CORROSION IN SOLAR PV GROUNDING AND BONDING

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ABSTRACT

Corrosion in outdoor environments is a topic that is gaining attention in the solar photovoltaic (PV) industry. Simple oxidation, galvanic, and crevice corrosion are mechanisms by which metals deteriorate when exposed to the elements. The rate and extent of corrosion depends on several factors, including environmental conditions such as moisture, temperature and pH. Galvanic action is also a common accelerator of corrosion, caused by dissimilar metals in contact with each other in the presence of an electrolyte (such as salt water). The impact of corrosion depends on the item being attacked – a large steel beam, or a small electrical connection. With regards to solar PV grounding and bonding, small electrical connections are the targets of corrosion, and the impact of such failed connections could be extensive.

1. INTRODUCTION

Galvanic corrosion between stainless steel and aluminum is a well-documented phenomenon. In many corrosive environments the combination of stainless and aluminum is avoided, whether the materials are used for mechanical or electrical connections. In some solar installations the two materials are used together in direct contact (for both mechanical and electrical connections), with little to no negative results. The same connections can deteriorate rapidly in environments where the PV array is constantly exposed to moisture, salt spray and heat.

2. COMMON APPLICATIONS

Nearly all grounding devices used to establish a ground bond to aluminum module frames incorporate a stainless steel to aluminum connection. Proper installation of these devices makes a huge difference in their long-term performance and ability to withstand corrosive environments. Many such items, even when installed properly, still damage the protective anodized coating on aluminum module frames and rails. In some cases the electrical connection is created by scraping, gouging or cutting through the anodizing. Without sealing or otherwise treating the connection they create, raw aluminum becomes exposed to the environment and increases the rate of oxidation and galvanic corrosion. This leads to an increase in the connection's resistance, and eventual failure of the ground bond. It cases where a grounding device does not directly rely on the stainless to aluminum electrical connection, the stainless mounting hardware can still damage protective anodizing and exposes the interface to corrosion. Such corrosion may lead to a mechanical failure of the connection, which in turn causes electrical failure.

2. GALVANIC POTENTIAL DIFFERENCE

Stainless steel is also commonly (and erroneously) used to provide galvanic isolation between copper and aluminum. As seen in Table 1, active 304 stainless steel is only slightly closer in galvanic potential to aluminum alloys than copper. Note the difference between active and passive alloys. Potential difference between two materials does not determine whether or not they will react in a galvanic cell, but rather how vigorously they will react. Other factors, such as relative size of the cathode (stainless steel, tin, or copper) compared to the size of the anode (aluminum) also affect the rate of corrosion. The lower potential difference between active 304 stainless steel and aluminum does not guarantee a suitable combination of materials in all environments.

