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ABSTRACT

The introduction of "Formed-in-Place" (FIP) technology in the 1970's led to development of many automotive, marine, and industrial powertrain applications. To encourage further growth of FIP gasketing, numerous production applications have been carefully analyzed; their design and processing details documented. Presented with a review of anaerobic and RTV silicone capabilities, this information bridges the gap from FIP theory to practice. It offers powertrain engineers the parameters necessary to successfully design, test and manufacture FIP gasketed assemblies.

INTRODUCTION: Recognizing the cost and performance benefits possible through FIP gasketing, interest generated quickly to exploit this new technology. Theoretical in nature, early technical papers offered the design engineer little direction. This absence of specifics led to a legitimate question: Why chance new "gasketless" technology with conventional gasketing methods so well defined? Application testing ultimately proved that manufacturing and performance benefits far outweighed the cost of development. The result is an expansive data base of successful FIP applications from which functional engineering formulas have been developed. Design and processing parameters documented represent the best available knowledge based on field successes. These guidelines make successful FIP gasketing applications possible the first time by using DFMA techniques.

CONCEPT REVIEW: Unlike conventional gasketing methods, FIP technology does not require extreme compressive loading to form a reliable seal. It offers use of lighter flanges, and expands the range of useable materials from which engineers may choose. While these designs are referred to as "metal-to-metal", FIP materials also work well on most engineering plastics.

Consider the behavioral attributes of anaerobic and silicone FIP materials as compared to conventional methods:

<u>Reliability Improvements</u>

- Seals all surface imperfections
- Allows true "metal-to-metal" designs
- Eliminates compression set and fastener loosening associated with conventional gaskets
- Anaerobics add structural integrity to assemblies

<u>Cost Reduction Opportunities</u>

- Relaxed machining & quality control standards
- Reduced labor content by automatic application
- Eliminate retorquing operations often necessary when using conventional gaskets
- Allows use of smaller fasteners, lighter flanges

<u>Ease of Application</u>

- Single component materials, no mixing required
- Applied semi- or fully-automatically by robotic tracing, silkscreen, and other methods
- Vertical and horizontal application possible

<u>Serviceability</u>

- FIP materials demonstrate better shelf-life than most composite gasket materials
- FIP service packages offer multiple application capability on flanges of any size or shape
- Anaerobics offer easy disassembly and clean up

SELECTION GUIDE

The following table compares the capabilities of anaerobic and silicone FIP materials. It presents current product data to assist material selection based on desired design and performance envelopes. Further, it includes processing information to assist in DFMA decision making.

Characteristic	Anaerobic	RTV Silicone
Cure mechanism	Absence of air & presence of metal	Atmospheric moisture
"Open time"	Indefinite	3-5 minutes maximum @ 50% RH/20°C
Cure through volume (CTV)	0.0 - 1.25mm	0.0 - 6.25mm
Tensile elongation	5 - 64%	250 - 600%
Shear resistance friction coeffecient	1.0u (*)	0.16u (*)
Operating temperature range	-54/+204°C	-70/+315°C
Operating pressure range	All pressures (**) Max. 34 MPa	Low pressures (**) Max. 1.75 MPa
Solvent resistance	Excellent, all automotive fluids	Fair, no fuel or aromatics
Hot oil resistance	Excellent	Fair/good
Surface oil resistance	Good	Poor/Fair
Substrate compatibility	All metals, thermoset & crystalline thermoplastics	All metals & engineering plastics
Flange requirements	Close-fitting machined castings & structural stampings only	Stampings & non-structural components, 0.5 - 1.25mm standoff desirable
Application methods/options	Tracing methods, silkscreen, stencil, transfer, roller	Tracing methods only

(*) For details see SAE #900200 "Structural Gasketing", 1990.

(**) Maximum sealing pressures require careful design, see also SAE #J1497 "Design Guide for Formed-in-Place Gaskets" 1988, SAE #841149 "Combating Leakage in Vehicle Assembly and Operation" 1984, and SAE #800451 "Advances in High-Performance Mechanical Fastening" 1980.

