

Formation of Galvanic Corrosion Between Metallic and Composite Aerospace Structure

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EXECUTIVE SUMMARY

This technical note describes galvanic corrosion between composites and metals. It includes discussion on the causes of galvanic corrosion and methods to mitigate it.

DEVELOPMENT OF GALVANIC CORROSION BETWEEN METALLIC AND COMPOSITE AEROSPACE STRUCTURE

Development of galvanic corrosion between metallic and composite constituents in a hybrid structure was recognized early in aircraft designs that employed such hybrid structures. In the classical case of metallic structures in which two dissimilar alloys are in contact, the textbook definition of galvanic corrosion is an electrochemical process in which one metal corrodes preferentially when in contact with a different type of metal and both metals are in an electrolyte [1]. Galvanic corrosion is an electrochemical process in which an oxidation-reduction reaction occurs. The anode is the electrode at which the oxidation half of the oxidation-reduction reaction takes place. The reduction half of the reaction takes place at the cathode [2].

There are five conditions that must be satisfied for composite-to-metal galvanic corrosion to develop [1]:

1. An actively corroding metal
2. An electrically conductive composite (usually carbon fiber)
3. An electrical connection between the composite and the metal
4. An electrolyte (usually salt water)
5. Oxygen

If any of these conditions are absent, galvanic corrosion will not occur. Instead, the components will corrode at the rates at which they naturally corrode when immersed in an electrolyte. The morphology and intensity of the galvanic corrosion strongly depend on the type of metal connected to the carbon composite, the cathode-to-anode surface area ratio, and environmental conditions [3].

Graphite (carbon) fibers (which are produced by burning polyacrylonitrile in air and then carbonized in an inert atmosphere at a much higher temperature) behave electrochemically like a noble metal, such as gold or platinum. This nobility results in an electrical potential difference that causes galvanic current to flow when graphite epoxy composite material is coupled to a less-noble metal or alloy in an electrolyte. The less-noble metal or alloy corrodes because of galvanic action.

The galvanic series is a popular method for estimating galvanic corrosion. This method of predicting galvanic corrosion ranks various metals and alloys in a specified corrosive environment. Alloys with higher potential differences are considered to be more susceptible to galvanic attack, whereas those alloys having a similar potential ranking would be less prone to corrode galvanically. If the potential difference between two dissimilar metals in a given electrolyte is less than 0.25 volts, then the alloy couple is considered compatible. However, the galvanic series method has been found unreliable for predicting the propensity for galvanic corrosion. Potentials vary with temperature, time, oxidizers in solution, and many other parameters. Therefore, extrapolation of data taken from one environment to another that is only slightly different can dramatically change corrosion rates, even to the degree that there is a cathode anode reversal.

A more reliable method is based on galvanic current density instead of potential difference in the galvanic series. With this method, alloys are ranked by the magnitude of their average galvanic current density, which can be successfully used by the designer only if the increase of corrosion

rate due to galvanic coupling is the primary corrosion mode. It follows that in a composite metallic hybrid structure, steel and aluminum alloys were least compatible. Stainless steel and beryllium-copper (Be-Cu) were better. The best alloys were nickel-base and titanium [2].

Other studies [3] have evaluated the galvanic corrosion compatibility between carbon-reinforced composites and metallic alloys. When considering aluminum alloys, there is a belief that the galvanic corrosion rate of aluminum can be reduced by the anodization process and the formation of a thick, protective aluminum-oxide layer on the surface. However, any breach to this protective layer by mechanical means can exacerbate the corrosion rate because of the high cathode-to-anode surface-area ratio. Similar to aluminum alloys, plain steels connected to a carbon composite showed increased corrosion rates by a factor of 25 and 60 when immersed in deicing solution and seawater, respectively. Conversely, stainless steel and titanium alloys exhibited a much better symbiosis with carbon composites. Most stainless steels showed no evidence of galvanic corrosion when coupled to carbon composites. The only exceptions were some types of stainless steel, such as 301 or 410, which showed susceptibility to localized corrosion (like pitting and crevice) when connected to carbon composite in aerated 3.5% NaCl solution (simulated seawater). By looking at the standard electrochemical potential galvanic series, it appears that titanium is an active metal. However, because of the formation of a dense and stable protective oxide layer, titanium is placed among the noble materials on par with carbon in the galvanic series. This implies that there is no significant gap between titanium and carbon-fiber-reinforced composites to create galvanic corrosion.

It is a misconception that galvanic corrosion in a metallic/composite hybrid structure is a concern for the metallic constituent only. However, the galvanic coupling of metals to carbon composites will not only cause problems for the metal, but also for the composite itself [3]. Because of hydrogen gas generation in defect sites of the composite (e.g., voids and cracks), hydrogen-filled blisters can form on the composite surface. Another concern in a galvanic couple is the formation of calcareous deposits on the surface of the carbon composite. In stagnant seawater, a large number of cathodic reactions take place on the surface of carbon fibers, including hydrogen evolution and oxygen reduction, which can lead to the creation of localized alkaline solution on the surface. In this condition, the carbonate salts in seawater are not soluble and will deposit in the form of an aragonite phase (calcium and magnesium carbonate). Because a high-hydrogen reduction rate is required to create such calcareous deposits, this phenomenon happens when an active metal, such as aluminum or magnesium, is connected to a composite material.

Practical means to mitigate the galvanic corrosion potential on metals connected to carbon composites have been employed in typical hybrid structures [1, 3–4]. These means include the following remedies:

1. Insert an insulating layer of E-glass barrier between the metal and composite-structure members. This eliminates the direct electrical connection of the two parts, but it does not completely electrically isolate the two constituents because the fastener on a bolted joint can still provide the electrical path if the electrolyte bridges over the E-glass barrier. Therefore, extending the size of the barrier beyond the faying surface of contact is recommended. This technique should also be used in conjunction with the application of sealants and plating methods to electrically isolate the two parts.

2. Substitute the metallic part with a high-corrosion resistance alloy, such as nickel-base and titanium alloys.
3. Use epoxy resins without any hydrolysable linkage, such as ester bonds, to mitigate water penetration into the composite and then to decrease the real cathodic surface area. For the latter, research has shown conclusively that if the area of the anode (Aa) (aluminum) is large compared to the area of the cathode (Ac) (carbon composite), then galvanic corrosion will be limited. This is known as the effect of the area ratio A_c/A_a , which directly contributes to the dissolution rate of the metal (anode).
4. Use sizing agents as a sealant on the surface of the carbon fibers before fabricating composites.

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