

AEROSPACE INFORMATION REPORT

AIR4069™
REV. D

Issued 1990-10
Revised 2022-07

Superseding AIR4069C

Sealing of Integral Fuel Tanks

RATIONALE

This is a Five-Year Review to update applicable sealant specifications and review/update engineering designs and sealing practices for producing reliable integral fuel tank sealing systems.

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1. SCOPE

This SAE Aerospace Information Report (AIR) presents preferred design, assembly, and repair practices for sealing of aircraft integral fuel tanks, including rework of applied fuel tank seals. It addresses engineering designs for integral fuel tanks as they are currently found in practice and discusses the most practical and conservative methods for producing a reliable, sealed system.

Although this AIR presents practices for sealing of integral fuel tanks, the practices presented within this report are practices that are carried throughout sealing that include both pressure and environmental aircraft sealing.

Design preferences for optimum sealing are not within the scope of this document. Such discussions can be found in the United States Air Force (USAF) sponsored report AFWAL-TR-87-3078, "Aircraft Integral Fuel Tank Design Handbook."

Key objectives of the fuel tank sealing process are to produce a sealing plane that is leak-free and corrosion resistant, especially at fastener locations, at environmental and operational conditions expected for the life of each aircraft. Factors that can influence the outcome of this process are:

- a. How well the basic design lends itself to good sealing (key design factors to consider include accessibility and minimal movement, among others).
- b. The choice of sealant, where it is applied, and how it is applied.
- c. How good substrate surfaces are prepared.
- d. Whether sealant fillet dimensions are optimum for aircraft configuration and flight dynamics.
- e. The degree of resistance sealants must have to fluid and thermal environments.
- f. The degree of engineering insurance—i.e., application of adhesion promoters to sealant bond surfaces, application of organic topcoats over sealants, proper drainage of the fuel tank, etc.—employed for technical risk reduction.

Effective and efficient sealing of aircraft fuel tanks are prime considerations in both commercial and military aircraft designs. Note, fillet seals inside fuel tanks are considered to be the primary fuel barrier seals.

Of nearly equal importance is corrosion control. It is generally accepted, for example, that a major objective of faying surface sealing is corrosion control. The faying-surface seal is not considered to be a primary fuel barrier seal, except in adhesive-bonded systems; the faying surface seal, however, does play an extremely important role as a secondary fuel barrier seal. It limits the length of a leak path and is a permanent, stable, protected, and essentially non-dislodgeable seal that is sandwiched between two mating surfaces. Extensive use of faying-surface sealing is highly recommended.

Sealing philosophies differ within industry and government. However, as stated in 3.1, there is much greater agreement than dispute. If a particular fuel tank sealing approach appears to be clearly more reliable, keeping production cycle time and costs in mind, it will be identified as a preferred method.

This report cannot specifically address each of the many individual designs. However, this report recommends preferred practices in the application of brushable, extrudable, and rollable sealants; it also points out the more desirable contours and thicknesses to be used in the application of sealant in seams, joints, fastener heads, voids, in faying surfaces, and in types of configurations that are common to all designs. Dimensions used in the text and figures of this document, even where the words "must" or "shall" are used, are typical but not universal across aircraft platforms. Individual aircraft manufacturers, whether by design, material selection, or risk tolerance, may have slightly different dimensional or tolerance requirements.

This report is based on technical opinions from a broad cross-section of engineering experts who specialize in aircraft sealing.

The user should consider the engineering requirements and options provided by this report; then develop an individual course (or plan) of action from a somewhat more informed position.

2. REFERENCES

See Appendix A.

3. SEALING PHILOSOPHY

3.1 Sealing Objectives and Basic Categories

The main objectives in aircraft fuel tank sealing are to preclude fuel leaks for the long term and to avoid the intrusion of moisture that can cause corrosion, especially at fastener locations.

Integral fuel tank designs fall into two basic categories: those with full access to the interior of the tank and those with limited access. Those in the latter category are repaired by: (1) injection of channel sealants from the exterior; or (2) retightening or replacing certain types of fasteners from the exterior; or (3) gaining access to the interior of the tank through disassembly of structure, as necessary, to reach the leak source (see Section 12).

Except for channel sealing or exterior retightening/replacing fasteners, all sealing is performed inside the fuel tank. Factors to be considered in sealing integral fuel tanks for the two basic categories are given in the following paragraphs.

3.1.1 Designs Providing Interior Access

Leak paths found in interior access designs originate from skin splice joints, spar-to-web joints, dry-to-wet bay interfaces, and access doors. Faying surfaces, lap joints, butt joints, fastener holes, and any other possible path between wet-to-dry sides represent opportunities for fuel leakage and for moisture intrusion, which may produce corrosion. (Moisture from water that has combined with fuel inside the tank also is a potential source of corrosion.) It is generally accepted by the industry that the primary seal plane is formed by sealant applied inside the fuel tanks at butt joints, lap edges, and fasteners. It is also generally accepted by the industry that secondary fuel containment barriers such as fay-surface and/or channel groove sealing is necessary to avoid costly leaks over the life of an aircraft or to ensure adjacent dry bays are not contaminated by fuel (liquid or vapor).

Fay-surface sealing is an important type of sealing because it limits the length of leak paths, contains fuel, prevents corrosion, and protects against fretting. Fay-surface sealing is an essential adjunct to fillet and fastener sealing to produce a reliable, sealed fuel tank that does not leak during the operational life of the aircraft. Fay-surface sealing is typically considered a secondary fuel containment barrier.

