Corrosion resistance of aluminum enclosures

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Galvanic corrosion, also called Bimetallic Corrosion

Protective housings may be subject to a special phenomenon which reduces their lifespan, up to the perforation of the envelope or complete locking of the closing screws. This is galvanic corrosion.

Although most standards specify that appropriate safeguards must be taken to avoid galvanic corrosion on aluminum boxes, none advocates any solution or imposes materials or precise compositions of alloys.

Galvanic (Bi-Metallic) corrosion is an electrochemical phenomenon that occurs when dissimilar metals are in contact in the presence of an electrolyte (e.g. water, sea water). This will cause additional corrosion that can occur with other phenomena and uncoupled metals, and its progression is usually much faster.

A difference of potential appears between the two metals depending on both the metal and the solution. Two metals or two different alloys in contact with the same medium generally take two different potentials. If both metals are electrically connected, their difference of potential generates electrochemical reactions and an electric current flows. The most negative metal (least noble) is positively polarized and the most positive metal is negatively biased. In the vast majority of cases, this configuration is an increase of the corrosion rate of the corroding metal most (most negative), and a decrease in the rate of corrosion of the least corroding metal (most positive).

Joint conditions necessary for the appearance of a galvanic corrosion couple.

Galvanic corrosion is a function of several different factors that need to be carefully evaluated when assessing the likelihood to have galvanic corrosion.

The simultaneous requirements for bi-metallic corrosion are as follows:
- An electrolyte bridging the two metals
- Electrical contact between the two metals.
- A difference in potential between the metals to enable a significant galvanic current
- A sustained cathodic reaction on the most noble of the two metals.

NB: If the metals are dry, bi-metallic (galvanic) corrosion cannot occur.

Electrolyte

The conductivity of electrolyte will also affect the degree of attack.

When the conductivity of the electrolyte is low, the corrosion is localized to the contact zones between the two metals. When the conductivity of the electrolyte increases, the corroded surface increases.

Electrical contact between metals

Galvanic corrosion potentials of various metals and alloys are listed in a table which gives the metal electrical potential values and are usually measured with respect to the Standard Calomel Electrode (S.C.E.).

"Anodic" metals such as magnesium, zinc and aluminum are more easily corroded metals than "cathodic" ones (titanium, silver, gold).

Corrosion is proportional to the potential difference between two metals.

The values to be considered are the potentials of the metals and alloys which form the couple with respect to the medium in question. These potentials are experimental values and must be distinguished from the standard potentials of thermodynamic tables. Experimental potentials are strongly influenced by parameters such as temperature, agitation and ventilation. In addition, some metals can take two different potentials when in the same environmental conditions according to whether they are active or passive (case of stainless steels in contact with sea water, for example).

These considerations show that it can be difficult to predict trends without the need for experimentation, as many parameters are likely to reverse the polarity of some galvanic couples.

Aggravation or reduction factors

- Area ratio of the two metals: the worst case is when a large cathode surface (the most positive material) is electrically connected to a small anode surface (metal most negative). The corrosion rate of the most negative metal can be multiplied by 100 or by 1000.

For instance, the assembly of a disc thermostat aluminum cup (dia 16mm) on a stainless steel tank will cause a quick corrosion of the cup if the necessary joint conditions are fulfilled.

On the other side, stainless steel screws closing an aluminum case will be much less subject to corrosion if the contact surfaces are minimized.

Resistance to corrosion of noble metals

- Regardless of its potential, the corrosion resistance of the most noble metal significantly influences the behavior of bimetallic couples. If the most noble metal corrodes, its corrosion products may, by motion, accelerate the corrosion of the most corroding metal. For instance, copper, yet considered as a noble metal and whose galvanic couple with aluminum is small, produces oxides that can corrode aluminum, which is a critical parameter in the design of earth terminals on aluminum housings that accommodate copper conductors.

If the noble metal couple is not corroding (Gold, Platinum), it will not present a risk of galvanic corrosion regardless of the metal that will be associated.

Sacrificial metal coatings

By applying to the cathode a sacrificial coating having a potential similar to or near that of the anodic member, the galvanic corrosion is reduced. Main design rules:
- The sacrificial element should be on the anodic side and smaller.
- Be careful to use fasteners that have intact coatings.

Examples:
- Cadmium plating on steel fasteners holding 2024-T4 aluminum plates, will sacrifice the cadmium instead of corroding the Aluminum. (Potential difference 100 to 200mV).
- Zinc plating on steel fasteners will sacrifice the zinc instead of corroding the Aluminum (Potential difference 100 to 200mV).