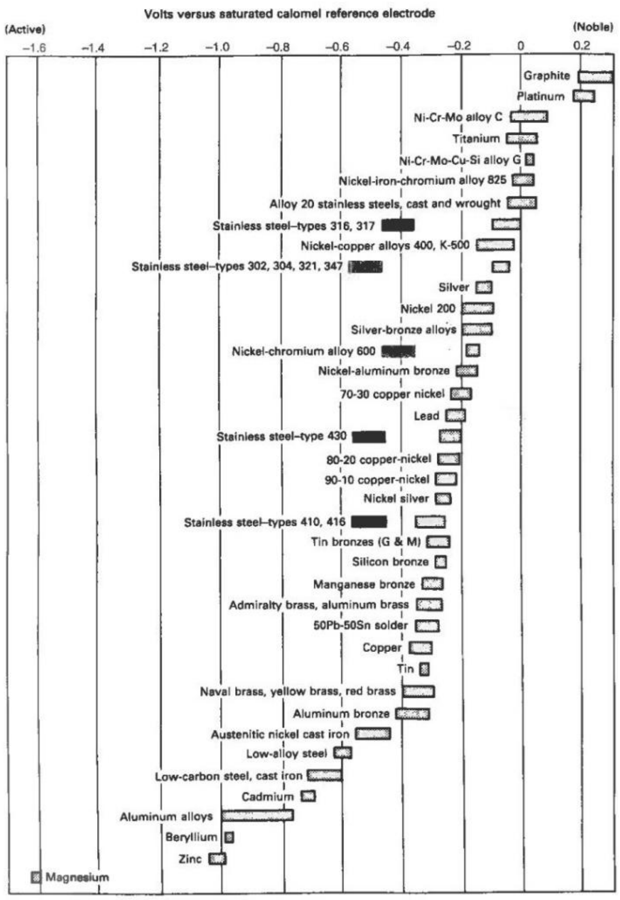

Table 1: Galvanic series for seawater. Dark boxes indicate active behavior of active-passive alloys. Adapted from ASM Handbook Volume 13A (p. 563), 2003. Reprinted with permission.

3. <u>TESTING OF MATERIAL COMBINATIONS</u>

Testing of representative assemblies of materials, in the configurations and applications they are intended for, reveals much more than a simple comparison of galvanic potentials.

Figures 1, 3 and 4 show some common combinations of materials and devices used in the solar PV industry. Figure 1 shows ¼”-20 bolts installed onto a 1.6 mm (0.063 in) thick anodized aluminum angle. The threaded hardware was tightened to 8.1 N-m (6 ft-lbs) of torque, with anti-seize lubricant applied to the threads. Figure 2 shows the flat washer installed under the head of the bolt, and the ¼”-20 serrated flange nut that secures the assembly to the angle. All hardware shown is 18-8 (304) stainless steel, and is commonly passivated during the manufacturing process. It is important to note that the passive oxide layer may be disturbed or removed during manufacturing or assembly. This combination of stainless hardware and anodized aluminum is extremely common in PV arrays.

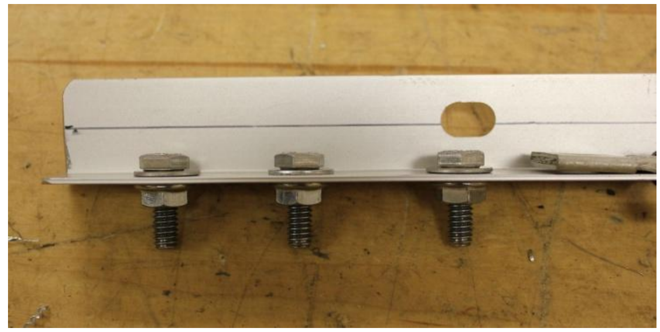

Fig. 1: Anodized aluminum angle with stainless hardware

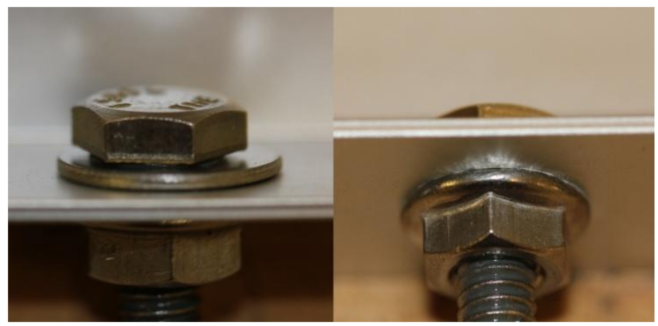

Fig. 2: Details of threaded hardware

Figures 3 and 4 show a tin-plated copper braid attached to and in contact with anodized aluminum angles. Figure 4 shows where anodizing has been removed from one of the aluminum angles. Both examples represent common applications seen in grounding and bonding device assemblies.