DESIGN CONSIDERATIONS

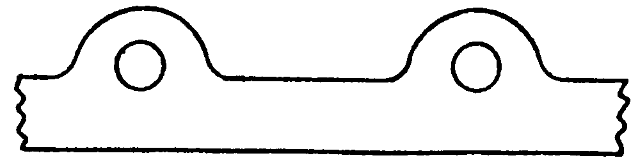
RESEARCH: The "design formulas" presented are based on extensive review of successful production FIP applications. Conservative values offer favorable outcome in the design, testing, and processing of new and retro-fit applications. Factors influencing the development of these formulas include:

- Flange structure/configuration
- Fluid(s) sealed
- Pressure(s) sealed
- Operating temperature range(s)
- Flange material(s)
- Flange width(s)
- Bolt span(s)
- Fastener size(s)/grade(s)
- Surface flatness (dimensional)
- Surface finish (roughness)
- Surface cleanliness (materials)
- Gap fill capability required/desired
- Application & assembly methods

Important: A successfully gasketed joint is a system of interacting parts. Never underestimate the significance of any individual component or feature. Castings, stampings, fasteners, fit, finish, and material selection all share interdependent duties in sealing the flanged assembly. Joints of dissimilar material generally require use of temperature stabilized light metals to limit differential thermal expansion. Unlike conventional gasketing methods, FIP designs require more careful attention to assembly processes. Cleanliness, open time considerations, and the need to torque fasteners immediately after assembly require the use of DFMA application development techniques. While a high degree of "scratch" design confidence can be achieved by adherence to these guidelines, there is no substitute for functional testing.

FLANGE DESIGN: Substitution of an FIP sealant in a joint designed for a compressible, load bearing gasket will most likely fail unless it conforms to design recommendations herein. Flanges originally designed for conventional gaskets must be changed to incorporate FIP gasketing parameters. Careful review of dimensional stack up requirements is necessary before gasket elimination. Illustrations shown serve to clarify successful FIP gasketing design efforts.

Correct design, consistent flange contact pattern



Incorrect design, broken flange contact pattern

CLEANING REQUIREMENTS: Surface oxidation and/or non-visual corrosion inhibitor residues can have a detrimental effect on FIP gasketing materials. Increased use of water-soluble cutting fluids and wash detergents necessitates cleaning process review. The following precautionary statement pertains to the cure mechanism and adhesion performance of anaerobics, and the adhesion performance of silicones.

There are two classes of chemicals commonly used for parts cleaning. Class A chemicals should be avoided, Class B chemicals should have no impact on FIP materials. Wash bath pH levels should not exceed 10 to 10.5, as high surface pH can retard cure times and lead to adhesion failures.

Class A: Alkali metal sales of nitrate, borate, silicate, or carbonate, and concentrated alkali metal hydroxide, etc. Alkali metal salts of nitrite should be avoided.

Class B: Ethanolamines (either diethanolamine or triethanolamine), dilute alkali hydroxides less than 3% by weight, etc.

Further analysis indicates the existence of a natural division between material performance, design options, and processing capability of anaerobics and silicones in FIP applications. Therefore, the paper is now divided into sections for in-depth review of each technology base.

GUIDELINES FOR ANAEROBIC FIP GASKETING

ADVANTAGES: Anaerobic FIP materials cure rapidly in close fitting metal joints where their "inside-out" cure behavior compliments high speed production. They offer virtually unlimited "open" time, and remain liquid in the presence of air. This characteristic enables multiple application methods, and reduces housekeeping problems associated with buildup of evaporation and/or moisture curing materials.

Anaerobics offer true "metal-to-metal" flange contact, and dramatically improve structural load carrying capability. They demonstrate excellent solvent resistance in the cured state, while uncured "squeeze out" dissolves with agitation in most solvents and automotive fluids. Anaerobic FIP materials can be used to seal plastic or chemically inactive flanges by using heat or surface primer/accelerators. Anaerobic FIP materials also double as a reactive dressing for augmentation of conventional gaskets in retro-fit applications where stack-up requirements preclude gasket elimination.

DISADVANTAGES: Anaerobics are limited in CTV, and slow to cure through large gaps (0.25mm-1.25mm) without the use of primer/accelerators. Temperature resistance and tensile elongation are likewise limited when compared to RTV silicones. Mating parts must be designed to eliminate relative movement. Anaerobics require use of temperature-stabilized light metals to limit differential thermal expansion in joints of dissimilar material. Due to rapid rate-of-cure, fasteners must be installed and torqued immediately after assembly (<3 minutes) to assure uniform flange contact without shimming.