3.1.1.1 Fasteners and Joints

All fasteners and rivets (even interference fit fasteners) at fuel tank boundaries should be wet installed and overcoated to ensure that the tank does not leak. All fasteners that penetrate dissimilar metals must be wet installed with fuel tank sealant; for example, refer to Figure 1 of ARP4118. If pre-cleaned fasteners are not available, fasteners being wet installed shall be cleaned using AMS3167 prior to installation. It is mandatory that cadmium-plated fasteners be coated with a fuel resistant epoxy primer before applying adhesion promoter. A solid-film lubricant that meets the engineering material property requirements of MIL-PRF-46010 does not need to be removed provided adhesion promoter is used. MIL-L-23398 solid-film lubricant coating, on the other hand, needs to be removed and adhesion promoter should be applied before sealant application.

Corners and joggles shall be injected or pre-packed with fuel tank sealant, except at a junction where three planes meet. Such a location shall be fitted with suitable reinforcement such as corner fittings or screens. Surge boxes and vent boxes should be sealed on both sides. Both sides of common fuel and pressure bulkheads should be sealed. All butt joints, lap joints, and seams should be sealed with full fillets.

3.1.1.2 Faying Surfaces

Fay-surface sealing should be employed on all lap joint surfaces in fuel tank boundaries and under all attachments to the fuel tank. Major examples of fay-surface sealing applications include:

- a. Skin-to-stringer interfaces.
- b. Web-to-spar chord.
- c. Spar chord-to-wing skin.
- d. Surface under any attachment to aircraft skin.
- e. Shims installed in faying surfaces.

After faying-surface sealant is applied, the two surfaces are joined (or clamped-up) to attain 100% extrusion or squeeze out of the faying surface sealant. Squeeze-out of the fay seal must be continuous around the entire periphery of the mated fuel tank structures. If 100% squeeze-out is not observed, the entire joint must be cleaned out and the entire process repeated unless other approved rework procedures exist. Next, excess fay surface sealant is removed (preferably while sealant is still wet), the surface is cleaned, and a full fillet of fuel tank sealant is applied around the periphery.

To simplify the manufacturing process, pre-assembly sealing should be done to the greatest extent possible. This includes application of fillets around faying surfaces on sub-assemblies so that 90% of the sealing is complete on assembly.

Some sub-assemblies that are often pre-assembly sealed include:

- a. Upper and lower wing panels.
- b. Front and rear spars.
- c. All intermediate bulkheads and webs.
- d. Boost pump cover plates.

Remaining fillets are then applied.

Injection sealing can also be a form of sealing that is accomplished during assembly. When possible, non-curing sealants should be injected while the curing faying-surface sealant in these locations is still uncured.

Final assembly sealing includes injection seals, hole, and slot seals, brushcoat (when specified), and fillet seals. All leak path entry edges should be covered with a minimum of 0.15 inch (3.81 mm) of sealant. The minimum sealant bondline on all fuel tank structure should be 0.25 inch (6.35 mm) thick layer of sealant. See Figure 12 for sealant coverage.

Pressure testing of faying surfaces of an assembled tank before fillets are applied reveals the effectiveness of the faying surface seal. Some original equipment manufacturers (OEMs) do not fillet seal sub-components until after final assembly pressure test, in order to monitor sealing effectiveness.

Generally, repairs should be made by fillet sealing edges of assembled faying surfaces (see 12.4.1.3), and not by disassembly of the faying surfaces. Depending on design configuration some faying surface seals can be repaired with a high-pressure injection gun and hollow injection bolts; the aircraft manufacturing industry refers to this method as “pressurized groove-injection sealing.”

3.1.1.3 Considerations in the Adhesive Sealing of Tanks

Adhesive sealing of faying surfaces of an integral fuel tank with a structural film adhesive requires particular design characteristics and special processes and equipment. Faying surfaces must not mismatch by more than 0.015 inch (0.38 mm). Tooling must be inspected and verified periodically. After application of film adhesive, full clamp-up of structural fasteners must be accomplished to produce the necessary mechanical force (or pressure) to ensure satisfactory adhesive bonding. Lockbolts, threaded fasteners, and crimp pins installed with non-metallic seal washers must be located in wet-to-wet areas of the fuel tank. The entire assembly must be placed in an oven to cure the adhesive per manufacturer instructions. Usually, structural voids at fuel tank boundaries are filled with polysulfide or polythioether sealant after oven cure is completed. Sometimes a high-temperature sealant (conforming to AMS3276, AMS3277, AMS3281) can be used to prepack voids.

3.1.2 Designs with Limited Access

Designs with limited (or no) access should use pressurized groove sealing or channel sealing to facilitate fuel tank sealing rework or repair. Grooves or channels using non-curing sealants provide greater repair capability than those filled with curing sealants. Use of curing sealants in grooves/channels typically require some structure disassembly to affect a repair.

3.1.2.1 Considerations in Groove-Sealing or Channel-Sealing

Groove-sealed or channel-sealed designs incorporate a continuous groove or channel in the faying surface around the entire seal plane. This allows injection of non-curing sealant from the outside by means of a series of ports spaced at 3 to 5 inches (76 to 127 mm) intervals. Some groove designs have the groove adjacent to a row of fasteners, or between two rows of fasteners; while others have the groove in-line with the fasteners, so that sealant will surround each fastener.

The groove design offers distinct advantages in thin-winged aircraft, such as military fighters, where internal access is extremely limited or impossible. This design offers a major advantage to this type of aircraft, since repairs can be made quickly under field conditions using a high-pressure sealant injection gun and an adapter. Fuel tanks need not be emptied to repair a leak. This design is selected for other aircraft due to the simplicity of maintenance and repair.

Grooves are machined into aluminum or titanium alloy component parts of the fuel tank faying surfaces; they are molded into carbon-reinforced epoxy, carbon-reinforced bismaleimide, or other composite parts. In the channel for pressurized, non-curing groove-injection sealant, fastener spacing should be a maximum of six times the diameter of the fastener. The minimum diameter of fastener used in channel seal grooves is 0.25 inch (6.35 mm).

