SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

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Superseding ARP4118

Isolation and Corrosion Protection of Dissimilar Materials, Carbon Composite Structure Repair

RATIONALE

This document is being revised to update the references called out, add new materials, and correct minor editorial errors.

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 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 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 involving reinstallation of metallic inserts into a carbon fiber reinforced plastic part.

1.5 Fiberglass and aramid fiber reinforced plastics 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 fiber reinforced plastics.

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) or Safety Data Sheet (SDS) and shall be handled in accordance with MSDS instructions.

1.7 Safety-Hazardous Materials

Shall be in accordance with AS5502 (1.1).

2.1 APPLICABLE DOCUMENTS

Shall be in accordance with AS5502 (2.).

2.2 SAE Publications

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

AMS2825 Material Safety Data Sheets

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)

AMS3284 Sealing Compound, Low Adhesion, for Removable Panels and Fuel Tank Inspection Plates

AMS3373 Compound, Silicone Rubber, Insulating and Sealing, 35 to 55

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

AS5502 Standard Requirements for Aerospace Sealants

2.3 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 Composite Materials Handbook (CMH-17, previously MIL-HDBK-17)

2.4 U.S. Government Publications

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, http://assist.daps.dla.mil/quicksearch/.

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

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

MIL-PRF-23377 Primer Coating, Epoxy Polyamide, Chemical and Solvent Resistant

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

MIL-PRF-85285 Coating, Polyurethane, High Solids

MIL-PRF-85582 Primer Coatings: Epoxy, VOC Compliant, Chemical and Solvent Resistant

2.5 Other Publications

AGARD-CP-550, Composite Repair of Military Aircraft Structures, NATO Research and Technology Organisation, 1995

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

Table 1 provides a guide to galvanic compatibility of metal patch materials in contact with carbon fiber reinforced plastics. This shows there is a considerably higher electrical potential difference between carbon and aluminum than between carbon and titanium or stainless steels. Non-stainless steels have higher electrical potential difference with carbon than stainless steels, and certain aluminum alloys, as well as clad alloys, have greater galvanic potential than others. It should be noted there are other factors such as uncoupled corrosion rates for the anodic metal material and the polarization reaction of the metal 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, however, since metallic fasteners are used in direct contact with the carbon-containing composite.

TABLE 1 - GALVANIC SERIES OF AIRCRAFT ALLOYS[1,2]

INCREASING TENDENCY TO CORRODE	Most Active (ANODIC)
↑	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 FIBER REINFORCED COMPOSITES
	Least Active (CATHODIC)

[1] Data Reported in Reference 2.1.3.1
[2] Electrolyte is Seawater

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, the initial 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 also prohibited in any carbon fiber reinforced plastic bolted joint, since the cadmium coating will be severely attacked (see Table 1). Titanium and stainless steel are recommended for composite fastener systems. Studies of fastener materials have established an order of preference for fasteners used in carbon composite joints (Table 2). 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 2 - 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 Sealing Compounds

The sealing procedures outlined below are mandatory 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 (Reference AGARD-CP-550).

The recommended sealing compounds for bolted repairs of carbon fiber reinforced plastics are the same as those used in metal-to-metal joints. For normal temperature applications from -65 to excursions at 325 °F (-54 to 163 °C), polysulfide and polythioether sealants are available in a wide variety of types, classes, and grades. 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 application 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 3. Most of these specifications have several types, classes, and grades which identify the application characteristics discussed above. It should be noted that polysulfide sealants vary somewhat in their maximum use temperature; maximum recommended temperatures vary from 180 to 320 °F (82 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 typical structural adhesive bond cycles of 1 to 2 h at 250 to 350 °F (121 to 177 °C). For cure cycle temperatures in excess of 350 °F (177 °C) or more than 2 h, 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 sealants are the most appropriate choice. 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 3 - FAYING SURFACE SEALANT CATEGORIES

Material Type	Use	Specification[1]
Polysulfide	General purpose, corrosion inhibiting sealant	AMS3265 and MIL-PRF-81733 Class 1
	Fuel tank sealant, also suited for general purpose, nonfuel areas	AMS-S-8802
	Low adhesion sealant for very frequently accessed fuel tank panels	AMS3284
	High temperature sealant to 360 °F (182 °C) peak	AMS3276
Polythioether	Fast curing fuel tank sealant, also suited for general purpose, nonfuel areas, continuous use to 320 °F (160 °C), intermittent use to 360 °F (182 °C)	AMS3277 and MIL-PRF-81733 Class 2
Silicone[2]	High temperature sealing applications from -80 to 400 °F (-62 to 204 °C)	AMS3373

[1] Some of 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, 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.