Fig. 3: Anodized aluminum angle with tin-plated copper braid

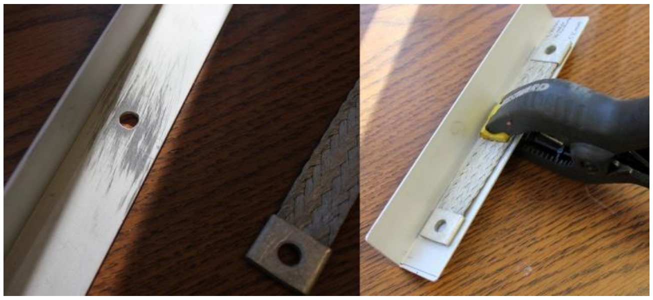

Fig. 4: Alternate braid configuration with some anodizing removed

4. ACCELERATED CORROSION

Due to the variety of environments in which solar PV is installed, accelerated corrosion testing results cannot be correlated to service life of grounding and bonding devices. That being said, such results can accurately predict failure methods and relative corrosion resistance of various assemblies.

The stainless hardware and braid assemblies were subjected to 500 hours of 5% NaCl solution salt fog at 95° Fahrenheit, as per ASTM B117-03. The disassembled and cleaned samples are shown in Figures 5-7.

Figure 5 provides a good illustration of the type of corrosion seen at bolted connections on typical PV arrays. Both the flange nut to aluminum interface and the flat washer to aluminum interface show evidence of crevice corrosion accelerated by galvanic action. This is expected under a serrated flange nut, which easily damages anodizing on aluminum, but is more surprising to find under a flat washer. Small localized cracks in the anodizing under the flat washer provided a starting point for a galvanic reaction.

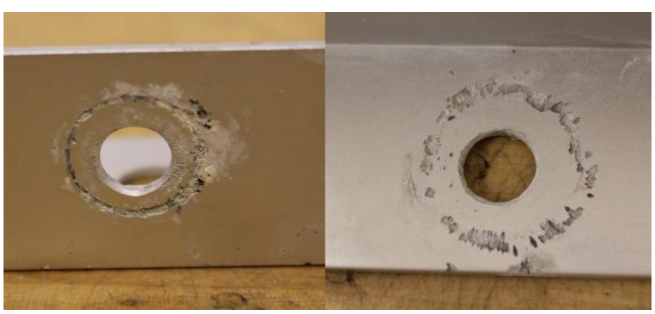

Fig. 5: Corrosion under nut (left) and under washer (right)

Figure 6 illustrates the kind of damage that can occur when tin-plated copper comes into contact with an un-protected aluminum edge. Tin and copper have galvanic potentials that are comparable, as seen in Figure 1.

Fig. 6: Corrosion at unprotected edge of aluminum angle

When compared with Figure 6, Figure 7 shows substantially less galvanic action on the tin plating. Damage to the exposed aluminum under the braid is comparable in severity to the damage and discoloration of the intact anodizing. A notable similarity is the increased rate of corrosion at edges and corners, due to additional surface area available for the reaction.

Fig. 7: Corrosion under alternate braid configuration

5. CONCLUSION

Solar PV installations with multi-material interfaces can be severely affected by galvanic corrosion in certain environments. Careful selection of materials, design of interfaces, and clear installation recommendations can all mitigate the impact of corrosion. Appropriate testing can indicate the limitations of certain equipment, and can reveal unforeseen points of failure. Accurate representative assemblies are crucial to meaningful test results.

There is a clear need for additional corrosion protection in harsh environments, aside from the assumed corrosion resistance of materials like stainless steel, anodized aluminum, and tin plated copper. Small components, such as grounding and bonding devices will fail before noticeable damage to the structure of the PV array occurs. Furthermore, failures in the ground path may not become apparent until there is significant damage from a ground fault. Electrical grounding and bonding connections used in PV installations must be able to withstand decades of harsh environmental exposure, or must be identified as not suitable for such environments.

6. REFERENCES

(1) ASM Handbook Volume 13A Corrosion: Fundamentals, Testing, and Protection. ASM International: Materials Park, OH, 2003, p 563

(2) "Standard Practive for Operating Salt Spray (Fog) Apparatus," ASTM B117-03, West Conshohocken, OA: ASTM International