SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

AEROSPACE RECOMMENDED PRACTICE

SAE ARP4118

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Submitted for recognition as an American National Standard

ISOLATION AND CORROSION PROTECTION OF DISSIMILAR MATERIALS

1. SCOPE:

1.1 This SAE Aerospace Recommended Practice (ARP) provides methods and guidelines for isolating dissimilar repair patch materials from carbon composite structure during a repair operation.

1.2 These procedures are applicable to any repair procedure for carbon composite 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 addressed are aluminum, titanium, and stainless steel.

1.3 The procedures are primarily concerned with bolted repairs that introduce the most severe, potential corrosion problem but bonded repairs are also considered.

1.4 The procedures are also applicable to repairs that involve reinstallation of metallic inserts into a carbon composite part.

1.5 Fiberglass and aramid composites do not have galvanic reactions with other materials, and the procedures outlined herein are, therefore, not essential with these materials. The sealing procedures covered herein are still recommended, however, as a means of preventing moisture entry. 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 composites.

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

1.7 Safety-Hazardous Materials:

While the materials, methods, applications, and processes described or referenced in this specification may involve the use of hazardous materials, this specification does not address the hazards which may be involved in such use. It is the sole responsibility of the user to ensure familiarity with the safe and proper use of any hazardous materials and to take necessary precautionary measures to ensure the health and safety of all personnel involved.

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this specification to the extent specified herein. The latest issue of all SAE publications shall apply. The applicable issue of other documents shall be the issue in effect on the date of the purchase order.

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

AMS 2825 Material Safety Data Sheets
AMS 3267 Sealing Compound, Low Adhesion, Corrosion Inhibiting, for Removable Panels and Fuel Tank Inspection Plates
AMS 3373 Compound, Silicone Rubber, Insulating and Sealing

2.1.2 U.S. Government Publications: Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-S-8784 Sealing Compound, Aluminum Integral Fuel Tanks and Fuel Cell Cavities, Low Adhesion, Accelerator Required
MIL-S-8802 Sealing Compound, Temperature-Resistant, Integral Fuel Tanks and Fuel Cell Cavities, High-Adhesion
MIL-S-81733 Sealing and Coating Compound, Corrosion Inhibitive
MIL-S-83430 Sealing Compound, Integral Fuel Tanks and Fuel Cell Cavities, Intermittent Use to 360@F (182@C)

2.1.3 Other Publications:

2.1.3.1 Riggs, E. L. and Krupp, W., "Corrosion Principle and Protection," Lockheed-Calif. Co., Paper presented at Technical Symposia for China, Oct. 1978.

2.1.3.2 Cole, R. T., Bateh, E. J., and Potter, J., "Fasteners for Composite Structures," Composites, Vol. 13, No. 3, July 1982, p. 233.

2.1.3.3 Silverman, B. and Norrbom, A., "Use of Polysulfide Sealants in Aircraft Composite Structures," Products Research and Chemical Corp., Adhesives Age, June 1983.

2.1.3.4 Askins, D. R. and Schwartz, H. S., "Durability of Adhesive Bonded Honeycomb Sandwich in Accelerated Adverse Environments," Univ. of Dayton and Air Force Wright Aeronautical Labs, Proceeding of the 9th SAMPE Technical Conference, "Materials and Processes - In Service Performance," Atlanta, GA, Oct. 1977.

2.1.3.5 Wanamaker, J. L., "Corrosion Characteristics of Graphite Composite Lightning Protective Systems," Lockheed-Calif. Co., Lockheed Report LR 28947, Jan. 1983.

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 composite parts that incorporate metallic patches or inserts

b. Surface preparation of metal patch and insert materials and carbon composite parts for bolted repairs

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

3.1 Patch Material Selection:

Figure 1 provides a guide to galvanic compatibility of metal patch materials in contact with carbon composites. This shows there is considerably more electrical potential difference between carbon and aluminum than between carbon and titanium or stainless steels. Nonstainless steels have considerably more electrical potential difference with carbon than stainless steels, and certain aluminum alloys, as well as clad alloys, have more of a galvanic potential than others. It should be noted that other factors such as uncoupled corrosion rates for the anodic metal material and the polarization reaction of the metal are also factors in determining severity of galvanic corrosion.