Ribs that do not assemble to skin splices, but which form the internal structure, do not normally require channel sealing. Self-sealing fasteners are used (Figure 1). Fasteners not located in the groove path are of self-sealing and can be tightened or replaced from the outside.

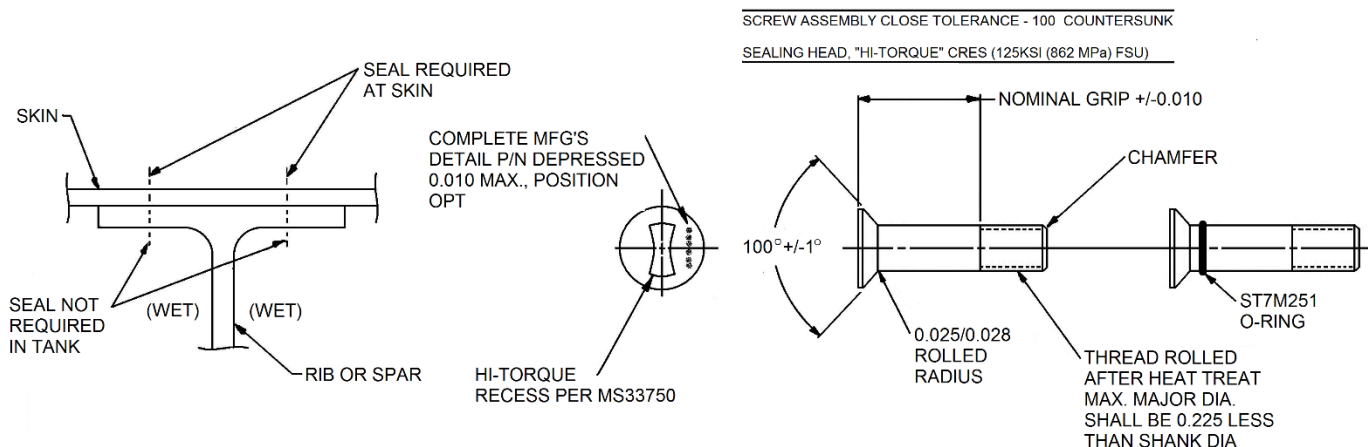


Figure 1 - Rib/skin assembly with self-sealing fastener

The size of the groove, the distance between the injection ports, and design features that can inhibit the flow of sealant through the groove are factors related to design that greatly affect the ease of sealing and, eventually, seal integrity. In many groove designs, joint intersections produce voids or open spaces in the groove line. Restrictions, called dams (see Figure 31), made with polysulfide or polythioether sealant (AMS-S-8802, AMS3276, AMS3277, or AMS3281) or epoxy adhesive are formed-in-place to preserve the continuity of the groove. Dam configuration includes chamfered lands at the ends (or terminations) of each dam. Metal clips (or retainers) may also be used to hold the dams in place.

It is best to faying surface seal around the grooves to provide the best seal. Shims should be avoided as much as possible. However, if a shim is required, it should not go across the groove and should be faying surface sealed.

Liquid shims made of epoxy, or adhesively bonded solid or laminated shims, are used to improve the basic structural fit up. Except for all fuel tank boundary locations, liquid shims may be used in integral fuel tanks, unless specifically prohibited by the engineering drawing. Note: Flexible liquid shims may be used in fuel tank boundaries provided testing is performed to determine thickness requirements and have been approved for use by appropriate engineering.

The use of shims should be controlled by engineering drawings or applicable specifications for allowable thickness and number of shims in accordance with the aircraft manufacturer's documents.

Sealant-related factors can affect application (processing) and operational performance. For example, non-curing, groove sealant must seal all gaps and stay in place, yet be injectable. If the viscosity is too low, separation of filler material from the sealant can occur, especially under high-injection pressures, resulting in sealant flowing into the tank. Bead-filled channel sealants are designed to be effective in filling larger gaps; but these bead-filled sealants can be more difficult to extrude because of their relatively-high viscosity. One technique that may be used to alleviate this problem is to warm the bead-filled channel sealant to approximately 95 °F (35 °C) maximum, to improve the extrudability (or flow) of this sealant.

Sealant is injected at pressures of several thousand pounds per square inch by sealant guns designed to augment the incoming plant air pressure of 80 to 100 psi (552 to 690 kPa) by approximately 40 to 50 times. Under these high injection pressures, it is possible to damage structure or distort aircraft wing skins, thus injecting (losing) sealant into the tank. Design thicknesses for tank components in the area of channel sealing and the dimensions of the channel determine the ability of the structure to withstand injection load pressures without causing damage to the surrounding structure.

Pressure regulators on high-pressure channel sealant injection guns are essential. Sealers must be made aware of injection pressure restrictions for the particular design they are servicing. Groove sealant can be extruded with as little as 40 psi (276 kPa) input pressure from plant air, using a 70:1 ratio.

Common failure mechanisms causing leaks in channel-sealed aircraft include:

- a. Excessive mismatch of parts—i.e., greater than 0.005 inch (0.13 mm).
- b. Large joint deflections.

Particular attention must be given to selection of a channel sealant that ensures reliable performance, consistent with the aircraft's design configuration and expected operational environment.

3.2 Redundancy in Sealing to Mitigate Technical Risk

Fuel leaks have been one of the most serious of integral fuel tank problems and a very expensive item of operational maintenance and repair. A sealing plan that maximizes redundancy can be a source of great savings during the operational life of the aircraft. Several methods for introducing redundancy into aircraft fuel tank sealing engineering requirements are provided in the following paragraphs.

3.2.1 Faying-Surface Sealing

This type of fuel tank sealing should be used to the greatest extent possible. Faying surface sealing reduces risks of incurring fuel tank leaks and corrosion, especially at fastener locations. Faying seals also fill potential leak paths, thus making repairs easier and less expensive.

