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IMPROVED BOLTED JOINT RELIABILITY: INNOVATIVE GASKET, UNSURPASSED RECOVERY

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Abstract

Current high performance and critical service gasket technology predominantly consists of spiral wounds and kammprofiles. After roughly a century with no significant advancement to high integrity semi-metallic sealing, spiral wound and kammprofile weaknesses are more apparent as production facilities push runtimes longer at higher pressures and temperatures.

A recently pioneered advancement in the semi-metallic gasket industry combines attributes of the spiral wound and kammprofile to offer a new seal with unsurpassed recovery called a 'Change' gasket. This paper discusses the limitations of current gasketing followed by the concept, design features, performance data, and successful applications of this innovative Change gasket.

Introduction

Plant Operability and Reliability has evolved and currently sets goals of 100% leak free operation. Strict low emission compliance is in the immediate future if not already present. As a potential source for leaks and emissions, bolted joints are a target area for improvement. Improved gasket technology is a cost effective way to produce immediate results. Furthermore, as operating units upgrade and debottleneck requiring gaskets to last longer and seal tighter, shortcomings of current gasket technology become apparent as well as the need for improvements that are not susceptible to typical methods of failure.

Current Technology

All gaskets come with their own advantages and disadvantages. Each unit must evaluate which gasket(s) best suits them based on flange type and condition, temperature, pressure, chemical, criticality of service, desired service life, etc. Due to the multitudes of gasket types and materials available, this paper will only make mention of some but focus first on how spiral wounds and kammprofiles led to the invention of the Change gasket.

Sheet Material

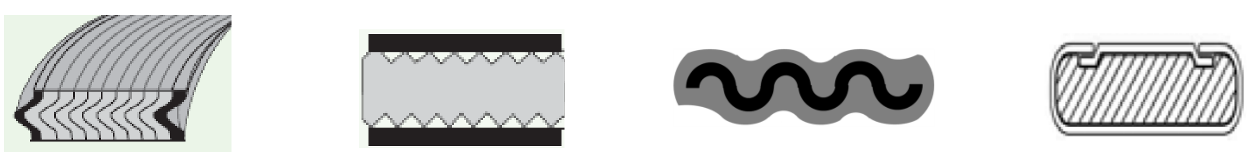
The chemical industry has traditionally used various PTFE, elastomer, and fiber sheet materials. Three common challenges with sheet material are 1) the higher risk for blowout, 2) the multitude of types available, and 3) most are not considered fire safe.

Regarding blowout protection, sheet sealing material contains no outer metal retaining ring like a spiral wound gasket. Although sheet material can be tested for its ability to resist blowout, there is no guarantee against it. For this reason, many chemical manufacturing facilities chose spiral wound gaskets on steel flanges as their failure mode is to leak but not blowout. A second challenge of sheet material is that specifying and warehousing multiple types typically leads to the wrong gasket put in the wrong service. Major outages have been attributed to a small error like this. Finally, despite various types of fire test protocols (API 6FB being the most strict and fire test of choice at present), the only sheet materials generally considered fire safe are graphite and exfoliated vermiculite.

Semi-Metallic

Gaskets included in the semi-metallic range are spiral wounds (SW), grooved metallic with covering layer (GMCL) also known as kammprofiles, corrugated metal with covering layer (CMG) and double jacketed (DJ). DJ gaskets were once a common equipment gasket but repeated failures due to poor recovery and difficulty of sealing metal-to-metal have rendered them obsolete. CMGs have presented themselves to be a lower upfront cost option but in general have shown a history of blow-out (even in recessed flanges), core failure, leakage and should not be used on raised faced flanges *(1)*.

The two most historically successful and well established types in this category are the spiral wound and kammprofile. The spiral wound was invented by Flexitallic in 1912 and features thin metal winding wire preformed into a ‘v’ shape and then wound with a soft filler material. The kammprofile originated in Germany almost a century ago and features a solid metal core with serrations machined on the face covered by a soft sealing material called facing.



