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

AEROSPACE INFORMATION REPORT

SAE AIR4069 REV. A

Issued 1990-10
Revised 1998-05

Submitted for recognition as an American National Standard

Sealing of Integral Fuel Tanks

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

1. SCOPE:

This SAE Aerospace Information Report (AIR) presents preferred 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 this document discusses the most practical and conservative methods for producing a reliable, sealed system.

Design preferences for optimum sealing are not within the scope of this document. Such discussions can be found in the Air Force sponsored handbook, entitled Aircraft Integral Fuel Tank Design Handbook, AFWAL-TR-87-3078.

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 air vehicle. Factors that can influence the outcome of this process are:

Effective and efficient sealing of aircraft fuel tanks are prime considerations in commercial and military aircraft designs. Sealant fillets inside the tanks are considered to be primary seals.

Of nearly equal importance is corrosion control. Sealants are used for fuel containment and corrosion protection, but the purpose of use should never be confused. 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 seal, except in adhesive-bonded systems; the faying surface seal, however, plays an extremely important role as a secondary 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 surfaces. Extensive use of faying-surface sealing is highly recommended.

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; how it is applied

c. How well the substrate surface is prepared

d. Whether sealant fillet dimensions are optimum for air vehicle configuration and flight dynamics

e. The degree of resistance of the sealant to the fluid and thermal environment

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.

1. (Continued):

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 document 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 document; 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, all sealing is done 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 from wet to dry side represent opportunities for fuel leakage and for moisture intrusion, which will 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 seams, lap edges, and fasteners.

Fay-surface sealing is also considered to be an important type of sealing because it limits the length of leak paths, contains the fuel, and prevents corrosion. Fay-surface sealing is an essential adjunct to fillet sealing to produce a reliable, sealed fuel tank that does not leak during the operational life of the air vehicle.

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, see Figure 2 of ARP4118. If pre-cleaned fasteners are not available, the fasteners to be wet installed shall be cleaned, using MIL-C-38736 Type I solvent, prior to installation. Dry film lubricants need not be removed but adhesion promoters should be applied before wet installation. It is mandatory that cadmium-plated permanent fasteners be coated with a fuel-resistant epoxy primer before adhesion promoter is applied. Solid-film lubricants that meet the engineering material property requirements of MIL-L-46010 need not be removed provided adhesion promoter is used. MIL-L-23398 coating, on the other hand, must 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 air vehicle 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 mated fuel tank structures. Next, excess sealant is removed (while sealant is still wet), the surface is cleaned, and a full fillet of fuel tank sealant is applied around the periphery.

3.1.1.2 (Continued):

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

Some subassemblies that are often preassembly sealed include:

a. upper and lower wing panels
b. front and rear spars
c. all intermediate bulkheads and webs, and
d. boost pump cover plates.

Remaining fillets are then applied.

Injection sealing (or non-pressurized groove-injection sealing) can also be a form of sealing that is accomplished during assembly. Where possible, sealants should be injected while the faying-surface sealant in these locations is still uncured.

Final assembly sealing includes injection seals, hole and slot seals, brushcoat, and fillet seals. All leak path entry edges should be covered with a minimum of 0.15 in (3.8 mm) of sealant. The minimum sealant bondline on all fuel tank structure should be 0.250 in (6.35 mm).

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

Generally, repairs should be made by fillet sealing the edges of assembled faying surfaces (see 12.4.2.3), and not by disassembly of the faying surfaces. 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. Mating surfaces must not mismatch by more than 0.015 in (1.5 mils; 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 nonmetallic seal washers must be located in wet-to-wet areas of the fuel tank. The entire unit must be placed in an oven to cure the adhesive at 300 °F (149 °C) for approximately 2 h. Usually, structural voids at fuel tank boundaries are filled with polysulfide sealant after oven cure is completed. Sometimes a high-temperature sealant (conforming to AMS 3276, AMS 3277, or AMS 3281) 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.

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 noncuring sealant from the outside by means of a series of ports spaced at 3 to 5 in (76 to 127 mm) intervals. Some groove designs have the groove adjacent to a row of fasteners, or between two rows of fasteners; 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 air vehicle, since repairs can be made quickly under battle 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, noncuring groove-injection sealant, fastener spacing is a maximum of six times the diameter of the fastener. The minimum diameter of fastener used in channel seal grooves is 0.250 in (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.

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, made of polysulfide sealant (MIL-S-8802 or AMS 3276) or epoxy adhesive (Fusor 309) 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 fay surface seal around the grooves to provide the best seal. Shims should be avoided as much as possible. Should a shim be required, it should not go across the groove and should be faying surface sealed.

Liquid shims made of polysulfide or 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. Gaps must be controlled to 0.005 in (0.127 mm) maximum.

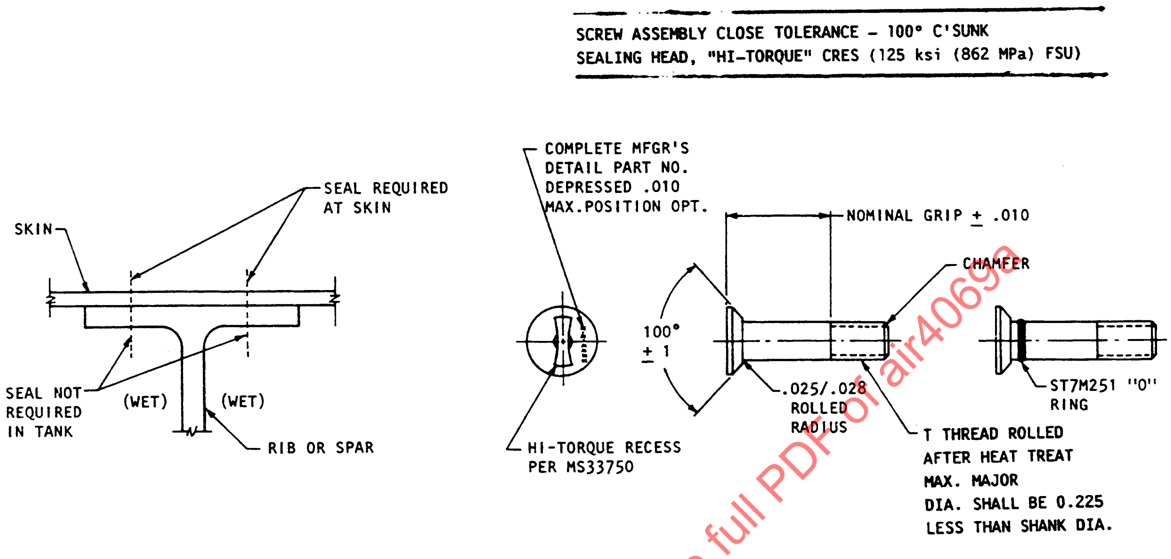


FIGURE 1 - Rib/Skin Assembly

3.1.2.1 (Continued):

Sealant-related factors concern application (processing) and operational performance. Flow characteristics are important. Although noncuring, groove sealant must seal all gaps and stay in place, yet be injectable. If the viscosity is too low, separation of filler 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 channel sealant to approximately 95 °F (35 °C; maximum) to improve the extrudability (or flow) of this material.

Sealant is injected at pressures of several thousand psi by sealant guns designed to augment the incoming plant air pressure of 80 to 100 psi (552 to 689 kPa) by approximately 40 to 50 times. It is possible to damage the structure, or to distort the air vehicle wing skin, losing sealant into the tank if pressures exceeding design structural limits are applied. Minimum design thicknesses for tank components in the area of the channel seal are as follows:

a. Aluminum alloys: 0.190 in (4.8 mm)
b. Titanium alloys: 0.160 in (4.1 mm)
c. Carbon epoxy composite: 0.190 in (4.8 m)

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.

3.1.2.1 (Continued):

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

a. Excessive mismatch of parts [i.e., greater than 0.005 in (5 mils; 0.127 mm)]
b. Large joint deflections
c. Thermal expansion and contraction of structure and sealant
d. Chemical degradation
e. Swelling of the fuel tank sealant
f. Vibration
g. Corrosion

Particular attention must be given to selection of a channel sealant that ensures good performance, consistent with the air vehicle’s design configuration and expected operational environment.

3.1.2.2 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. Mating surfaces must not mismatch by more than 0.015 in (1.5 mils; 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 nonmetallic seal washers must be located in wet-to-wet areas of the fuel tank. The entire unit must be placed in an oven to cure the adhesive at 300 °F (149 °C) for approximately 2 h. Structural voids at fuel tank boundaries are filled with polysulfide sealant after oven cure is completed.

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. Fay seals also fill potential leak paths, thus, making repairs easier and less expensive.

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 in (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, 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.

3.2.4 Topcoats (MIL-S-4383 BUNA-N or MIL-C-83019 Polyurethane) 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 on sealant chalking 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. (See General Dynamics, Inc. report number GD-16PR1412, dated August 1980.)

3.2.5 Adhesion Promoters (or Adhesive Primers) for Polysulfide Sealants: The use of adhesion promoters (or adhesive primers) with polysulfide sealants for post-assembly seals in fuel tanks and in-service repairs have proven to be particularly effective. Studies by the U.S. Air Force and private industry have demonstrated good adhesive bonding of fuel tank sealant to substrates that are properly cleaned and adhesion promoted. This positive outcome occurred regardless of whether the surface was aged polyurethane or some other material to which it is normally difficult to obtain a good adhesive bond. Extensive use of adhesion promoters in initial manufacture and any repair operations is highly recommended.

3.2.6 Redundancy in Sealing Groove Designs and Adhesively Sealed Designs: Polysulfide fillet sealing of all joints, structural voids, etc. in the air vehicle'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 companies treat difficult-to-seal areas in the upper skin by applying polysulfide sealant to upper faying surfaces of groove-designed tanks as a back up to the noncuring channel sealant. The channel must not be blocked with curing-type fay surface sealant. In such cases, it is prudent to assume that faying-surface sealant squeeze-out is performed successfully and completely when the residual faying-surface sealant -- in between the mating surfaces -- occupies a space not greater than a 0 to 0.003 in (0 to 3 mils; 0 to 0.08 mm).

3.3 Composite Construction - Sealing Philosophy:

An increasing percentage of aircraft structure consists of composite parts to reduce air vehicle weight. Composites usually are carbon-fiber-reinforced thermosetting materials; but, in some cases, composite structure with a thermoplastic matrix is used. Extensive round robin testing has demonstrated that thermoset 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. Non-interference fit fasteners are used with composites; therefore, all permanent fasteners penetrating composite structure must be wet installed and overcoated with fuel tank sealant. Fuel tank sealant performs an important secondary role as a nonconductor between carbon fiber and aluminum, thereby helping to prevent galvanic corrosion (see ARP4118).

4. SUBSTRATES:

Possible metal surfaces present within an integral fuel tank include corrosion-resistant (stainless) steel, cadmium (must be coated), titanium, nickel-based alloys, such as Inconel, and aluminum (bare or treated). These surfaces, however, are almost always coated by a polyurethane or epoxy corrosion-preventive coating, (exception: titanium is not coated); thus, fuel tank sealant will be required to bond to the polymeric surface. When the corrosion-preventive coating on aluminum structure is scratched or damaged, the surface is cleaned, and a chemical conversion coating is applied to the aluminum. If sealant will entirely cover the area, it is not necessary to reapply the urethane or epoxy coating before applying the sealant; otherwise, after chemical conversion coating application, the polymeric corrosion-preventing coating is reapplied. If only the polyurethane coating has been damaged, it can be touched up with an epoxy. Polysulfide sealants 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 MIL-C-38736, Type I or Type II in areas where sealant will be applied.

4.1 Corrosion-Preventive Coatings:

MIL-C-27725 fuel-resistant and microbial-resistant polyurethane 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 h 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 primer to become resistant to methyl ethyl ketone (MEK).

The exterior of the fuel tank is usually covered with an epoxy-based corrosion-preventive coating such as epoxy-polyamide (MIL-P-23377).

Normal techniques for spray painting apply. The gun should be moved parallel to the work. Find the proper distance and speed to avoid running or orange peel effects. The orange peel effect can be produced by being too far away as well as too close. Second coats of primer should not be applied until the first coat is tack free.

4.2 Titanium:

Titanium parts are usually treated with an inorganic chemical conversion coating; 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 and promoting prior to sealant application.

4.3 Composite Surfaces:

Composites will be prevalent in aircraft fuel tanks produced in the future. It is beyond the scope of this document to review the status of present investigations regarding application of sealants to composite surfaces; however, it is well known that current composite structural materials essentially present an epoxy or bismaleimide surface for bonding. Polysulfide sealants bond well to these surfaces. It has been established, however, that composite surfaces must be scuff sanded, then solvent cleaned. Fuel tank sealant should be applied as soon as possible after completion of solvent cleaning, abrading, and adhesion promoting.

4.4 Dry Film Lubricants:

In 1984, AFML tested seventeen dry film lubricants with polysulfide sealants for bonding characteristics with and without the use of dry film lubricants. 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)/salt water]. While the results were not as clear cut with dichromate-cured polysulfides, it left no doubt that it is highly desirable to use polysulfide adhesion promoters (conforming to AMS 3100) on parts containing dry film lubricant before application of fuel tank sealant for satisfactory bonding of sealant to structure.

Reports pertaining to the 1984 AFML study of the bonding characteristics of polysulfide sealants (with and without dry film lubricants) are listed as follows by report number:

a) MLS 85-27
b) MLS 85-28
c) MLS 85-29
d) MLS 85-30
e) MLS 85-31
f) MLS 85-32
g) MLS 85-33
h) MLS 85-34
i) MLS 85-35

5. SURFACE PREPARATION:

AMS 3090 has been prepared for dry film lubricants to which sealants will adhere; the appropriate adhesion promoter is still needed when AMS 3090 dry film lubricant is on the surface to be sealed.

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; do not use air pressure.

b. Prepare an aerospace cleaning compound that conforms to engineering material property requirements of MIL-C-87937, Type optional, or AMS 3166.

c. Pour the cleaning compound (or squirt the cleaning compound) from bottles onto low-linting wipe cloths (AMS 3819, Type 1 or Type 2, Grade A) and scrub the surface transversely -- for example, starting from the top down, followed by left to right. Stiff bristle brushes can be used to facilitate cleaning if necessary.

5.1 (Continued):

d. Rinse the cloth or brush frequently in water (not in the cleaning compound) to avoid build-up of contaminants.

e. Rewet the cloth or brush with cleaning compound; and wipe the surface until it is clean.

f. Using a fresh low-linting cloth, thoroughly rinse with water and perform a final wipe down.

g. Wipe dry with a dry cloth. Do not allow the cleaner to air-dry; evaporation of surface cleaners will redeposit dissolved materials on the surface.

h. Repeat the cleaning process as follows using an approved organic solvent blend, such as MIL-C-38736, Type I or Type II, or AMS 3166:

(1) Dispense the solvent mixture from a polyethylene squeeze-bottle onto a clean low-linting cloth (AMS 3819, Type 1 or Type 2, Grade A). Do not dip the wiper into the solvent.

(2) Clean the surface thoroughly with the cloth, turning it frequently. Change to a new cloth as soil becomes evident.

(3) Clean from the top down and from the inside out.

(4) 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.

(5) Before the solvent has a chance to evaporate, rinse the structure using a clean, solvent-wetted cloth.

(6) Finally, when there is no further evidence of soil, wipe the surface dry with a clean and dry cloth.

Reclean the surface, in accordance with the above procedure, if the surface is not sealed within 24 h.

The following solvent mixtures, which conform to MIL-C-38736, Type I or Type II, are among the most widely used solvent cleaners:

TABLE 1

	Percent by Weight Type I	Percent by Weight Type II[1]
Toluene	0	18.5 ± 1.5
Aromatic naphtha (containing 30 parts toluene)	50 ± 2.0	0
Ethyl acetate	20 ± 1.0	35.5 ± 1.0
Methyl ethyl ketone	20 ± 1.0	36.0 ± 1.0
Isopropyl alcohol	10 ± 1.0	10.0 ± 1.0

[1] Nonphotochemically reactive solvent blend.

5.1 (Continued):

Other solvents used successfully for cleaning include the following:

a) ASTM D 740 Methyl ethyl ketone (MEK), technical grade
b) Naphtha, aliphatic
c) Naphtha, aromatic
d) Toluene, technical grade
e) Dry cleaning solvent, high flash

NOTE 1: Do not use methyl alcohol on titanium.

NOTE 2: Methyl ethyl ketone (MEK) and toluene are classified by the Environmental Protection Agency (EPA) as hazardous air pollutants (or HAPs); therefore, these materials will be discontinued. Environmentally-compliant cleaners, conforming to AMS 3166, should be substituted.

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 nonfibrous) material (see ASTM D 2257). The cloths should be open weave or nonwoven to allow for easier absorption of bulk contamination. AMS 3819 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.

c. Chlorinated cleaners generally should not be used on titanium structures.

d. Titanium surfaces should be cleaned using both an aqueous alkaline detergent cleaner and 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 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 h, 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, molybdenum disulfide or graphite 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:

Adhesion promoters for polysulfide sealants were developed primarily to ensure adhesion to aged, fuel soaked MIL-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 containing MIL-C-27725 polyurethane coatings.

c. Receiving-inspection should conduct acceptance testing with adhesion promoter conforming to AMS 3100. During use, it should be periodically retested.

