

GASKET HANDBOOK
1st Edition



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Acknowledgements

The FSA and ESA are pleased to recognize the co-operation of their Member Companies in the preparation of this document. Without their support, this document would not have been possible. Individuals who have made a particularly significant contribution to this publication include:

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FOREWORD

This Handbook was produced by the Gasket Division of the Fluid Sealing Association (FSA) and the Flange Gasket Division of the European Sealing Association (ESA). This Handbook is part of a mutual commitment to industry consensus technical education for end users, contractors, distributors, students and others interested in gaskets. It is focused on technical information for gaskets as components of bolted flange connections. This Handbook is provided in the public interest to help ensure bolted flange connection integrity; with maximum safety and environmental compliance.

Both the Gasket Division of the FSA and the Flange Gasket Division of the ESA are one of several divisions with a specific product technology focus. As part of their mission they develop joint publications, such as the newly revised ESA/FSA Flange Gaskets – Glossary of Terms and Guidelines for Safe Seal Usage, as well as the pocket-size FSA/ESA Gasket Installation Procedures which are available in eight languages. These are intended to complement the more detailed manufacturers' documents produced by the member companies.

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The FSA and ESA also support development of harmonized standards in all areas of fluid sealing technology.

Founded in 1933, the FLUID SEALING ASSOCIATION (FSA) is an international trade association. Member companies are involved in the production and marketing of a wide range of fluid sealing devices primarily targeted to the industrial market. FSA membership includes a number of companies in Europe and Central and South America, but is heavily concentrated in North America. FSA members account for a majority of the manufacturing volume of fluid sealing devices in the Americas market.

The EUROPEAN SEALING ASSOCIATION (ESA) is a pan-European organization established in 1992, representing a strong majority of the fluid sealing market in Europe. Member companies are involved in the manufacture and supply of sealing materials, crucial components in the safe containment of fluids during processing and use.

For a current list of FSA and ESA members, refer to the following websites:

Fluid Sealing Association

www.fluidsealing.com

European Sealing Association

www.europeansealing.com

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PREFACE

Successfully sealing a bolted flange connection is dependent on all components of a well-designed system working together, effectively and safely. This Handbook provides technical information on gaskets as a constituent part of a bolted flange connection, typically employed in chemical, petrochemical, refinery, power plant and other industrial facilities. It includes guidance to plant engineers on specifying gaskets; maintenance operators on installing and trouble-shooting bolted flange connection leaks, as well as purchasing personnel on the important functional distinctions between various gasket types.

Contents include definition of mechanical considerations for a bolted flange connection, important considerations for flanges, fasteners, and installation best practices; with a focus on gasket selection and gasket-to-flange system interaction. Gasket storage and handling also are addressed. This Handbook is arranged and detailed to serve as a useful tool for those who presently use or are interested in using gaskets. Contents are organized for the reader to quickly and efficiently find the information needed, while still maintaining important technical detail. It is intended to complement plant approved documents. This Handbook does not address compliance requirements of regulations specific to a particular industry, facility, or regulation body; therefore, readers should consult appropriate local, regional, national, or federal authorities for precise compliance requirements.

It is essential to note that the condition and maintenance of the connection will affect and cause variations in the results obtained from installation and use of any gasket. Readers must ensure products and procedures are suitable for their specific application by reference to the manufacturer.

The guidelines in this Handbook represent the combined efforts of member and associate member companies of the FLUID SEALING ASSOCIATION (FSA) and the EUROPEAN SEALING ASSOCIATION (ESA) who have provided the material and technical personnel

needed to complete this work. While this work was developed with a global perspective in mind, some regional nuances are highlighted.

The members and associates of the FSA and the ESA are established, reputable gasket manufacturers, producing quality products in accordance with modern manufacturing practices.

The suggested procedures are based on substantial and proven experience. However, the Associations and its members do not accept responsibility for failures or damage resulting from recommendations or suggestions within this Handbook.