Aluminum patch repairs of carbon composite 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, as well as consideration of matching coefficients of thermal expansion in the joint. Design of repairs for composite structures thus 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 of course carbon composite itself, and this should be a consideration in materials selection. Carbon-to-carbon bolted repairs still present a galvanic problem however, since metallic fasteners will be used in direct contact with the carbon composite.

Most Active
(ANODIC)

Increasing Tendency to Corrode ↑

Alclad 7000 Series aluminum alloys
5000 Series aluminum alloys
7000 Series aluminum alloys
Pure aluminum and alclad 2000 Series alloys
Cadmium
2000 Series aluminum alloys
Steel and iron
Stainless and heat resistant steels
Titanium
Nickel and nickel alloys
Carbon composites

[1] Data reported in Reference 2.1.3.1.
[2] Electrolyte is seawater.

FIGURE 1 - Galvanic Series of Aircraft Alloys[1,2]

3.1 (Continued):

One of the most critical requirements for metal patch repairs of composite parts is, therefore, 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 which are outlined in the following sections.

3.2 Bolted Repairs:

3.2.1 Fastener Selection: For bolted repairs, the initial consideration is fastener selection. The use of aluminum fasteners, collars, and nut plates is never permitted in any joint with carbon composites. Cadmium-plated fastener system elements are also never permitted in any carbon composite bolted joint, since the cadmium coating will be severely attacked (see Figure 1). Titanium and stainless steel are the recommended materials for composite fastener systems. Studies of fastener materials (Reference 2.1.3.2) have established an order of preference for fasteners used in carbon composite joints (Table 1). Even with the best fastener materials, proper sealing procedures are required since a galvanic potential still exists. This means wet fastener installation and use of a faying surface sealant as described in 3.2.2.

TABLE 1 - Galvanic Compatibility of Fastener Materials[1]

Preference No.	Material	Compatibility With Carbon/Epoxy
1	Titanium, Ti alloys, Ti-Cb	Compatible
2	MP-35N, Inco 600	Compatible
3	A286, PH13-8Mo	Marginally acceptable
4	Monel	Marginally acceptable
5	Low-alloy steel; martensitic stainless steel	Not compatible

[1] Data summary compiled by National Aerospace Standards Committee of the Aerospace Industries Association (AIA) of America, Inc.

3.2.2 Sealing Procedures for Bolted Repairs:

3.2.2.1 Sealant Materials: The sealing procedures outlined below are mandatory for all bolted metal patch repairs of composite parts. The effectiveness of these sealing procedures has been demonstrated by extended sea-coast exposure (Reference 2.1.3.3).

The recommended sealant materials for bolted repairs of carbon composites are the same as those used in metal-metal joints. For normal temperature applications (-65 to +325 °F) (-54 to +163 °C) polysulfide sealants are available in a wide variety of types. These include systems specifically formulated for faying surface sealing and wet fastener installation. Other types are specifically formulated for fillet and aerodynamic sealing, fuel tank sealing, low density, low adhesion sealing for removable assemblies, and other special conditions. Within each of these categories, there are long pot life, fast cure, low viscosity (spray or brush application), and thixotropic (spatula or extrusion gun application) versions.

A list of sealants identified by specification and usage is shown in Table 2. Most of these specifications have several types, grades, and classes which identify the application characteristics discussed above. It should be noted that polysulfide sealants vary somewhat in their maximum use temperature, with maximum recommended temperatures varying from 180 °F (82 °C) (continuous) to 360 °F (182 °C) (peak). Some sealants have been formulated to withstand typical adhesive bond cycles of 1 to 2 h at 250 to 350 °F (121 to 177 °C). For temperatures in excess of 200 °F (93 °C), care should be taken to select a system capable of operating under the required environmental conditions. For applications requiring temperature extremes (-80 to over 400 °F), (-62 to over 204 °C), silicone sealants are the appropriate choice.

TABLE 2 - Faying Surface Sealant Categories

Material Type	Use	Specification[1]
Polysulfide	General purpose, corrosion inhibiting sealant	MIL-S-81733
	Fuel tank sealant (also suited for general purpose, nonfuel areas)	MIL-S-8802
	General purpose, low adhesion sealant	MIL-S-8784
	Low adhesion sealant for fuel tank areas	AMS 3267
	High temperature sealant (to 360 °F (182 °C) peak)	MIL-S-83430
Silicone	High temperature sealing applications (-80 to +400 °F)[2] (-62 to +204 °C)	AMS 3373

[1] Some of these specifications have several types, grades, and classes. A careful review of these categories and the recommended use for each must be made prior to sealant selection.