Flange design parameters for anaerobics:

Statistical analysis of recorded data provides the following joint design formulas:

1) Surface finish required: 0.8 - 3.2 mM (*)
2) Surface flatness required: 0.1mm @ 400mm
3) Continuous flange width vs. bolt span:

4mm flange (+/- 1.4mm)/52mm span (+/- 30mm)
8mm flange (+/- 2.0mm)/77mm span (+/- 30mm)
12mm flange (+/- 1.9mm)/94mm span (+/- 25mm)
16mm flange (+/- 3.0mm)/99mm span (+/- 44mm)

DESIGN & PROCESSING TIPS: Surface finish is critical to joint integrity. Thermal shock and/or severe structural loading may shear anaerobic FIP material from very smooth surfaces (<1.6mM). Chamfer all dowel/bolt holes to eliminate raised metal and shimming. Regardless of method, apply a continuous pattern of FIP gasketing material inside (or around) dowel/bolt holes to eliminate secondary leak paths. Although anaerobic FIP materials exhibit indefinite "open" time once applied, it is recommended that assembly take place within one hour to reduce the potential for particle contamination. Likewise, silkscreen/stencil application devices should incorporate dust hoods to prevent contamination. Use alignment dowels for assembly of large parts to prevent pattern smearing.

Anaerobics cure rapidly between metal surfaces and are further accelerated by heat or primer/accelerators. To ensure FIP gasketing success, all fasteners must be run down and torqued to specification immediately (<3 minutes) after assembly. Sub-assembled components may require slave fasteners to assure consistent clamp load during the curing process. Allow the maximum possible fixture time prior to quality control pressure testing. Use minimum possible air pressure and duration to assure a quality assembly without inducing joint damage. Start with 6.9-10.3 kPa @ 10 seconds duration after 30 minutes cure time before optimization. Note that short term pressure resistance is dependent on flange width, FIP material static viscosity, and induced gap. Allow 24 hours cure time before performance testing experimental joints.

GUIDELINES FOR SILICONE FIP GASKETING

ADVANTAGES: RTV silicones cure rapidly through large gaps due to their "outside-in" cure behavior, making great use of their large CTV. They offer "metal-to-metal" contact, but are better suited to standoff designs because of their moisture dependent cure. Silicones offer tremendous temperature resistance and range, with equally impressive elongation characteristics, especially beneficial in joints exhibiting extreme differential thermal expansion. High elongation makes possible the use of thinner, more flexible flanges, with fewer fasteners in low pressure joints. Most RTV silicones exhibit great adhesion to ELPO and powder-painted parts without primers. Adhesion is largely unaffected by surface finish.

DISADVANTAGES: RTV silicones are limited to sealing oil, coolant, and air; they exhibit poor fuel and aromatic solvent resistance. Adhesion through surface oil contamination is generally poor. Dependence on atmospheric moisture produces a very slow rate-of-cure in close-fitting joints as vapor penetration is inversely proportional to film build. Silicones are not well suited to heavily stressed or high pressure applications. Due to extreme moisture sensitivity, RTV silicones are limited to bead tracing application methods, furthermore, parts must be assembled immediately after application to preclude shimming and poor adhesion caused by rapid skin-over. Fasteners should be run & torqued as soon as practical after assembly (<3 minutes). Acetoxy types (vinegar odor) liberate acetic acid vapors upon curing which corrode metal parts inside enclosures. RTV silicones require air exchange to drive off volatiles liberated during the curing process: Captive beads may never fully cure, causing chemical reversion at elevated temperatures.

(*) Surface cleanliness becomes increasingly critical to adhesion for long term joint durability when finishes fall below 1.6mM

Flange design parameters for silicones:

Statistical analysis of recorded data provides the following joint design formulas:

1) Surface finish required: 0.4 - 0.8 mM [**]
2) Surface flatness required:
   - Machined components: 0.1mm @ 400 mm
   - Stamped components can vary widely
3) Stand off distance required: 1.0mm - 3.0mm
4) Continuous flange width vs. bolt span:

4mm flange (+/- 1.9mm)/107mm span (+/- 43mm)
8mm flange (+/- 1.9mm)/100mm span (+/- 43mm)
12mm flange (+/- 1.9mm)/94mm span (+/- 43mm)
16mm flange (+/- 1.9mm)/87mm span (+/- 43mm)

DESIGN & PROCESSING TIPS: Surface cleanliness is critical to joint integrity. RTV silicones are dependent on adhesion for sealing: Thermal cycling and/or severe loading may shear fully-cured material from contaminated surfaces. Allow for plenty of air exchange; design standoffs as necessary (1.0 - 3.0mm recommended). Although CTV is 6.25mm, cure time through gaps larger than 3.0mm is generally too slow for high speed production. Be sure to apply a continuous bead of FIP gasketing material inside (or around) dowel/bolt holes to eliminate secondary leak paths. RTV silicones begin curing immediately when exposed to atmospheric moisture; assemble parts quickly after pattern generation (< 3 minutes @ 50% RH/20°C). Use alignment dowels for assembly of large parts to prevent pattern smearing.