INTRODUCTION

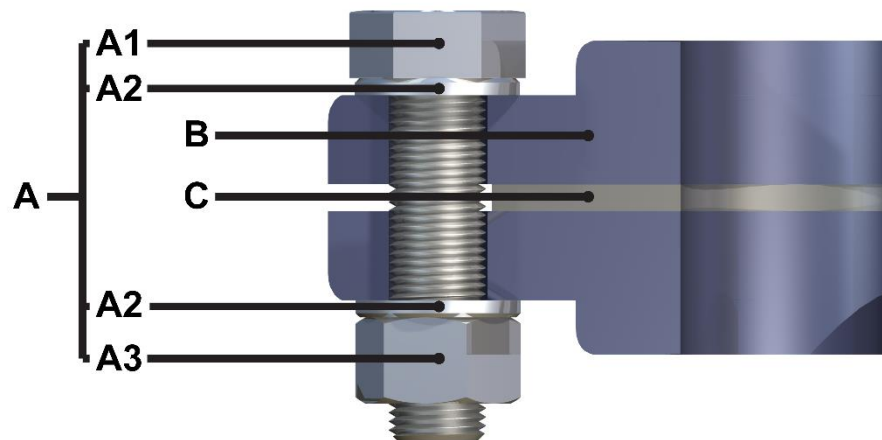
The gasket in a bolted flange connection is but one essential component in that complex mechanical device that enables low-leakage service. Nowadays so-called fugitive emissions are considered and these will occur always and in every bolted flange connection. Fugitive emissions should be reduced as much as possible. Each component must be designed, selected and installed within acceptable limits to ensure reliable, long term system tightness. Failure to consider all these important aspects can lead to serious product loss, environmental impact, and personal injuries. The gasket design and material(s) of construction ideally need to be taken into consideration at the design stage, to obtain optimum operating results. Unfortunately, it is usually not the case. This Handbook provides important guidelines to enable proper selection, installation and assembly of gaskets into both new and existing installations. Rationale for material selection is explained on the basis of application variables such as system temperature, pressure, as well as chemical and flange compatibility. Complexity and breadth of application conditions do not allow for details on bolt-up procedures within the scope of this Handbook. References to current best practice documents, such as ASME PCC-1, as well as relevant standards and regulations are included to enable the reader to access to those documents.

Chapter 1: Forces Acting on the Bolted Flange Connection

Connection

A. An Overview

A bolted flange connection is a complex mechanical system whose components must be selected and assembled properly to provide reliable sealing over a wide range of operating conditions. All of the various components of the assembled bolted flange connection are important to the proper operation of the joint. The components consist of the piping, or vessels, the flange(s), the gasket(s) and bolts. In addition to the components themselves, the joint design and assembly are critical to the long-term operation of the joint. This Handbook will focus on the practical aspects of component selection and assembly and for design, it will reference the appropriate design code.



A=Fastener (A1=Bolt, A2=Washers, A3=Nut); B=Flange; C=Gasket

Figure 1: The Bolted Flange Connection

A gasket is used to create and retain a static seal between two flanges which connect a series of mechanical components while containing a wide variety of fluids (liquids and/or gases). These static seals aim to provide a complete physical barrier against the fluid contained within and block any potential leak paths through gasket material or between

surfaces of flange and gasket, while still being capable of being disassembled and reassembled.

B. Creating the Seal

To achieve a successful seal, the gasket must be resilient enough to conform to any irregularities in the mating surfaces. The gasket must also be sufficiently tough (rugged) enough to resist extrusion, creep and blowout under the operating conditions and unexpected pressure/temperature excursions. The seal is created by the clamping forces acting upon the gasket surface, compressing the gasket and causing the gasket to conform to flange imperfections. The conformance of the gasket material to the flange surface under the compressive load (contact pressure) fills any leak paths and prevents the escape of the contained fluid from the bolted flange connection while maintaining a specified leakage rate. Additional information on generating the initial seating stress can be found in Chapter 4 on Joint Assembly or in ASME PCC-1.

Once seated, a gasket must be capable of overcoming minor alignment issues, flange sealing face imperfections and operating variations such as, but not limited to:

- Non-parallel flange faces
- Misaligned flanges (Figure 3)
- Distortions, troughs, or grooves
- Surface waviness (deviation) (Figure 4)
- Surface scorings (Figure 5)
- Other surface imperfections (Figure 6)
- Flange rotation during assembly
- Operating Temperature / Design Temperature / Thermal Cycling
- Operating Pressure / Design Pressure / Pressure Cycling
- External environmental conditions
- Startup and shutdown processing variations
- Hydro test pressure during leak testing
- System internal cleaning/flushes

Refer to ASME PCC-1 Appendix A for additional details on flatness and defects.