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

5.3 (Continued):

Repair of in-service aircraft dictates the mandatory use of adhesion promoters because, as a result of long-term aging and fuel soaking, the surface of the corrosion-protective fuel tank primer 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 primer's surface. Adhesion promoters ensure excellent chemical bonding and provide an added degree of insurance of good adhesive bonding of the fuel tank sealant.

Adhesion promoters that are qualified to AMS 3100 must be kept in closed, sealed containers at all times except when being used. They 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 as follows:

a. Red, chlorinated, after 7 days;
b. Blue, non-chlorinated, after 24 h, or discarded earlier if the material appears cloudy.

Always keep the container tightly capped when not removing material.

The storage life of PR-182 waterborne adhesion promoter is 6 months (minimum) at 40 to 80 °F, in the original, unopened containers. PR-182 waterborne adhesion promoter is hygroscopic, and shall be kept free of moisture. Discard waterborne adhesion promoter if a cloudy precipitate is formed.

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 stand for a minimum of 30 min before sealant is applied. If the humidity level is excessively low, allow 1 h before sealant application. A thin, continuous coat of adhesion promoter should be applied without a subsequent wipe-off. Excessive amounts of applied adhesion promoter can reduce sealant adhesion and, therefore, must be removed from (by wiping) the sealant bond surface.

If the sealant is not applied over the adhesion promoter within 3 h, reclean the surface and reapply the adhesion promoter. Adhesion promoter is available in two versions (in bottles and aerosol cans): one in a chlorinated solvent, the other in a nonchlorinated solvent.

6. SEALANT SELECTION:

Integral fuel tank sealants are available in several polymer types: polysulfides, polyurethanes, nitrile, fluoro-or cyano-silicones, and polythioethers. Within the polymer types they are available in several forms: sprayable, brushable, extrudable, rollable, 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 polysulfides. Several decades ago, BUNA-N rubber was used as a coating over the fuel tank sealant. This practice has been discontinued due to the excellent fuel resistance of present polysulfide sealants.

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: Formulations used in integral fuel tanks are two-part materials consisting of a separately packaged base compound and a 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 catalyst side contains the catalyst and its solvent or its inert carrier. The catalyst can be manganese dioxide (a black powder) or it can be a dichromate mixture.

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

The base compound and catalyst are combined in accordance with the prescribed weight ratio to produce a sealant with the expected rheological and physical/mechanical properties. Some polysulfide sealants contain corrosion inhibitors and are so identified in their accompanying data sheets and recognized by specifications designed for them (for example, see MIL-S-81733). Corrosion inhibited sealants are used, primarily, in faying sealing of aluminum surfaces of integral fuel tanks and in wet installation of fasteners. Polysulfide and polythioether based sealing compounds are available in several basic types for fuel tank application as listed in Table 2:

TABLE 2

Integral Fuel Tank Sealant	MIL-S-8802	-65 to +250 °F	-54 to 121 °C
Nonchromate, Corrosion Inhibiting, Polythioether Sealant	AMS 3259	-65 to +320 °F[1]	-54 to 160 °C
Ambient or Immediate Heat Cure Polythioether Sealant	AMS 3263	-67 to +320 °F[2]	-55 to 160 °C
Integral Fuel Tank Sealant (High Temp)	AMS 3276	-65 to +250 °F[1]	-54 to 182 °C
Integral Fuel Tank Sealant (Low Density)	AMS 3281	-65 to +250 °F[1]	-54 to 182 °C
Corrosion Inhibiting Sealant	MIL-S-81733	-65 to +200 °F	-54 to 93 °C
Nonchromate Corrosion Inhibiting Sealant	AMS 3265	-65 to +200 °F	-54 to 93 °C
High Strength Fuel Tank Sealant	AMS 3269	-65 to +250 °F[1]	-54 to 121 °C
One Part, Fuel Resistant Fluoro-silicone Adhesive/Sealant	AMS 3375	-65 to +400 °F	-54 to 204 °C
Quick Repair Sealant	MIL-S-83318	-65 to +250 °F	-54 to 121 °C
Access Door Sealant (Low Adhesion)	MIL-S-8784	-65 to +180 °F	-54 to 82 °C
Corrosion Inhibiting Access Door Sealant	AMS 3267	-65 to +250 °F	-54 to 121 °C
Adhesion Promoter for Polysulfide Sealants	AMS 3100		

[1] These sealants have a maximum continuous use temperature of 250 °F; but they are resistant to degradation in short-term exposures -- approximately 1 h, maximum -- of up to 360 °F.

[2] Sealants conforming to AMS 3263 have a maximum continuous use temperature of 320 °F, but are resistant to degradation in short-term (1 h, maximum) exposures at up to 360 °F.

6.1.1 (Continued):

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

TABLE 3

Base	Viscosity Range at 77 °F (25 °C) (Poise)
Sprayable	50 to 150
Brushable (Class A)	100 to 500
Rollable (Faying Surface, Class C)	1,000 to 4,000
Extrudable/Trowelable (Class B)	6,000 to 16,000
Catalyst	700 to 1,600

6.1.1.1 Brushable Sealants: Class A and Class C sealants are brushable. 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 precoat before application of Class B sealant. Class A sealants are available in application times ranging from 1/6 to 4 h; application times for Class C sealants typically range from 2 to 48 h. Brushable fuel tank sealants are applied with a stiff, short brush. One of the aerospace industry's primary manufacturers applies Class A sealant as an overcoat to Class B material. Since brushable sealants can contain as much as 16% volatile solvent, at least 1/2 h must be allowed after application for evaporation (or flash-off) of solvent before a top coat 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 in (125 mils; 3.18 mm).

6.1.1.2 Extrudable Sealants: Class B thixotropic fuel tank sealants have no more than 8% of volatile materials and are used primarily for fillets; these materials are also used for a wide variety of other applications, such as hole filling, prepacking, injection sealing, and for topcoating (brushcoating) of fasteners after the Class A material has been applied. Class B fuel tank sealant is available in application times ranging from 10 min to 12 h. The short (10 to 15 min) application time material, which conforms to MIL-S-83318, is highly useful for quick repairs especially at low temperatures; at lower temperatures, the application and cure times are longer. Most of the fuel tank sealing is accomplished with the 2 h application time (Class B-2) material. For repairs, the 1/2 h application time (Class B-1/2) material is used. Class B-1/2 sealant is sometimes used during the winter when plant temperatures fall below 70 °F (21 °C).

During hot summer months, 4 h application time material (Class B 4) is sometimes used. For faying-surface sealants, 4 and 6 h application time materials (Classes B 4 and B 6) are sometimes used.

It is important to note that humidity as well as temperature strongly affect the application time, tack-free time, and cure rate. Cure rates are accelerated by temperature and high humidity.

6.1.1.3 Rollable Sealants (long work life and open time): Class C fuel tank sealants contain about 10% or less of volatiles with longer application times (2 to 48 h) and very long assembly times (ranging from 12 to 336 h); and Class C materials are generally used for faying surfaces where, after sealant application, other work must be done before the two surfaces can be drawn together. At the time the two surfaces are pulled together tightly with fasteners, the sealant must still be sufficiently uncured to enable the sealant to flow and extrude, or squeeze out. Generally, a 0.010 to 0.015 in (1 to 15 mils; 0.25 to 0.38 mm) thick coating is applied and is subsequently squeezed out to approximately 0 to 0.003 in (0 to 3 mils; 0 to 0.08 mm). Class C fuel tank sealant cure time can range from 5 to 14 weeks depending upon the assembly time of the product selected. Moisture cured, one-part sealants are not used as Class C faying-surface sealants, since moisture would not be available to activate cure once the two surfaces are brought together.

6.1.2 Polyurethanes: Polyurethanes have not been used as integral fuel tank sealants, since elastomeric urethanes with adequate fuel resistance are not available. Highly crosslinked and rigid urethane-based primers are fuel resistant and are used almost exclusively in the form of a corrosion-protective coatings over structure inside the fuel tank. Engineering material property requirements applicable to such a product are defined in MIL-C-27725. This material has been discussed in 4.1.

6.1.3 Fuel Resistant Fluorosilicones (Curing Type): Fuel resistant fluorosilicones are used where air vehicle service temperatures of up to 375 °F (191 °C) are expected. Peel strengths for these sealants are significantly lower than those associated with polysulfides (approximately 10 lb/in width (1.79 kg/cm width) versus 20 to 40 lb/in 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 lb/in-width (0.36 to 0.90 kg/cm-width) at 400 °F (204 °C), but the bond remains intact. A primer must be used with the fluorosilicone sealant to produce good adhesion.

Two types of fluorosilicone sealants are available:

a. A one part, moisture-curing material that produces acetic acid upon cure; and

b. A two-part moisture-curing and condensation-curing sealant that does not release acetic acid during the curing process.

Adhesive bonding tests on various surfaces and fluid immersion tests of samples bonded to different surfaces were conducted between 1984 and 1985; these studies were sponsored and conducted by the U.S. Air Force Materials Laboratory at Wright-Patterson Air Force Base (Dayton, Ohio).

6.1.4 BUNA-N Polymers: These polymers systems are used infrequently, and only as a protective overcoat (MIL-S-4383) over integral fuel tank sealants. A totally different use of BUNA-N coatings is represented by fill-and-drain sealants. A fuel tank is filled with a medium viscosity, high volatile content BUNA-N-based sealant. It is then drained from the tank, leaving a coating over the entire surface of the interior. Solvents evaporate leaving a tough, durable coating. It is seldom used in large aircraft sealing due to lack of thickness control and weight and because of difficulty in removing cured materials for other work, such as sealant rework or repair jobs. Weight penalties resulting from coating surfaces in the tank that need no protection are also a factor.

6.2 Noncuring Polymer Systems for Groove Design:

Fuel-resistant channel or groove sealants are putty-like, one-part, formulations that are nonvulcanizing (noncuring). 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. These materials are produced from fluorosilicones, cyanosilicones, polysulfides and polyesters. Materials currently chosen by aircraft design engineers for this application are usually fluorosilicone-based. MIL-S-85334 is a military specification that addresses fluorosilicone-based channel sealants. Engineering requirements for qualification and acceptance of polysulfide-based noncuring groove-injection sealants are provided by a new industry specification -- AMS 3283.

Fillers (often microspheres) are used in channel sealants for several reasons:

a. to minimize thermal expansion;
b. to modify viscosity, and
c. to serve as a gap plugger by producing a log-jamming effect.

Groove-injection sealant fillers are typically incorporated into the sealant formulation as shown in Table 4:

TABLE 4

Noncuring Polymer Microspheres	% by Weight
#20 to #50 mesh	90.0
#50 to #100 mesh	6.0
#200 to #400 mesh	1.3

Volume change from thermal expansion over the temperature range -65 to +350 °F (-54 to +177 °C) is on the order of 15% with high-quality formulations and can be as high as 22% with some formulations. Such volume changes, plus volume increases of up to 25% (fluorosilicones) due to fuel swell, create pressures that can force sealants through faying surfaces and distort or damage structural members. Large viscosity changes with temperature also contribute to problems in maintaining a sealed tank.

6.2 (Continued):

The most common failure mode is gap extrusion caused by pressure build-up resulting from thermal expansion, fuel swell, internal tank pressure, and joint flexing.

AMS 3376 covers material property requirements for channel-sealant.

Selection of the appropriate channel sealant involves consideration of the following factors:

(1) Fuel resistance
(2) Resistance to pressure rupture
(3) Seal efficiency and flexibility at low temperature
(4) Corrosion inhibition
(5) Extrusion force
(6) Degree of tack or adhesion to:

    (a) Anodized aluminum
    (b) Titanium
    (c) Aluminum and MIL-C-27725 fuel tank coating
    (d) Aluminum and MIL-C-5541

(7) Nonvolatile content
(8) Specific gravity
(9) Reinjection time

The following acceptance tests should be conducted on each lot of channel sealant received:

1. Nonvolatile content
2. Extrusion force
3. Fuel resistance

Sealant is supplied in both plastic cartridges and 5-gal pails.

6.3 Selection of Polysulfide Sealant Types and Classes Versus Application:

As mentioned previously, there is a wide variety of available polysulfide-based fuel tank sealants to choose from. Table 5 gives examples of the appropriate matching of sealant to each specific application. It is not suggested that other types and classes cannot be used. Those given below are appropriate to the application indicated:

TABLE 5 - Sealant Class Versus Use

Use/Application	Class	Method	Time (hours) Application	Assembly
Brushing of Fasteners, Seams	A-1/2, A-2, A-4, C-2	Brush	1/2, 2, and 4	2 (Class C only)
Fillets and Overcoating of Fasteners	B-1/2, B-2, B-4, B-12	Extrude	1/2, 2, 4, and 12	None
Repair of Fillets and Fasteners	B-1/2	Extrude	1/2	None
Faying Surfaces	B-2	Roll or Spread	2	None
	B-4		4	None
	B-12		4	None
	C-20		8	20
	C-80		8	80
	C-168		48	168
	C-336		96	336

NOTE: It is important that application and assembly times will vary with temperature and relative humidity at the manufacturing facility.

6.4 Key Points Concerning Curing of Polysulfide Sealant:

The cure rates of polysulfide sealants are significantly influenced by temperature and humidity. At 55 °F (13 °C) and 40% RH an AMS 3276 Class B 2 sealant requires nearly 100 h to cure; whereas, at 85 °F (29 °C) and 80% RH, the same material will cure in approximately 24 h.

Work lives assigned to particular fuel tank sealants are stated for a reaction temperature of 77 °F (25 °C) and 50% relative humidity (standard conditions). Factory conditions are seldom at standard conditions; thus, sealant cure rates will be faster or slower than the stated ideal.

Experiments with variations in humidity, holding the temperature at 77 °F (25 °C) showed that a B 2 sealant (i.e., 2 h worklife) acted like a B 1 when the humidity was raised to 65% RH, and acted like a B 3 when the humidity was lowered to 35% RH.

Anticipation of weather conditions can enhance selection of faster or slower curing sealants as appropriate. Moderate acceleration of cure after sealant application can be accomplished by the use of heat lamps if surface temperatures are monitored closely to 140 °F (60 °C) or less. Increasing the humidity will also increase the cure rate.

6.4 (Continued):

Changing the ratio of catalyst (or accelerator) to base is not recommended. Such modifications are possible with some products but only under instructions from the sealant supplier. For example, large increases in the quantity of manganese dioxide catalyst can result in softening of the sealant, which is caused by the sealant's organic plasticizer carrier and makes adhesion more difficult.

7. SEALANT PACKAGING:

Two-part polysulfide sealants can be purchased from suppliers in a variety of package sizes. The sizes are: 1/2 pt (0.24 L), pint (0.47 L), quart (0.9 L), gallon (3.8 L), and 5-gal (19 L) can kits, as well as in 50-gal (189 L) drum kits. Can kits (up to the gallon sizes) include three-fourths of the total quantity of base compound; this is to allow room for addition of the catalyst and mixing within the base compound container.

Sealant is also available in two component plastic injection kits with the 2-1/2 fl oz (74 mL) and 6 fl oz (177 mL) sizes being the most popular. Where large quantities will be used, 50-gal (189 L) drums of base materials with its accompanying 5 gal (19 L) pail of catalyst are purchased and later repackaged by machine mixing and freezing in 2-1/2, 6, and 12 fl oz (74, 177, and 355 ml) polyethylene cartridges for later thawing and use in sealant guns.

It is convenient to use two-component plastic injection kits for both production plant and field repairs. These two-component plastic injection kits meet the engineering requirements of MIL-C-38714. The base material is contained in the cartridge, and the catalyst in a hollow dasher rod that extends into the cartridge. The rod serves as a shaft for a dasher (agitator blade) for mixing the base and catalyst once they are combined. The catalyst is forced out of the dasher rod and into the base material through the use of a ram rod. After mixing is complete, the dasher rod is removed, and the nozzle is installed on the end of the cartridge. The cartridge is then placed in a pneumatic or manual sealant gun for use by the sealer. These kits have the following advantages:

a. They eliminate mix/freezing cartridges of sealant and storing frozen tubes;
b. They eliminate the need for weighing out sealant base and catalyst in the proper ratio from a larger quantity in a two-part kit.

Sealants can also be purchased from the sealant manufacturer in pre-mixed and quick-frozen form with the material packaged in 2-1/2 fl oz (74 mL) and 6 fl oz (177 mL) polyethylene cartridges. Purchasing sealant in this form is a cost-saving convenience for end-users who have no facilities or equipment for meter mixing and freezing of the sealant. Responsibility for supplying a properly mixed and frozen product is also shifted to the sealant supplier when the material is purchased directly from the supplier in pre-mixed and quick-frozen form. For certain polysulfide-based aircraft sealants, Classes A-½ and B-½ are available in premixed and frozen form; however, these faster curing classes of sealing compound are not available for polythioether-based products.

8. STORAGE OF SEALANT BEFORE USE:

8.1 Uncured Two Part Sealant Kits:

Uncured sealants are chemically reactive and perishable systems. Both the sealant manufacturer and the user share a responsibility for protecting the fuel tank sealant's shelf life. The manufacturer will formulate a chemically compatible and stable system; then the manufacturer packages it in sealed containers under an inert atmosphere to maximize the material's shelf life. The user must recognize the activating effect of temperature and relative humidity on aircraft sealants. Appropriate temperature and humidity controls should be implemented during storage to ensure that the rated shelf life is not reduced. The user must also appreciate the fact that when containers are opened (cans, foil bags, drums), the inert atmosphere is lost. If only partial use of the material is made, the inert atmosphere (dry nitrogen purge or carbon dioxide) should be restored.