[2] Two-part silicone sealant, with catalytic curing agents, must be used. One-part silicones require moisture (from exposure to air) for cure, and thus cannot be used in a faying surface greater than 1 in (25 mm) width.

3.2.2.1 (Continued):

Table 3 summarizes some of the sealant types covered by military and industry specifications and the ranges of service temperatures, application methods, application times, and cure times that are available. The applicable specifications and/or suppliers should be consulted for specific selections.

The polysulfide sealants listed in Tables 2 and 3 are generally usable either as faying surface sealants or fillet/brush sealants. There are some instances where the curing system is anaerobic and cure will take place only in the absence of air. These sealants would be suited only for faying surface sealing and wet fastener installation. One major precaution for use of sealants in faying surfaces and fastener installation is that some types, especially low viscosity sprayable and brushable sealants, have significant amounts of solvents. Sufficient time after application (typically 15 min) must be allowed for the solvent to flash off before assembling the joint or installing the fasteners.

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. As mentioned previously, most sealants come in varying types and grades suited for each application: i.e., (1) minimum viscosity, sprayable; (2) low viscosity, brushable; or (3) thixotropic, spatula or extrusion. Sealants applied by extrusion gun are typically supplied in the form of frozen cartridges (or cartridges containing both sealant and catalyst separated by a breakable membrane) which can be used in the extrusion gun. The sealant may be applied to both faying surfaces, but

TABLE 3 - Characteristics of Selected Sealant Materials

Specification	Continuous Service Temperature °F (°C)	Application Method	Application Time or Assembly Time After Mixing	Time at 77 °F (25 °C) to Tack-Free Condition (h)
MIL-S-8802 (Polysulfide)[2]	-65 to +250 (-54 to +121)	Class A - Brush Class B - Extrusion gun or spatula Class C - Brush or spatula (for faying surface sealing)	For Class A and B, dash numbers refer to minimum application time in hours. Available dash numbers are: -1/2, -1, -2, and -4 (Class B only).	Classes A and B: -1/2: 10 -1: 20 -2: 40 -4: Class B-48
			For Class C, dash numbers refer to assembly time in hours, all with 8 h application time. Available dash numbers are: -20 and -80.	Class C: -20: 96 -80: 120
MIL-S-83430 (Polysulfide)	-65 to +250 (-54 to +121) Short-term to 360 (182)	Same Classes as MIL-S-8802	Dash numbers in most cases refer to minimum application time in hours. Available dash numbers are: Class A: -1/2, -2, -4 Class B: -1/4, -1/2, -2, -4, -6 Class C: -1/2, -2, -6, -20 (Class C -6 and -20 refer to assembly time in hours)	Classes A, B, C as applicable: -1/4: 6 -1/2: 10 -2: 24 -4: Class A-TBD[2] Class B-36 -6: 48 -20: 96

TABLE 3 (Continued)

Specification	Continuous Service Temperature °F (°C)	Application Method	Application Time or Assembly Time After Mixing	Time at 77 °F (25 °C) to Tack-Free Condition (h)
MIL-S-81733 (Polysulfide)	-65 to +200 (-54 to +93)	Type I - Brush or dip Type II - Extrusion or spatula Type III - Spray gun Type IV - Extrusion gun or spatula (for faying surface sealing)	Dash number for all types refer to minimum application time in hours. Available dash numbers are: Type I : -1/2, -2 Type II : -1/6, -1/2, -1/2, -4 Type III : -1 Type IV : -12, -24, -40, -48	Types I, II, III as applicable: -1/6: 4 -1/2: 16 -1: 8 -2: 24 -4: 32 Type IV: Not specified
AMS 3373 (Silicone)	-80 to +400 (-62 to +204)	Primarily for potting or encapsulation of electrical components; viscosity range suited for brush application for sealing	1-3 h but may be ordered with longer or shorter pot life	Not specified

[1] Available in two types: Type I, dichromate cured and Type II, manganese cured.
[2] TBD - To be determined.

