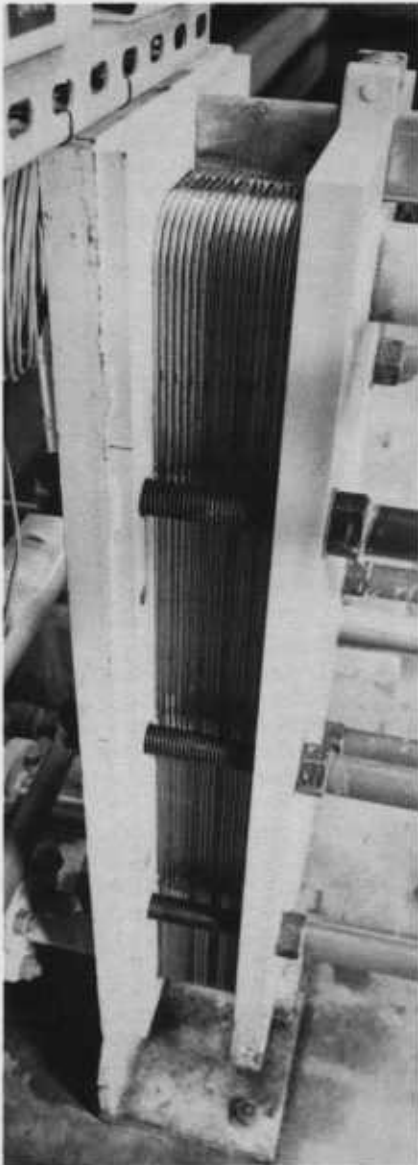


Figure 5a.—A plate heat exchanger is made from several corrugated plates pressed together.



Figure 5b.—A neoprene gasket seals the edges of these heat exchanger plates.



Figure 5c.—Crevice corrosion in several areas under the gasket of these 316 stainless heat exchanger plates has penetrated the thickness.

Stainless steel. What does this have to do with stainless steel? It turns out that a given piece of stainless steel can *act like* two entirely different metals in the galvanic series.

Under most conditions, stainless steels are coated with a protective chromium oxide layer that gives them the passive position they have in the galvanic series.

However, if the oxide layer should be removed, that same stainless steel becomes very active. For 316 alloy stainless steel—probably the type most commonly used in seawater applications—the *active* and *passive* versions differ by around 0.4 volt in the galvanic series. This difference is about equal to the voltage difference between zinc and mild steel.

And if these two stainless steel pieces should be fastened together (electrically connected) while immersed in seawater, corrosion of the active metal—the one *without* the oxide coating—would occur.

This is exactly what happens in crevice corrosion. The stainless steel in the crevice has lost its oxide coating. Therefore, it becomes a more *active* metal in the galvanic series.

The small active metal area in the crevice (under a wet gasket, for example) behaves just as a small zinc anode would, trying to protect a large steel plate—it corrodes, forming deep crevices or pits.

How the crevice metal loses the oxide coating in the first place relates to some concepts of corrosion chemistry. A lower dissolved oxygen content in the crevice water, relative to that in the water flowing outside, causes a corroding current to begin to flow.

In addition, chlorine in the water will tend to prevent a re-forming of the oxide layer, insuring that corrosion continues. Chlorine, remember, is a component of seawater because of the salt (sodium chloride) present.

It can also be present as a sanitizing agent in some wash water on stainless steel food-processing equipment.

Crevice corrosion can be a problem in most of the stainless alloys used in the marine environment. These are often stainless steels in the 300 series (the numbers identify different mixtures of metals that make up a given alloy).

Perhaps the most common of the 300 series are the stainless alloys 304 and 316; both have about 18% chromium and 8 to 12% nickel added to the iron. Type 316 also has a little molybdenum, which gives it a slightly better resistance to corrosion.

Some remedies

When we understand better the factors that cause or support crevice corrosion, we have some clues about how to avoid it. Consider four general approaches:

Using sealants. If there is no crevice, there won't be a problem. Technicians attempted to seal the threads in the pump housing (figure 3) with teflon tape.

There was apparently enough tape to keep water from leaking out, but not enough to completely fill all the voids. Some water seeped into the threads, and corrosion was on its way.

Use of a heavy sealant (petroleum-based grease is not good enough) on these threads or around the housing gasket (figure 2) might have given a longer life to this 1-inch pump, which has a replacement cost approaching \$700.

Note, however, that corrosion engineers add a caution that relates to the *area effect* mentioned earlier. If your sealing job isn't perfect, a tiny hole or gap will expose active metal that might corrode faster than if no sealant were used at all.

Gaskets around the heat exchanger plates shown in figure 5b are sealed by squeezing the plates between two heavy end plates (figure 5a).

In this case, perhaps more pressure might have prevented the formation of small crevices under a few stretches of the gasket where the corrosion started. Replacement cost for each of these 316 stainless plates is around \$100.

Cathodic protection. We can "protect" an underwater metal by fastening to it a second metal that's more active in the galvanic series. The more active metal, like the zinc that protects a steel hull, corrodes as a "sacrificial anode."

Some details of this process are explained in the OSU Extension publication SG 46, *Cathodic Protection for Boats in Saltwater* (see "Additional Reading," page 6).

The use of sacrificial anodes can also control crevice corrosion in stainless steel. Mild steel, cast iron, aluminum, and zinc are all good sacrificial anode materials for submerged stainless steels.

The crab pot shown in figure 1a did not have the exposed iron ballast bars that are standard on the more traditional pots shown in figure 6. These bars also act as sacrificial anodes and will prevent onset of the crevice corrosion seen in figure 1b.