If 100% squeeze-out is not observed, the entire joint must be cleaned out and the entire process repeated unless otherwise approved rework procedures exist.

3.2.2 Wet Installation and Overcoating of Fasteners

Fasteners are the principal sources of leaks. An investigation by the U.S. Air Force's Flight Dynamics Laboratory in 1983 revealed that even with interference fit fasteners, unless an interference of at least 0.003 inch (0.08 mm) is present, acceptable sealing by the fastener alone could not be expected (see report number AFWAL-TR-83-3089). Additionally, if one considers the possibility of incurring out-of-round holes and other potential manufacturing errors, it becomes evident that there is significant value in wet installing and overcoating fasteners in aircraft fuel tank structure. Overcoating can be accomplished by applying multiple brushcoats (when specified), by applying a brushcoat followed with an extrudable Class B overcoat, or by the application of a single, continuous coat of Class B coat alone.

3.2.3 Fillet Sealing - Extrudable Sealant (Class B) Over Brushable (Class A or Class C) Fuel Tank Sealant

A thin layer of Class A or Class C sealant is worked into the seams and around fasteners with a brush to ensure all leak paths are closed. Prior to when the Class A brushcoat becomes tack-free, Class B material is applied to form fillet and fastener seals. If the brushcoat reaches tack-free before Class B sealant is applied, the brushcoat must be allowed to cure; then the brushcoat is scuff sanded, cleaned, and adhesion promoted prior to application of Class B material. The more viscous Class B sealant provides sealant dimensions necessary for protection against joint movement, temperature cycling, and possible mechanical impact. See Table 5 for sealant type and class versus use.

3.2.4 Topcoats (AMS-S-4383 Buna-N) Over Fuel Tank Sealant

Topcoats designed for long-term protection of sealant surfaces (and used by some OEMs) are applied over fuel tank sealant inside the tanks as a protective shield between sealant and metal ions in the fuel. An extensive Industry-Air Force investigation discovered that metal ions in fuel can cause heavy chalking of fuel tank sealant. Chalking was observed primarily on the surface of the sealant; but heavy chalking can result in deterioration of the sealant. Use of Buna-N topcoats has largely been discontinued due to improvements in fuel and chalking resistance of present polysulfide/polythioether sealants.

3.2.5 Adhesion Promoters for Polysulfide/Polythioether Sealants

The use of adhesion promoters with polysulfide/polythioether sealants for post-assembly seals in fuel tanks and in-service repairs has proven to be particularly effective. Good adhesive bonding of fuel tank sealant to substrates is highly dependent on thoroughly cleaned and adhesion promoted surfaces. With proper surface preparation, strong bonds occur regardless of whether the surface is aged polyurethane, fuel aged sealant remaining in the tank, or some other difficult to bond material. Use of adhesion promoters in initial fuel tank sealing and later tank sealant operations is highly recommended.

3.2.6 Redundancy in Sealing Groove Designs and Adhesively Sealed Designs

Polysulfide/polythioether fillet sealing of all joints, structural voids, etc., in the aircraft's lower skin area (before the fuel tank is finally assembled) is strongly recommended. This is a one-time opportunity to add redundancy to sealing of that portion of the tank that will be continuously wet with fuel.

Some Original Equipment Manufacturers (OEMs) treat difficult-to-seal areas of the tank by applying a continuous bead of polysulfide/polythioether sealant to faying surfaces adjacent to the groove in groove-designed tanks as a back up to the non-curing sealant. To ensure the channel groove is not blocked with curing-type faying surface sealant, careful planning and tooling is required to not over-apply the faying surface sealant such that it will squeeze into the channel during assembly. Pre-packing the channel with non-curing sealant may help minimize clogging of the channel but extreme care is necessary to not containment the faying surface. Faying surface gaps for this approach should be no greater than 0.003 inches (0.08 mm) and continuous squeeze-out of the curing type sealant may or may not be evident after matting the surfaces.

3.3 Composite Construction - Sealing Philosophy

An increasing percentage of aircraft structure consists of composite parts to reduce aircraft weight. Composites usually are carbon-fiber-reinforced thermosetting materials; however, in some cases, thermoplastic composites are used. Testing and practical experience has demonstrated that composites should be scuff sanded prior to sealing (to remove surface gloss), due to difficulty in obtaining good sealant adhesion to these materials.

Composite-to-metal joints must be fay-surface sealed and fillet sealed after assembly including composite-to-aluminum metal joints which also requires a composite fiberglass isolation ply extending a minimum of 1.0 inches (25.4 mm) beyond the aluminum edge to help prevent galvanic corrosion (refer to ARP4118). Non-interference fit fasteners are used with composites assemblies; therefore, all permanent fasteners penetrating composite structure must be wet installed and overcoated with fuel tank sealant. Fuel tank sealant also performs an important secondary role as a non-conductor between carbon fiber composite and aluminum structure.

4. SUBSTRATES

Possible metal surfaces present within an integral fuel tank include corrosion-resistant (stainless) steel, cadmium plated parts (fasteners, dome nuts, fittings, etc., must be sealed) titanium, nickel-based alloys, such as Inconel and aluminum (bare or treated). These surfaces, except titanium, are almost always coated with a polymeric corrosion-inhibiting epoxy or polyurethane coating such as AMS-C-27725 or other approved coating. Fuel tank sealant must be able to bond to metal substrates but will most often bond to the polymeric coating. Surface preparation recommendations prior to application of sealant is covered in AS5127; the general instructions in this document are brief paraphrases of the guidance in AS5127. When the corrosion-preventive coating on aluminum structure is scratched or damaged, the surface is cleaned, and a chemical conversion coating (MIL-DTL-5541) is applied to the aluminum. If sealant will entirely cover the scratched or damaged area, it is not necessary to reapply the polyurethane or epoxy coating before sealant application. Otherwise, after chemical conversion coating application (MIL-DTL-5541), the polymeric corrosion-preventing coating is reapplied. If only the polyurethane coating has been damaged, it can be touched up with either polyurethane or epoxy coating. Polysulfide/polythioether and polyurethane sealants when used with recommended adhesion promoter, bond well to most surfaces that will be encountered.