SW GMCL CMG DJ

Figure 1. Typical cross section of semi metallic gaskets.

Disadvantages of SW and GMCL

Spiral Wound Limitations

Spiral wounds are inherently resilient due to their spring-like profile but are not without limitations. ASME B16.20 recommends inner rings on spiral wounds with graphite filler and inner rings are mandatory for large diameter and higher pressure classes as well as all PTFE filled spirals **(2)**. Even with an inner ring and outer locating ring, handling of large diameter spirals can be precarious and still spring apart.

Although spiral wounds are designed to recover, highly cyclic circumstances demand a special winding wire called Heat Treated Inconel X-750 (HT X-750) that roughly doubles the winding wire's usable recovery (recovery while bolted in a live joint) (3).

Another disadvantage of a spiral wound is its higher minimum seating stress of 10,000 psi. More than 10ksi is preferred to affect a tighter seal with lower emissions. Low stress construction is available, but they are only suitable for low pressure applications. Achieving such a high minimum seating stress is very difficult when redesigning a gasket for existing, under-bolted flanges. For example, a common task of a gasket designer is to replace double jacketed gaskets for a leak-prone heat exchanger. Unfortunately, most heat exchanger flanges were designed with minimum available bolt load to pass the Boiler & Pressure Vessel (B&PV) Code calculations which do not take into consideration the pass partition area, relaxation, leak performance, tightness, or emissions. In such cases, there is insufficient bolt load to upgrade to a spiral wound gasket as its minimum seating stress is too high (higher than a DJ).

Kammprofile Limitations

Kammprofile gaskets were recently added to ASME B16.20 as Grooved Metal gaskets with Covering Layers (GMCL). GMCL have shown better handleability than spiral wounds, have the advantage of a low minimum seating stress (2,500 psi (4) but often 5,000 is preferred in practice), and are capable of low emissions sealing. Unfortunately a kammprofile cannot recover very well on its own. The gasket itself is solid metal. Its only resiliency comes from the facing material itself which is very minimal for the overall gasket. Industry has found success with GMCL gaskets but when the flange thermal cycles or sees high differential thermal expansion common in heat exchanger flanges, kammprofile sealed joints typically need the addition of spring washers and need a re-torque with every cycle if not hot torquing (re-torquing a live joint).

These scenarios add a level of complexity, man hours, and even risk. Regarding complexity, spring washers require a specific orientation when installed. Each washer is also designed for a specific load. That load must be acceptable to achieve desired seating stress on the gasket without over-stressing it. Precision installation (hydraulic torquing or tensioning preferred) is recommended to achieve that specified load as other more casual methods of installation are not accurate enough. Also consider the time involved to re-torque every thermal cycled bolted joint. It can significantly delay unit start-up. Finally, if a leak occurs during operation, personnel are put at risk when asked to hot torque.

The Change Gasket

The Change gasket is a technological advancement to semi-metallic gaskets meant to further reduce bolted joint leaks and emissions while overcoming existing gasket limitations.

Design

The Change gasket design combines aspects of both a traditional spiral wound and a kammprofile, improving upon both using reinvented winding wire approximately five times thicker than traditional spiral wound wire. The new heavy gauge metal wire is formed with a functional edge that simulates the serration profile of a grooved metal gasket. The heavy wire is wound like a SW, incorporating filler material, and is held together via a unique and optimized laser welding process. Change is finished with layers of facing similar to a kammprofile. Refer to Figures 2 through 5 for visual representation.