Be a little cautious when you apply untried cathodic protection measures to fixed gear like crab pots. The resulting electric currents and fields have been known to repel (or attract) various marine animals.

Corrosion engineers have found that 304 and 316 can be adequately protected by the use of sacrificial anodes. However, watch out for stainless alloys in the 400 series. Although they are rarely found in marine applications, these have different ingredients and can be damaged by cathodic protection measures.

Alternative materials. Going to all the trouble of adding a sacrificial anode, like zinc, to protect a submerged piece of stainless steel raises a question: is stainless steel necessary? Another, cheaper metal, if similarly protected, might be quite suitable.

There are alternative materials that might avoid crevice corrosion problems. Plastics like PVC don't corrode at all and represent a suitable alternative in some circumstances.

Some metal alloys like Inconel are far less corrosive than 316 stainless, particularly in crevices. And some metals such as low-carbon steel might, for some applications, be sufficiently inexpensive that periodic replacement is feasible.

The rubber band hooks shown in figure 4a would have lasted longer if they'd been made from plastic. Using galvanized low-carbon steel might also have provided a feasible design option, given a suitable replacement schedule.

The heat exchanger plates shown in figure 5b would have lasted longer had they been made of titanium. Cost would have been about double, but a greatly extended lifetime could have made such an increase worth considering.

Watch out for certain materials in seawater used to keep marine animals alive, because some metals have a toxic effect. Copper alloys such as bronze, cupronickel, and Monel can be particularly harmful.

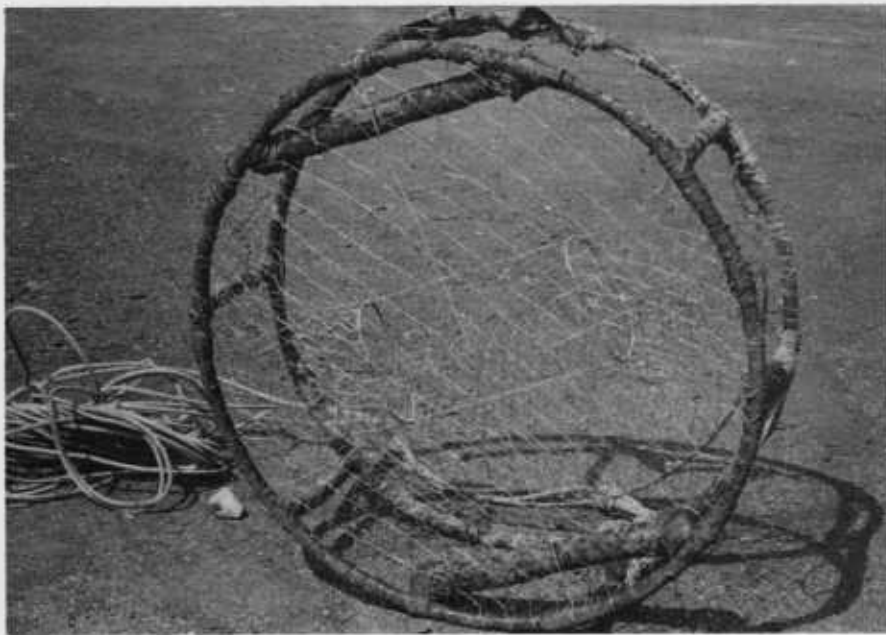


Figure 6.—Traditional Dungeness crab pots have iron bars crossing the floor—for ballast and for cathodic protection of the stainless wire mesh. Compare this one with the pot without iron bars shown in figure 1a.

Changes to design and maintenance procedures. You can often modify a configuration or method of assembly to avoid or minimize some crevice corrosion problems. For example, here are some recommended practices:

- Avoid pipeline flanges or gaskets on stainless fixtures that would allow stagnant water areas.
- Design tanks, tables, or basins so that stagnant water can't be trapped and held after cleanup and sanitation (even chlorine concentrations in a city water supply have been linked to stainless steel corrosion problems).
- Join stainless steel parts by a continuous weld, rather than rivets.

A preplanned maintenance program can also help. Some examples:

- Specify that a stainless steel exchanger or pump be flushed and drained when not in use.
- Periodically inspect stainless components in which crevice corrosion is a concern.
- Make sure that chlorine-based sanitizers are thoroughly flushed after application.

The options are as numerous and varied as the potential applications for stainless steel in the marine environment.

An understanding of the mechanism and some careful planning and construction steps will help you avoid serious crevice corrosion.

Additional reading

- LaQue, Francis L., *Marine Corrosion: Causes and Prevention* (New York: John Wiley & Sons, 1975). 332 pp. Standard engineering text for corrosion engineers.
- Mallon, Michael H., and Edward Kolbe, *Cathodic Protection for Boats in Sea-water: A Review of Recommendations*, Oregon State University Sea Grant College Program publication ORESU-T-79-003 (Corvallis, 1979). 53 pp. Summary of engineering design approaches. \$2.00.

Mallon, Michael H., and Edward Kolbe, *Cathodic Protection for Boats in Saltwater*, Oregon State University Extension Service, Marine Advisory Program publication SG 46 (Corvallis, 1979). 8 pp. Popular version of the technical report above; single copy 50¢ plus postage from Bulletin Mailing Office, OSU, Corvallis, OR 97331.

Pretzger, Roger, *Marine Metals Manual: A Handbook for Boatmen, Builders and Dealers* (Camden, Maine: International Marine Publishing Co., 1975). 64 pp. Discusses details of marine materials and hardware common in boating.

Warren, Nigel, *Metal Corrosion in Boats* (Camden, Maine: International Marine Publishing Co., 1980). 220 pp. Intermediate level approach; details specific problems of corrosion control in boats.

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