Composite substrates might not be coated with a corrosion-preventive coating. This surface is scuff sanded and cleaned with a solvent blend conforming to AMS3167 in areas where sealant will be applied.

4.1 Corrosion-Preventive Coatings

AMS-C-27725 fuel-resistant, microbial-resistant corrosion-preventive coating is a widely-used primer for coating the entire interior surface of the integral fuel tank. It is applied before accomplishing any sealing processing, such as filleting, overcoating, or void filling. It will cure sufficiently for handling in approximately 24 hours at 77 °F (25 °C) and 50% relative humidity (RH), but it will not be fuel resistant for 3-1/2 days. It takes approximately 14 days for this coating to become resistant to methyl ethyl ketone (MEK) or other approved cleaning solvents.

NOTE: Depending on engineering design requirements, the use of composite materials may not require application of AMS-C-27725.

4.2 Titanium

Titanium parts are usually treated with an inorganic chemical conversion coating (anodized); however, organic primer or topcoat is not generally required on titanium parts. Proper sealant adhesion to titanium parts can only be achieved by scuff sanding or vacu-blasting and the use of an adhesion promoter prior to sealant application.

4.3 Composite Surfaces

Composite materials are prevalent in aircraft fuel tanks currently being produced. While it is beyond the scope of this document to detail the application of sealants to composite surfaces; typical structural composite parts provide an epoxy or bismaleimide surface for bonding. Polysulfide/polythioether sealants bond well to these surfaces. Some parts/assemblies may require a primer/topcoat prior to sealing and the user should check engineering processes for specific applicable requirements. Composite surfaces must be cleaned prior to sealing operations. For specific parts and assemblies, the user should check the established engineering processes for specific methods for cleaning. If no process has been established, the basic recommended process would be as follows:

1. For composite tool-side or bag side (without peel ply) surface: Solvent clean (if required to remove mold release material), scuff sand glossy surface, dry wipe any remaining composite dust, solvent clean followed by wiping surface dry of solvent, and then apply adhesion promoter. Fuel tank sealant should be applied as soon as possible following cleaning and drying of adhesion promoter.
2. For composite peel ply surface: Remove peel ply, scuff sand (if required), dry wipe surface, and apply adhesion promoter. Fuel tank sealant should be applied as soon as possible following cleaning and drying of adhesion promoter.

4.4 Dry Film Lubricants

In 1984, Air Force Material Lab at Wright-Patterson AFB (AFML) tested seventeen dry film lubricants with polysulfide sealants for bonding characteristics. It was concluded that adhesion promoters are required in fuel tank structure surface preparation when using manganese-dioxide-cured polysulfide sealants. Adhesion promoters are required to ensure 100% cohesive failure [tested after aging 7 days followed by 70 days at 140 °F (60 °C) in jet reference fluid (JRF-1) (JRF)/salt water]. While the results were not as clear cut with dichromate-cured polysulfide, it left no doubt that it is highly desirable to use polysulfide adhesion promoters (conforming to AMS3100) on parts containing dry film lubricant before application of fuel tank sealant for satisfactory bonding of sealant to structure.

AMS3090 has been prepared for dry film lubricants to which sealants will adhere; the appropriate adhesion promoter is still needed when AMS3090 dry film lubricant is on the surface to be sealed.

NOTE: Dry film lubricant testing performed by AFML and AMS3090 specification were conducted with polysulfide type sealants. Currently there are no published reports or specifications which have tested the performance of dry film lubricant with polythioether type sealants. Use of polythioether sealant in dry film applications should be evaluated by the end users before use.

5. SURFACE PREPARATION (REFER TO AS5127)

5.1 Cleaning

It is impossible to achieve a good sealant bond if the substrate has not been adequately cleaned, abraded, and protected against contamination. Fuel tank sealant bond surfaces are cleaned as follows:

- a. Remove all chips and foreign material, using vacuum cleaners and dry wipe cloth; do not blow off with air pressure.
- b. Pour or squirt AMS3167 cleaning compound from container onto low-linting wipe cloth (AMS3819, Class 1 or 2, Grade A, Form 1). Do not dip the wipe cloth in the solvent. An alternate process would be to use a pre-saturated, low-linting wipe cloth (AMS3819, Class 1 or 2, Grade A, Form 2). Stiff (non-metallic) bristle brushes can be used to facilitate cleaning, if necessary.
- c. Clean the surface thoroughly with the cloth, turning it frequently. Change to a new cloth as soil becomes evident.
- d. Clean from the top down and from the inside out.
- e. Continue cleaning. A brush may be used to apply solvent or to promote rapid cleaning. Rinse the brush by squirting bristles with solvent, not by dipping the brush into the solvent.
- f. Before the solvent has a chance to evaporate, rinse the structure using a clean, solvent-wetted cloth.
- g. Finally, when there is no further evidence of soil, e.g., particulate or staining/discoloration wipe the surface dry with a clean and dry cloth.
- h. Re-clean the surface, in accordance with the above procedure, if the surface is not sealed within 24 hours.

