

**AIChE Paper Number 125f
Presentation ID# 351282**

**FLANGE CORROSION: PREVENTION AND MITIGATION THROUGH
BETTER GASKETING**

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Abstract

Typical bolted joints utilize gaskets that leave crevices at the flange ID. Coupled with aggressive chemicals, dissimilar metals, and typically conductive sealing materials, flange corrosion is prevalent in the chemical processing, petrochemical industries and beyond. Corrosion and subsequent leaks cause unplanned downtime, costly flange repair, or the need to apply an industrial clamp to maintain operation.

A special composite gasket utilizing semi-metallic and non-metallic components has demonstrated the ability to eliminate crevices, to prevent the onset of corrosion, to seal existing flange corrosion, and to resist further deterioration. This offers plants a cost effective flange corrosion management system that can increase plant runtime, greatly reduced cost and time spent on flange repair, and increase safety and joint reliability, all while eliminating corrosion related clamps. This gasketing concept, design, and application history will be discussed in this paper.

Flange Corrosion

Operating units plagued with flange corrosion continually face repair and replacement challenges that increases maintenance and operation costs and increase downtime for repair or replacement. If the corrosion is aggressive enough to cause a leak during operation, the plant faces additional consequences of loss of containment. Flange corrosion is likely preventable.

Common gaskets contain two features that can lead to aggressive flange corrosion. First, they leave crevices at the flange ID. Second, most utilize graphite as the main sealing material which may further propagate corrosion in solutions that allow the creation of an electrochemical cell.

Flange Crevices

Consider bolted flanged connections using different gaskets in Figures 1 through 3. In each situation there is a crevice or gap at the ID of the gasket to the bore of the pipe. Furthermore, even if a spiral wound has an inner ring, it will not necessarily be fully engaged when compressed, leaving crevices above and below the inner ring. It is possible for aggressive media to gather in crevices and initiate flange corrosion.

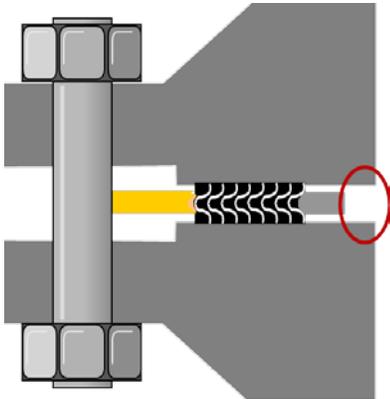


Figure 1. Standard spiral wound with inner ring – crevice at ID

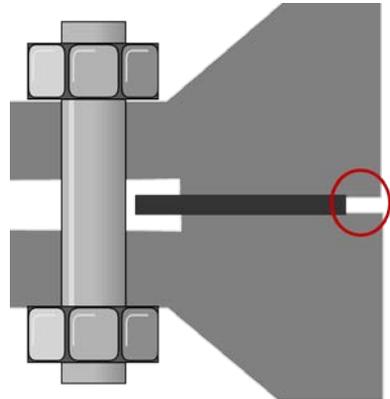


Figure 2. Standard cut sheet gasket – crevice at ID

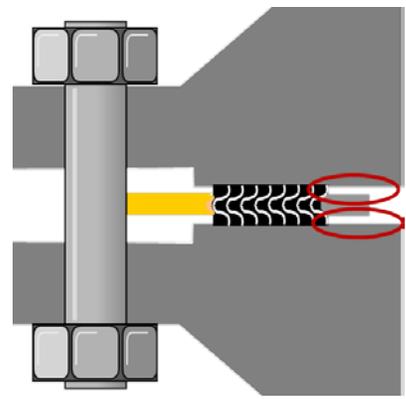


Figure 3. Crevices above and below spiral wound inner ring

Recent flange corrosion history in hydrofluoric acid has also shown that thick, rigid inner rings – for example a kammprofile inner ring shown in Figure 4 – will also leave crevices. Insufficient compression, combined with natural flange bending and rotation, prevent full engagement of the kammprofile inner ring. Bolt load is around the OD of the flange which causes bending around the bolt circle and the flange to lift off the gasket ID. Refer to Figure 5.