Figure 2. Change gasket cross sectional cutaway showing construction: wound like a spiral wound, faced like a kammprofile

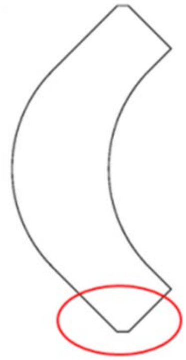


Figure 3. Heavy gauge winding wire with an edge that simulates the serration of a kammprofile

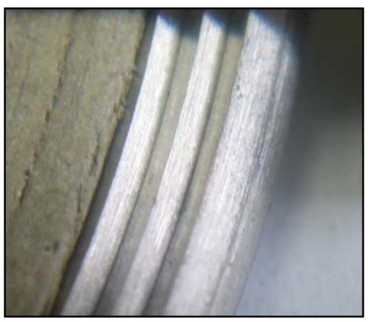


Figure 4. Profile of Change wire wound together beneath the facing

Figure 5. Laser weld at Change gasket OD

The estimated minimum seating stress for a Change gasket is 6,400 psi, making it a low seating stress option over DJ and SW gaskets. Upon evaluation, the Change gasket was found to be a robust and incredibly resilient semi-metallic gasket capable of outperforming even the HT Inc X-750 spiral.

Recovery

Gasket recovery is essential to overcome temperature swings inherent to the chemical manufacturing process; to overcome temperature swings from planned and unexpected shutdowns (not every gasket is replaced); to overcome differential thermal expansion and contraction between two flanges (typical of heat exchangers); and to overcome natural flange bending and stresses from adjoining piping and equipment.

Compression & Recovery

A basic compression/recovery test measures the distance a gasket compresses under a given load and measures the distance the gasket recovers after the load is removed.

Compression is traditionally expressed as a percentage of the initial thickness. Recovery is expressed as a percentage of compression. A common error is to compare recovery directly. Because recovery is a function of compression, compression must be taken into consideration. Table 1 shows results of common semi-metallic gaskets. To aid in direct comparison, a third column shows recovery compared to initial thickness so compression is considered. The gaskets were fabricated in house to normal Flexitallic Engineering Standards. In all cases the materials of construction were 300 series stainless steel and graphite except for the SW with Heat Treated Inconel X-750 winding.

Table 1. COMPRESSION vs. RECOVERY, 18,000 psi (124 MPa) Gasket Stress

Gasket Style	% Compression	% Recovery	% Recovery (as a function of Initial Thickness)
Change	30	34	10.2
SW w/inner, HT X-750 wire	24	34	8.2
SW w/inner	30	26	7.8
DJ	26	7	1.8
Kammprofile	25	6	1.5

A high level of stored energy gives the Change gasket superior recovery. It has the most resiliency of all those tested, recovering 10.2% of its initial thickness, 6.8 times more than a kammprofile, 30% more than a standard spiral, 24% more than the HTX750 spiral previously used for its superior recovery.

Thermal Cycling Testing

The sealing industry and some major end users have developed series of tests to determine gasket sealing characteristics and constants. Such tests can be used internally at a gasket manufacturer as part of a quality assurance program or product development. Certain tests are also specified by the end user for type approval testing. One example, used for over 20 years for gasket prequalification, is the widely known Shell Thermal Cycle test. An excellent way to assess a gasket's useable recovery is to perform this thermal cycle testing.

This end user designed rig and test (see Figures 6 and 7) employs two NPS 4 inch ASME B16.5 Class 300 raised face flanges, fitted with internal heating elements. Internal heating best simulates the real world compared to moving blind flanges in and out of an oven to heat and cool. Gasket compression is achieved through hydraulically tensioning standard ASTM A193 B16 UNC bolts to a pre-set nominal stress of 290 MPa (42 ksi). Test pressures and temperatures are kept within the B16.5 Class service envelope. An initial room temperature assembly screening test is carried out in which the assembly is pressurized with nitrogen to 51 bar (740 psi). The maximum allowable pressure drop after 1 hour is 1 bar. The assembly is then subjected to thermal cycling.