Do not use nickel plated on steel fasteners as the potential difference (450mV) between nickel and aluminum is too high and will corrode aluminum.

Note: The current trend is the search for an alternative to cadmium because of its toxicity, and its prohibition by the RoHS European Directive.
Some special cases of bimetallic electrochemical couples

Corrosion risks with galvanized steel and stainless steel in contact

Galvanized steel in contact with stainless steel is not normally considered to be a serious corrosion risk, except possibly in severe (marine type) environments.

In these situations, precautions such as insulating barriers are usually considered adequate to avoid bimetallic corrosion in most practical situations.

Galvanic corrosion between stainless steel and aluminum

The corrosion potentials of the stainless steels are “cathodics” and located in the “noble” area. 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, depending on local conditions.

Stainless steel fasteners in aluminum plates or sheets are normally considered safe, whereas aluminum rivets or bolts holding stainless steel parts together is an unwise combination, as there is a practical risk of corrosion.

Even with no insulation between the metals, there should be little risk of corrosion, in continental weather conditions.

In contrast, in a marine environment, severe localized pitting corrosion to the aluminum treads has been observed where un-insulated stainless steel bolts were used to secure the treads in place.

On the same ladder however, bolts with sound insulating washers did not show any pitting on the surrounding aluminum.

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).
- The same metal or more noble (Cathodic, higher number in the table) metals should be used for small fasteners and bolts.
- Avoid crevices in stainless steel: In the presence of crevices stainless steels may feature less noble potentials due to oxygen depletion within the crevice. Therefore, coupling a relatively large aluminum area with a small creviced area of a stainless steel part may result in rapid attack of the material within the crevice leading to stainless steel corrosion.
- Exclude electrolyte from around the bimetallic junction e.g by painting. Paint both metals where possible: if impractical paint the most noble metal
- Seal: insure that faying surfaces are water-tight.
- Apply corrosion-inhibiting pastes or compounds under screw heads or bolts inserted into dissimilar metal surfaces whether or not the fasteners have been previously plated or otherwise treated.
- In some instances, it may be feasible to apply an organic coating to the faying surfaces prior to assembly. This would be applicable to joints which are not required to be electrically conductive.
- Where practicable or where it will not interfere with the proposed use of the assembly, the external joint should be coated externally with an effective paint system.
- Avoid threaded joints for materials far apart in the galvanic series

Steel and Stainless steel phosphate coating

The phosphate coating is a conversion process used to form layers obtained by a reaction of the substrate with a selected medium. It is particularly applied to carbon steels and stainless steels. In the case of steel parts, phosphate coating is used primarily to enhance the adhesion of paints.

Aluminum Anodization

Anodizing consists in strengthening the natural oxide film by anodic oxidation. The thick anodizing provides a good galvanic insulation

Joining metals by non-metallic materials

To be suitable for joining to metals, non-metallic materials must be:
- free of corrosive agents (salts)
- free of acid or alkaline materials (neutral pH)
- free of carbon or metallic particles,
- Must not be subject to bio-deterioration
- Must not support fungal growth
- Must not absorb or wick water

Do not use: non-metallic materials that will initiate corrosion of metals to which they are joined, e.g., cellulosic reinforced plastics, carbon or metal loaded resin materials, asbestos-cement composites.
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Electrochemical couples between aluminum alloys
(Names highlighted in yellow or blue) and other base metals, in a 2% saline solution.
There is no appearance of significant corrosion when the galvanic couple value is less than 300mV

Other limitations in the use of aluminum alloys

To avoid ignition hazards due to impact or friction, standards for explosion-proof equipment (IEC 60079-0) restrict the use of aluminum.

**Enclosures for group I:**
The total weight of aluminum + magnesium + titanium should not exceed 15% of the total weight (or 6% of the total weight of magnesium + titanium alloys having no aluminum), which eliminates, for that group, most alloys containing aluminum.

**Enclosures for group II:**
- For zone 0: the total weight of aluminum + magnesium + titanium + zirconium should not exceed 10% of the total weight (or 7.5% of the total weight of magnesium + titanium + zirconium alloys for not containing aluminum), which eliminates, for this group and this zone most alloys containing aluminum.
- For zone 1: the weight of magnesium should not exceed 7.5% of the total weight.
- For zone 2: no specifications.