Figure 4. Spiral wound with kammprofile inner ring

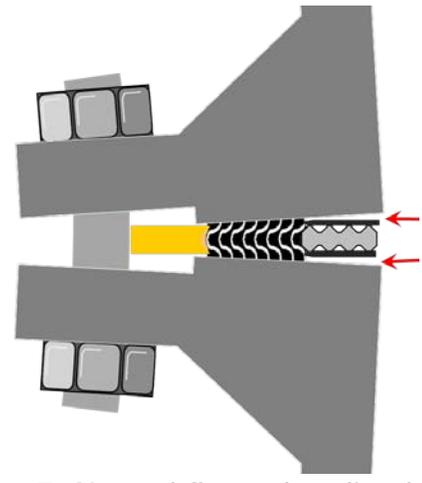


Figure 5. Natural flange bending leaving crevices above a kammprofile inner ring.

Conductive Sealing Materials

Flexible graphite is the most common sealing material due to its wide range of chemical resistance, wide temperature capability, low cost, excellent sealing performance, and capacity for being fire safe. However, graphite is an excellent electrical conductor and can play an important role in corrosion initiation and propagation depending on service conditions (1). Studies show that when graphite is in contact with process chemicals that ionize in solution, like acids and seawater, corrosion is significantly more aggressive compared to a non-conductive material in contact with the process fluid (2).

An example of the crevice corrosion described in both sections above is shown in Figure 6 for a typical raised faced flange.

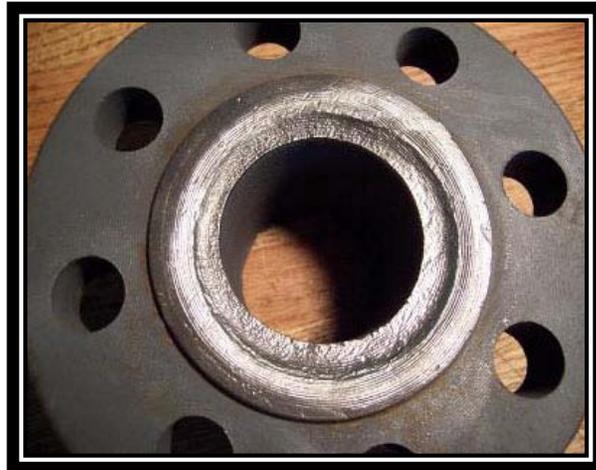


Figure 6. Crevice Corrosion at the ID of the flange

Consequences

A unit experiencing flange corrosion may eventually be able to predict the rate of decay in hopes of catching it prior to leak or major loss of containment. This requires more frequent shutdowns for preventative maintenance. Such maintenance is very costly based on the level of damage, which at minimum requires weld build-up and re-machining the flange face if not complete removal and replacement of the flange. When corrosion is on dozens of flanges within a unit, significant time and dollars are continually spent on flange repair and replacement.

Most plants don't have the luxury of shutting down for frequent flange repair. If the flange corrosion progresses to a point at which leak occurs (see Figure 7), an industrial clamp must be applied to contain the leak and sustain operation. Industrial clamps have become a tolerable necessity for maintaining production but are a bandage for the real problem. The above risk, repair time, and funds spent are preventable with the right gasket.

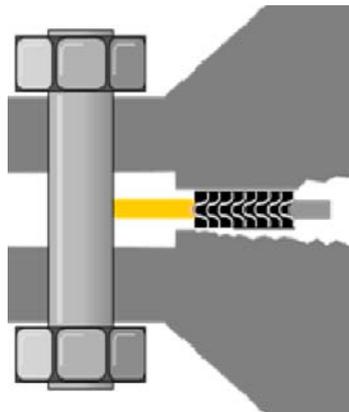


Figure 7. Corrosion eventually extends across the sealing face to the point of leak.

Corrosion Prevention Gasket

A special composite gasket containing both metallic and non-metallic components was introduced to combat the problems described above. This special composite gasket will be referred to as the Corrosion Prevention Gasket, or CPG, for this discussion.