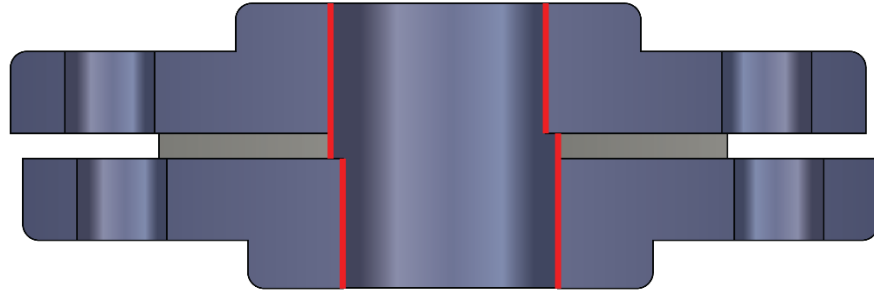


Figure 3: Misaligned flanges

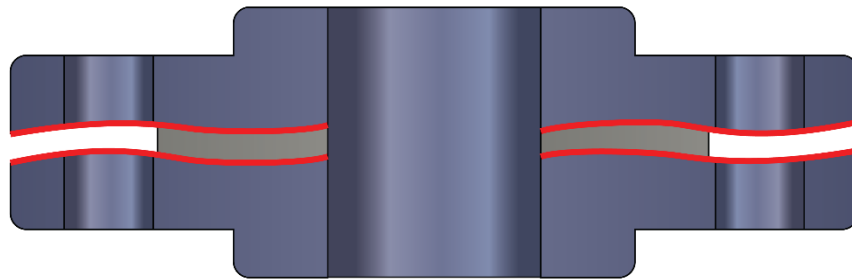


Figure 4: Flange surface waviness

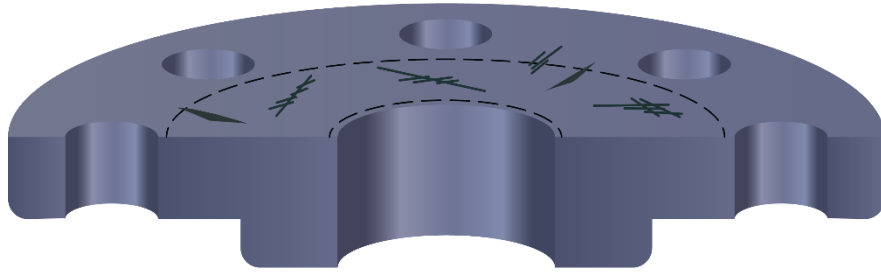


Figure 5: Surface scorings

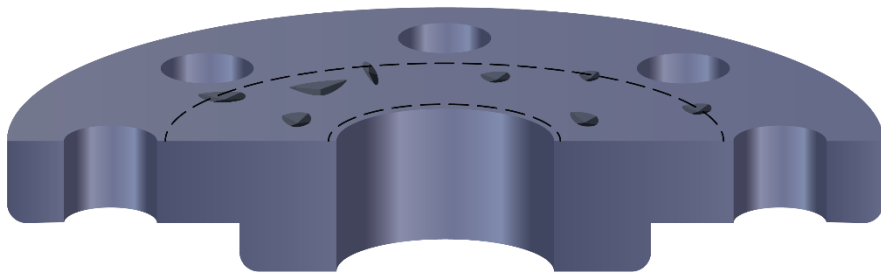


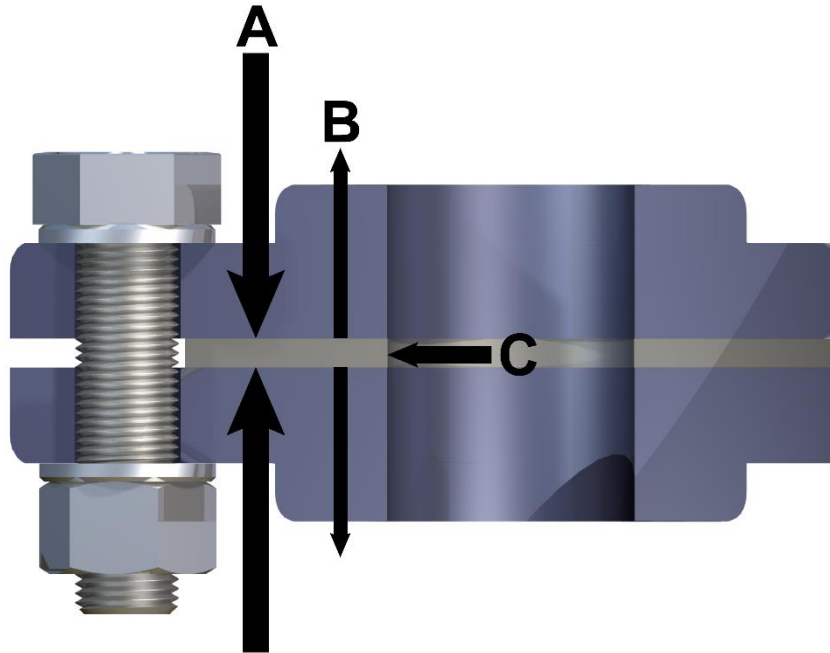
Figure 6: Other surface imperfections

C. Maintaining the Seal

When the bolted flange connection is assembled, the gasket is subject to compressive load between the faces of the flanges. The compressive load is the force which is often generated by bolts under tension. The compressive load on the gasket must be high enough to compress the gasket into the surface finish of the flanges to fill any potential leak paths. In order to maintain the seal throughout the lifetime of the assembly, sufficiently high residual gasket load must remain on the gasket to minimize leakage. Under operating conditions the compressive forces on the gasket is reduced by the hydrostatic end load and influenced by other factors, such as thermal expansion behavior of flanges and bolts, lever arms, etc. The hydrostatic end load is the force generated by the internal fluid pressure acting to separate the flanges. The residual gasket load is the compressive load minus the hydrostatic end load. The gasket itself is also subjected to radial forces due to the internal pressure tending to extrude the gasket through the flange clearance space. To maintain the seal integrity, the residual gasket load must be greater than the internal pressure, usually by some multiple. This multiple depends on the gasket material, gasket type and level of tightness required.

In addition, safety factors are generally recommended to insure the residual gasket load is sufficiently higher than the load required to maintain the seal. Safety factors are generally applied to allow for any relaxation of the gasket compressive forces and to accommodate the application process involved.