The shelf life quoted on labels of most sealant suppliers are based on a recommended storage temperature of no more than 80 °F (27 °C). Many user storage facilities have no air conditioning. Temperatures can reach 130 to 150 °F (54 to 66 °C) in the summer months. As a result of these high storage temperatures, both base and catalyst will increase in viscosity; this can result in skinning on the surface of the base compound, and the resultant changes will cause rejection upon inspection.

Users may significantly extend the useful life of unmixed sealant by storage at 60 °F (16 °C) rather than 80 °F (27 °C). A broad rule of thumb with chemically reactive systems states that an 18 °F (10 °C) reduction in temperature reduces reaction rates by 50%. It is obvious then that the lower the storage temperature, the less change will occur in the unmixed kits in storage. Storage of unmixed kits at 32 °F (0 °C) or below should be done only in accordance with instructions from the sealant manufacturer.

8.2 Storage of Mixed and Frozen Tubes:

The reactivity of mixed and frozen polysulfide sealant can be essentially suspended by storage at -40 °F (-40 °C) or below. Such is not the case for mixed and frozen polyurethanes, which will begin to show significant loss of work life after 30 days at -40 °F (-40 °C). While polyurethanes are not currently available as fuel tank sealants, it is important to note this difference between polysulfide and polyurethane sealants.

Industry data has indicated that Class B polysulfide sealants (2 h of application time, or worklife) can be stored approximately 10 days at -10 °F (-23 °C), maintaining an acceptable work life. Class A (2 h work life) polysulfide sealants can be stored no longer than 48 h at 0 °F (-18 °C). Unfortunately, there is no data substantiating effects of intermediate subzero storage temperatures upon the slow loss of worklife of frozen sealant. Storage of polysulfide-based fuel tank sealants at -40 °F (-40 °C) has been proven safe with respect to ensuring sealant application time, or worklife; storage life of premixed and quick-frozen polysulfide-based sealants can be extended slightly -- i.e., not greater than approximately 3 days -- by maintaining the freezer temperature at -60 °F (-51 °C).

8.2 (Continued):

Premixing and freezing of polythioether-based sealants, which are available only in Semkit form, is not recommended; however if polythioether-based products are premixed and frozen, they shall be stored at -80 °F (-62 °C).

Frequent opening of the freezer or coldroom door will adversely affect the inside temperature. It should be noted that setting racks of frozen cartridges outside the box or room to rearrange inventories will also cause sealant cartridges to increase in temperature and lose work life.

Awareness and good practice will protect the sealant's shelf life. Most users of frozen cartridges have established shelf life limits for frozen cartridges; many use 30 days as the limit. Rather than scrap the cartridges at the end of the period, it is practical and worthwhile to conduct a worklife test (or retest) to determine acceptability. Based on retest results, the user determines if shelf life should be extended. Generally, when supported by satisfactory retest data, sealant shelf life extensions enhance continuity of manufacturing operations and contribute to reduction of hazardous waste.

8.3 Storage of Elastomeric One Part Fluorosilicones (Fuel Resistant):

Significant quantities of Dow-Corning Q4-2817, a one-part, fuel-resistant, moisture-curing fluorosilicone, integral fuel tank sealant have been used on certain military aircraft. Its shelf life is 1 year from date of manufacture; no storage conditions (temperature and relative humidity) are specified for this product. General Electric produces a similar material, FRV1106; and its shelf life is six months when stored at temperatures that do not exceed 110 °F (43 °C). Dow-Corning 5-8733 is a relatively new one-part fluorosilicone that cures by condensation and by a reaction with moisture. Dow-Corning 5-8733 has been applied recently on a military fighter aircraft for bonding a premolded fluorosilicone gasket into a titanium groove machined into the entryway structure of one of this air vehicle's fuel tanks.

8.4 Storage of Channel Sealants:

Both the noncuring high viscosity fluorosilicones and the noncuring polysulfide channel sealants are stored at ambient temperature and have the manufacturer's recommended shelf lives indicated in Table 6. The channel sealants referred to in this group are:

TABLE 6

Material	Spec	Manufacturer	Product #	Comment
Polysulfide (noncuring)	None	Courtaulds Aerospace, Inc.	PR-705 and PR-706	PR-705 and PR-706 contain both silica and plastic beads
Fluorosilicones	None	Dow-Corning	94-031[1]	Contains plastic beads
	MIL-S-85334	General Electric	G-651	Contains plastic beads
	MIL-S-85334	Dow Corning	Q4-2805[1]	Contains plastic beads
	AMS 3376A	(No Qualified Products List)		

[1]Shelf life is 36 months (or 3 years) from date of shipment.

9. SEALANT MIXING:

Each individual batch of a two-part polysulfide integral fuel tank sealant has a custom matched catalyst system to produce the properties required by the applicable material specification. A particular batch of base must be used only with its matched batch of catalyst if the expected properties are to be realized. Catalyst of different batches of the same product shall not be interchanged.

Thoroughly mix the base and catalyst to produce the engineering material properties required for the cured fuel tank sealant. Effective blending of fuel tank sealants is important factor in producing a uniform mixture without entrapping air in the sealants.

Class A sealants have the lowest viscosity (approximately 250 poises), and they can be applied by brushing, injecting, and spraying. Class C products are medium-viscosity sealants (approximately 3,000 poises) that are rollable. Class B extrudable materials have a relatively high viscosity (approximately 12,000 poises), and they are thixotropic. In all cases, no swirling motion should be produced through stirring (to aid in mixing), in order to prevent air entrapment. All of the base (Part B) and catalyst, or accelerator, (Part A) must be moved physically by the stirrer. The container walls should be scraped frequently during mixing to blend the two parts together.

9.1 Hand Mixing:

Small two-part can kits (up to and including gallon sizes) provide enough space above the base compound in the container to permit all of the catalyst (or accelerator) to be transferred into the base container for blending. A sufficient amount of catalyst -- including some excess catalyst -- is included to accommodate normal transfer losses and still produce the correct ratio of base to catalyst in the mixed sealant.

It is recommended that the full kit be catalyzed to ensure that the proper mix ratio is obtained, rather than using small portions of a kit, weighing out partial amounts, and encountering the dangers of incorrect weighing.

It also precludes other sources of error, such as removal of nonuniform amounts of catalyst from the catalyst's container by failing to stir before removal. There is added danger of not purging the remainder with an inert gas, nor sealing the lid tightly.

Transfer of catalyst can be more readily accomplished by inverting the closed can and cutting out the bottom with a can opener. This produces a continuous opening -- which allows the material to flow, lengthwise, through the can. The latter procedure also eliminates the need to manually transfer catalyst that tends to accumulate around the rim of the can when the can is positioned right-side up with the bottom of the can left intact.

Hand mix the base and catalyst thoroughly for 5 min with frequent scrape down of the walls. Fold the material over itself. Don't whip it, incorporating air. If the warehouse storage temperature is greatly different from standard temperature -- i.e., 77 °F (25 °C) -- bring kits into this standard temperature range well in advance of mixing to assure that application time and extrusion rates will be in the range expected.

Hand mixing does not necessarily mean that all mixing is achieved by hand with a spatula. It also refers to mixing with hand held or mounted lighting mixers or similar motor driven agitators. In all cases the movement of the mixer blade throughout the material and frequent scrape down will aid immeasurably in producing a uniform mix.

WARNING: Extremely fast stirring can cause vortexing, resulting in the incorporation of air; it can also heat up the sealant, which will change its viscosity and shorten its work life.

Hand mixing of small quantities of two part sealant in two-component polyethylene plastic injection kits is described in 11.1.3.1.

9.2 Machine Mixing:

This type of mixing refers to small batch mixing on a special piece of equipment called a Dasher Mixer. It also refers to continuous mixing on a meter/mixer machine.

9.2.1 Dasher Mixer/Filler Batch: Small batches of material 1 qt (0.9 L); 5 qt (4.7 L) are sometimes mixed in a Dasher Mixer (SEMCO Models #1350 and 1378); see Figure 2.

There are no other similar or equivalent products on the market. An air cylinder forces the dasher agitator to make full strokes up and down (top to bottom) through the material, mixing it thoroughly without incorporating air. The top of the mixer is in contact with the surface of the sealant. A counter registers the dasher cycles, ensuring uniformity of each cycle from batch to batch. A machine adjustment converts the agitator to a pressure disc forcing the material out through a port into polyethylene cartridges for quick-freezing or for immediate use.

9.2.2 Meter Mix Machines (Continuous Mixing): Two-part sealant is mixed with a meter/mix machine when large quantities of mixed sealant are required. Cartridges are filled and immediately quick frozen to -40 °F (-40 °C) or below for storage until use. A diagram of a typical 5-gal (19 L) catalyst pump and a 50 gal (189 L) base compound pump with proportioning and mixing equipment mounted on its stand is shown in Figures 3 and 4. Generally, a 50 gal (189 L) drum of base material is positioned on a sealant pump. A follower plate is positioned in the drum on the surface of the sealant.

The follower plate stays in contact with the surface as the positive action of the pump moves the material through hoses to the metering system and to the mix head and delivery valves. The catalyst, in a 5 gal (19 L) pail, is fitted with a 5 gal (19 L) pump that operates in similar fashion. The separate streams of catalyst and base exit the metering system in the proper ratio and are fed into either a static or dynamic mix head, where a uniform mixture is produced (see Figure 5).

Sealant exits the mix head and passes through a valve into a 2-1/2, 6, or 12 fl oz (74, 177, and 355 mL) polyethylene cartridge, which after filling, is immediately submerged into a cold bath [methanol and dry ice (CO_2) at -100 °F (-73 °C) or liquid nitrogen at -320 °F (-196 °C)], where the temperature of the cartridge should be reduced to -40 °F (-40 °C) or below before moving it to a -40 °F (-40 °C) storage box.

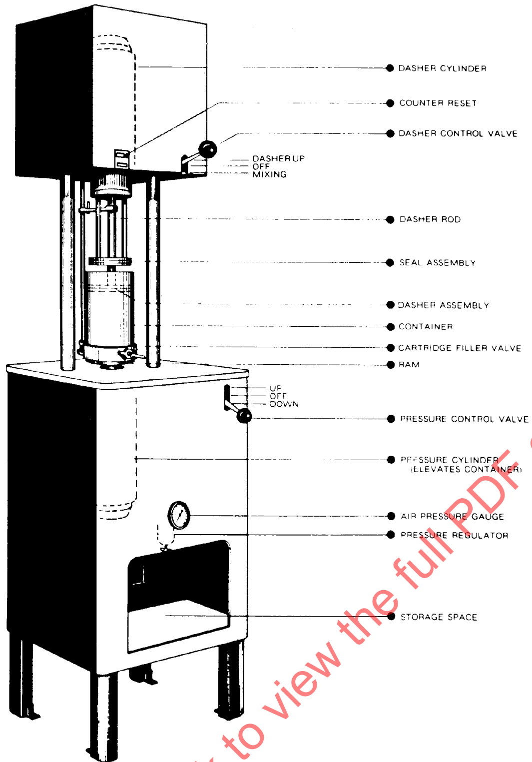


FIGURE 2 - Dasher Mixer

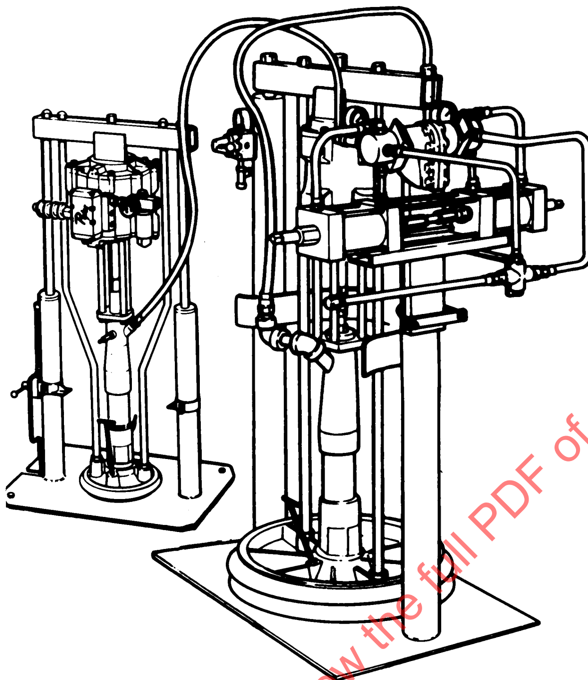


FIGURE 3 - Diagram of 5 gal (19 L) Catalyst Pump, 50 gal (189 L) Base Pump, Proportioning Device, and Mix Head

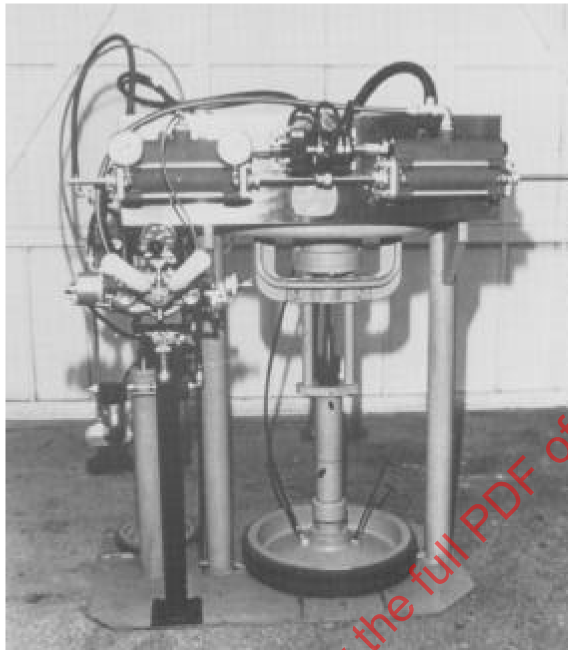


FIGURE 4 - Photo of 5 gal (19 L) and 50 gal (189 L) Pumps, Proportioning Device, Mix Head, and Fill Valves

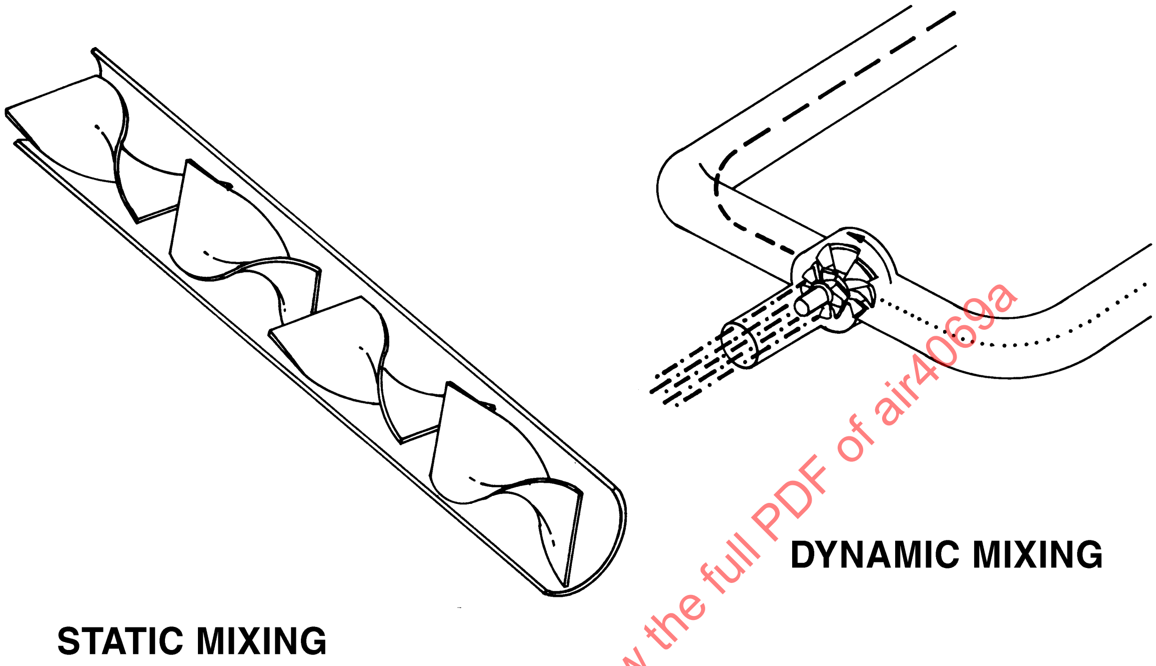


FIGURE 5 - Static and Dynamic Mix Heads

9.2.2.1 Dynamic Mix Heads: Separate streams of base and catalyst are fed into a dynamic mix head where a low speed impeller (approximately 300 rpm) provides good shearing action, mixing the two materials as they pass through the 1 to 2 in (25 to 51 mm) long x 2-1/2 in (63.5 mm) diameter chamber. The opening and closing action of the fill valve, which is downstream of the mix head, controls the entire meter/mix system including supply pumps, pressures, material flow, and mix rpm. This single valve action provides uniform operation of all the systems and a positive shut off with the absence of back pressure. Positive shut off valves, positioned at the mixing head inlets, prevent compounds from entering the mixing chamber unless the fill nozzle valve is activated. The mix head is double walled and may be cooled by refrigerated water.

