AEROSPACE RECOMMENDED PRACTICE

ARP4118™	REV. C
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Isolation and Corrosion Protection of Dissimilar Materials, Carbon Composite Structure Repair

RATIONALE

Five-Year Review. Removed the galvanic series table and referenced MIL-STD-889 for the determination of galvanic compatibility. Updated compatibility table to call out the ratings in MIL-STD-889.

1. SCOPE

1.1 This SAE Aerospace Recommended Practice (ARP) provides methods and guidelines for isolating dissimilar repair patch materials from carbon fiber reinforced plastic (herein also referred to as carbon composite) structure during a repair operation.

1.2 These procedures are applicable to any repair procedure for carbon fiber reinforced plastic parts in which the repair patch is a metallic alloy that can form a galvanic cell with carbon in the presence of moisture or other electrolytes. The principal patch materials, discussed in terms of their relative galvanic compatibility with carbon composites, are aluminum, titanium, stainless steel, and carbon composite.

1.2.1 While not covered directly under this specification, reinforced plastics used in structural repairs also include parts made with fiberglass, aramid, or boron fibers. Fiberglass and aramid fiber reinforced plastics do not have galvanic reactions with other materials. The procedures outlined herein are not essential with these materials; however, the sealing procedures covered are still recommended as a means of preventing moisture entry.

1.2.1.1 Rarely used boron filaments can produce a galvanic reaction by contact between the tungsten core of the fiber and adjacent metal, particularly in a bolted repair where the metal fasteners can contact cut fibers. Thus, the procedures outlined herein are advisable for bolted repairs of boron fiber reinforced plastics.

1.3 The procedures are primarily concerned with bolted repairs that introduce the highest corrosion risk due to the addition of holes and dissimilar fastener materials, but bonded repairs are also considered.

1.4 The procedures are also applicable to repairs involving reinstallation of metallic inserts into a carbon fiber reinforced plastic part.

1.5 Generic materials and parts are described with no specific vendor identifications. All materials used in the procedures outlined shall be accompanied by a Safety Data Sheet (SDS) and shall be handled in accordance with SDS instructions.

1.6 Safety-Hazardous Materials

Shall be in accordance with AS5502 (refer to 1.1).

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https://www.sae.org/standards/content/ARP4118C/

2. REFERENCES

2.1 Applicable Documents

Shall be in accordance with AS5502 (refer to Section 2).

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AMS2471 Anodic Treatment of Aluminum Alloys, Sulfuric Acid Process, Undyed Coating

AMS3265 Sealing Compound, Polysulfide (T) Rubber, Fuel Resistant, Non-Chromated Corrosion Inhibiting for Intermittent Use to 360 °F (182 °C)

AMS3276 Sealing Compound, Integral Fuel Tanks and General Purpose, Intermittent Use to 360 °F (182 °C)

AMS3277 Sealing Compound, Polythioether Rubber, Fast Curing for Integral Fuel Tanks and General Purpose, Intermittent Use to 360 °F (182 °C)

AMS3281 Sealing Compound, Polysulfide (T) Synthetic Rubber for Integral Fuel Tank and Fuel Cell Cavities, Low Density for Intermittent Use to 360 °F (182 °C)

AMS3374 Sealing Compound, Aircraft Firewall, Silicone

AMS-S-8802 Sealing Compound, Fuel-Resistant, Integral Fuel Tanks and Fuel Cell Cavities

AS5502 Standard Requirements for Aerospace Sealants and Adhesion Promoters

R-424 Composite Materials Handbook Volume 3, Polymer Matrix Composites: Materials Usage, Design, and Analysis (formerly MIL-HDBK-17-3)

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D1141 Standard Practice for Preparation of Substitute Ocean Water

2.1.3 U.S. Government Publications

Copies of these documents are available online at https://quicksearch.dla.mil.

MIL-A-8625 Anodic Coatings for Aluminum and Aluminum Alloys

MIL-A-46146 Adhesives-Sealants, Silicone, RTV, Noncorrosive (for Use With Sensitive Metals and Equipment)

MIL-DTL-5541 Chemical Conversion Coatings on Aluminum and Aluminum Alloys

MIL-DTL-81706 Chemical Conversion Materials for Coating Aluminum and Aluminum Alloys

MIL-PRF-23377 Primer Coatings: Epoxy, High-Solids

MIL-PRF-81733 Sealing and Coating Compound, Corrosion Inhibitive

MIL-PRF-85285 Topcoat, Aircraft and Support Equipment

MIL-PRF-85582 Primer Coatings: Epoxy, Waterborne

MIL-STD-889 Galvanic Compatibility of Electrically Conductive Materials

MIL-STD-7179 Finishes, Coatings, and Sealants, for the Protection of Aerospace Weapons Systems and Support Equipment

2.1.4 Other Publications

Advisory Group for Aerospace Research & Development. (1995). AGARD Conference Proceedings 550: Composite repair of military aircraft structures (AGARD-CP-550). North Atlantic Treaty Organization.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 Other Publications

Miller, A.B., Jr. (1976). *Effect of graphite-epoxy composites on the galvanic corrosion of aerospace alloys* (Report no. AFML-TR-76-121). Air Force Institute of Technology.