Table 4 summarizes some of the sealant types covered by military and industry specifications and the ranges of service temperatures, application methods, application times, and tack free times that are available. The applicable specifications and/or suppliers should be consulted for specific selections.

The polysulfide and polythioether sealants listed in Tables 3 and 4 are generally usable as faying surface sealants or fillet/brush sealants. If anaerobic curing systems are ever considered, cure will take place only in the absence of air and therefore 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, classes, and grades suited for each application: i.e., (1) lowest viscosity, sprayable; (2) low viscosity, brushable; or (3) thixotropic, spatula or extrusion. Sealants applied by extrusion gun are typically supplied as pre-mixed and frozen in cartridges (or cartridges containing both sealant and curing agent separated by a breakable membrane) which can be used in the extrusion gun. The sealant may be applied to both faying surfaces, but application to only one surface is recommended by some fabricators to avoid excessive sealant causing surface separation which may prevent proper fastener seating. A lightweight scrim cloth may be laid down onto one of the surfaces if desired for thickness control, but this is generally discouraged as it may result in a leak path along the fibers in the scrim.

TABLE 4 - 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)
AMS-S-8802[1] (Polysulfide)	-65 to 250 °F (-54 to 121 °C)	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: -1/2, -1, -2, and -4 (Class B only). (For Class C, the number in parentheses refers to assembly time in hours) Available dash numbers: -8(20) and -24(80).	Classes A and B: -1/2: 10 -1: 20 -2: 40 -4 (Class B) : 48 Class C: -8(20): 96 -24(80): 120
AMS3284 (Polysulfide)	-65 to 250 °F (-54 to 121 °C)	Class A - Brush Class B - Extrusion gun or spatula	Dash numbers refer to minimum application time in hours. Available dash numbers: -1/2 and -2	Classes A and B: -1/2: 10 -2: 24
AMS3276 (Polysulfide)	-65 to 250 °F (-54 to 121 °C) Short-term to 360 °F (182 °C)	Same Classes as AMS-S-8802 Class D - Extrusion gun or spatula (thicker than Class B) Class E - Automatic riveting equipment application	For Class A and B, dash numbers refer to minimum application time in hours. Available dash numbers: Class A: -1/2, -2, -4 Class B: -1/4, -1/2, -2, -4, -6, -12 Class C: -1/2, -2, -8(20) (For Class C, the number in parentheses refers to assembly time in hours) Class D: -1/4, 1/2 Class E: -6	Classes A, B, C, D, E, as applicable: -1/4 (Class B, D): 6 -1/2: 10 -2 : 24 -4 : 36 -6 (Class B): 48 -6 (Class E): 120 -12 (Class B): 120 - 8(20) (Class C): 96
AMS3265	-65 to 250 °F (-54 to 121 °C) Short-term to 360 °F (182 °C)	Same Classes as AMS-S-8802	For Class A and B, dash numbers refer to minimum application time in hours. Available dash numbers: Class A: -1/2, -2, -4 Class B: -1/4, -1/2, -1, -2, -4, -12 Class C: -2(2), -8(24), -12(48), -48(168), -96(336) (For Class C, the number in parentheses refers to assembly time in hours)	Classes A and B, as applicable: -1/4 (Class B): 8 -1/2 (Class A): 10 -1/2 (Class B): 12 -1: 16 -2: 24 -4 (Class A): 48 -4 (Class B): 36 -12: 120 Class C: -2(2): 24 -8(24): 96 -12(48), -48(168), and -96(336) take 2 to 16 weeks to cure

TABLE 4 - CHARACTERISTICS OF SELECTED SEALANT MATERIALS (CONT.)