CPG Design – Inner Ring

CPG combines a kammprofile sealing element with a ¼" thick inner ring made of highly compressible and conformable, fully restructured PTFE (henceforth referred to as fr-PTFE). This is the most important component of the CPG and is essential to eliminating crevices. This in turn prevents the onset of corrosion. The ¼" thick inner ring is designed to the pipe bore (specifically 1/16" outside to account for minor misalignment) to eliminate any crevices at the ID. Its thickness also eliminates crevices that might be left from a rigid inner ring. Refer to Figures 8 & 9 for cross-sectional representation in a bolted joint before and after compression.

Other features critical to the PTFE inner ring material are its fully restructured PTFE fibers, also known as biaxially oriented PTFE. The manufacturing process involves orienting the individual PTFE fibers in both x & y directions through a multi-layering process. Restructuring of the fiber aids in preventing cold flow, or creep relaxation, of the PTFE which is typical of virgin, skived, and semi-structured PTFE sheet. This is followed by a heating step to fully sinter the sheet. Fully sintered PTFE is more thermally stable, creeps less at elevated temperatures, and adds strength. The fr-PTFE used in the CPG contains no filler material allowing it to be universally compatible with almost all known chemicals.

It is important to note that fr-PTFE is typically 60 to 70% compressible (3). It seals best when such compression is achieved as all the micro-voids within the structure are closed and the sheet is more densified. Sealing can be achieved with less compression, but with more load, it becomes less permeability, has higher tightness, and lower leak rates/emissions. This generally applies to all fr-PTFE and expanded type PTFE sheet.

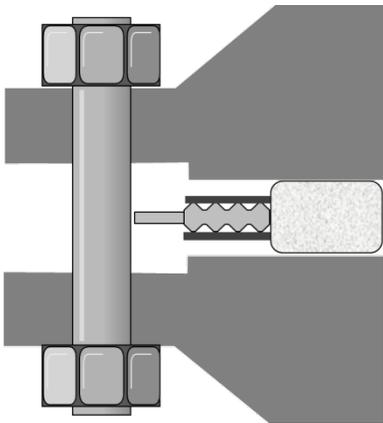


Figure 8. CPG, ¼" inner ring designed to eliminate crevices; Kammprofile is the primary seal

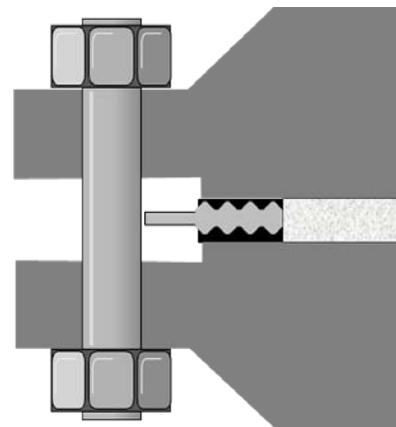


Figure 9. CPG inner ring fills all crevices upon compression

CPG Design – Primary Seal

The primary seal is a kammprofile, also known as grooved metal with covering layer, or GMCL and is illustrated in Figure 8 and 9 above. A solid metal core machined with concentric serrations and faced with a sealing material provides for high tightness and low emission sealing. Because of its solid metal core construction, it is capable of sealing Class 150 to 2500 flange applications. Metallurgy is selected to fit the service. Facing may be chosen from the common options of PTFE, graphite, and exfoliated vermiculite. Graphite is acceptable in the CPG because it is isolated from corrosive media by the fr-PTFE inner ring, and graphite remains the standard choice. Another fire safe and high temperature facing option is exfoliated vermiculite. Figure 10 illustrates a complete gasket.

It's important to note that the CPG kammprofile core is not of standard 1/8" thickness. It is specifically designed thinner (0.08 to .094" depending on sheet metal availability) for the purpose of achieving optimal compression of the inner ring. If the core were the typical 1/8" thick, the ¼" inner ring would only achieve 50% compression. This situation might occur when CPG is used on corroded flanges (discussed later), but when used on repaired or new flanges in good condition, the preferred design is to achieve full compression of the inner ring.