Rambalakos, A. (2017). *Formation of galvanic corrosion between metallic and composite aerospace structure* (Report no. DOT/FAA/TC-TN17/42). U.S. Department of Transportation, Federal Aviation Administration.

Yari, M. (2017). Galvanic corrosion of metals connected to carbon fiber reinforced polymers. Corrosionpedia.

3. REPAIR OPERATIONS

The critical repair operations related to galvanic isolation and corrosion protection are categorized as follows:

a. Sealing operations for bolted repairs of carbon fiber reinforced plastic parts incorporating metallic patches or inserts

b. Surface preparation of metal patch and insert materials and carbon fiber reinforced plastic parts for bolted repairs

c. Galvanic isolation and sealing for bonded repairs incorporating metallic patches or inserts

3.1 Patch Material Selection

Tables 1, 2, and 3 in MIL-STD-889 provide the galvanic compatibility of electrically conductive materials in an artificial seawater environment as defined in ASTM D1141 (without heavy metals) and is used as a guide for materials in contact with carbon fiber reinforced plastics. It shows there is a considerably higher material incompatibility between carbon and aluminum than between carbon and titanium or most stainless steels. It should be noted there are other factors such as uncoupled corrosion rates for the anodic metal material, the anode-to-cathode surface area ratio, and environmental conditions in determining severity of galvanic corrosion.

Aluminum patch repairs of carbon fiber reinforced plastic parts represent a potentially serious corrosion problem but are not prohibited because of aluminum's availability and ease of machining. The use of titanium, stainless steel, or carbon composite patches in place of aluminum is always desirable from the consideration of galvanic corrosion. Consideration of patch/substrate stiffness and thermal expansion coefficient differences in the joint is also required. Design of repairs for composite structures often involves a trade-off of aluminum's lower cost, lighter weight, availability, and ease of machining with the better match of properties attainable with titanium or stainless steel. The best galvanic and thermal match is carbon fiber reinforced plastic itself, and this should be a consideration in materials selection. Carbon-to-carbon bolted repairs still present a galvanic problem since metallic fasteners are used in direct contact with the carbon-containing composite.

One of the most critical requirements for metal patch repairs of composite parts is the use of suitable measures for separating the two faying surfaces being joined and preventing moisture entry. Bolted and bonded joints each require special approaches and are outlined in the following sections.

3.2 Bolted Repairs

3.2.1 Fastener Selection

For bolted repairs, a critical consideration is fastener selection. The use of aluminum fasteners, collars, and nut plates is never permitted in any joint with carbon fiber reinforced plastics. Cadmium-plated fastener system elements are prohibited in carbon fiber reinforced plastic bolted joints, since the cadmium coating will be severely attacked (refer to MIL-STD-889). Titanium, Inconel, or stainless steel are recommended for fastening of carbon composite structure. For carbon fiber reinforced plastic using metal for repair, selection of the fastener requires a compromise between compatibility with both materials; for this reason, titanium is commonly selected for bolted repairs and wet installation is required. Studies of fastener materials have established an order of preference for fasteners used in carbon composite joints (see Table 1). Precoated fasteners (resin-based coatings, sulfuric acid anodizing, baked-on solid film lubricants, etc.) provide some corrosion protection; however, any damage to the protective layer can increase corrosion susceptibility by increasing the anode-to-cathode surface area ratio. Proper sealing procedures utilizing wet fastener installation and use of a faying surface sealant (see 3.2.2) are required to preclude moisture ingress and maximize corrosion protection.

Other design factors for fastener selection (fastener type and dimensions, head geometry, hole tolerances, backside slope limits, internal versus external repair, etc.) are used to optimize the repair depending on load requirements and have less impact on corrosion performance. The R-424 (CMH-17 Volume 3) publication contains useful “lessons learned” regarding fastener selection and use in design and repair of carbon composite structure.

Table 1 - Galvanic compatibility of fastener materials[(1)(2)]

Preference No.	Material	Galvanic Compatibility Rating with Graphite According to MIL-STD-889
1	410SS	0 (<0.009 mil/yr)
2	A286	0 (<0.009 mil/yr)
3	Inconel 600	1 (0.01-0.09 mil/yr)
4	PH 13-8	1 (0.01-0.09 mil/yr)
5	Monel 400	1 (0.01-0.09 mil/yr)
6	Ti-6Al-4V	2 (0.1-0.9 mil/yr)
7	4340 Steel	5 (10-99.99 mil/yr)
8	1018 Steel	5 (10-99.99 mil/yr)
9	Cadmium-plated steel	6 (>100 mil/yr)

(1) Based on R-424 (CMH-17 Volume 3) and MIL-STD-889. Refer to MIL-STD-889 for the most up-to-date compatibility results and for information on how compatibility was determined.
(2) Refer to MIL-STD-889 for additional materials and compatibility ratings.