For non-metallic (soft) gaskets where the tensile strength of the gasket material may be less than the internal fluid pressure, there must be adequate friction (created by the compressive load) between the gasket and flange faces to prevent extrusion (blowout) of the gasket from the joint.

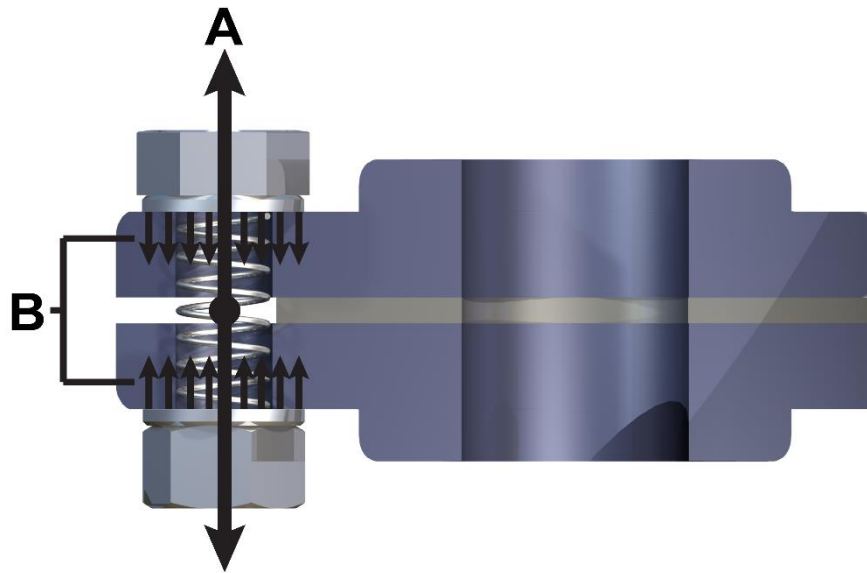


A=Flange/Bolt Load; B=Hydrostatic End Load; C=Internal (Blow out) Pressure; G=Gasket

Figure 7: Forces in a bolted flange connection

D. Forces Acting on the Bolted Flanged Connection

The most common way to generate the compressive load required to seal a flanged connection, is through bolts. The bolts, as shown below, when tightened act like springs, pulling the flanges together. These bolts need to be stretched enough to keep the load on the gasket as the system is pressurized (during startup) and pressure and temperature is cycled (during normal usage). Additional loading above the minimum load required to seal, will give the bolted joint flexibility to absorb these load changes and a safety margin to maintain the seal as these system forces fluctuate.



A=Bolt (Spring) Stretch; B=Opposite Force Pulling Flanges (Spring) Together

Figure 8: Bolts acting like springs

Bolt yield strength is a measure of the bolt load required to stretch the bolt and still allow it to spring back to its original length. If the bolt is overstretched and is loaded beyond its yield strength, the bolt will not "spring back" when the load is removed. Continued tightening of the bolts will not necessarily increase gasket load or stop a gasketed joint leak and may lead to bolt failure. Caution should be used to avoid overloading bolts which can cause them to stretch beyond their yield strength and actually result in lower than expected loads exerted on the gasket.