Be aware that RTV silicones cure more slowly during Winter months when plant humidity levels fall due to forced-air heating: Rate-of-cure can be accelerated in humidity ovens. Fasteners must be run down and torqued immediately after assembly (< 3 minutes). Sub-assembled components may require slave fasteners to assure consistent clamp load during the curing process. Allow the maximum possible cure time prior to quality control pressure testing. Use minimum possible air pressure and duration to assure a quality assembly without inducing joint damage. Start with 6.9-10.3 kPa @ 10 seconds duration after 30 minute cure-time before optimization. Note that short term pressure resistance is dependent on flange width, FIP material static viscosity, and induced gap. Allow 72 hours cure time before performance testing experimental joints.

[**] Surface finishes up to 6.2mM can be used although optimal cleaning is required to assure adhesion for long term joint durability.

PROCESSING METHODS REVIEW

MACHINE TRACING: Repeatable bead application of FIP anaerobics or RTV silicones is accomplished by CNC robotics, CNC plotter, cam tracer, optical tracer, circle generator, etc. Most adaptable are CNC driven machines, the least flexible are cam tracers.

Anaerobic FIP materials can be dispensed from 850 ml cartridges by a positive displacement cartridge dispensing system equipped with a "suck-back" valve. Coupled with a suitable pattern generator, this device is capable of delivering beads from 0.5mm to 2.0mm at rates up to 375mm/second.

RTV silicone FIP materials can be dispensed from 20 Kg pails, or 200Kg drums by ram/follower, pump, and "snuff-back" valving systems built by several manufacturers. Attached to a suitable pattern generator, beads from 1.5mm to 6.25mm can be dispensed at rates up to 750mm/second.

MANUAL TRACING: Pneumatic or manually powered caulking guns can be used to dispense beads of FIP anaerobics or RTV silicones from 300 ml or 850 ml cartridges. Simple and inexpensive, can be messy. Subject to wide variation in placement and quantity; heavily dependent on operator skill. Recommend for prototype or low volume production applications.

SILKSCREEN: Most anaerobic FIP materials can be applied by industrial silkscreen applications devices. Fed from 300 ml or 850 ml cartridges, sealant quantity, location, and pattern are controlled by the screen mesh, orientation, and emulsion thickness. Most repeatable of all FIP application, this method offers a lower cost alternative to semi-or fully-automatic tracing.

STENCIL: Teflon coated steel stencil mounted on a wood or aluminum frame supplied with a "free" urethane squeegee. Dowel pins affixed to frame index stencil for repeatable application placement. Quantity and patten dependent on stencil thickness and pattern width. Developed for manual application on prototype or low volume production parts, much more durable than manual silkscreen albeit at slightly higher cost.

ROLLER: Short fiber or hard silicone rubber rollers can be used in conjunction with a silicone rubber lined tray for application of anaerobic FIP materials. Simple and inexpensive, can by messy. Subject to variation in film thickness, heavily dependent on operator skill. Recommended for prototype or low-volume production, and for manual roll-coating of conventional gaskets where anaerobics are used as an augmentation dressing.

For a commercial source list of application equipment manufacturers please write to: Loctite Corporation 705 N. Mountain Road, Newington, CT 06111

REFERENCES:

1. Haviland, Barseness, and Barbeau; "Loctite Guide to Designing with Threaded Fasteners" 1986, LT-825-A

2. Andreasen, Haviland, and Tokarski; "Technology of Sealing Threaded and Flanged Systems" 1986, LT-1087

3. Girard S. Haviland; "Machinery Adhesives for Locking, Retaining, and Sealing" 1986, Marcel Dekker, Inc.

4. Society of Automotive Engineers; "Design Guide for Formed-in-Place Gaskets" 1989, SAE J1497

5. Society of Automotive Engineers; "Structural Gasketing" 1990, SAE #900200

6. Society of Automotive Engineers; "Combining Leakage in Vehicle Assembly and Operation" 1984, SAE #841149

7. Society of Automotive Engineers; "Advances in High Performance Mechanical Fastening", 1980, SAE #800451

8. Bonzak, Christie, Oda, Sykes, Wood; "Education and Material Quality Control" SAE Sealant Subcommittee, Jan. 30, 1984

9. Aramian, Beckett, Bonzak, Christie, Menko, Vorobel; "Engineering Design, and in-process Handling" SAE Sealants Subcommittee, Feb. 6, 1984

10. Loctite ACG; "Underhood Chemistry; The Silatech Solution" 1988, Loctite Corporation

11. Loctite UK; "The Loctite Design Programme: Sealing Flat Surfaces with Anaerobic Gaskets" 1988, Loctite UK