Figure 10. NPS 2" Class 150 Schedule 40 CPG

Reduced Load Requirements

A key feature of the CPG is the overall low load required to compress the gasket. Design concepts that seal to the bore of standard flanges have to account for the additional gasket area to be sealed. Standard flanges have a predetermined available bolt area designed to seal standard gaskets which are not designed to the bore. The CPG is comprised of two low seating stress components. Fr-PTFE minimum seating stress for steel flanges is 1,600 psi (4). A kammprofile's minimum seating stress is 2,500 psi (5).

Compare this to a gasket that utilizes a spiral wound as the main sealing element (minimum seating stress 10,000 psi) and a kammprofile inner ring taken to the bore (shown in Figures 4 & 5). Gaskets combining spirals and kammprofiles designed to the bore require tremendously high bolt stresses to seal the full gasket area. On some NPS and pressure class combinations, one would have to exceed flange or bolt yield stresses to compress the full gasket area. Furthermore, compressing the full gasket area on some sizes won't be possible as flange rotation will occur preventing a kamm inner ring from ever engaging. For these reasons, this style is not ideal for corrosion prevention.

Inner Ring Retainer

To prevent the inner ring from falling out, machined 'blades' extend from the kammprofile core and are placed into a groove around the OD of the fr-PTFE. Refer to Figure 11 & 12. Blade quantity increases with gasket diameter. Less than NPS 2" CPG utilizes an interference fit.

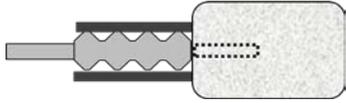


Figure 11. Cross Section of blade retainer



Figure 12. Photo of blade retainer

Emergency Seal for Existing Corrosion

The CPG has been found to seal existing flange corrosion in emergency situations. As long as the corrosion has not extended to the ID of the kammprofile core, the CPG may be considered for sealing against flange corrosion and resisting further flange deterioration. To allow for this possible use, the CPG core is dimensioned slightly more narrow than standard and also further outboard so sealing will begin immediately at the OD of the raised faced. See Figures 8 and 9 above. As depicted in Figure 13, the ¼" thick fr-PTFE inner ring conforms to the corroded flange in the same fashion described previously to eliminate crevices.

While most plants utilize this option as a last resort and opt to repair or replace flanges, there are instances where clamps are not available or repair cannot be achieved quickly at a reasonable cost. An emergency gasket may be necessary to seal against existing corrosion.

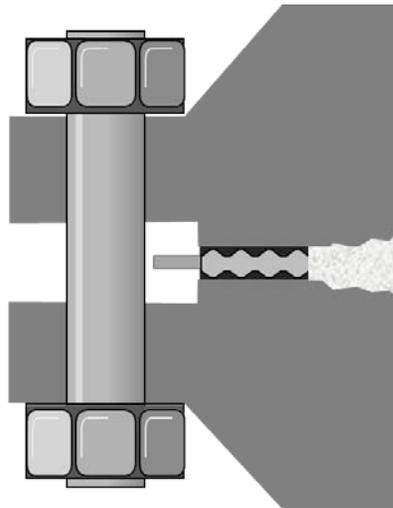


Figure 13. CPG sealing existing corrosion; Corrosion is inboard of the kamm ID.

Successful Applications

Successful Application 1 – Hydrofluoric Acid Alkylation

The majority of HF acid alkylation systems are designed with carbon steel flanges. Although this metallurgy is acceptable, in certain areas of the alkylation process where there is higher risk and tendency for moisture to enter the system, flanges often corrode like that shown in Figure 6. Coupled with the requirement to use graphite based gaskets for compatibility and fire safety, corrosion can easily be initiated and accelerated. Operating with industrial clamps is a fact of life in these plants and every turnaround is lengthened by costly, detailed work to repair and replace corroded flanges.