5.1.1 Important Points to Remember Concerning Surface Cleaning

- a. Cleaning cloths should be low-linting and snag resistant and contain less than 0.5% extractable (or non-fibrous) material (refer to ASTM D2257). The cloths should be open weave or non-woven to allow for easier absorption of bulk contamination. AMS3819 defines the properties and the allowable contamination levels of cleaning cloths.
- b. All solvents shall be free of particulate matter and shall leave no residue upon evaporation. Solvents shall be dispensed from clean, oil-free containers. Container design should preclude the possibility of dipping cleaning cloths and brushes into clean solvent. Slow evaporating solvents, such as AMS3167, should be wiped dry from the surface and not allowed to evaporate.
- c. Chlorinated cleaners generally should not be used on aircraft structure, and should never be used on titanium.
- d. Titanium surfaces should be cleaned first with an aqueous alkaline cleaner followed by an approved organic solvent blend.
- e. General cautions:

Be aware of possible sources of surface contamination in the sealing area; these should be eliminated. Wind-blown dust, unfiltered air from ventilators, air conditioners, fans, metal chips, and metal or plastic dust from nearby drilling or sanding are potential sources of contamination. Additional sources of contamination include:

- 1. Personnel transmitting soaps, oils, grease silicone wrist bans, or sweat from hands and clothing; a key engineering requirement related to this is that sealant bond surfaces must not be touched with bare hands.
 - 2. Contamination from equipment.
 - 3. Moisture condensation on sealant bond surfaces, which will occur if temperatures are allowed to drop while humidity is high.
- f. Never dispense silicone materials in the vicinity of sealing operations.
 - g. Filtered air should be used when forced into integral fuel tanks for ventilation, curing, drying, or purging.
 - h. Very important:

If adhesion promoter or sealant is not applied within 4 hours, reclean the sealant bond surface. Only one surface cleaning does not mean that the bond surface will remain clean. When in doubt, reclean the sealant bond surface.

5.2 Special Considerations Regarding Surface Preparation

Following are engineering requirements which directly affect the cleanliness of fuel tank sealant bond surfaces:

- a. Lubricants containing silicones shall not be used in drilling, reaming, riveting, in machine operations, swaging, or in lubricating fasteners on any component of the integral fuel tank.
- b. The preparation and use of silicone material should be isolated from the sealing area and from the area where sealants are prepared and handled.
- c. Where fasteners are installed on automatic fastening machines or where tapered fasteners are used and detail parts cannot be disassembled after drilling of holes, the detail parts should be cleaned first, sealant applied to faying surfaces, and the parts assembled and held together with sufficient clamping force to ensure intimate contact of detail parts prior to and during the drilling or fastener holes. The permanent fasteners should be wet installed.
- d. It is acceptable to apply sealant for wet installation to fasteners lubricated with cetyl alcohol or lauric acid lubricants.

5.3 Adhesion Promoters

5.3.1 Polysulfide/Polythioether Sealant Adhesion Promoters

Adhesion promoters for polysulfide/polythioether sealants were developed primarily to ensure adhesion to aged, fuel soaked AMS-C-27725 polyurethane fuel tank corrosion coatings; however, they are extremely important in several applications and must be used properly in order to be effective, as indicated below:

- a. They provide additional insurance for guaranteeing the integrity of sealant adhesion; and they are strongly recommended for this purpose.
- b. Their use should be considered mandatory in making in-service repairs to fuel tanks.

NOTE: Polysulfide sealants qualified to AMS specifications may specify AMS3100 adhesion promoter. Polythioether sealants qualified to AMS specifications will either be specified in the specification or by the sealant manufacturer.

In new aircraft production, some OEMs consider it mandatory to use adhesion promoters after cleaning and prior to post-assembly fillet and brushcoat polysulfide/polythioether sealing of joints in integral fuel tanks. Adhesion promoters may also be used during assembly for faying-surface sealing, and on surfaces under fasteners.

Repair of in-service aircraft dictates the use of adhesion promoters because, as a result of long-term aging and fuel soaking, the surface of the corrosion-protective fuel tank coating loses chemically active groups, which augment sealant adhesion. Sealants, therefore, do not bond well when these chemically active groups are removed from the fuel tank coated surface. The use of adhesion promoters improves chemical bonding and provides an added degree of insurance of good adhesive bonding of the fuel tank sealant.

Adhesion promoters that are qualified to AMS3100 must be kept in closed, sealed containers at all times except when being used. Certain adhesion promoters will absorb moisture from the air readily and will thereby become ineffective. If the material is transferred to smaller bottles for use on the production line, transfer of material should be accomplished as quickly as possible; then the bottles must be sealed. Small bottles with screw caps once opened and in use on the line, should be discarded at the end of shelf life.

Always keep the container tightly capped when not applying material.

It is important to know that, while absorption of moisture eventually renders the adhesion promoter ineffective, it is mandatory that some moisture be absorbed by the applied adhesion promoter to activate it. For this reason, applied adhesion promoter should air dry for a minimum of 30 minutes before sealant is applied, unless otherwise instructed by the manufacturer. If the relative humidity level is excessively low, less than 20%, allow 1 hour before sealant application. A single continuous coat of adhesion promoter should be applied to the intended sealing area without any subsequent wiping off. Provided the area is completely covered with adhesion promoter, there is no need for a second application. Only areas missed during adhesion promoter application shall be touched up with promoter.

If the sealant is not applied over the adhesion promoter within 4 hours, reclean the surface and reapply the adhesion promoter.

5.3.2 Polyurethane Sealant Adhesion Promoter

Adhesion promoter for polyurethane sealant was developed primarily to ensure adhesion to aged AMS-C-27725 polyurethane fuel tank corrosion coatings and other aircraft structural materials. Their use is required in accordance with AMS3278 for all applications to maximize adhesion.

The adhesion promoter used with AMS3278 sealants is a two-component formulation and shall be prepared and applied in accordance with the manufacturer's instructions.

