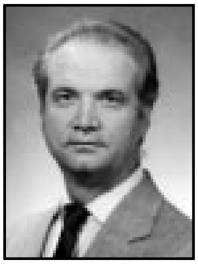

Advice & Counsel

Frank Altmayer, CEF
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3158 Kolin Avenue
Chicago, IL 60623-4889

Corroding Away—Part II

Dear Advice and Counsel,

We have an air-agitated wastewater treatment basin made of concrete, with a "gate" that is made of aluminum (6061 alloy). Some of the gate parts are 316 stainless steel. Over several years, the aluminum gate has suffered severe corrosion (Fig. 1) and has had to be replaced. Because the treatment tank contains bio-organisms, we have been told that the corrosion may be the result of biological action. We are aware, however, of numerous other installations using aluminum gates in tanks with biological treatment and they have not experienced this problem. What is going on here?

Signed, Wasted Away

Dear Wasted,

A number of factors are most likely involved. Let's first look at the data:

Parameter	6061 Requirements (%)	Analysis of Alloy (%)
Silicon	0.6	0.61
Copper	0.28	0.21
Magnesium	1.0	0.88
Chromium	0.2	0.13
Zinc	——	0.02
Iron	——	0.24
Titanium	——	0.01
Aluminum	Balance	Balance

A spectrographic analysis of the aluminum alloy yielded the following:

A microscopic cross-section showed that the corroded aluminum part exhibited both intercrystalline and exfoliation corrosion (Fig. 2). The corrosion appeared to travel between grain boundaries and rolling faults outlined by physical inclusions deposited along the same boundaries.

The physical structure of the aluminum indicated the presence of inclusions that appeared to be precipitated at grain boundaries. X-ray analysis of these inclusions indicated that they were composed almost entirely of silicon (whereas 6061 alloys typically contain inclusions composed of both magnesium and silicon, where the ratio of magnesium to silicon is 1.73:1).

The surface of the corrosion product was found to contain significant quantities of the following elements:

Corrosion Surface	Cross-section
Aluminum	Aluminum
Sulfur	Sulfur
Chloride	Chloride
Copper	Copper
Calcium	Calcium
Iron	——————
Phosphorus	——————
Oxygen	Oxygen
Silicon	Silicon

Quantitative analysis of the corrosion products for chloride and sulfate (common corrosives for aluminum) indicated that the corrosion product contained 0.1% sulfate, 0.1% copper, 0.1% iron, and 0.5% chloride.

As for the possibility that the corrosion was caused by biological action, we refer to information from Oliver Siebert*:

Aluminum is an active metal and oxidizes rapidly when exposed to water or air. The corrosion resistance of aluminum depends upon the stability and continuity of this film or passive layer. If the film is locally damaged, under conditions which prevent the normal self-healing of the film, then localized corrosion, such as pitting or intergranular corrosion, results. Unfortunately, the stability and continuity of the protective film is affected by aggressive ions (such as chlorides and other halides), complexing agents, local shifts in pH and crevices.

Aluminum is very susceptible to microbiologically influenced corrosion (MIC). Corrosion attack occurs in both aerobic and anaerobic systems. Of the several bacteria and fungi are the sulfate-reducing bacteria, SRB, type.

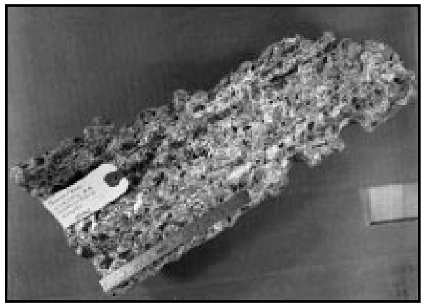

Fig. 1—Corroded aluminum part.

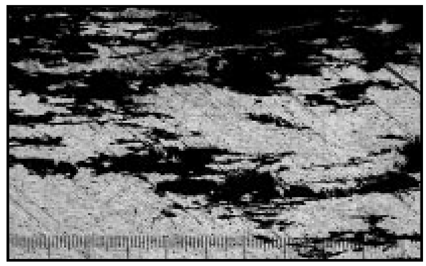

Fig. 2—Cross-section of corroded part.

Is the Alloy Correct?

The aluminum part supplied meets alloy 6061 compositional requirements.

The use of 6061 alloy in this application may be questioned, because this alloy is more susceptible to intergranular corrosion than a 5xxx series alloy.