Dynamic mix heads are far more expensive than static mix heads; and they are more complicated with drive motors, impellers, heat exchangers, and refrigeration systems. The residence time in the small mixing chamber is only a matter of seconds. The sealant is not heated appreciably if refrigerant is continuously passed through the heat exchanger in the mix head. Build-up of sealant on the impeller is very slow, so downtime for cleaning is infrequent. It is generally cleaned only by circulation of solvent through the head -- not by disassembly. The drive motor for the dynamic mix head is powered by plant air [20 cfm (566 L/m) at 90 psi (620 kPa)]. The meter/mix system (pumps, metering system, and mix head) are all pneumatically driven and, therefore, can be used in areas where explosion-proof equipment is required.

Following are several important points concerning the use of meter/mix equipment:

9.2.2.1 (Continued):

a. Stir the 5 gal (19 L) pail of catalyst thoroughly with a mechanical agitator.
b. Do cause air entrapment within the catalyst -- i.e., do not raise the mixing blade too close to the surface, and do not form a vortex by stirring too rapidly.
c. Scrape down the walls frequently.
d. If the catalyst sits for 48 h after stirring, stir it again.
e. Either start with clean hoses for base and catalyst and with an empty meter/mix machine or purge the lines and meter/mix equipment with at least 2 gal (7.6 L) of base and equivalent catalyst.
f. Purge air from the equipment and hoses, otherwise a large number of sealant cartridges will contain air in the mixed sealant. Bleeder valves are available in appropriate locations.
g. Calibrate a variable ratio machine initially, and frequently thereafter. Check a fixed ratio machine frequently -- i.e., at beginning of each shift and with change of containers.
h. Collect button samples from each cartridge. Number the cartridges and corresponding buttons. This will reveal unexpected or undetected changes in ratio by differences in cure rate of the buttons. It is also an indicator of the uniformity of mixing (observation of streaks or homogeneous color) and whether there is excessive air entrapment.
i. If manufacturing operations are to be shut down temporarily, the mix head can be removed, sealed, and frozen. The base and catalyst lines should be sealed.
j. If a static mix head is used, clean it if the flow rate decreases substantially.
k. Air pressure to meter mix equipment should be sufficient in volume as well as pressure. 60 cfm (1700 L/min) at 90 psi (621 kPa) is standard.

An automated mixer for mixing a small amount of sealant in a two component polyethylene plastic injection kit is discussed in 11.1.3.1.

9.2.2.2 Static Mix Heads: A static mix head is a tube containing an internal metal ribbon, or containing a series of cylindrical elements with drilled holes, that cause catalyst and base to achieve a thorough and uniform mix. There are no moving parts. The tube can be 2 to 4 ft (610 to 1219 mm) long and 2 to 8 in (51 to 203 mm) in diameter depending upon the degree of mixing required and the rate of throughput required.

Static mix heads are available from several manufacturers and in several basically different designs. The appropriate diameter and length must be selected in relation to the viscosities of the materials involved, the ease with which they combine, and the flow rates desired.

A major consideration in the selection of a static mix head is its ease of disassembly and cleaning. Partially cured sealant tends to build up on internal elements due to the frictional heat developed through forcing material through the unit. A design containing a permanently installed metallic ribbon can be difficult to clean. Circulating solvent through the unit is a time-consuming process. In some cases, it is necessary to heat the mix head to facilitate removal of residual sealant. Mix heads containing a series of removable plastic or metallic cylindrical elements is easier to clean but often the elements must be forced out of the tube with a mechanical press. The elements once removed are soaked in solvent and cleaned with brushes.

10. FREEZING AND THAWING OF MIXED CARTRIDGES:

10.1 Freezing:

Once the-base compound and catalyst are mixed (see Figure 6), the fuel tank sealant's application time (worklife) will rapidly decrease unless the temperature of the 2-1/2, 6, or 12 fl oz (74, 177, or 354 ml) cartridge of mixed sealant is quickly reduced to -40 °F (-40 °C) or below. The preferred practice is to position the mixing/filling equipment immediately adjacent to a bath of methanol/dry ice at approximately -100 °F (-73 °C) or liquid nitrogen at -320 °F (-196 °C). Metal baskets containing 30 to 48 open compartments are submerged in the coolant to receive the cartridges immediately after filling (see Figure 7). The cartridges are capped on the nozzle end and placed in the basket with nozzle end facing down. The plunger end, including the top 1-1/2 to 2 in (38 to 51 mm) of the cartridge, remain above the surface of the liquid.

Another technique is to place the cartridges in the freezer bath in thin-walled aluminum sleeves that are closed at the bottom, thus, eliminating any possibility of contamination from the coolant. After 10 min, the basket of cartridges can be removed from the bath and transferred to a cold box or cold room for storage at -40 °F (-40 °C) or below. At this temperature there is essentially no loss of application time. Cartridges have been held as long as 6 months at -40 °F (-40 °C) without noticeable loss of application time.

Another approved but seldomly-used method of quick freezing is to place the freshly-filled cartridge into a liquid nitrogen chamber for 1 to 2 min to reduce the temperature to -40 °F (-40 °C) or below.

10.2 Thawing:

Frozen cartridges of mixed sealant are thawed by three approved methods. These methods are discussed in the following paragraphs.

10.2.1 Ambient Air: Frozen cartridges are laid on a bench or table top and allowed to warm at room temperature. The rate of warm-up is variable depending upon the temperature of the cartridge, the temperature of the ambient air, the closeness of one cartridge to another, and whether they are standing vertically or lying horizontally. Ambient thaw usually takes about 30 min. The core of the cartridge should reach 60 °F (16 °C) before sealant application is started.

10.2.2 Enclosed or Open Water Bath: Two approaches are used with hot water baths:

a. An enclosed metal water bath with metal sleeves welded in place top and bottom provides a dry cylinder into which the cartridges fit snugly. Heat transfer from the water through the metal sleeve and polyethylene cartridge is good. With the water bath at 120 °F (49 °C), thawing takes about 4 min.
b. Frozen cartridges are placed directly into heated or unheated water. The cartridges are closed with caps on both ends. As the cartridge warms, the material inside expands slightly, and water is not drawn into the container. Thus, the approach is acceptable.

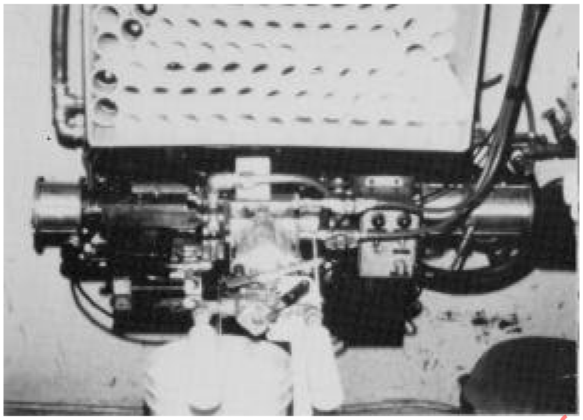


FIGURE 6 - Meter/Mixing and Dispensing Equipment

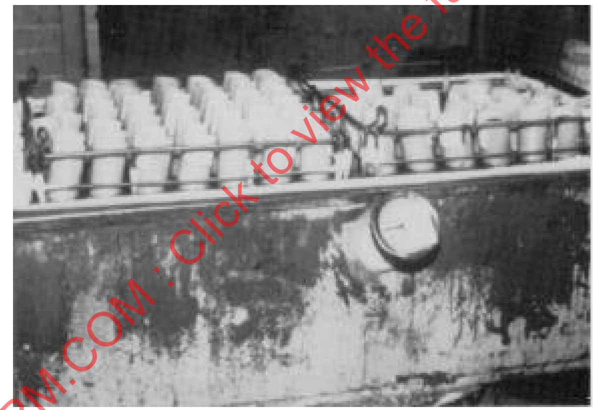


FIGURE 7 - Quick Freezing of Cartridges of Sealant in a Cold Bath

10.2.3 Microwaves: A microwave oven may be used for sealant thawing, provided that the same microwave oven is not used for thawing of other items, especially food. Microwaves can produce hot spots in the sealant. If a microwave oven is used, the power level should be on the order of 650 W; there should be an interrupted defrost cycle (i.e., 20 s of heat, 20 s of soak). A 6-fl oz (177 mL) cartridge can be thawed in approximately 2 min. This method is fairly reproducible if the same number and size of cartridges are used each time. It is most important that the carousel feature be used to produce uniform radiation and to mitigate the occurrence of hot spots.

In summary, there are several acceptable methods for thawing frozen cartridges. Hot spots can be produced by microwaves; they can also be produced by electrical cartridge heating jackets (not mentioned previously) that can produce very high skin temperatures and cause partial cure of the outer layer of material as heat is penetrates into the core. Heat guns should not be used.

11. SEALANT APPLICATION:

Aircraft designs produce a variety of configurations of integral fuel tanks and a variety of subassemblies, attachments, and fit ups associated with each design. In all cases, two-part, curing-type sealants (mostly polysulfide-based) are utilized in several of four general forms: sprayable, brushable, extrudable, and rollable.

This document cannot specifically address each of the many individual designs. However, this report recommends preferred practices in the application of sprayable, 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.

This section on two-part sealant application will, therefore, address first the techniques for applying various forms of sealant; then it discusses several specific configurations where additional comment is appropriate. It also mentions specific methods of protecting applied sealant in its early, tacky state of cure. The application of groove/channel sealant (noncuring type) will be discussed, focusing on key factors necessary for proper application.

11.1 Two-part Curing-Type Sealant:

Sealant is applied in accordance with the following purposes:

a. To achieve a good adhesive bond with the substrate, and
b. To produce a long-term seal through proper thickness and contour.

The following are required to achieve a good bond:

a. A clean surface;
b. Sealant with the proper adhesion characteristics for that surface (or use of an appropriate adhesion promoter); and
c. Application of the sealant during its worklife, when it is still capable of wetting the surface.

It is appropriate to reiterate that the use of adhesion promoters for polysulfide sealants during the initial production as well as in later repair is highly recommended. Experience has shown that even though acceptance tests are conducted on every batch of sealant and on a variety of coated panels, the production surface can be different and the production cleaning may not be as thorough or complete as that produced under laboratory conditions.

Engineering testing and evaluation of adhesion promoters have proven that whether the surface is old or new, clean or partially dirty, and whether it consists of acrylic, polyurethane or treated aluminum, a good bond is produced through its use with polysulfide fuel tank sealants. A discussion of adhesion promoters is given in 5.3.

11.1 (Continued):

The adhesion promoter may be applied by aerosol spray, brush, or by wiping it on with a clean cloth saturated with the materials. It is preferred that a thin coat be applied without a subsequent wipe-off of excess adhesion promoter. The adhesion promoter is slightly colored, permitting visual examination to ensure that the entire surface has been coated.

The applied adhesion promoter should be allowed to stand for at least 30 min (especially when humidity is low) to permit activation of the promoter and evaporation of the solvent; then the fuel tank sealant can be applied. If sealant is not applied to the adhesion promoted surface within 3 h, the surface should be recleaned and the adhesion promoter reapplied.

Adhesion promoters are available in both chlorinated and nonchlorinated solvents. Local company policies dictate which can be used. Adhesion promoters with chlorinated solvents should never be used on titanium or titanium alloy surfaces.

Whenever sealant application is delayed, the cleaned and adhesion promoted bond surfaces must be protected from contamination -- which includes, but is not limited to, shop machining fluids, fingerprints, dust, and other particulate matter.

11.1.1 Sprayable Sealants: Two-part sprayable polysulfides are used by some aircraft manufacturers for corrosion control on exterior fuel tank structure. Pint, quart, and gallon (0.47 L, 0.95 L, and 3.8 L) sizes can be mixed by transferring all the catalyst for the kit into the base compound container, replacing the lid on the base compound container and shaking it on a standard gallon (3.8 L) capacity paint shaker at 1,350 vibrations per minute in the upright position for 3 min followed by another 3 min in the inverted position. Larger quantities such as 5 gal (19 L) are generally mixed in 10 gal (38 L) pressure pots using an air driven agitator.

When a paint shaker is not available for the 1 gal (3.8 L) and smaller can kits, they can be mixed mechanically with a Jiffy mixer (air motor, Jiffy blade, T-blade, or flat blade). Limit the speed to 80 rpm to avoid whipping air entrapment in the mixed sealant and to avoid temperature rise from frictional heat. Scrape down the sides frequently during mixing.

Thinning the material -- i.e., reducing the sealant's viscosity with toluene or with another solvent or solvent mixture -- should not be done, unless thinning is specified in processing instructions from the sealant manufacturer.

The following types are examples of spray equipment that perform satisfactorily:

1. DeVilbiss gun MBC-510 with nozzle combination 704-E Fluid tip 0.070 in (1.8 mm) i.d., AV-601 Air cap AV-1239 #704 Fluid needle MBC-444-E.
2. Binks Model 18 spray gun 62B tip, 01046 orifice 83A needle 63PB air cap, 3/8 in (9.5 mm) fluid lines.
3. Graco airless spray gun, Model No. 220-959, 0.013 in diameter orifice, 2 to 3 in fan.

11.1.1 (Continued):

A line pressure of 45 psi (310 kPa) and a pot pressure of 5 psi (34.5 kPa) is recommended. Sprayable sealants are generally applied to a wet-film thickness of 0.003 to 0.007 in (3 to 7 mils; 0.08 to 0.18 mm) and to a dry-film thickness of approximately 0.0015 to 0.025 in (1.5 to 2.5 mils; 0.038 to 0.06 mm).

Sprayable sealant is usually of the polysulfide-based, corrosion-inhibitive (chromate) type, used for overcoating slots and depressions and for gapfilling. It is important to note that sprayable polysulfide sealants generally are not used within integral fuel tanks.

Polythioether-based sprayable sealant also is available for production and repair sealing of aircraft integral fuel tanks. Engineering material property requirements for qualification and acceptance of sprayable polythioether-based sealant are provided by AMS 3279.

One such sprayable polythioether-based sealant is PR-2911, which has been used for fuel containment on an aging fleet of DC-8 commercial aircraft. The sprayable polythioether material was applied in high-risk areas as a back-up seal -- directly over the Class-B-over-Class-A polysulfide-based sealing system. No leaks have been reported since this implementing this sealing design on the fleet of DC-8 commercial aircraft.

11.1.2 Brushable Sealant Application: Class A brushable sealants are applied as brushcoat seals on fasteners, and in locations where a flowable material is needed. The first coat is worked in and around all leak source areas with a short and stiff brush. The second brush coat is applied after the first coat is tack-free. Overcoats on fasteners are built up to a thickness of 0.030 to 0.060 in (30 to 60 mils; 0.76 to 1.52 mm), depending upon the location of the fasteners.

Brushable sealant is used around crevices, holes, seams, fasteners, and, in some cases, as a precoat on seams and surfaces to be covered later with the thicker Class B extruded fillet of sealant.

It is important that, during application, brushable sealant be applied thoroughly into crevices and seams; some use a circular motion on the fuel tank structure surface to ensure adequate wetting by the sealant. This prevents voids; and it minimizes the formation of air bubbles.

Figures 8 and 9 illustrate application of the Class A brushcoat sealant over rows of fasteners prior to the application of Class B extrudable material.

Class B fuel tank sealant should be applied only within its application time (worklife) to ensure good wetting of the surface. It is not acceptable to have air bubbles in the Class B fuel tank sealant. The width of the brushcoat should exceed the width of the fillet to be applied by at least 0.10 in (100 mils; 2.5 mm) on each side. Thinning of brushable sealant should not be attempted unless the sealant supplier provides specific instructions regarding the type and grade of solvent to be used and the allowable amount of solvent to add. An adhesion promoter (or adhesive primer) should be applied to cleaned fuel tank structure surfaces before sealant is applied, whether initial production or repair is being accomplished. A brushcoat is considered to be a primary seal only when applied in more than one layer, such as in overcoating of fasteners with a double brushcoat.

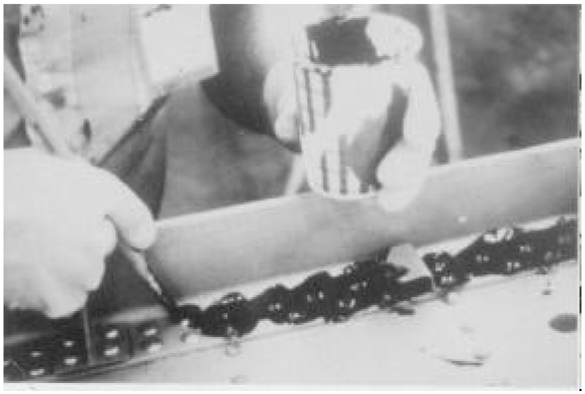


FIGURE 8 - Application of Brushable Sealant

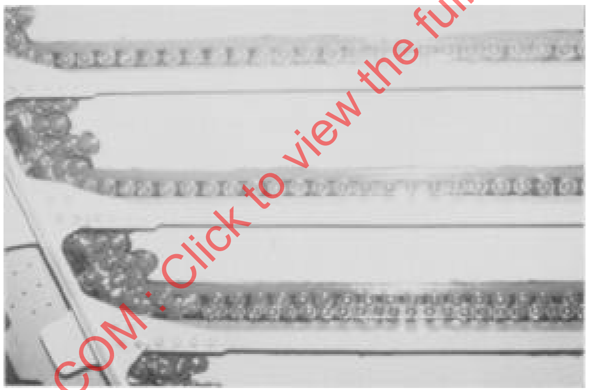


FIGURE 9 - Brushable Sealant
Applied as shown in Figure 8

11.1.3 Extrudable Sealant Application:

11.1.3.1 General: Extrudable Class B materials are used for the following types of sealing:

a. filleting over joints, splices, seams, and shims;
b. injecting slots and joggles;
c. filling corner close-out cups;
d. overcoating and crowning fastener heads, bolts, and rivets;
e. hole filling;
f. faying surface sealing applications; and
g. aerodynamic smoothing and gap filling.