6. SEALANT SELECTION

Integral fuel tank sealants are available in several polymer types: polysulfides, polyurethanes, nitrile, fluoro- or cyanosilicones, and polythioethers. The polymer types are available in several forms: sprayable, brushable (typically Class A and C), extrudable/trowelable (typically Class B and C), rollable (Class C), and in a number of cure rates, providing short or extended work lives and cure times. Nearly all of the sealants found within integral fuel tanks are either polysulfide or polythioether.

Fuel resistant fluorosilicones are used in fairly rare instances where temperatures above 300 °F (149 °C) are expected on a fuel tank wall in high performance aircraft. Only fluorosilicones can be used to repair fluorosilicones because other sealants will not bond well to the fluorosilicone rubber surface.

6.1 Polymer Types (Curing-Type Systems)

6.1.1 Polysulfide and Polythioether Sealants

NOTE: The following sections provide generalized characteristics by sealant classes.

Formulations used in integral fuel tanks are two-part materials consisting of a separately packaged base compound and a curing agent (catalyst). The base compound contains the prepolymer and additives that influence viscosity, thixotropy, reaction rate, wettability, adhesion, tensile and peel strength, hardness, and, in some cases, the ability of the sealant to inhibit corrosion when moisture intrudes. The base compound may also contain a pigment or small amounts of solvents, or both pigment and solvents. The curing agent side contains curing agent and its solvent or its inert carrier. Polysulfide curing agent may either be manganese dioxide (a black powder) or a dichromate mixture. Polythioether curing agents are typically epoxy-based resin mixtures.

The manganese dioxide is suspended in an inert organic plasticizer. The dichromate carrier contains water to solubilize some of the reactive materials. The curing agent side may also contain reaction modifiers and viscosity modifiers.

The base compound and curing agent are combined in accordance with the prescribed weight ratio to produce a sealant with the expected rheological and physical/mechanical properties. Some polysulfide and polythioether sealants contain corrosion inhibitors and are so identified in their accompanying data sheets and recognized by specifications designed for them (e.g., MIL-PRF-81733, AMS3265). Corrosion inhibitive sealants are used, primarily, in faying surface sealing of aluminum surfaces of integral fuel tanks and in wet installation of fasteners to protect metal from corrosion. They should be evaluated before being used as a fillet seal and fastener overcoating within fuel tanks as inhibitors will leach out from the sealant into fuel which may impact the fuel but will also quickly remove their corrosion-inhibiting properties. Polysulfide and polythioether based sealing compounds are available in several basic types for fuel tank application, as listed in Tables 1 and 2.

Table 1 - Polysulfide/fluorosilicone type fuel tank sealants

Polysulfide Type Sealant	Specification	Operating Temperature
Fuel Resistant, Non-Chromated Corrosion Inhibiting Sealant	AMS3265	-65 to +250 °F (-54 to 121 °C)
Integral Fuel Tank and Fuel Cell Cavities High Strength Sealant	AMS3269	-65 to +250 °F (-54 to 121 °C)
Integral Fuel Tanks and General Purpose Sealant	AMS3276	-65 to +250 °F (-54 to 121 °C)
Integral Fuel Tank and Fuel Cavities Low Density Sealant	AMS3281	-65 to +250 °F (-54 to 121 °C)
Low Adhesion, Removable Panels and Fuel Tank Inspection Plates Sealant	AMS3284	-65 to +250 °F (-54 to 121 °C)
Fluorosilicone Aromatic Fuel Resistant One-Part RT Adhesive/Sealant	AMS3375	-65 to +400 °F (-54 to 204 °C)
Integral Fuel Tanks and Fuel Cell Cavities, High Adhesion	AMS-S-8802	-65 to +250 °F (-54 to 121 °C)

Table 2 - Polythioether type fuel tank sealants

Polythioether Type Sealant	Specification	Operating Temperature
Cure on Demand Integral Fuel Tanks and General Purpose	AMS1389	-80 to +320 °F (-62 to 160 °C)
Fast Curing Integral Fuel Tank and General Purpose Sealant	AMS3277	-80 to +320 °F (-62 to 160 °C)
Sprayable Integral Fuel Tanks and Fuel Cell Cavities Sealant	AMS3279	-65 to +250 °F (-54 to 121 °C)

The different viscosities of polysulfide or polythioether based fuel tank sealants are designed for specific applications as indicated in Table 3:

Table 3 - Polysulfide and polythioether base compound viscosities

Base Compound	Viscosity Range (Poise) at 77 °F (25 °C)
Class A Sealant - Brushable Applications	100 to 600
Class B Sealant - Extrusion Gun/Spatula Applications	6000 to 18000
Class C Sealant - Brushable, Extrusion Gun, Roller, or Spatula Applications	1000 to 4000
Sprayable Sealant Applications	100 to 400

6.1.1.1 Brushable Sealants

Class A and Class C sealants are brushable. The following are typical characteristics of these Classes of sealants. They contain approximately 12 to 16% volatiles and flow more than Class B sealants. Class A and Class C brushable sealants are used around metal fasteners and over seams and often as a pre-coat before application of Class B sealant. Class A sealants are available in application time (worklife) ranging from 10 minutes to 4 hours; application time (worklife) for Class C sealants typically range from 2 to 48 hours. Brushable fuel tank sealants are most easily applied with a stiff, short brush. Since brushable sealants can contain as much as 16% volatile solvent, at least 1/2 hour must be allowed after application for evaporation (or flash-off) of solvent before a topcoat of any kind is applied; this flash-off time is based on a recommended Class A or Class C sealant thickness of not greater than 0.125 inch (3.18 mm).

