English version

Jacques Jumeau

ULTIMHEAT® MUSEUM

Technology of components used in heating.

Chapter 7

Corrosion resistance of aluminium

1st edition 2017/12/16

Corrosion resistance of aluminum

Chemical composition of standard alloy used

Standard	Si	Cu	Mg	Zn	Mn	Fe	Ni	Sn	Ti	Al
ADC12 (JIS H5302:2000)	9.6-12.0	1.5-3.5	<0.3	<1.0	<0.5	0.6-0.9	<0.5	<0.2	-	Remainder

General corrosion resistance of aluminum enclosures when used outdoor

General information on the corrosion of aluminum

Aluminum and alloys generally have good resistance to atmospheric corrosion, in marine, urban and industrial environments. Molded under pressure, aluminum enclosures offer many possibilities of forms and treatments of the surface, require little maintenance and resist well in the time. In addition, with a view to sustainable development, aluminum is one of the metals whose recycling is the most economical. Aluminum remelting is only 5% of the energy required to make the metal from the ore. Aluminum naturally overlies with an oxide layer, which protects it most often against corrosion. In neutral aqueous solutions (4 <pH <9), this oxide film has a thickness of 50 Å and protects the metal (passivation). Aluminum is corroded homogeneously only in a very acidic solution, or in an alkaline solution. The strength and stability of the oxide layer depend on the ambient environment, the alloy composition and the microscopic structure of the metal (depending on the heat treatments applied). The electrochemical behavior of aluminum is influenced by the natural oxide film that governs the corrosion.

The boxes are massive and thick-walled (2 to 4mm); the corrosion is then superficial and affects only the appearance, without modifying the mechanical strength. In neutral environments, the overall corrosion rate of passive aluminum alloys is very small, but it is never totally zero. It thus keeps a value of the order of 5 µm per year, which can lead in the long run to a gradual change in the surface state to an unsightly appearance due to a change in roughness (orange peel).

The most common alteration is in the form of pitting corrosion which develops as cavities of varying depths. This is a very complex phenomenon, the mechanism of which is not fully determined.

In common industrial environments, aluminum housings can therefore be used without surface treatment other than deburring and standard vibration polishing.

Aluminum Galvanic corrosion, also called Bimetallic Corrosion

Aluminum enclosures may be subject to a particular phenomenon which reduces their service life, can go as far as the perforation of the envelope or the complete locking of the closure screws. It is galvanic or bimetallic corrosion.

Although most standards specify that appropriate safeguards must be in place to prevent galvanic corrosion on aluminum enclosures, none advocates a solution or requires specific material or composition of alloys. However, even if the aluminum is in an unfavorable position in the galvanic scale, it is most often covered with its passive film, which ennobles it considerably and makes it much less sensitive to corrosion.

Galvanic (Bi-Metallic) corrosion is the additional corrosion that occurs when dissimilar metals are in contact in the presence of an electrolyte (e.g. water, sea water). The corrosion of a metal, the anode, results from the positive current flowing from the anode to the less reactive (more noble) metal, the cathode, through the electrolyte.

This process is similar to the conventional corrosion of a single, uncoupled metal but generally proceeds at a higher rate depending on the difference in electrochemical reactivity of the anode and cathode metal.

There is a potential difference between the two metals that depends on both the metal and the solution. Two different metals or two alloys in contact with the same medium usually take two different potentials. If these two metals are electrically connected, their potential difference gives rise to electrochemical reactions and to the circulation of an electric current.

The most negative (the least noble) metal is positively polarized and the most positive metal is negatively polarized. In the vast majority of cases, this configuration corresponds to an increase in the corrosion rate of the most corrodible metal (the most negative), and a decrease in the corrosion rate of the least corrodible metal (the most positive).

Galvanic corrosion only occurs if the following 4 conditions are present and simultaneous:

- A: An electrolyte bridging the two metals.
When the conductivity of the electrolyte is low, corrosion is localized to the contact areas between the two metals. As the conductivity of the electrolyte increases, the corroded surface increases.
- B: An electrical contact between the two metals.
If the electrical contact is not established between the two metals by the interposition of an insulator (aluminum oxide, phosphating, paint, oil, etc.), the current does not circulate, there is no corrosion.
- C: A difference in potential between the metals to enable a significant galvanic current .
The higher this value, the greater the electromotive force of the phenomenon.
A difference of several hundred millivolts will result in strong galvanic corrosion, whereas a difference of less than 200-300mV will not have significant consequences. These galvanic corrosion potentials are given by a table which gives the electric potential of metals, usually measured by a so-called "Standard Calomel Electrode (S.C.E.)" technique. (See below)
- D: A sustained cathodic reaction on the more noble of the two metals.

The ratio of the surfaces of the two metals

- The most unfavorable case is that of a large cathodic surface (the most positive material) electrically connected to a small anodic surface (the most negative metal). The corrosion rate of the most negative metal can be multiplied by 100 see per 1000.
For example, stainless steel screws enclosing an aluminum housing will be prone to corrosion due to surface differences.