11.1.3.1 (Continued):

Class B fuel tank sealants are known for their low slump (thixotropic or low blockflow) characteristics. The latter engineering properties directly contribute to the extrudability of these viscous materials.

While Class A and Class B integral fuel tank sealants are resistant to jet fuel, the Class B material, which contains fewer volatile solvents, is used in providing the required sealant dimensions (or thickness) without entrapment of air or solvents.

The mixed sealant is generally applied from a 2-1/2, 6, or 12 fl oz (74, 177, or 355 mL) low-density polyethylene cartridge contained in a sealant gun powered by plant air 80 to 90 psi (552 to 621 kPa). Manual guns are also available. Use of greater pressure may cause a high incidence of plunger flipping (overturning), resulting in air being blown directly through the cartridge. A sealant gun with cartridge and nozzle is shown in Figures 10 and 11.

The handle of the sealant gun is removable. A trigger mechanism, which extends parallel with the barrel, is available for use in restricted areas. More than fifty nozzle shapes and sizes are available from several manufacturers to accommodate most sealing situations. For another view of the gun and nozzle, see Appendix B, Figure B2.

For field repair, and for repairs or sealing where frozen cartridges of mixed sealant are not available, small quantities of sealant [2-1/2 fl oz or 6 fl oz) (74 mL or 177 mL)] can be mixed on site using the two-component polyethylene plastic injection kit illustrated in Figure 12.

The sealant base compound is contained in the cartridge, the catalyst in the hollow stem (dasher rod). A ram rod is used to force the catalyst into the body of the base compound as shown in Figure 13.

An open spoke agitator on the end of the dasher rod is used for mixing the catalyst with the base compound as the dasher rod is pushed and pulled, rotating clockwise slightly each time. Automated equipment is also available to do the mixing (see Figure 14).

The stroking of the dasher rod is accomplished by means of a reversing air cylinder, and rotation of the dasher rod is accomplished by a low speed electric gear motor. The service requirements are compressed air [approximately 90 psi (621 kPa)] and 110 V AC, 60 cycle (or 220 V, 50 cycle). The most effective stroking speed is between 16 and 22 strokes per minute. When the sealant has been mixed to produce a uniform (or homogeneous) compound, the dasher rod is unscrewed from the agitator and removed. The cartridge is fitted with a nozzle and placed in a pneumatic or hand operated sealant gun for application.

Dispensing the fillet from the nozzle (i.e., applying the fillet to a seam or joint) in aerospace work is done in a different manner than caulking in the architectural (commercial building construction) industry. When the architect's method is used -- where a trail of sealant is deposited as the delivery tip of the gun points behind the direction of travel -- air can be trapped under the sealant bead as it is applied to structure.

FIGURE 10 - Sealant Gun

FIGURE 11 - Several Sizes and Shapes of Cartridges and Nozzles

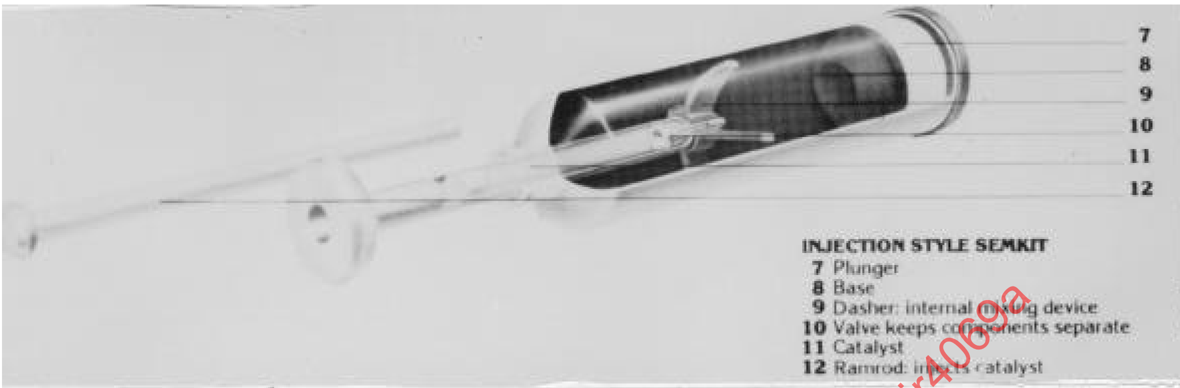


FIGURE 12 - Two-Component Plastic Injection Kit

FIGURE 13 - Catalyzing the Base Compound: Two-Component Plastic Injection Kit

FIGURE 14 - Automated Mixer for the Two-Component Injection Kit

11.1.3.1 (Continued):

If a large fillet bead is specified, it is not necessary to apply an undersized fillet, followed by application of another fillet over the undersized fillet. While this technique is practiced by some, it introduces an unnecessary step and creates yet another interface where a new bond line must be established. It is preferred that a larger nozzle orifice be used initially and that only one fillet be applied, then tooled (or faired) to dimensions required by engineering.

The preferred technique is to hold the gun approximately 30° off-perpendicular, and point the nozzle in the direction of travel as the fillet is extruded into the joint or seam. This forces sealant into the crevice and minimizes the possibility of air entrapment. Some hold the gun nearly perpendicular to the work. Do not apply sealant with the tip pointing opposite the direction of travel.

After the bead of sealant is applied, the sealant is tooled as shown in Figures 15 and 16. This produces a faired configuration that eliminates the possibility of reentrant edges and trapped air and ensures satisfactory contact with the fuel tank structure surface.

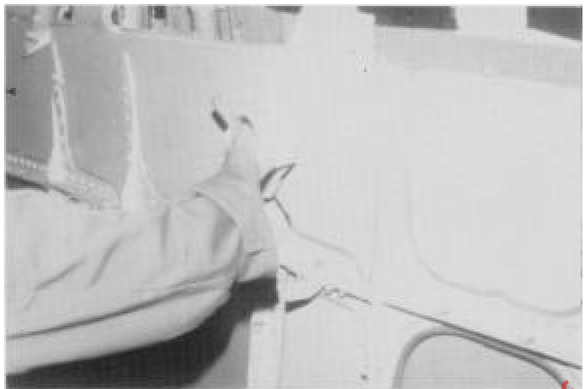


FIGURE 15 - Tooling (or Fairing) a Fillet

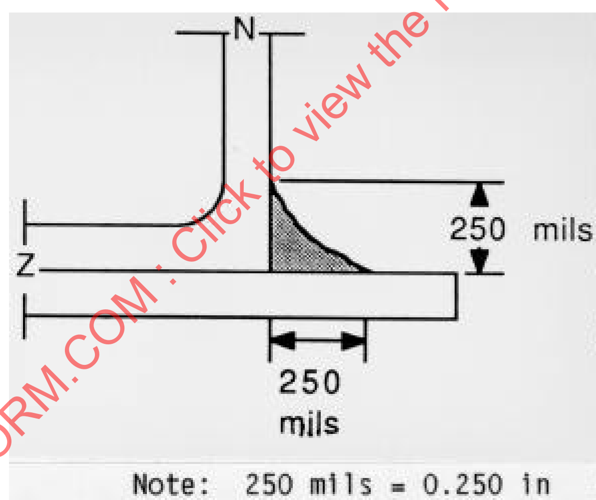


FIGURE 16 - Fillet Contour

11.1.3.1 (Continued):

The principal goal in applying the appropriate thickness and contour of sealant at any potential leak source is to use a thickness, relative to sealant elongation, that will allow joint movement under operational conditions without tearing the sealant. For example, if a sealant with an elongation of 100% were used to seal a joint, and the thickness of the sealant at the joint were only 0.001 in (1 mil; 0.025 mm), the maximum allowable movement at that interface would be only 0.001 in after which sealant failure would occur. A thickness of 0.003 in (3 mils; 0.08 mm) on the other hand, with the same 100% elongation, would permit 3 times that amount -- i.e., 0.003 in -- of joint movement without failure.

There are numerous joint and gap configurations and a preferred sealant configuration for each. The major types are illustrated in Figures 17 and 18.

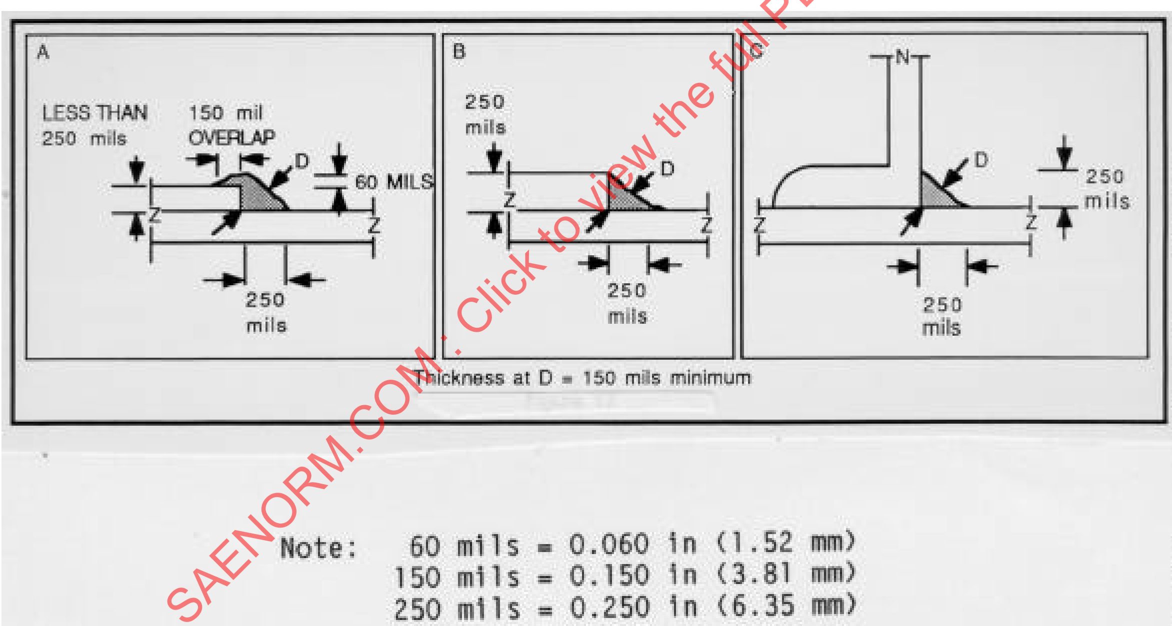


FIGURE 17 - Sealing Offsets and Joints

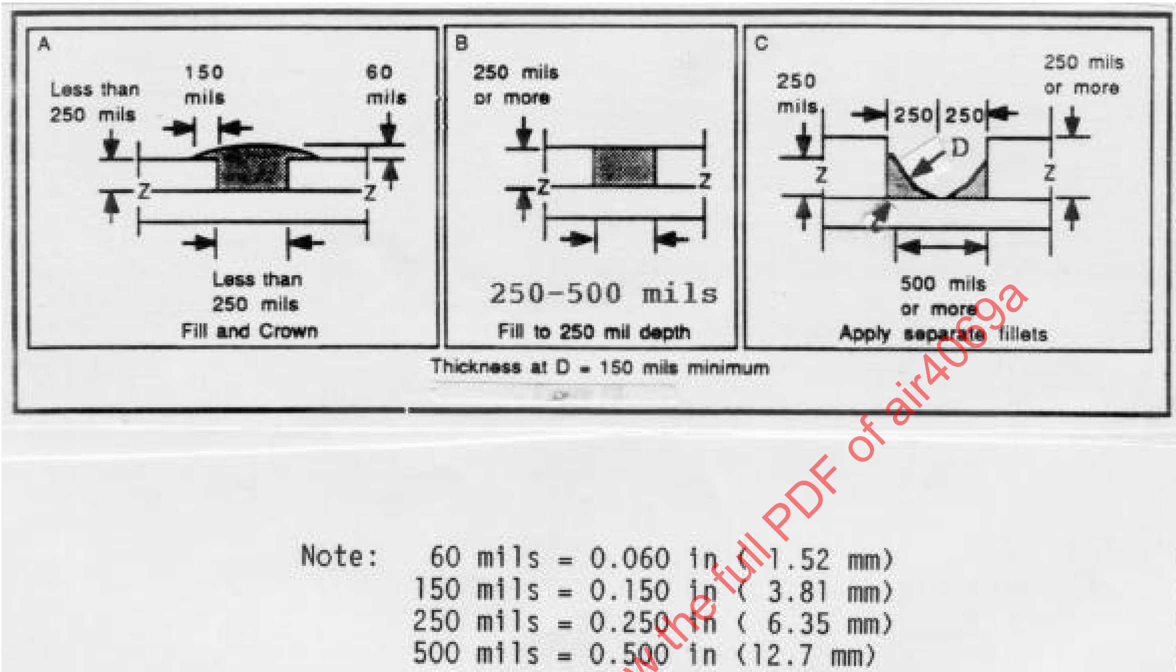


FIGURE 18 - Sealing Butt Gaps

11.1.3.2 Offsets and Joints: The application of fillets to offsets and joints is illustrated in Figure 17.

11.1.3.3 Butt Gaps: Butt gaps vary in width and height. The preferred method for sealing them is shown in Figure 18.

Preferred sealant configurations vary company to company and with various government documents. The dimensions given in Figures 17 and 18 present a safe average.

Two major factors govern sealant contour:

a. Sealant should extend at least 0.250 in (6.35 mm) from the potential leak source;
b. The diagonal thickness (also called the throat) from the leak source should be at least 0.150 in (3.81 mm).

If the thickness of a plate or offset is less than 0.250 in (6.35 mm), it should be crowned.

Extreme care must be taken to ensure that butt gaps are filled and not bridged. When a butt gap is wider than 0.500 in (500 mils; 12.7 mm), two separate fillets can be laid, each extending from its potential leak path by 0.250 in (250 mils; 6.35 mm).

11.1.3.4 Holes and Slots: Holes and slots in the integral fuel tank may be sealed with Class B extrudable sealant alone if the opening is less than 0.125 in (125 mils; 3.18 mm). Larger openings to 0.250 in (250 mils; 6.35 mm) may be accommodated if the slot is sufficient to give adequate surface area for adhesion. The Class B fuel tank sealant should protrude through the hole and be tooled on both sides to dimensions shown in Figure 19.

If the opening is between 0.125 in (125 mils; 3.2 mm) and 0.500 in (500 mils; 12.7 mm), it can be sealed with a combination of sealant plug and sealant (see Figure 20), or a combination of annealed aluminum wire screen and sealant.

Metal clips or plastic blocks can be used to reduce the hole size before sealing. When a wire screen (or mesh) is used (Figure 21) it must be trimmed to overlap the hole or slot by approximately 0.250 in (250 mils; 6.35 mm).

A thin layer -- i.e., approximately 1/16 in (63 mils; 1.6 mm) -- of sealant is applied around the opening first. The screen is then embedded in the sealant. A tie wire is laced to the screen and put through the hole. The hole is then filled with sealant from the opposite side. A second piece of screen of similar size is similarly positioned in the sealant over the hole on the opposite side. The tie wire is laced to the second screen. The screens are then further impregnated with sealant, and the seal is completed by crowning both sides of the screens and fairing the sealant approximately 0.100 in (100 mils; 2.54 mm) beyond the edge of the screen.

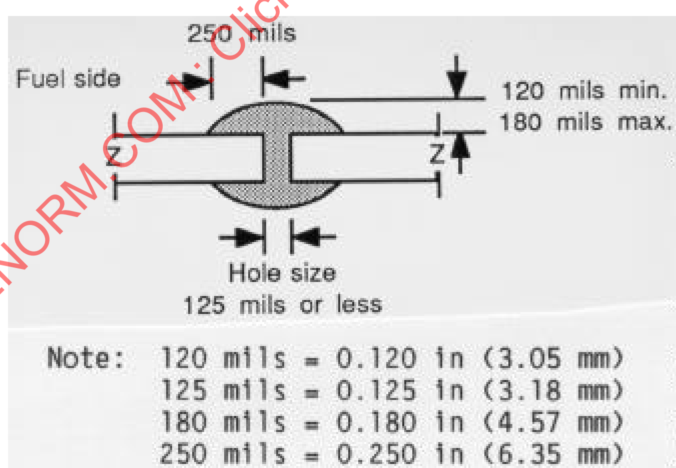


FIGURE 19 - Sealing a Small Hole

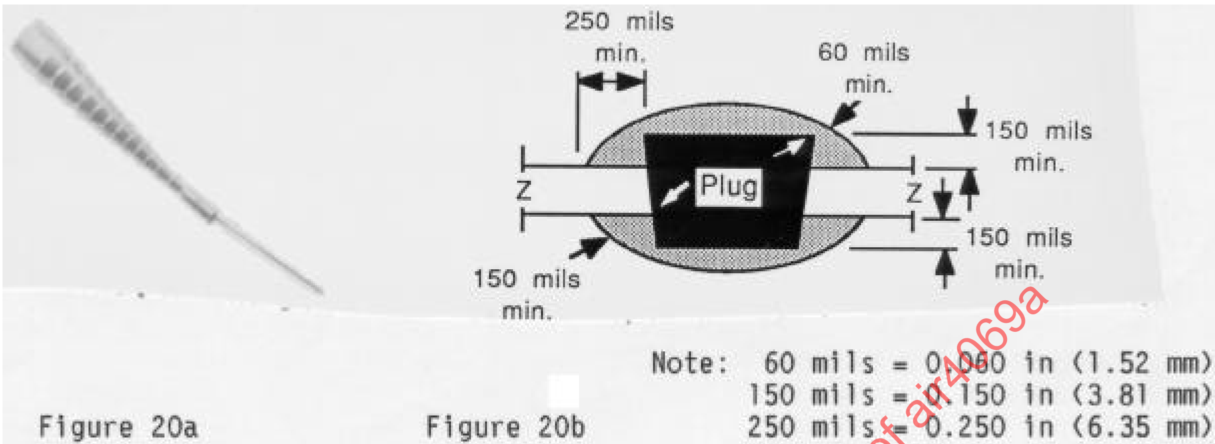


FIGURE 20 - Sealing a Large Hole or Slot with a Plug and Sealant

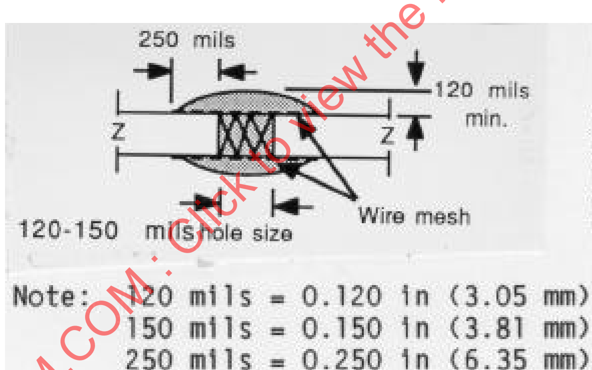


FIGURE 21 - Sealing a Large Hole or Slot with Screen and Sealant

11.1.3.5 Fastener Sealing: All fasteners penetrating the fuel tank boundary (or sealing plane) must be wet installed. Sealant can be extruded onto the fastener or into the hole and on the surface under the head of fastener. An alternate approach is to use a special floating plug nozzle on the sealant gun, injecting sealant into the hole as shown in Figure 22.