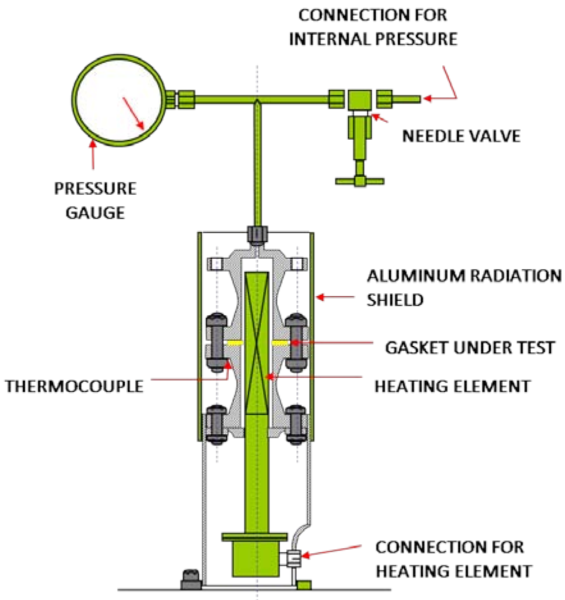


Figure 6. Thermal cycle test rig schematic

Figure 7. Thermal cycle test rig photograph

To test the Change gasket, a well know oil & gas refiner suggested a test with 24 thermal cycles to compare performances of commonly used semi-metallic gaskets. The requested test was to simulate the potential temperature excursions of a moderately efficient refinery between major outages (approx. every 4 years) with no bolted joint re-torque. The assembly is purged and heated to 320°C (608°F) at a rate of 2°C/minute followed by pressurization with nitrogen to 33 bar (478 psi). The assembly is then isolated and left at temperature for 1 hour after which the pressure is recorded. The rig is allowed to cool to room temperature before the next thermal cycle begins. Each thermal cycle takes approximately 24 hours to complete and is run without stoppage until completion of the cycles. Maximum allowable pressure drop after 24 cycles is 1 bar (14.5 psi).

The gaskets were fabricated in house to normal Flexitallic Engineering Standards with the exception of the corrugated metal gasket (CMG) which was purchased through a distributor. In all cases the materials of construction were 300 series stainless steel and graphite except for the SW with Heat Treated Inconel X-750 winding. Both SWs had inner rings. Results show in Figure 8.

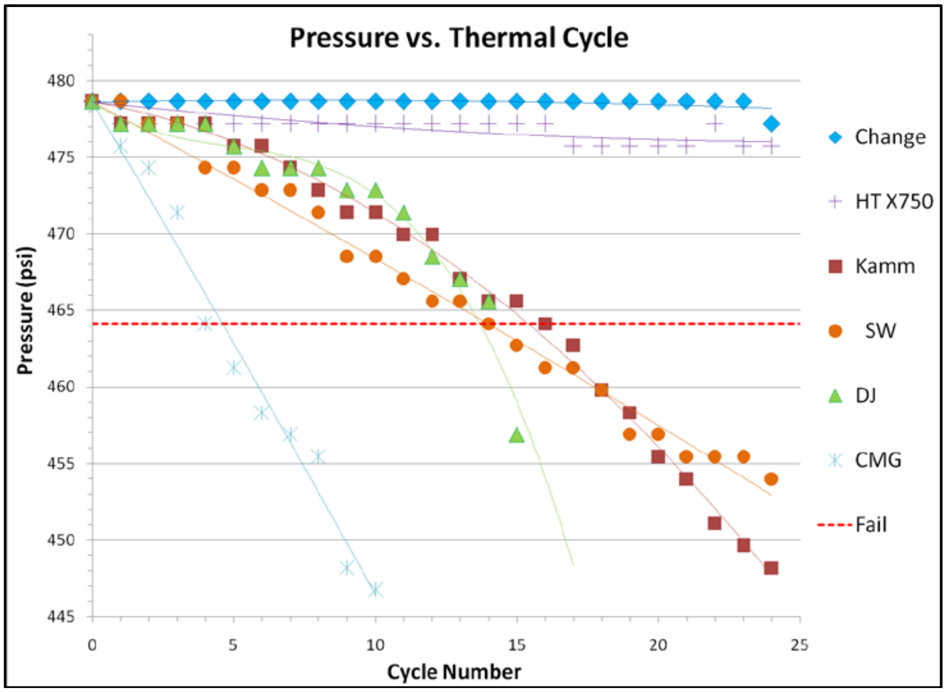


Figure 8. Thermal Cycle Test Results - 24 cycles to 320°C (608°F)