Corrosion of the noble metal, and influence of the salts produced by its corrosion

- The corrosion resistance of the noblest metal, regardless of its potential, has a considerable influence on the behavior of the bimetallic corrosion. If the noblest metal corrodes, its corrosion products may, by displacement, accelerate the corrosion of the most corrodable metal. For example, copper, although considered as a noble metal and whose galvanic torque with aluminum is small, produces oxides that can corrode aluminum, which is a critical parameter when designing earth terminal blocks on aluminum housings that can accommodate copper conductors.

Sacrificial metal coatings

By applying to the cathodic side a sacrificial coating having a potential similar to or near that of the anodic member, the galvanic corrosion is reduced.
Main design rule:
- The sacrificial element should be on the anodic side and smaller.
- Be careful to use fasteners that have an intact coating.
Example:
Zinc plating on steel fasteners will sacrifice the zinc instead of corroding the Aluminum (Potential difference 100 to 200mV).
Caution:
Do not use nickel plated steel fasteners, as the potential difference (450mV) between aluminum and nickel is too high and will corrode aluminum.

Specific issue of galvanic corrosion between Stainless steel and aluminum

The corrosion potentials of the stainless steels are "cathodics" and located in the "noble" area and the corrosion potentials of aluminum are "Anodic" and located in the "non-noble" area, with a large potential difference. This means that there will be no galvanic corrosion on stainless steel when placed in contact with aluminum while aluminum will corrode.
Although aluminum is anodic to stainless steel, large relative surface areas of aluminum to stainless steel can be acceptable, dependent on local conditions.
Stainless steel fasteners in aluminum plates or sheets or massive parts are normally considered safe. Even with no insulation between the metals, there should be little risk of corrosion.
In contrast, in a marine environment, severe localized pitting corrosion to the aluminum treads has been observed where un-insulated stainless steel screws were used.

Mechanical methods of reducing galvanic corrosion between aluminum and stainless steel

- Isolating the two materials by means of an electrical insulating material, like plastic, wherever practical.
- Avoid relatively small areas of the less noble metal (Aluminum) and large areas of the more noble metal (Stainless steel).

NB: Coupling a relatively wide area of aluminum with a small surface area of a cracked stainless steel part can cause a rapid attack of the material inside the crevice and corrode the stainless steel.

- Protect against the electrolyte presence around the bimetallic junction. For example, if possible, paint both metals.
- Apply corrosion inhibitors under screw heads and threads
- Apply an insulating organic coating to the contact surfaces before assembly.

Table of electrochemical voltage between aluminum alloys (Names highlighted in yellow and blue) and other common metals, in a 2% salt water solution.

There is no noticeable occurrence of corrosion when the value of the galvanic torque is less than 300mV.