Once permanent fasteners and bolts are installed and tightened, they must be overcoated with sealant. An overcoat of sealant can be formed using only Class B sealant, by applying multiple layers of Class A sealant, or from a Class A single brushcoat followed by an overcoat of Class B sealant.

When multiple layers of sealant brushcoats are applied, wait until the surface is tack-free before applying the next layer of material.

Note that multiple layers of Class A can be considered a primary seal. Slug rivets, on the other hand, are considered absolute seals and, therefore, overcoating of these parts is not required.

Fasteners are overcoated by several techniques:

FIGURE 22 - Floating Plug Nozzle

11.1.3.5 (Continued):

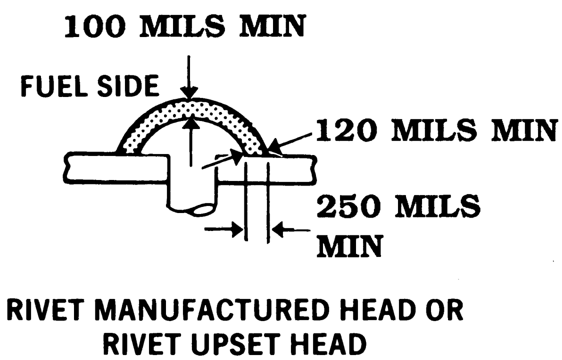
a. Artist's Brush - Starting at the base of the fastener, rotate the brush around the head and adjacent surface until it is coated and surrounded by faired fillet, as shown in Figures 23 and 24.
b. Beehive Technique - Start the application of sealant from the nozzle of the sealant gun at the base of the fastener head. Rotate the nozzle in a spiral motion until the head is completely covered. Tool to the proper configuration.
c. Flared Tube Applicator (Daubing) - The flared tube applicator is a beveled or flared copper or aluminum tube (see Figure 25) that is closed at one end. It is filled with sealant from the sealant gun, pressed over the fastener head to the surface, and slowly rotated as it is withdrawn.
d. Seal Caps - A variety of sizes of premolded seal caps cast from polysulfide sealant, including material that conforms to MIL-S-8802, and aluminum seal caps are available. Caps of the proper size are selected, filled with Class B sealant, and pressed into place -- directly over the fastener head and collar. Excess sealant squeezes out at the base of the cap and is formed into a fillet. The cap is left in place permanently.
e. e.Miscellaneous - All of the techniques mentioned herein are acceptable if care is taken to exclude air bubbles, to avoid air entrapment, to avoid bridging, and to tool -- i.e., to shape or fair --- the configuration to provide the dimensional thickness required by engineering. When fasteners are overcoated or filleted near a vertical obstruction, care must be taken that no bridging of sealant will occur. If the fastener is closer than 0.250 in (250 mils; 6.35 mm) to the vertical structure, apply sealant completely around the fastener. Wait until the sealant becomes tack-free; then fill in the space between the fastener and the vertical structure, and fair the sealant up the side as shown in Figure 26.

Some companies use seal caps only at lower levels where foot traffic during production operations may bump and scuff coated fasteners. Others use seal caps because they are quick and convenient and do not limit their use to special areas.

Nylon caps are not recommended, due to difficulty in bonding to the surface and lack of a sufficiently broad data base to recommend this type of seal cap.

If fasteners are widely separated -- i.e., greater than 0.500 in (500 mils; 12.7 mm) apart -- they can be overcoated (filleted) individually as shown in Figure 27.

11.1.3.6 Dome Nut Sealing: Extrudable sealant is applied around the base of dome nuts as shown in Figure 28. Completely encapsulate the dome nut, including the base and fasteners, holding the dome nut in place and using Class B sealant, or by applying two coats of Class A brushable sealant. Thicknesses of sealant and tooling (or fairing) requirements described earlier apply to this sealing operation.



Note: 100 mils = 0.100 in (2.54 mm)
120 mils = 0.120 in (3.05 mm)
250 mils = 0.250 in (6.35 mm)

FIGURE 23 - Overcoating a Rivet

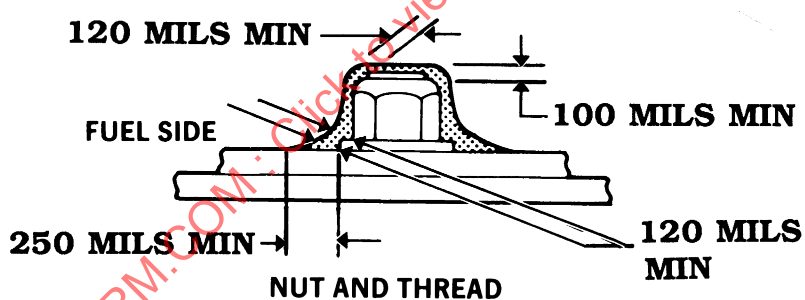


FIGURE 24 - Overcoating a Fastener

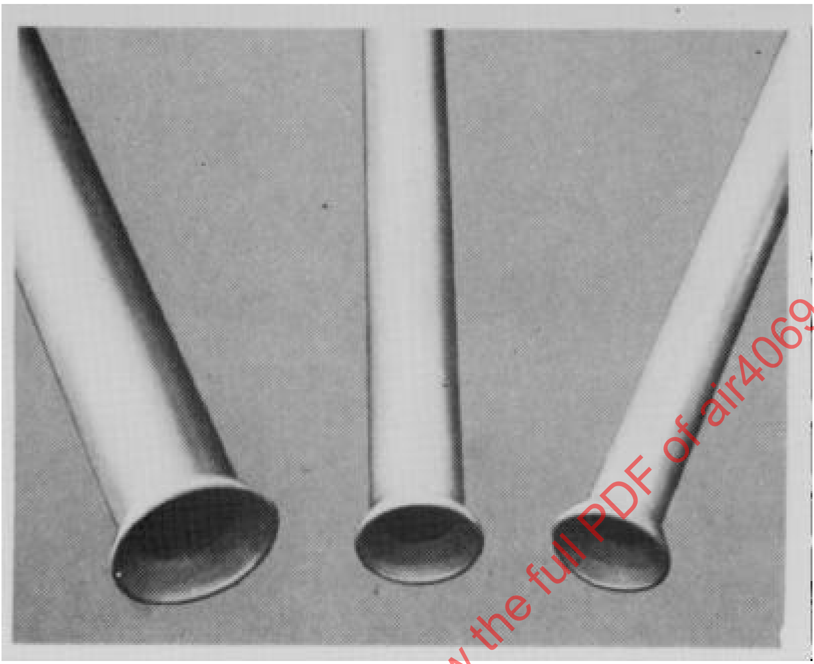
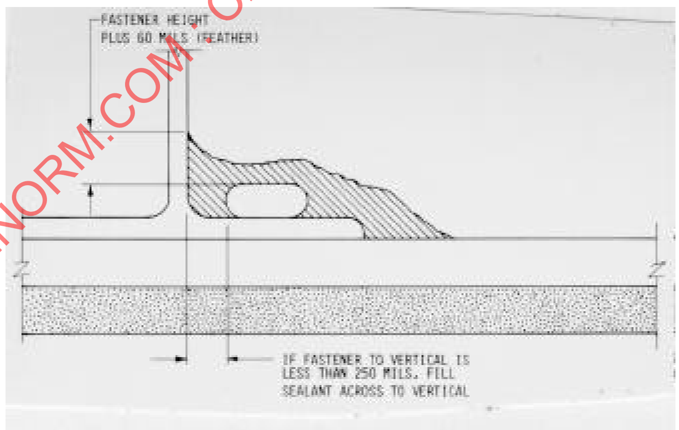


FIGURE 25 - Fastener Sealing Applicator



Note: 60 mils = 0.060 in (1.5 mm)
120 mils = 0.250 in (6.4 mm)

FIGURE 26 - Sealing Fastener Near a Vertical Surface

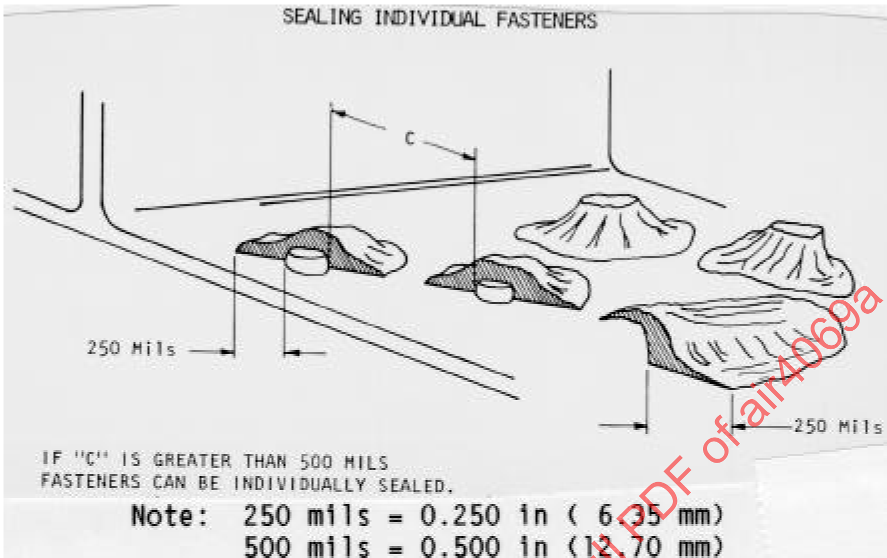


FIGURE 27 - Sealing Individual Fasteners

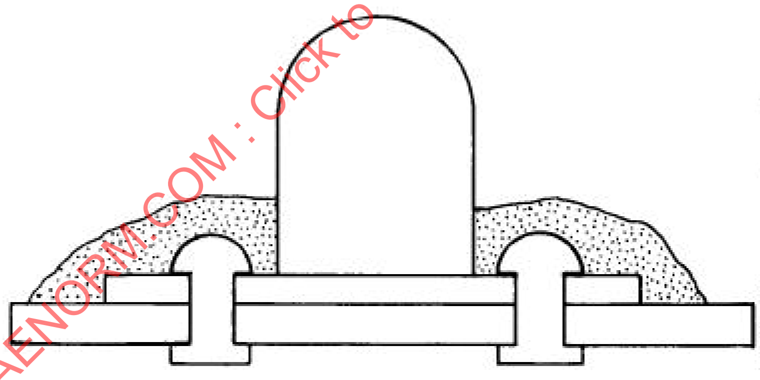


FIGURE 28 - Dome Nut Sealing

11.1.3.7 Prepacking: Extrudable (i.e., Class B) sealant is also used for prepacking voids created at structural intersections. Sealant is packed into the void area and onto fuel tank structure surfaces that will enclose it. The parts are then joined together, avoiding entrapment of air.

Sealant must squeeze out from all edges of the part. After assembly of these parts, remove excess sealant using a nonmetallic tool and fair the material to form fillets at structure edges.

An example of prepacking is given in Figure 29. When prepacking a gap is impossible or inappropriate, use injection sealing (see 11.1.3.8).

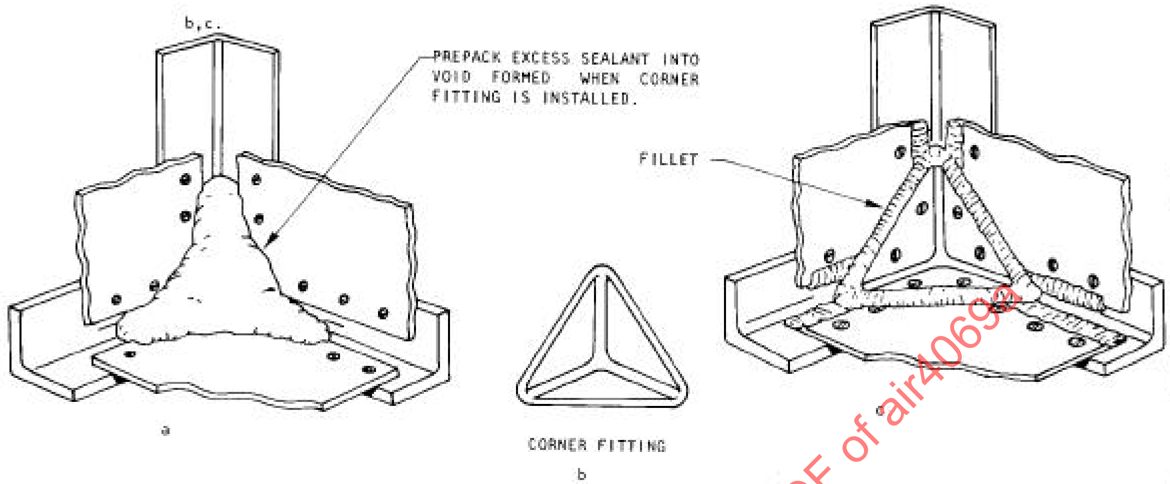


FIGURE 29 - Prepack Sealing

11.1.3.8 Injection Sealing: After assembly, various channels, crevices, and holes result from assembly of sections and subassemblies of integral fuel tanks. Such voids cannot be left open to collect debris or to become unobserved areas for degradation. All voids and channels must be filled. Pipe cleaners can be used with solvent cleaners to clean and adhesion promote these areas.

Finally, Class B extrudable sealant is injected, using an appropriate nozzle shape and length. Inject sealant until it extrudes from the opposite side. Extrusion of sealant from a structural opening opposite to where sealant injection begins is an indication that the opening is completely filled.

If there is more than one opening, plug the other openings (or exits) until sealant has extruded from the first opening; then sequentially unplug each of the other openings. When sealant has extruded from each opening, withdraw the nozzle and ensure that the entrance is filled with sealant. Remove excess sealant with a nonmetallic tool; and fair the sealant at each exit area.

Injection sealing is illustrated in Figure 30.

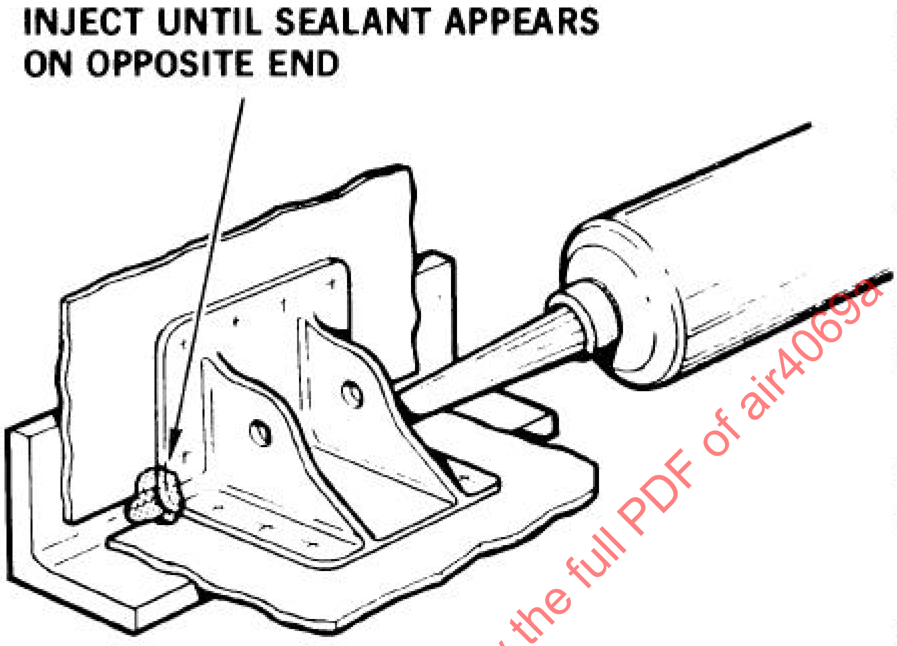


FIGURE 30 - Injection Sealing

11.1.3.9 Access Door: There are three types of access door seals:

a. Molded-in-place seals;
b. Bonded-in-place seals; and
c. Formed-in-place seals, which are also called formed-in-place gaskets. These seals, or gaskets, are not used because of the permanent compression set of the polysulfide). A formed-in-place seal is produced using a two-part polysulfide sealant.