3.2.2.2 (Continued):

application to only one surface is recommended by some fabricators to avoid excessive surface separation which may prevent proper fastener seating. A lightweight scrim cloth can be laid down onto one of the surfaces if desired for thickness control, but may result in a leak path along the fibers in the scrim.

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 composite part.

Figure 2 gives a typical configuration for a carbon composite joint, showing both permanent and removable installations. The sealant materials used are the same as given for faying surface sealing in Tables 2 and 3, except that only the higher viscosity, thixotropic types are used when application is by spatula or extrusion gun.

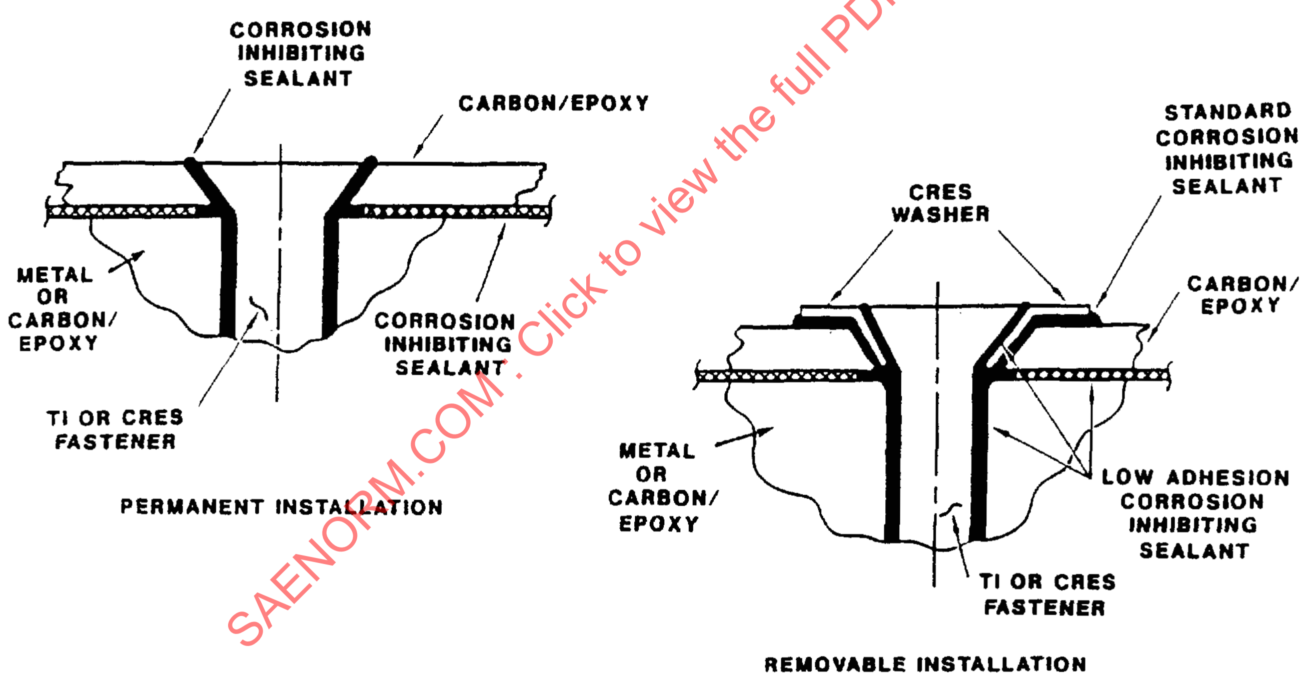

FIGURE 2 - Sealing Arrangement for Carbon Composite Assemblies

3.2.3 Surface Preparation Procedures for Bolted Repairs: The following additional precautions are strongly recommended for aluminum patch repairs of carbon composite parts, the worst case galvanically. The aluminum should be surface treated by a suitable corrosion protection procedure such as chromic or sulfuric acid anodizing treatment. A protective conversion coating (chemical film treatment) can be used but it is less effective than the anodize, and it is conductive, which could be a problem. Application of a finish system to the aluminum such as epoxy primer and aliphatic polyurethane topcoat is a further protective measure which can be used if a particularly corrosive environment is anticipated and which can be readily