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-PRF-81733 (Class 1: Polysulfide; Class 2: Polythioether)	Class 1: -65 to 200 °F (-54 to 93 °C) Class 2: -80 to 320 °F (-62 to 160 °C)	Type I - Brush or dip Type II - Extrusion gun or spatula Type III - Spray gun Type IV - Extrusion gun or spatula (for faying surface sealing)	For Types I, II, and III, dash number refer to minimum application time in hours. Available dash numbers: Type I: -1/4, -1/2, -2 Type II: -1/6, -1/4, -1/2, -2, -4 Type III: -1 For Type IV, dash numbers refer to assembly time based on a squeeze-out test. Available dash numbers: Type IV: -4, -12, -24, -40, -48	Types I, II, III as applicable: -1/6 (Ty II): 4 -1/4 (Ty I, Cl 2): 4 -1/4 (Ty II, Cl 1): 8 -1/4 (Ty II, Cl 2): 1 -1/2 (Ty I, Cl 1): 16 -1/2 (Ty I, Cl 2): 8 -1/2 (Ty II, Cl 1): 16 -1/2 (Ty II, Cl 2): 2 -1 (Ty III): 8 -2 (Cl 1): 24 -2 (Ty I, Cl 2): 16 -2 (Ty II, Cl 2): 12 -4 (Ty II, Cl 2): 24 Type IV: N/A
AMS3277 (Polythioether)	-80 to 320 °F (-62 to 160 °C)	Same Classes as AMS-S-8802 Type I - requires an adhesion promoter Type II - does not require an adhesion promoter	For Class A and B, dash numbers refer to minimum application time in hours. Available dash numbers: Class A: -1/4, -1/2, -1, -2 Class B: -1/4, -1/2, -2, -4, -6, -12 Class C: -4(4) (For Class C, the number in parentheses refers to assembly time in hours)	Classes A and B, as applicable: -1/4: 1 -1/2: 3 -1 (Class A): 6 -2: 12 -4 (Class B): 48 -6 (Class B): 72 -12: 96 Class C: -4(4): 24
AMS3373 (Silicone)	-80 to 400 °F (-62 to 204 °C)	Primarily for potting or encapsulation of electrical components; viscosity range suited for brush application for sealing	Application life is typically 1-3 h but sealant 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.

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.

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 in Tables 3 and 4, except that only the higher viscosity, thixotropic types are used when application is by spatula or extrusion gun.

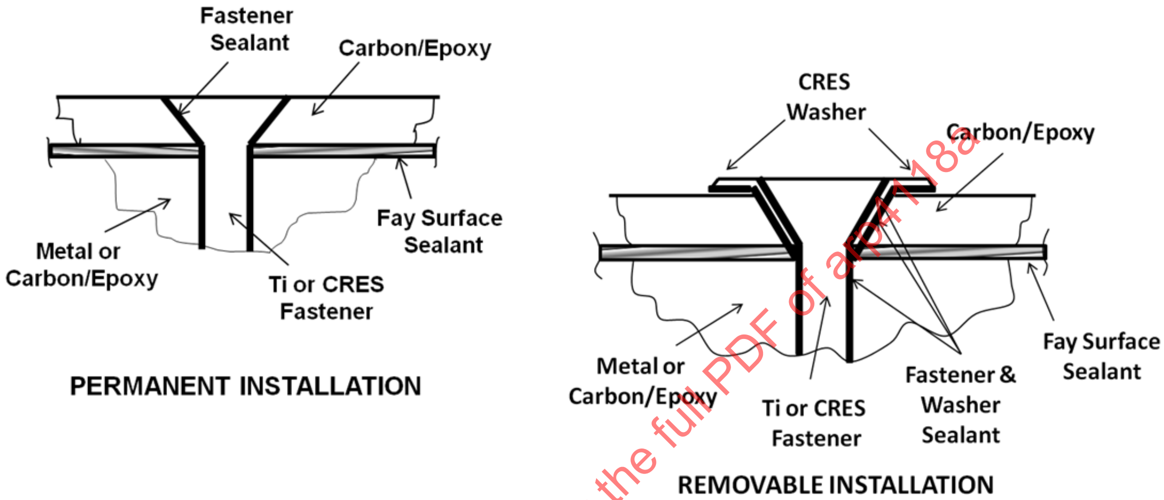

FIGURE 1 - SEALING ARRANGEMENT FOR CARBON FIBER REINFORCED PLASTIC ASSEMBLIES

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 such as MIL-A-8625. A protective conversion coating (chemical film treatment) such as MIL-DTL-81706 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. Application of a finish system to the aluminum such as epoxy primer (i.e., MIL-PRF-23377 or MIL-PRF-85582) and an aliphatic polyurethane topcoat (i.e., MIL-PRF-85285) are further protective measures which may be used if a particularly corrosive environment is anticipated and if application of the finishes can be readily accomplished at the repair facility. 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 in (25 mm) beyond the edges of the joint. Another protective measure is 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. The isolation ply should also extend at least 1 in (25 mm) beyond the edges of the joint. This is equally applicable to bonded repairs, and is described in 3.3.

Surface treatment and finishing as described above are supplemental procedures only, and proper faying surface sealant and wet fastener installation as described in 3.2.2.2 and 3.2.2.3 are the essential procedures required to protect against galvanic corrosion. Comparable surface treatment procedures can be used for carbon fiber reinforced plastic repairs with titanium and steel patches, but in most cases are not essential.