The following types of sealant are used for sealing of access doors:

a. Low peel strength [2 lb/in (350 N/m) of width], in accordance with MIL-S-8784 or AMS 3267.
b. MIL-S-8802 and AMS 3276 polysulfide-based sealants with a nonsilicone parting agent on the door. The sealant (Class B) is applied to the door frame and smoothed uniformly over the surface to a thickness of approximately 0.020 in (20 mils; 0.51 mm). The door is installed while sealant is still tacky. The fastener should be tightened sufficiently to obtain continuous squeeze-out of the sealant. After the sealant has become tack-free, which requires approximately 24 h (or less) at standard conditions, the specified torque can be applied for installation of the fasteners. The faying surface should be wide enough (i.e., greater than 0.25 in (6.4 mm)) to form a good seal.

11.1.4 Faying-Surface Sealant Application: Faying-surface sealants are applied between overlapping surfaces (see 3.1.1.2 and 3.2.1). Since those surfaces will be drawn tightly together by fasteners, rivets, bolts, and screws, most of the applied sealant will be squeezed out. Squeeze-out must occur during the assembly time (or squeeze-out life) of the faying surface sealant.

After surface cleaning and application of adhesion promoter, the sealant is applied by extruding several beads across the surface to be coated. The sealant is then spread to a uniform thickness of approximately 0.010 in (10 mils; 0.25 mm) by a spreader or roller, as shown in Figure 31.

An alternative method of application is through use of a roller nozzle assembly that attaches to the threaded end of a standard cartridge in a sealant gun (see Figure 32).

When the two surfaces are fastened together, the sealant squeezes out uniformly around the periphery of the overlap. (If permanent fasteners are not installed within the assembly time, temporary fasteners should be installed in every other hole and tightened to appropriate torque value within the sealant's assembly time.)

If a continuous squeeze out is not achieved, the panels must be opened; and the sealant must be reapplied. For maximum structural strength, and to minimize later metal fatigue, the two faying surfaces are fastened together with the objective of achieving metal to metal contact. The sealant remaining is a thin film, approximately 0.003 to 0.005 in (3 to 5 mils; 0.08 to 0.13 mm) thick, and only a stain in the immediate area of the fastener.

Several alternative approaches are taken after obtaining fay seal squeeze out, depending upon the company:

a. Wipe off excess sealant and apply a fillet;
b. Wipe off the excess sealant, and do not apply a fillet until after final assembly and pressure testing for faying-surface leaks;
c. Wipe off the excess sealant, retaining enough sealant for forming and fairing of a fillet; apply a tack-free time accelerator to avoid entrapment and accumulation of debris -- i.e., chips, dirt, and other particulate matter -- in the applied sealant.
d. If the faying-surface sealant is corrosion-inhibiting, wipe off the excess sealant and apply a fillet of sealant that conforms to the engineering requirements of MIL-S-8802 or AMS 3276.

Most companies favor application of the fillet at the subassembly stage, during close-out of the faying surfaces.

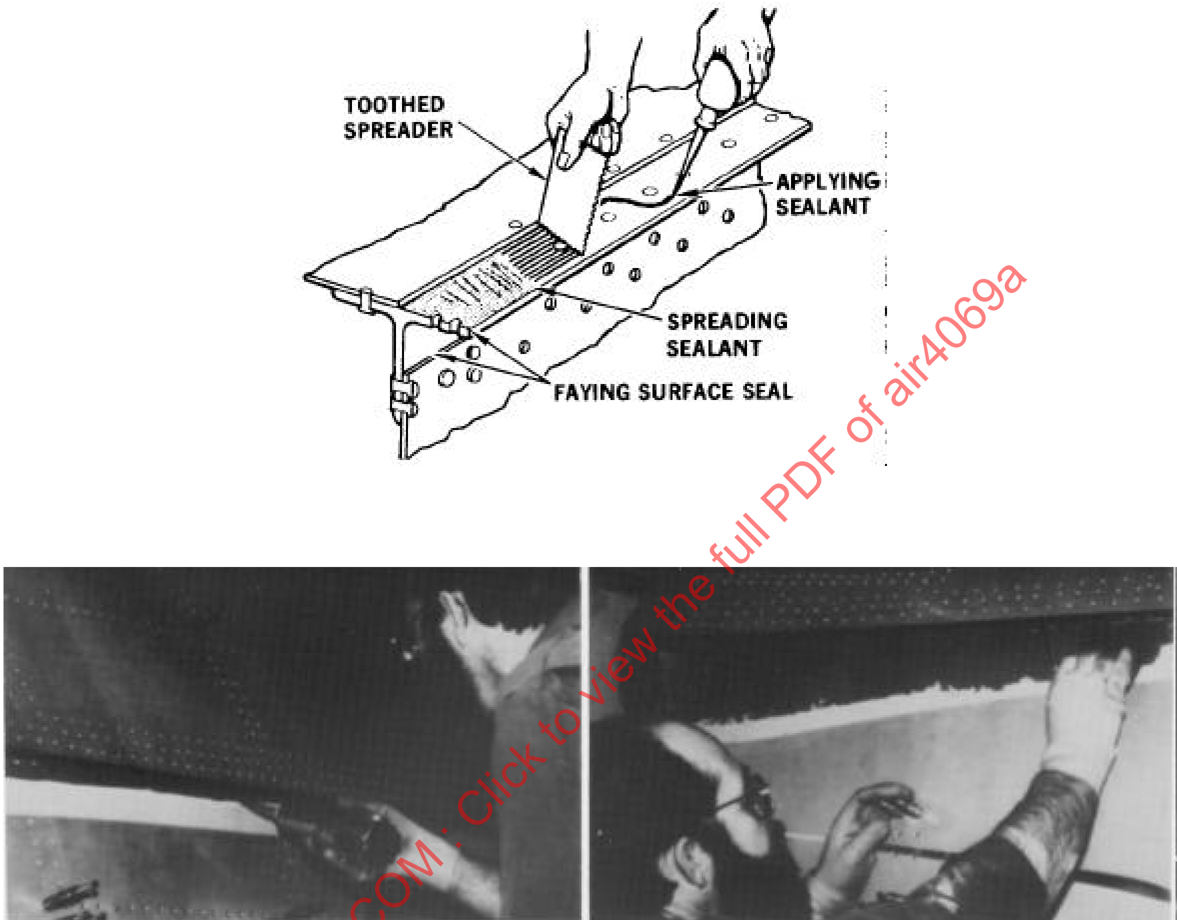


FIGURE 31 - Application of Sealant to Faying Surface

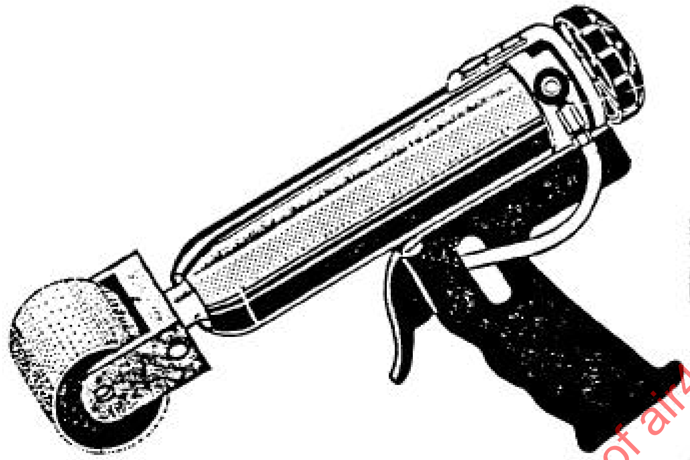


FIGURE 32 - Roller Nozzle for Faying-Surface Sealing Application

11.1.5 Protection of Sealant During the Tacky State: After sealant application -- i.e., brushcoating, fillet sealing, or faying-surface sealing -- the sealant surface is quite tacky, eventually becoming tack-free (usually within the first 7 to 24 h). During this period, it is vulnerable to collection of metal chips, dust, and other debris from manufacturing operations in the area. Too much surface contamination will require that fuel tank sealant be removed, the sealant bond surface recleaned, and sealant reapplied.

Three techniques are used for protecting the tacky sealant:

a. Physical protection by polyethylene plastic sheet, paper, cardboard, etc.;
b. Application of a quick-drying overcoat;
c. Application of an organic, chemical and corrosion-resistant fuel tank primer, such as primer that conforms to requirements of MIL-C-27725;
d. Application of a tack-free time accelerator (or detakifier).

Sealing should be performed in a facility where the air is filtered. It is also desirable that no drilling or sanding, or other machining operations, be done in the area during the tacky period. Since this is not always possible, protection must be provided. Draping plastic sheets over applied fuel tank sealant is not without problems including the risk of marring the sealant surface.

A quick-drying, sprayable overcoat (see item b., above), such as Courtaulds Aerospace's PR-715, will protect the surface of the fuel tank sealant. PR-715 is a sprayable, one-part, water-based polyurethane, which becomes tack-free in approximately 30 min at standard conditions. It is applied with a soft, camel hair brush to avoid disturbing the surface of the sealant. Do not apply by spraying and restrict overlap to 0.25 in (6.4 mm).

11.1.5 (Continued):

The last method mentioned above (item d) -- a tack-free time accelerator (or detakifier) -- is not a coating; it is applied from an aerosol can as a mist-coat to the surface, and it accelerates the polymeric reaction on the surface of the sealant, producing a thin and tough skin in 1 to 2 h. The sealant under the surface continues to cure at its normal rate. It is preferred because it does not introduce a foreign substance or change surface characteristics in any way.

The tack-free time accelerator (or detakifier) does not cure the fuel tank sealant sufficiently for pressure testing or fueling of the air vehicle; thus, when a sealant is made tack-free by the tack-free time accelerator, it should be done only for surface protection -- not for quicker refueling or pressure testing.

11.2 Application of Groove-Injection (Channel)-Sealant:

Groove and channel design and sealants were discussed in 3.1.2.1 and 6.2.

This section discusses preparation of surfaces and application of sealant, including equipment used during sealant application.

11.2.1 Surface Preparation and Pretreatment:

11.2.1.1 Substrates: Substrates may be aluminum alloys, titanium, or composites. Aluminum alloys are finished with one of the following coatings:

a. MIL-A-8625, Type I, Class 1 (chromic acid anodize);
b. MIL-A-8625, Type II, Class 1 (sulfuric acid anodize);
c. Ion vapor deposited aluminum, in accordance with MIL-C-83488, Type II, Class 1.

Ion vapor deposition of aluminum is used mostly for fatigue and fracture critical parts. Occasionally, MIL-C-5541, Type 1A, chromate conversion coating will be employed for fatigue-critical reasons, but this is actually less desirable because of reduced corrosion resistance.

The fuel-wetted aluminum surfaces and the aluminum faying surfaces are normally coated with the MIL-C-27725 polyurethane-based fuel tank primer to a thickness of approximately 0.001 in (0.025 mm). Injection grooves in carbon-epoxy, carbon-bismaleimide, and other composite laminates do not normally require finish treatments other than cleaning to remove parting agents. Titanium and composite surfaces are coated only if they interface with galvanically dissimilar materials.

Application of fuel tank primer to detail parts can be performed either before or after fitting, drilling, and reaming operations, provided the surfaces are clean, scratch-free, and chip-free prior to assembly. Subsequently, any scratched or damaged areas of this coating can be locally repaired.

11.2.1.2 Substrate Cleaning: After initial assembly of all parts forming the fuel containment area and all fitting, filling, drilling, reaming, and countersinking is completed, parts are disassembled and chips and burrs removed.

Prior to reassembly of aircraft wing skins to substructure, faying surfaces and channel grooves, and all interior surfaces of the fuel tank, are cleaned using one of the following cleaning solvents:

a. MIL-C-38736, Type I;
b. ASTM D 740 methyl ethyl ketone (technical grade); or
c. AMS 3166 cleaning solvents.

The above solvents are applied with an absorbent, low-linting, low-extractable cloth (see 5.1). The cleaned surface should be given a final wipe with a clean cloth, not allowing rinse solvent to evaporate to dryness on the substrate.

Protect the surface from recontamination after cleaning. Paper masking tape or masking discs can be applied to the exterior of all fastener holes designated as injection or observation ports if they are to be left open for any length of time.

Wherever there are discontinuities in the channel, such as openings or mismatches, these discontinuities must be closed using solid shims or moldable plastic shims (MPS). No gaps in the fuel tank should exceed 0.005 in (5 mils; 0.13 mm).

MPS -- an epoxy-based material in use within the aerospace industry -- includes Hysol's EA 9394 and EA 9377. EA 9377, which is designed for high-temperature applications with continuous service to 190 °F (88 °C), has been applied on military aircraft fuel tank structure.

11.2.1.3 Prepacking and Cleaning: The grooves may be prepacked with channel sealant before assembly, or the structure can be assembled then injected with channel sealant. In the former case, it is still necessary to inject after assembly to ensure that no voids remain.

Dams made of MIL-S-8802 or AMS 3276 can be installed during the prepacking operation (if the manufacturing plan calls for prepacking the grooves prior to assembly), or later. Install the dam by injecting MIL-S-8802 or AMS 3276 polysulfide sealant using a standard (not high-pressure) sealant extrusion gun fitted with a plastic nozzle. The injection is accomplished by inserting the nozzle into the dam area with the initial nozzle position at the edge of the channel, withdrawing it slowly as sealant is extruded, filling the dam area. No polysulfide sealant should enter the channel groove itself.

Once the polysulfide sealant has cured completely, the prepacking with channel sealant can be completed (or can be started if the dam is built first, before any prepacking has been accomplished).

11.2.1.3 (Continued):

To prepack the grooves, place a plastic cartridge of channel sealant in a standard (not high pressure) sealant extrusion gun. Do not fit the cartridge with a nozzle. Hold the gun perpendicular to the surface with the cartridge opening pressed against the groove edges. Inject the sealant, moving the gun along the groove at a rate sufficient to continuously fill the channel groove. If the dam has not yet been installed, terminate prepacking within 1 in (25 mm) of area(s) where a sealant dam will be installed.

Once the channel has been filled, trowel the prepacked sealant level with the groove edges using a plastic (or other nonmetallic) scraper. If necessary, fill voids or low spots with channel sealant. Ensure that all corners are filled. Solvent clean excess sealant from adjacent mating surfaces.

Appropriate sealing operations, including (but not limited to) fillet sealing and faying-surface sealing, must be accomplished on joints and overlap edges of lower skins, using fuel tank sealant conforming to MIL-S-8802 or AMS 3276.

Once all fasteners and fittings are installed in accordance with applicable engineering drawing requirements, the assembly is ready for injection of channel sealant. Channel sealant is injected with a high-pressure injection gun through external ports spaced at intervals of approximately 3 to 5 in (76 to 127 mm).

11.2.2 Equipment for Groove Injection: Equipment used for injecting channel sealant is radically different from standard sealant extrusion guns used, for example, in fillet applications. Several brand names and models are mentioned as examples of the aerospace industry's most-widely-used types of equipment necessary to perform this task. Although this equipment is the most-widely-used, it is not the only equipment that is available and capable of accomplishing groove-injection sealing operations.

The Grover #223 injection gun (see Figure 33) magnifies the plant air pressure by a ratio of 70-to-1. Since tip injection pressures required for the various groove sealants range from 2,000 to 6,000 psi (13,790 to 41,369 kPa), factory air pressure must be regulated to a lower pressure range -- from approximately 80 to 90 psi (552 to 621 kPa) to approximately 25 to 60 psi (172 to 414 kPa). The regulator component of the Grover injection gun allows full-line pressure to accumulate within the chamber; and it regulates the pressure for controlled injection of noncuring groove sealant.

Tip pressures are kept under 3,000 psi (20,684 kPa) [air pressure at 27 to 29 psi (186 to 200 kPa)] for thin-skinned aircraft, but can be as high as 6,000 psi (41,369 kPa) for heavier-winged aircraft. It is critical to the success of sealant application that the operator be acutely aware of the limitation on line pressure since the structure can be damaged, panels can be distorted or rippled, and sealant can be forced into the tank itself.