The Change gasket lost only 1.5 psig total and even outperformed a spiral wound with HT X-750 winding wire which was previously considered the best gasket available for cycling applications. Change is now a more cost effective alternative. Note that common gaskets such as a spiral wound and kammprofile were not able to pass. The extremely poor performance of the CMG is attributed in part to the rig flange design being raised face. CMG's are not generally recommended for raised faced flanges.

Successful Applications

Although the Change gasket can be used on standard raised face flanges, ideal applications are heat exchangers. Not only can there be unit thermal cycling, heat exchangers offer the challenge of thermal variation across the face of a flange (for example a multi-pass shell-n-tube heat exchanger) but also sheering across the gasket face due to differential thermal expansion and contraction between the shell, tubesheet, and channel flanges. Since the Change gasket was introduced in 2012, several successful applications have been documented.

Successful Application 1 - Nitric Acid Heat Train

Nitric acid production starts by reacting ammonia & air over a platinum gauze catalyst. The reaction is highly exothermic generating temperatures up to 1700°F. A series of heat exchangers called the Heat Train follow the reactor. The oxidation reaction continues while opposing streams capture the generated heat. Thermal cycling to ambient temperature occurs every 70 - 90 days when the catalyst is changed. If the gauze trips between a catalyst change, the unit also sees a fairly abrupt heat cycle. Therefore, heat train exchangers are often cycled but the gaskets are not changed. Cycling ranges from ambient to 850°F on the low end and ambient to 1400°F on the high end (5). Since September 2013, Change gaskets have successfully prevented leaks and downtime while improving bolted joint reliability in nitric acid heat train exchangers. Application details at three nitric acid producers are shown in Table 2.

Table 2. Change gaskets in nitric acid heat train exchangers.

Since	Chemical	Process Conditions	Previous Gasket	Gasket details	Misc.
Sept 2013	NOx, O2, Natural Gas	850 F, 550 psi	GMCL	316L/316L/TH, 31-7/8" OD x 0.177" wire	Qty 4, Natural Gas Preheater
Oct 2013	NOx, O2, Steam	865F, 150 psi	DJ	304/304/TH835, 35-15/16" OD, 0.177"	Qty 2, Steam Superheater
Oct 2013	NOx, O2	Tube 1000F, Shell 1400F		42-7/8" OD with & w/out ribs, 347/347/TH835/347 69-1/8" OD x 0.177"	2 ea, Qty (6) total; Tail Gas Reheater
Nov 2013	NOx, O2	1000F max, 125 psi	DJ, SW	304/TH835, 34-1/8" OD, 0.177" wire	Qty 1, Tail Gas Heater

As indicated in the gasket details above, improved handleability of Change gaskets over traditional spiral wounds has been accomplished for larger diameter gaskets by creating a taller 0.177" wire, compared to a 0.125" Change wire for smaller diameters.

Successful Application 2 - Exchangers with Nubbins

Some exchangers have been designed with stress raising nubbins on the sealing face for use in conjunction with double jacketed gaskets. Figure 9 illustrates such a joint. The intent was to increase gasket stress by concentrating applied bolt load over a smaller area. Tests including the 24 day thermal cycle test detailed above and the original RaST testing performed at TTRL (6), combined with history of performance, have confirmed that DJs are not idea for cycling or radial shear circumstances like heat exchangers.