	Pt (Platinum/ Platine)	Au (Gold/ Or)	Ti (Titanium / Titane)	AISI 316L(passive/passif)	Ag (Silver/ Argent)	Ni (Nickel/ Nickel)	Ni Cu 30 (Monel 400)	NiCr15 Fe8 (Inconel 600)	Cu55 Zn23 Ni22 (Arcap)	Cu (Copper/ Cuivre)	Al10 Sn66 Pb34	Cu Zn34 (Brass/ Laiton)	Cu88 Sn12 (Bronze)	Sn (Tin/ Etain)	Pb (Lead / Plomb)	Al Cu Mg1(Duralumin)	Mild steel / Acier doux)	Al Si 10Mg (Alpax H)	Al 99.5 (Aluminum)	Hard steel/ Acier dur	Al Mg5 (Duralinox)	ADC12 (Aluminum alloy)	Cd (Cadmium/ Cadmium)	Fe (Steel / Fer)	Cr (Chromium/ Chrome)	Al Mg Si0.7 (Almasilium)	Sn75 Zn25	Zn (Zinc/ Zinc)	Al PVD (Physical vapor deposition)	Mg (Magnesium)
Pt (Platinum/ Platine)	0	130	250	250	350	430	430	430	450	570	600	650	770	800	840	940	1000	1065	1090	1095	1100	1100	1100	1105	1200	1200	1350	1400	1400	1900
Au (Gold/ Or)	130	0	110	110	220	300	300	300	320	410	470	520	610	670	710	810	870	935	960	965	970	970	970	975	1070	1070	1230	1270	1270	1820
Ti (Titanium / Titane)	250	110	0	0	110	180	180	180	200	320	350	400	520	550	590	690	750	815	840	845	850	850	850	855	950	950	1100	1150	1150	1700
AISI 316L(passive/passif)	250	110	0	0	110	180	180	180	200	320	350	400	520	550	590	690	750	815	840	845	850	850	850	855	950	950	1100	1150	1150	1700
Ag (Silver/ Argent)	350	220	100	100	0	80	80	80	100	220	250	300	420	450	490	590	650	715	740	745	750	750	750	755	850	850	1010	1050	1050	1600
Ni (Nickel/ Nickel)	430	300	180	180	80	0	0	0	20	110	170	220	340	370	410	510	570	635	660	665	670	670	670	675	770	770	930	970	970	1520
Ni Cu 30 (Monel 400)	430	300	180	180	80	0	0	0	20	110	170	220	340	370	410	510	570	635	660	665	670	670	670	675	770	770	930	970	970	1520
NiCr15 Fe8 (Inconel 600)	430	300	180	180	80	0	0	0	20	110	170	220	340	370	410	510	570	635	660	665	670	670	670	675	770	770	930	970	970	1520
Cu55 Zn23 Ni22 (Arcap)	450	320	200	200	100	20	20	20	0	120	150	200	320	350	380	490	550	615	640	645	650	650	650	655	750	750	910	950	950	1500
Cu (Copper/ Cuivre)	570	440	320	320	220	140	140	140	120	0	30	80	200	230	270	370	430	495	520	525	530	530	530	535	630	630	780	830	830	1380
Al10 Sn66 Pb34	600	470	350	350	250	170	170	170	150	30	0	50	170	200	210	310	400	465	490	495	500	500	500	505	600	600	760	800	800	1350
Cu Zn34 (Brass/ Laiton)	650	520	400	400	300	220	220	220	200	80	50	0	120	150	190	290	350	415	410	445	450	450	450	455	550	550	710	750	750	1300
Cu88 Sn12 (Bronze)	770	640	520	520	420	340	340	340	320	200	170	120	0	30	70	170	230	295	320	325	330	330	330	335	430	430	590	630	630	1180
Sn (Tin/ Etain)	800	670	550	550	450	370	370	370	350	230	200	150	30	0	40	140	200	265	290	295	300	300	300	305	400	400	560	600	600	1150
Pb (Lead / Plomb)	840	710	590	590	490	410	410	410	380	270	240	190	70	40	0	100	160	225	250	255	260	260	260	265	360	360	520	660	560	1110
Al Cu Mg1(Duralumin)	940	810	690	690	590	510	510	510	490	370	340	290	170	140	100	0	60	125	150	155	160	160	160	165	260	260	420	560	560	1010
Mild steel / Acier doux)	1000	870	750	750	650	570	570	570	550	430	400	350	230	200	150	60	0	65	90	95	100	100	100	105	200	200	360	400	400	950
Al Si 10Mg (Alpax H)	1065	935	815	815	715	635	635	635	615	495	465	415	295	265	225	125	65	0	25	30	35	35	35	40	135	135	295	355	355	885
Al 99.5 (Aluminum)	1090	960	840	840	740	660	660	660	640	520	490	440	320	290	250	150	90	25	0	5	10	10	10	15	110	110	270	310	310	860
Hard steel/ Acier dur	1095	965	845	845	745	665	665	665	645	525	495	445	325	295	255	155	95	30	5	0	5	5	5	10	105	105	265	305	305	855
Al Mg5 (Duralinox)	1100	970	850	850	750	670	670	670	650	530	500	450	330	300	260	160	100	35	10	5	0	0	0	5	100	100	260	300	300	850
ADC12 (Aluminum alloy)	1100	970	850	850	750	670	670	670	650	530	500	450	330	300	260	160	100	35	10	5	0	0	0	5	100	100	260	300	300	850
Cd (Cadmium/ Cadmium	1100	970	850	850	750	670	670	670	650	530	500	450	330	300	260	160	100	35	10	5	0	0	0	5	100	100	260	300	300	850
Fe (Steel / Fer)	1105	975	855	855	755	675	675	675	655	535	505	455	335	305	265	165	105	40	15	10	5	5	5	0	95	95	255	295	295	845
Cr (Chromium/ Chrome)	1200	1070	950	950	850	770	770	770	750	630	600	550	430	400	380	260	200	135	110	105	100	100	100	95	0	0	160	200	200	750
Al Mg Si0.7 (Almasilium)	1200	1070	950	950	850	770	770	770	750	630	600	550	430	400	380	260	200	135	110	105	100	100	100	95	0	0	160	200	200	750
Sn75 Zn25	1350	1230	1110	1110	1010	930	930	930	910	790	760	710	590	650	520	420	360	295	270	265	260	260	260	225	160	160	0	40	40	590
Zn (Zinc/ Zinc)	1400	1270	1150	1150	1050	970	970	970	950	830	800	750	630	600	560	460	400	335	310	305	300	300	300	295	200	200	40	0	0	550
Zn Al4 (Zamak3/Zamac 3)	1400	1270	1150	1150	1050	970	970	970	950	830	800	750	630	600	560	460	400	335	310	305	300	300	300	295	200	200	40	0	0	550
Al PVD (Physical vapor deposition)	1400	1270	1150	1150	1050	970	970	970	950	830	800	750	630	600	560	460	400	335	310	305	300	300	300	295	200	200	40	0	0	550
Mg (Magnesium)	1900	1820	1700	1700	1600	1600	1600	1600	1520	1500	1390	1300	1180	1150	1110	1010	950	885	860	850	850	850	850	845	845	845	590	560	560	0

- 0-300 mV
- 301-500 mV
- 501-800 mV
- > 800 mV