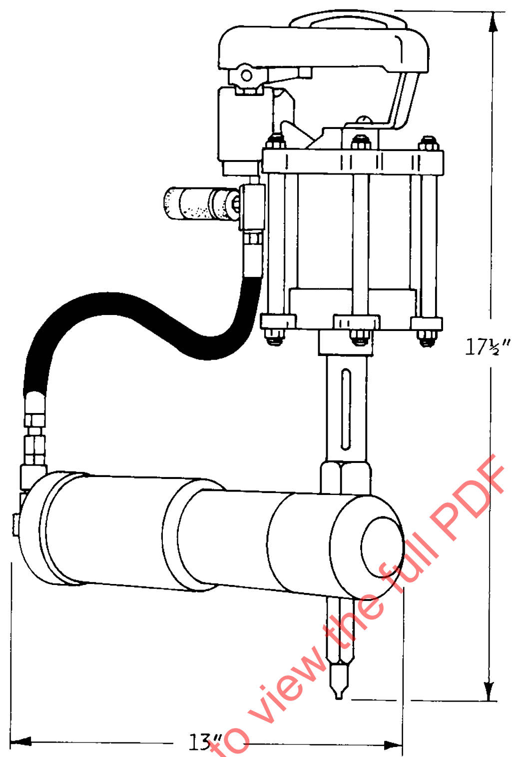


FIGURE 33 - Grover # 223 High Pressure Injection Gun

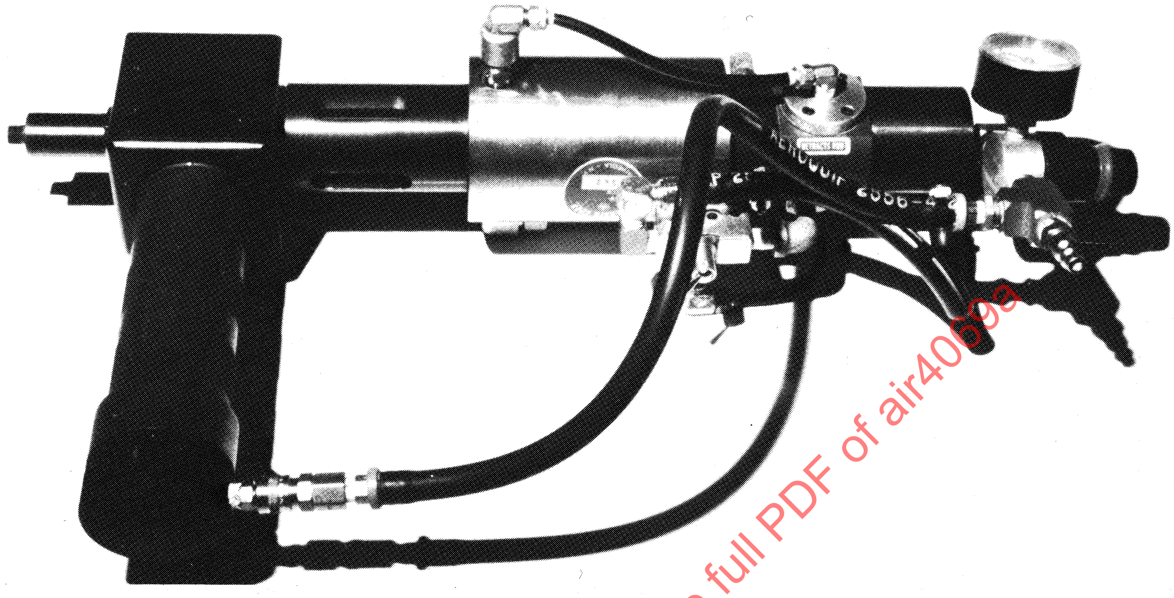


FIGURE 34 - SEMCO Model # 510 High-Pressure Injection Gun

11.2.2 (Continued):

The Grover #223 gun utilizes a #226358 SEMCO cartridge adapter to permit use of a 6-fl oz (177 mL) plastic cartridge of channel sealant. The Courtaulds Aerospace SEMCO Model #510 injection gun (see Figure 34) provides a 110-to-1 ratio of line pressure magnification. The Model #510 injection gun is fitted with a regulator for adjusting to viscosities of various channel sealants and for controlling tip pressure; it can accept 6, 8, or 20 fl oz (177, 237, or 591 mL) cartridges of channel sealant, and it provides a continuous bead of material when actuated. Line pressure limits must be a part of the process instructions to ensure that design structure channel width and cross-section, sealant viscosity, and injection gun pressure are compatible.

Another method of injecting channel sealant is from equipment that contains the sealant in bulk [5 gal (19 L)], rather than through the use of small plastic cartridges. The equipment that pumps from a 5 gal (19 L) container generates 2,000 psi (13,789 kPa) or greater tip pressure from the pump. The application gun is therefore quite small.

The Pyles Dispenser System Model 710018-462-000 is connected to shop air pressure supply. The equipment has a 38-to-1 pressure multiplier ratio. When the air pressure setting is 100 psi (689 kPa) the tip pressure will be on the order of 3,700 psi (25,511 kPa); when the air pressure is 50 psi (345 kPa) the injection pressure is approximately 1,900 psi (13,100 kPa). The lower pressure is used for injection sealing of thin carbon-fiber-reinforced epoxy (composite) skins to metal or carbon-epoxy substructure.

11.2.3 Injection of Channel Sealant: The injection procedure can be started at any point on the fuel tank. Applicable materials and processes specifications or engineering drawings indicate where the injection procedure begins. The starting point is not critical. It is critical, however, that the port adjacent to the port in which the injection fitting is installed is open for the sealant to exit, indicating that the channel in between has been filled.

It is necessary to provide proper clamp up of the seal-groove structure during injection of the channel sealant. Only fasteners from the injection port in use and its adjacent port are removed. All other fasteners must be installed and tightened to specified torque values.

When removable (or temporary) fasteners are involved, injection fittings should be installed into injection and exit holes. It is necessary to measure the depth of the sealant groove and match it to the size (depth) of the port's injection fitting. Some permanent fasteners have a set screw in the fastener; this set screw can be removed when attaching the injection fitting.

Injection fittings are installed and torqued so that the slot in the fitting is aligned with the direction of the sealant groove, being careful not to exceed the torque range for the fitting. With the adjacent exit hole open, the gun is attached to the injection fitting and the sealant flow started. When sealant appears at the level of the skin or spar, or at the bottom of the countersink, the sealant flow is stopped. The injection fitting is then installed in the hole previously used for sealant exit and the next adjacent fastener is removed to permit exit of sealant when the process is systematically repeated. Continuity is thus ensured, port to port.

The sealant gun is hand held and pressed against the injection fitting while sealant is injected. Fixtures are also available for supporting the weight of the gun when overhead parts are injected.

Some noncuring sealants are stiff when cold and extrude at a much lower rate, producing more back pressure. Local heating of the structure with heating pads will aid in movement of the sealant. Once the sealing operation is completed, all accessible excess sealant should be removed from the tank's interior and exterior surfaces.

Fasteners used in addition to those in the groove path must be of the self-sealing type (O-rings) and capable of being replaced from the outside of the tank.

12. LEAK REPAIR:

12.1 Repair Philosophy:

During initial manufacture, leaks are repaired when discovered. During the aircraft's service life, repairs may be noted; but they may be deferred for action at the time of scheduled maintenance. If the leak is significant, it may be downgraded by use of a temporary repair, with permanent repair deferred until the time of scheduled maintenance. If a significant leak cannot be downgraded to a no leak or small leak condition, the aircraft must be grounded.

Temporary repairs are made to the outside of the integral fuel tank sometimes without defueling. Such a repair can never be accepted as a permanent repair. Permanent repairs are made inside the tank.

Leaks are caused by design deficiencies, material deficiencies, poor workmanship, and flight environment which can produce bond failures, structural cracks, corrosion, and loosening of fasteners. The most common leak sources are non-self-sealing fasteners penetrating fuel tank barrier structure. Proper initial sealing of all fasteners is imperative. Repairing leaking fasteners in the field is more difficult, since some types may require somewhat different sealing contours and dimensions; and repair personnel must recognize the differences in the sealing requirements of each type of fastener.

Fuel tank leaks have been classified by the military and by commercial industry in much the same way. Internal, nonvented leaks are more serious than internal vented ones, which are more serious than external leaks. Rate of leaking is another element used for determining the seriousness of the leak.

12.2 Leak Classification:

The severity of aircraft fuel tank leaks is categorized by the U.S. Air Force as follows:

a. A - slow seep;
b. B - seep;
c. C - heavy seep;
d. D - running leak.

12.2 (Continued):

These leaks are classified as described in the following paragraphs. The level of action to be taken depends upon the magnitude and location of the leak.

Following are the three levels of action:

a. A and B are essentially the same - the small leak is documented to be periodically inspected for leak growth. Under level A, it is not mandatory to repair when the tank is opened for inspection or other repair.
b. Under level B, repair should be scheduled when the aircraft is down for maintenance or when it is opened for another inspection or repair.
c. Level C requires documentation and repair to a no-leakage or small- leakage condition -- i.e., to Level A or Level B.

Slightly different stain areas and drip rates are spelled out for AV Gas and for JP-5 and JP-8. JP-5 and JP-8 are categorized the same.

Further information concerning fuel tank leak classifications can be obtained from the following document:

Mahoney, J. W., et. al., AFWAL-TR-87-3048, "Aircraft Integral Fuel Tank Design Handbook," Rockwell North American Aircraft Operations, Los Angeles, CA, December 1987.

12.3 Temporary Repairs:

External repairs are considered temporary. Groove-injection repairs are permanent. Temporary repairs are designed to downgrade the leak classification to a flyable condition until scheduled permanent repairs can be accomplished. Several types of patch kits are available.

12.3.1 Aluminum Foil Patch Kit: Leaking fasteners are repaired most effectively by applying an aluminum foil patch. This patch is bonded with an extra-fast-setting epoxy or polysulfide sealant. All of the necessary items are provided in a kit (see Figure 35).

Defueling the aircraft is not necessary if a fast-setting epoxy is used. The procedure for use is as follows:

12.3.1 (Continued):

1. Clean the fastener area with MIL-C-38736 cleaner.
   NOTE: Do not remove the original sealant topcoat on the fastener before applying the patch.
2. Use a patch cut from the 0.002 in (0.05 mm) thick aluminum foil supplied in the repair kit. The diameter should cover the head of the fastener and extend 1/2 in (12.7 mm) beyond the head of the fastener.
3. Clean the surface of the foil patch with MIL-C-38736 cleaner.
4. Mix and apply the quick setting epoxy to the cleaned side of the aluminum patch. Apply it to a thickness 0.015 to 0.020 in (0.38 to 0.51 mm).
5. Press the patch into place over the fastener head. Hold in place with the kit fixture provided. Cure time: approximately 15 min at 75 °F (24 °C).
6. CAUTION: Do not heat to accelerate cure. Heat curing causes the epoxy to become brittle and fail.
7. To remove the patch (when a permanent repair is to be made, heat the patch to 200 to 250 °F (93 to 121 °C) with a heat gun. Use a plastic scraper to pry up the patch. Use needle-nosed pliers to remove the patch. Heat and scrape until epoxy is removed.

NOTE: If a two-component polysulfide sealant is used in place of fast setting epoxy, the aircraft must be defueled to a level below that of the leak. Proceed as above. After the patch is applied, apply heat to the patch using the heat applicator in the repair kit. Cure for approximately 30 min at 140 °F (60 °C). At temperatures below 50 °F (10 °C), preheat the surface around the fasteners for approximately 3 to 5 min before applying the patch.

12.3.2 Injection-of Sealant Around Flush Fasteners: Temporary repair of fuel tank sealant on flush fasteners can be accomplished, without defueling the air vehicle, by injection of a single-component, anaerobic, thread-locking compound that conforms to the requirements of MIL-S-46163. After the area surrounding the fastener has been cleaned, including removal of any paint, injection is performed at a pressure of approximately 900 psi (6,205 kPa).

After the Compressed Air Injector Kit has been used, the head of the fastener is covered with aluminum tape and the sealant is heat-cured to stop the leak. Heat-curing is performed for approximately 5 to 10 min, with the heating iron set at 140 °F (60 °C).

NOTE: When the aircraft employs BUNA-N seals in faying surfaces, high-pressure injection repair should not be used.

The equipment required is a part of the kit and includes a position locator, suction cups, cylinders, and jacks for holding the assembly to lower-wing surfaces. After the sealant is cured, the tape is removed.

FIGURE 35 - Aluminum Foil Patch Kit
(National Stock No. 4920-450-6925)

12.3.3 Application of Quick Hardening Material: A simple method for temporary repair of fastener leaks requires cleaning the surface around the fastener with methyl ethyl ketone (MEK) or methyl propyl ketone (MPK), then applying a material that will harden over the fastener head.

a. Use Oyltite Stik (Air Force ID is D-103). Soften it by dipping the end into MEK;
b. Firmly apply the quick-hardening material around the fastener head until the leak stops;
c. Remove excess material with a plastic scraper or spatula.

12.4 Permanent Repairs:

Depending on the degree to which access into the fuel tank is possible, permanent sealant repairs can be made with polysulfide or polythioether sealants. Other repairs not achievable by groove-injection or by access into the tank can be done only by disassembly.

Permanent repairs are generally made from inside the tank; exception to this is groove-injection sealing. Designs on some military airplanes include a channel (or groove) between double rows of fasteners around the perimeter of the fuel tank to allow future repair by injection.

Each leak requires a leak path analysis to identify the leak exit point, the leak path, and the leak source. The appropriate aircraft sealing engineering materials and processes specification, technical manual, or technical order will identify sealants used on the structure, fasteners, access doors, and components.

12.4 (Continued):

Types of fuel tank seals made with curing-type sealant are:

a. Prepack and injection seals - Inject if possible and add a fillet seal around the periphery and at any other opening.
b. Faying surface - Disassembly would be necessary. Normally leaks are repaired using fillet seals. In some cases hollow bolts can be used for injecting faying-surface sealant to effect repair. Apply manual pressure to prevent panel distortion. The fastener is then reinstalled and sealed.
c. Fillet Seals - Repaired by removal of the fillet in the affected area, then tapering the remaining ends to an angle of approximately 30°. Abrade 1/2 in (12.7 mm) on each end, clean, apply adhesion promoter, apply brushcoat Class A sealant, then apply the fillet.
d. Brushcoats - The brush coat is recommended for fillets; and it is applied before the fillet is deposited. It is never applied over fillet seals as a leak repair.
e. Hole and slot - Repaired by removing old sealant and seals, then reapplying sealant.
f. Overcoat Seals - As previously mentioned, the following four approaches are acceptable:

    1. Multiple layers of Class A material if each layer is applied after the prior layer surface is tack free.
    2. Class A sealant layer followed by a layer of Class B sealant. The layer of Class B material is applied after the Class A sealant is tack-free.
    3. Class B material applied alone.

With any of these approaches, it is recommended that adhesion promoter be applied prior to resealing.

12.4.1 Leak Path Analysis: There is a leak source inside the tank, a leak path to the outside of the tank, and a leak exit point. A leak can occur directly through a fastener hole to the outside or it can travel many feet through crevices in assembled structure before appearing at an exit point. The task of leak path analysis consists of associating the leak exit to the leak source. Study of the tank design drawings and the method by which it was sealed can give valuable clues as to the probable path from exit to source. Locating all leak exits and tying them to their leak sources is a necessary prerequisite to making permanent repairs. When the tank is opened, all the leak sources must be identified and repaired and other defects corrected to make the total effort cost effective. For this reason, the value of leak path analysis cannot be overstated.

12.4.1.1 Finding the Leak Exit: The following four widely used methods are used for determining the location of a leak exit:

1. Addition of Zyglo dye or red talcum powder to the fuel; red talcum powder turns bright-red when wetted by fuel; Zyglo-dyed fuel is detectable with UV light;
2. Application of torn paper (absorption of fuel on the paper reveals a leak);
3. Tank pressurization with gas -- i.e., helium, argon, ammonia, or nitrous oxide -- with outside detection using soap solution.

The currently-used method is Zyglo-dyed fuel [see 12.4.1.1, item (1)], followed by inspecting for fuel leaks with ultraviolet (UV, or black) light.

12.4.1.1 (Continued):

Recommended Methods:

1. Addition of Zyglo dye or Red Talcum Powder (see Figures 36a and 36b):

   a. Conditions: Usually performed on external surfaces of fuel tank, prior to defueling, where fuel leaks are observed or suspected. The Widger Chemical Dye-Lite leak detection system has been adopted by several major airframe manufacturers and air carriers for fuel tank leak detection. A dye which fluoresces in ultraviolet (UV) light is added to the fuel; one such dye is called Zyglo. The exterior is then examined with the light. Procedures control the concentration of the dye -- which is approximately 2%, by volume, the method of dispersing it in the fuel, the time before UV detection scanning starts, and specifications for the UV lamp.

      (1) Strip excess sealant from exterior fuel tank surfaces, including seams, in the suspected area.
      (2) Wipe off the leak area thoroughly with cotton wipes (3 to 4 changes or turns).
      (3) Blow out all seams and corners with compressed air 100 psi (689 kPa) maximum; and hold the nozzle at least 0.5 in (12.7 mm) away from sealant and fuel tank structure.
      (4) Dust immediately; using a thick camel's hair brush or aerosol dust spray. Wetted powder will turn bright red.
      (5) Observe long enough to detect sequence in case other potential leak exits appear. If the Zyglo dye is used, observe any fuel leaks using UV (black) light.
      (6) Identify the leak exit point (or exit points) with a marking pencil; if talc application method was used, wipe off remaining talc.

2. Torn Paper:

   Conditions: Used only external to the tank, prior to defueling.

   a. Recommended Method:

      (1) Strip exterior fuel tank sealant from structural seams in suspected area.
      (2) Wipe off the leak area thoroughly with cotton wipes (3 to 4 changes or turns).
      (3) Blow out all seams and corners with compressed air 100 psi (689 kPa) maximum: hold nozzle at least 0.5 in (12.7 mm) away from all sealant and structures.
      (4) Apply fuzzy edge of absorbing type of torn paper to suspect area.
      (5) Move fuzzy edge of paper gradually along surface of the suspect area.
      (6) Mark the spots where liquid is absorbed.