3.2.2 Sealing Procedures for Bolted Repairs

3.2.2.1 Sealing Compounds

The sealing procedures outlined below are highly recommended for all bolted metal patch repairs of carbon fiber reinforced plastic parts. The effectiveness of these sealing procedures has been demonstrated by extended sea-coast exposure (refer to AGARD-CP-550).

A list of sealants identified by specification and usage is shown in Table 2. Polysulfide sealants have recommended use temperatures from -65 to 250 °F (-54 to 121 °C) for continuous operation and up to 360 °F (182 °C) for short-term or intermittent durations. Recommended use temperatures for polythioether sealants are -80 to 320 °F (-62 to 160 °C) for continuous operation and up to 360 °F (182 °C) for short-term or intermittent durations. Some sealants have been formulated to withstand structural adhesive bond cycles of 1 to 2 hours at 250 to 350 °F (121 to 177 °C). For cure cycle temperatures in excess of 350 °F (177 °C) or more than 2 hours, care should be taken to select a system capable of operating under the required processing and environmental conditions. For applications requiring temperature extremes below -80 to over 400 °F (-62 to over 204 °C), silicone or fluorosilicone sealants are the most appropriate choice; however, they generally provide much lower adhesive strength than the polysulfides or polythioethers. Silicone or fluorosilicone sealants which generate acetic acid during cure should be avoided when the application involves sensitive electronics or where these by-products would create rather than solve corrosion issues.

Table 2 - Faying surface sealant categories

Material Type	Use	Specification[1]
Polysulfide	General purpose, corrosion inhibiting sealant, non-fuel areas.	AMS3265 and MIL-PRF-81733 Class 1
	General purpose, non-corrosion-inhibiting, fuel and non-fuel areas. Low density rubber.	AMS-S-8802, AMS3276, AMS3281
Polythioether	General purpose, corrosion inhibiting sealant, non-fuel areas.	MIL-PRF-81733 Class 2
	General purpose, non-corrosion-inhibiting, fuel and non-fuel areas, fast-curing.	AMS3277
Silicone or Fluorosilicone[2]	High temperature sealing applications from -65 to 400 °F (-54 to 204 °C).	AMS3374 or MIL-A-46146

(1) These specifications have several types, classes, and grades. A careful review of these categories and the recommended use for each must be made prior to sealant selection.
(2) Two-part silicone or fluorosilicone sealant, with catalytic curing agents, are recommended for repair of faying surfaces. One-part silicones require moisture (from exposure to air) for cure, so have limited use in faying surfaces greater than 1 inch (25 mm) in width.

Specifications listed in Table 2 cover a variety of sealant types. Ranges of service temperatures, application methods, application times, and tack free times are in the listed specifications. The applicable specifications and/or manufacturers should be consulted for specific selections.

3.2.2.2 Faying Surface Sealing Procedures for Bolted Repairs

These procedures are identical to those used in the bolted assembly of metal components and consist of application of the selected sealant to one or both faying surfaces by brush, spray, or spatula, depending on the sealant type and viscosity. Most sealants come in varying types, classes, and grades suited for particular applications. The lowest viscosity sealants may be sprayable and low viscosity sealants are well-suited for brush coating. Thixotropic sealants, typically applied by spatula or extrusion, are suitable for thicker coatings or in vertical or overhead areas where non-sag performance is valuable. Sealants applied by extrusion gun are typically supplied either in cartridge kits (cartridges containing both sealant and curing agent separated by a breakable membrane) or pre-mixed and frozen in cartridges. Sealant may be applied to one or both faying surfaces: Application to only one surface is recommended by some fabricators, particularly for larger joints, to avoid excessive sealant causing surface separation or improper fastener seating.

The polysulfide and polythioether sealants listed in Table 2 are generally usable as faying surface sealants or fillet/brush sealants. One precaution for use of sealants in faying surfaces and fastener installation is that the low-viscosity sprayable and brushable sealants have higher solvent content. Sufficient time after application (typically 15 minutes) must be allowed for the solvent to flash off before assembling the joint or installing the fasteners.

3.2.2.3 Wet Fastener Installation

Wet fastener installation is equally important to faying surface sealing as a means of galvanically isolating a bolted metal patch from the carbon fiber reinforced plastic part. The impact of hole tolerances and other fastener design factors on wet installation with sealant should be considered.