To test the capability of the CPG design, this HF Alkylation unit installed three CPGs with Monel cores for testing purposes at various times. After no leaks during 3 to 6 months of operation, the CPGs were removed. Flange surfaces were evaluated and found to be in good condition.

A small shutdown was scheduled for January 2012 and twenty CPGs were installed in problem areas, the majority being clamped locations that always develop leaks right after startup. During the TAR, flanges were inspected, in some cases replaced, in others re-surfaced, and still others had no remediation. New CPGs were installed. Installation technique was no different than those used for the previous spiral wound gaskets – casual bolt up practices either by feel or with impacts (6). Only a select few flanges utilized a clicker torque wrench. Sizes included ¾" to 8".

Safety was first priority as clamps were ready in case of leakage, and operations were in tune to watching these areas more closely due to their history of leak with spiral wound gaskets.

After just over 2 years of operation, not one single clamp has been needed. Only one very minor leak occurred on a Depropanizer pump suction block valve and was determined to be from poor installation. It was stopped by simply re-tightening the bolts. This flange has been inspected monthly with no new buildup seen so there was no need for a clamp. (7)

Successful Application 2 – Hydrochloric Acid

The phosgene tower at this specialty chemical manufacturer is a dry system. However when moisture accidentally enters the tower, phosgene reacts to produce hydrochloric acid which aggressively corrodes the carbon steel flanges. Every plant must balance the need to operate safely (which is paramount) while satisfying budget constraints and customer order requirements. After evaluating the NPS 1" Class 150 Schedule 160 corroded flange shown in Figure 14, measurements indicated the corrosion did not extend to the kammprofile ID of a CPG 1" 150. A CPG with an Alloy C-276 core was installed on this flange as well as a 2" 300 Schedule XXS. Although the manufacturer considers this a temporary fix until they can shutdown long term to replace each flange, these CPGs installed on May 2013 have allowed them to operate continuously leak free as of March 2014.



Figure 14. NPS 1" Class 150 SCH 160 Carbon steel flange corroded by HCl.

Successful Application 3 – Offshore

The need for a corrosion prevention gasket initiated on offshore platforms where corrosion ranked second for frequency in initiating loss of hydrocarbon containment (8). Systems holding stagnant seawater especially tend to corrode, drastically reducing operational efficiency. Multiple platforms, in the North Sea in particular, now use hundreds of CPG gaskets to prevent corrosion, seal existing corrosion, maintain longer operation, and reduce costs of flange repair and maintenance.

CPG has been very beneficial in produced water and firewater systems since 2009 and is the gasket of choice on piping systems acting to cure and prevent corrosion problems. Additional designs have been developed and employed for RTJ and subsea flanges as well.

Conclusion

Managing corrosion is challenging in all aspects as each plant must balance safety, containment, operability, reliability, and cost. The Corrosion Prevention Gasket discussed in this paper offers a cost effective tool to not only proactively prevent corrosion but also mitigate the burden of existing corrosion should the need arise.

References

- (1) A. Turnbull, Impact of graphite gasket / duplex stainless steel couples on crevice chemistry and likelihood of crevice attack in seawater, proceedings of NACE Corrosion 1998, Paper No 682.
- (2) Crevice corrosion testing of 254SMO flanges with different gaskets in seawater, Troels Mathiesen, Force Technology. 11023385-2
- (3) Determined via ASTM F36 Compressibility testing

- (4) Estimated by Flexitallic Engineering Department
- (5) Estimated by Flexitallic Engineering Department; Often 5,000 psi is preferred in practice
- (6) Flexitallic does not recommend casual bolt-up practices on process lines and recommends more precise techniques on critical joints. See ASME PCC-1-2013 Guidelines for Pressure Boundary Bolted Flange Joint Assembly and ASME B31.3 Process Piping Design for defined categories of service.
- (7) Letter to Flexitallic written by Engineering Manager, Refinery with Licensed UOP Alkylation Unit, Louisiana, April 15, 2013. Subsequent follow-up of results by Flexitallic to the alkylation unit March 13th, 2014.
- (8) Guidance for corrosion management in oil and gas processing, Energy Institute, London, May 2008