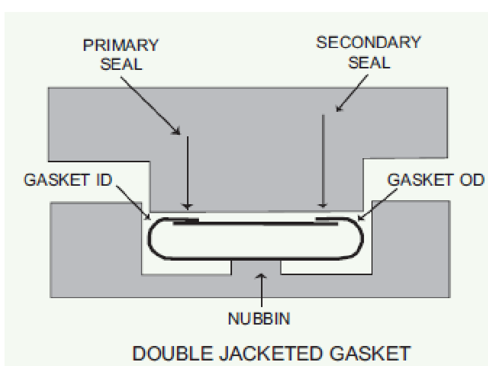


Figure 9. Tongue-to-groove joint with stress raising nubbin and a double jacketed gasket

Replacing a double jacketed gasket requires machining off the nubbin, an expensive prospect when every gasketed connection of an exchanger has a nubbin. One particular refinery considering the Change gasket was seeking an alternative to spending ~ $10,000 per flange to machine the nubbin. There intent was to eliminate the use of DJ gaskets to reduce leaks and improve bolted joint reliability. In response via lab testing, a 9 x 10" Change gasket was compressed in a tongue-n-groove joint with a standard 1/64" tall x 1/8" wide nubbin. Pressure testing was conducted and leakage was measured in bubbles as the internal pressure was increased by 250 psi nitrogen every 5 minutes. Results shown in Table 3.

Table 3. Bubble test results, Change gasket sealing against nubbin

Internal Pressure	Bubbles in 5 minutes, 30,000 psi gasket stress	Bubbles in 5 minutes, 15,000 psi gasket stress
250	0	0
500	1	0
750	1	0
1000	0	0
1250	0	0
1500	0	0

The Change gasket performed successfully in lab testing. Inspection of the tested gasket showed that it maintained its structural integrity while achieving little to no recorded leakage. A cross sectional cutaway of the tested gasket is shown in Figure 10.

Figure 10. Cross Section through Change tested on stress raising nubbin

Subsequent to this lab testing, the refinery installed 30 Change gaskets on exchanger flanges with nubbins in January 2013. Applications were mostly hydrocarbons; temperatures ranging from 275 - 440°F; pressures ranging from 165 - 400 psi; size ranging from 33.75" ID to 42.88" OD, some with ribs. All gaskets have sealed with no leak to date and all have been through a full thermal cycle that would have normally caused a DJ to leak. Additional applications over nubbins have been added at other end users since this success. Gasket design and installation is critical. The Change must be centered over the nubbin.

Range of Applications

Change gaskets are currently solving sealing problems in industries like Chemical Processing, Metal Manufacturing, NGL, Nuclear Power, OEM, Petrochemical, Power Generation, Pulp & Paper, and Refining. The first installation dates back to 2012. The majority of applications thus far have been those where all other options have failed. Therefore each success is a true testament to the Change gasket's ability to achieve and maintain a seal under extreme conditions.

Conclusion

When compared to rotating equipment and pressure vessels, bolted connections are not the first item considered in the scope of reliability. However, they can shut down a unit just as easily. Immediate improvements can be made to overall reliability by upgrading bolted connections with gaskets able to withstand all the standard and unexpected cycling within a unit and within a piece of equipment. The new Change was designed for this purpose and with recovery characteristics surpassing even the most successful gaskets in the industry. It offers a unique opportunity for plants to further reduce leaks and emissions. Based on test results and current in-service performance, the Change offers the potential to reduce complexity by eliminating spring washers, reduce man hours required for re-torque, and reduce risk associated with hot-torquing (7).

References

(1) Based on decades of Flexitallic Applications Engineering history and failure analysis

(2) Standard ASME B16.20 - 2012 Metallic Gaskets for Pipe Flanges

(3) Flexitallic Design Criteria page 28

(4) Per Flexitallic Engineering

(5) Based on application information from three nitric acid producers

(6) Radial Shear Tightness testing conducted at TTRL in Montreal, 2001; Results available through Flexitallic

(7) Flexitallic recommends proper installation with all gaskets.