6.1.1.2 Extrudable Sealants

Class B thixotropic fuel tank sealants are used primarily for fillets; but they are also used for a wide variety of other applications, such as hole filling, prepacking, injection sealing, and for overcoating of fasteners after the Class A material has been applied. Class B fuel tank sealants have no more than 8% of volatile materials and are available in application times (worklife) ranging from 10 minutes to 12 hours. The short (10 to 15 minutes) application time (worklife) sealant, which conform to AMS3277, are useful for repairs at low temperatures when cure profiles are slowed, and the application and cure times are longer. Most fuel tank sealing is accomplished with the 2-hour application time (worklife) (Class B-2) material. For repairs, the 1/2-hour application time (worklife) (Class B-1/2) sealant is used. Class B-1/2 sealant is used when plant or application temperatures fall below 70 °F (21 °C).

It is important to note that polysulfide sealants, depending on the type and application time (worklife), are strongly affected by humidity and temperature in their application time (worklife), tack-free time, and curing rate. As temperature and humidity rise, tack free times and cure rates are shortened for polysulfide sealants. Polythioether sealants are, typically less sensitive to temperature and humidity variations and AMS3277 sealants will cure at temperatures of 20 to 40 °F (-7 to 4 °C).

6.1.1.2.1 Class B, Cure on Demand

There are two Class B cure on demand polythioether fuel tank sealants: (1) sealant cures only by exposure to a light source, and (2) sealant cures by exposure to a light source or by chemical reaction. Cure on demand fuel tank sealants are used primarily for fillets, and overcoating of fasteners. Class B fuel tank sealants have no more than 3% of volatile materials and are available in application times (worklife) ranging from 2 to 8 hours.

It is important to note that polythioether sealants are less sensitive to temperature and humidity, depending on the class and application time (worklife), in their application time (worklife), tack-free time, and curing rate for chemical reaction cure process.

6.1.1.2.2 Class R, Cure on Demand

There is a Class R cure on demand polythioether fuel tank sealant that is suitable for robotic applications and cures by exposure to light source. The robotic sealant is used primarily for fillets and overcoating of fasteners. The Class R fuel tank sealant have no more than 15% of volatile materials and is available in application time (worklife) of 8 hours.

6.1.1.3 Rollable Sealants—Long Application Time (Worklife) and Open Time

Class C fuel tank sealants are generally used for faying surfaces where, after sealant application, other work must be done before the two surfaces can be drawn together. Class C sealants contain about 10% or less of volatiles with longer application times (worklife) (2 to 96 hours) and exceptionally long assembly times (ranging from 12 to 336 hours). The long assembly times mean that at the time two surfaces are pulled together tightly with fasteners, the sealant will still be sufficiently uncured to enable the sealant to flow and extrude or squeeze out. Generally, a 0.010 to 0.015 inch (0.25 to 0.38 mm) thick coating is applied and is subsequently squeezed out to approximately 0.000 to 0.003 inch (0.00 to 0.08 mm). Class C fuel tank sealant cure time can range from 7 days to 16 weeks depending upon the assembly time of the product selected.

6.1.2 Polyurethane Sealants

Polyurethane sealants (AMS3278) are high-strength, high adhesion integral fuel tank sealants particularly useful in high strain fuel tank areas/applications (i.e., jack pads and wing roots). Use of adhesion promoters is recommended by the manufacturer as the sealant is extremely tough and high adhesion is required since failure mode is almost exclusively adhesive.

6.1.3 Fuel Resistant Fluorosilicones (Curing Type)

Fuel resistant fluorosilicones are used where aircraft service temperatures of up to 375 °F (191 °C) are expected. Peel strengths for these sealants are significantly lower than those associated with polysulfides and polythioethers (approximately 10 pounds per inch width (1.8 kg/cm width) compared to 20 to 40 pounds per inch width (3.6 to 7.2 kg/cm width). For certain locations in the design of aircraft fuel tanks, these lower peel strengths are adequate. The peel strength is reduced to approximately 2 to 5 pounds per inch width (0.36 to 0.90 kg/cm width) at 400 °F (204 °C), but the bond remains intact. A silicone primer (adhesion promoter) material must be used with the fluorosilicone sealant to produce good adhesion. Silicone primers must air dry as specified by the manufacturer prior to the application of the fluorosilicone sealant.

Two types of fluorosilicone sealants are available:

- a. A one part, moisture-curing sealant that produces acetic acid upon cure.
- b. A two-part moisture-curing sealant that does not release acetic acid during the curing process.

NOTE: Fluorosilicone one-part sealants produce a byproduct during their cure that can be damaging to surrounding electronics.

6.1.4 Buna-N Polymers

These polymers systems are used infrequently, and mainly as a protective overcoat (AMS-S-4383) over integral fuel tank sealants. A different use of Buna-N polymers is represented by fill-and-drain sealants. A fuel tank is filled with a medium viscosity, high volatile organic content (VOC) Buna-N-based sealant. It is seldom used in large aircraft sealing due to lack of thickness control, weight penalties, environmental concerns (high VOC) and because of difficulty in removing cured materials for other work, such as sealant rework or repair jobs.

6.2 Non-curing Polymer Systems for Groove Design

Fuel-resistant channel or groove sealants are putty-like, one-part, formulations that are non-vulcanizing (non-curing). They must be fuel resistant and possess a tacky-type adhesion to groove surfaces that prevents fuel from migrating through the groove and out of the fuel tank. Table 4 provides examples of channel type sealants. These sealants are produced from fluorosilicones, cyanosilicones, and polysulfides. Sealants currently chosen by aircraft design engineers for this application are usually fluorosilicone-based. AMS3376 is a specification that addresses fluorosilicone-based channel sealants. AMS3283 is a specification that addresses polysulfide-based channel sealants.

Fillers (often microspheres, plastic beads, or cured crumb sealant) are used in channel sealants for several reasons:

- a. To minimize thermal expansion.
- b. To increase viscosity.
- c. To generate a log-jamming effect to plug gaps which could result in fuel leakage.