Figure 1 gives a typical configuration for a carbon fiber reinforced plastic joint, showing both permanent and removable installations. The sealant materials used are the same as given for faying surface sealing. Higher viscosity, thixotropic types are used when application is by spatula or extrusion gun; lower viscosity types may be used when applied by brush.

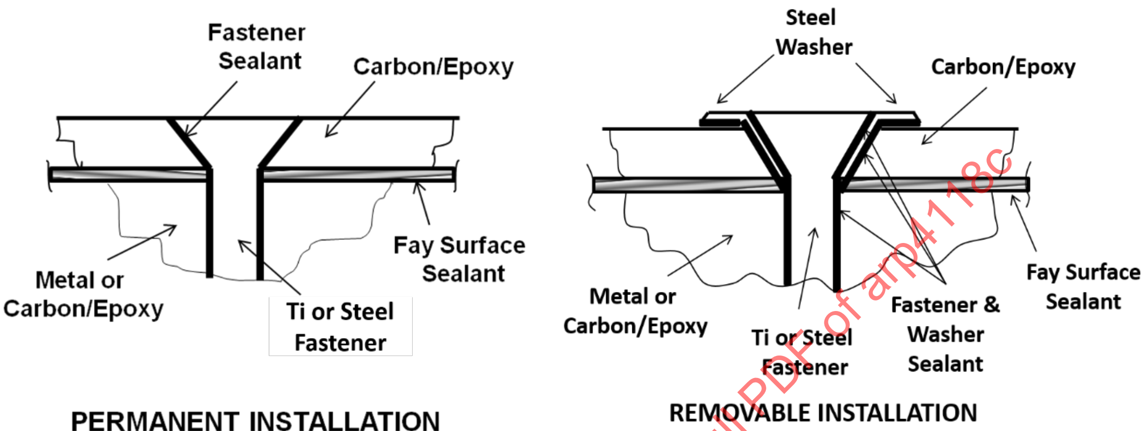

Figure 1 - Sealing arrangement for carbon fiber reinforced plastic assemblies

3.2.3 Surface Preparation Procedures for Bolted Repairs

The following additional precautions are strongly recommended for the high galvanic potential in using an aluminum patch for repair of a carbon fiber reinforced plastic part. The aluminum should be surface treated by a suitable corrosion protection procedure such as chromic or sulfuric acid anodizing treatment per MIL-A-8625 or AMS2471. A protective conversion coating (chemical film treatment) such as MIL-DTL-81706 or MIL-DTL-5541 may be used; however, it is less effective in corrosion protection than anodization. Conversion coatings may be conductive, and conductivity competes with the goal of galvanic or electrical isolation. MIL-STD-7179 recommends application of a corrosion-inhibitive finish system such as epoxy primer (i.e., MIL-PRF-23377 or MIL-PRF-85582) to each of the interface surfaces prior to bonding; application of an aliphatic polyurethane topcoat (i.e., MIL-PRF-85285) provides additional protection if a particularly corrosive environment is anticipated and if application of the finishes can be readily accomplished at the repair facility. In addition to application of primer to the faying surfaces, application of an aliphatic polyurethane topcoat to the carbon fiber reinforced plastic is an additional protective measure that is strongly recommended. Any surface treatments and finishes on the part should extend at least 1 inch (25 mm) beyond the edges of the joint. Application of an isolation ply, typically an electrochemically inert fiberglass cloth reinforced adhesive layer, to the surface of the carbon fiber reinforced plastic part in contact with the aluminum provides optimal protection against corrosion. For epoxy-based carbon composites, the barrier ply should extend a minimum of 1 inch (25 mm) beyond the metal patch footprint; for bismaleamide (BMI) carbon composites, the entire surface of the joint should be covered with the barrier ply. The barrier ply protects both the metal and composite from degradation by corrosion. Despite the very low activity/highly cathodic nature of carbon fiber reinforced parts, galvanic coupling may result in evolution of hydrogen gas filled blisters at composite defect sites (voids or cracks). Epoxy resins with hydrolysable linkages allow water penetration into the composite's carbon fibers and result in a very high cathode-to-anode surface area ratio. While use of barrier plies is required in aircraft production and is applicable to repair, it is less feasible for most repair locations. This procedure is described in 3.3.

Aluminum surface treatment and finishing as described above are highly recommended for bolted repairs; however, proper faying surface sealant and wet fastener installation as described in 3.2.2.2 and 3.2.2.3 are essential procedures required to protect against galvanic corrosion. For galvanically incompatible joints, it is generally understood that a minimum of three layers of protection using combinations of primers, topcoats, and fiberglass isolation plies in combination with faying surface sealant and wet fastener installation is sufficient for corrosion protection. Comparable installation procedures can be used for carbon fiber reinforced plastic repairs with titanium and most stainless steel patches but in most cases are not essential.