Referring to *Metals Handbook*, Ninth Edition, Volume 13, page 586:

5xxx Wrought and Cast Alloys*—have high resistance to corrosion, and this accounts in part for their use in a wide variety of building products and chemical processing and food-handling equipment as well as applications involving exposure to sea water. Alloys in which the magnesium is present in amounts that remain in solid solution, or is partially precipitated as AL_8Mg_5 particles dispersed uniformly throughout the matrix, are generally as resistant to corrosion as commercially pure aluminum and are more resistant to salt water and some alkaline solutions such as those of sodium carbonate and amines.*

6xxx Wrought Alloys*—Moderately high-strength and very good resistance to corrosion make the heat-treatable wrought alloys of the 6xxx series (aluminum-magnesium-silicon) highly suitable in various structural, building, marine, machinery, and process-equipment applications, The Mg_2Si phase, which is the basis for precipitation hardening, is unique in that it is an ionic compound and is not only anodic to aluminum, but also reactive to acidic solutions.*

When magnesium and silicon contents in a 6xxx alloy are balanced (in proportion to form only Mg_2Si), corrosion by intergranular penetration is slight in most commercial environments. If the alloy contains silicon beyond that needed to form Mg_2Si or contains a high level of cathodic impurities, susceptibility to intergranular corrosion increases.

The spectrographic analysis of the aluminum indicates that it has approximately 20 percent more silicon than that required to form Mg_2Si. The proper magnesium content for 0.61 percent silicon would be 1.0 percent. Therefore, while the supplied aluminum can be considered to be of a composition in compliance with what was requested in the contract, it was not of a composition that would result in the best corrosion-resistance performance. Also, a 5xxx series alloy would have been a better choice for the gate.

The corrosion product analysis indicates that the aluminum has formed primarily sulfate, copper, iron, and chloride compounds. The water in

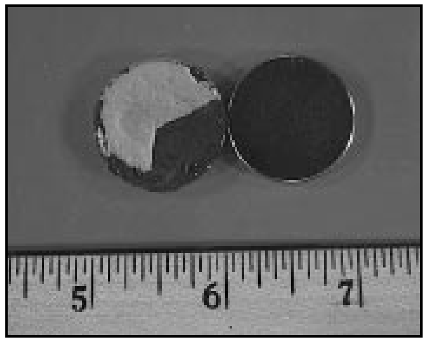

Fig. 3—Corrosion on gold plate.

the wastewater treatment plant contained significant amounts of chloride, copper, iron and sulfate, which contributed to the corrosivity of the liquid to which the aluminum was exposed. The literature indicates that aluminum alloys are subject to accelerated corrosion in the presence of copper ions.

In light of the fact that other installations around the country have aluminum alloy components exposed to the activity of micro-organisms and do not corrode at the same accelerated pace, we suspect corrosion occurred in this case because of the exposure of this alloy to water containing corrosives and copper ions. Further, stainless steel and aluminum (any alloy) will form a galvanic couple, with the aluminum behaving anodically to the stainless steel (resulting in the dissolution of the aluminum). The presence of chloride and sulfate in the liquid in which the two metals are immersed provides a very conductive electrolyte for this "battery." Copper makes an additional anodic metal for aluminum. Because copper is far more noble than aluminum, one can expect the dissolved copper ions to deposit onto the aluminum, creating additional "batteries." The stainless steel components on the gate should be replaced with aluminum components (or better yet, replace the gate with a stainless steel gate).

Dear Advice and Counsel,

We nickel- and gold-plate round permanent magnets. These are worn by consumers who wish to expose their bodies to a magnetic field, which is supposed to provide some health benefits. Unfortunately, some of these discs are returned to us in a very corroded condition (Fig. 3). What is going on here? I thought gold did not corrode very easily. The plating is 0.5 microns of gold over 2.5 microns of bright nickel.

Signed Auric Goldfinger

Dear Auric,

You are right in expecting gold not to corrode when worn by your clientele. Gold electroplate, however, can be very porous, and human perspiration can be very corrosive to metals that are underneath the gold plate.

You need to eliminate the porosity of the gold plate. This can be accomplished by increasing the thickness to 2.5 microns, or by applying a pure gold strike followed by 1.5 microns of gold. You should also have a laboratory check the purity of your plating solution, because contamination by undesirable metals can yield increased porosity in the gold electroplate.

The part you submitted evidenced severe corrosion of the basis metal, indicating that the 2.5 microns of nickel provide insufficient protection of the basis metal. Nickel is also a very porous metal in the "as-plated" condition. You will need at least 25 microns of nickel before the porosity is decreased to an acceptable level. A better system of corrosion protection would involve the application of a "duplex" nickel plating (semi-bright nickel, at least 15 microns, followed by bright nickel of equal thickness) prior to application of the gold strike and final plate. P&SF

***Reference:** *Private communication, Oliver W. Siebert, Siebert Materials Engineering, Inc.*