The minimum bolt load should be at fifty percent (50%) of bolt yield strength to ensure the "spring" is stretched enough. The bolt load typically used is at eighty percent (80%) or even one hundred percent (100%) of bolt yield; if the calculation method and assembly is very accurate. Modern recommended calculation methods such as EN 1591-1, include tolerances on assembly methods for example, so the use of one hundred percent (100%) bolt yield can be acceptable. However, this recommendation should be tempered by the amount of gasket and flange stresses generated and ensuring that the applied load will not overload, damaging the gasket or flange. The flange connection will lose compressive

load due to system relaxation. If the bolt is not stretched enough, the gasket residual load may drop below the load required to maintain a seal, thereby, causing a leak.

Bolts come in a variety of grades, each with individual yield strength and properties. Proper bolt selection is critical to the proper assembly of a bolted flanged joint. Refer to [Chapter 3 Section C](#).

Friction between the bolt, nut and the flange surface is a force often overlooked during gasketed joint assembly. When determining the torque required to properly tighten the bolts, a nut factor or friction factor needs to be taken into consideration. Using well lubricated nuts, bolts, and nut and bolt faces can help control the frictional load losses during assembly. The use of hardened steel washers between the nut and bolt heads and the flange is recommended to help control frictional losses from embedment of the bolt/nut face into the flange.

Bolt tightening should be controlled to insure proper bolted flanged connection assembly. See Chapter 4 and consult the ASME PCC-1 Guidelines for additional information.

E. Other Factors affecting the Seal

After the initial assembly of a bolted joint, there are many other factors acting on the joint that work to compromise the initial seal (Cycling, Gasket Material, Bending moments).

Most applications undergo pressure and thermal cycles which work to decrease the compressive load on the gasket. Pressure cycles change the hydrostatic end load. Thermal cycles can change the stretch in the bolts through various mechanisms, including bolt material modulus changes due to temperature, differential thermal expansion of the flange component materials and thermal transients, in heat-up and cool-down. These pressure and thermal cycles cause fluctuations on the compressive load of the gasket and may increase the potential for a leak.

Temperature and time can affect gasket materials in a variety of ways. Gasket material degradation due to thermal or chemical exposure can result in a change of material properties, making them less resilient and reducing their ability to spring back under fluctuating loads. Temperature and compressive load can cause creep relaxation in the gasket material itself. Some gasket materials or styles have inherently less creep relaxation and are less susceptible to temperature or chemical exposure than other materials or styles. These factors are covered in Chapter 3 on choosing the correct gasket material.

External bending moments or forces can also affect an assembled joint. Bending moments tend to unload one side of the flanged joint and increase load on the other side creating load changes that can result in leakage. Misalignment of piping and flanges should be minimized. Flange misalignment creates additional loads that the bolts have to overcome before the bolt loads can be applied to the gasket. Minimizing alignment issues will help to minimize bending issues, but external forces such as weight of fluid in the piping, or thermal expansion, can create external bending forces. Proper piping supports and piping design can help minimize these external bending forces.

Chapter 2: Gasket Categories

Gaskets can be segregated into three (3) main categories:

- Non-metallic (soft)
- Semi-metallic
- Metallic

It should be noted that gaskets may be categorized differently in other documents i.e. ASME categorizes gaskets into two basic groups, metallic (i.e. ASME B16.20 “Metallic Gaskets for Pipe Flanges which includes spiral wound gaskets) and non-metallic. For the purposes of this Handbook illustrating the features and characteristics of gaskets have been segregated as noted above.

The mechanical characteristics, performance and capabilities of these categories will vary extensively, depending on the type of gasket selected and the materials from which it is manufactured. Obviously, mechanical properties are an important factor when considering gasket design, but the selection of a gasket is also influenced by:

- temperature and pressure of the fluid to be contained
- chemical nature of the fluid, compatibility with the operating fluid
- mechanical loading affecting the gasket
- variations of operating conditions (i.e. during cycling)
- type of joint involved

This Handbook is focused on maintenance engineers and fitters and it is assumed that, in general, the selection of gasket type and material(s) will be decided by the plant operator or designer in the first instance. Hence, the maintenance operator may have little flexibility to choose the sealing material. Consequently, this section provides only brief guidance notes about the majority of sealing materials and gasket types available.

Each gasket category has an associated set of materials to consider which is dependent upon the specific gasket style and operating conditions. In the following sections, is a brief review of considerations to be aware of, what materials are required when selecting a

specific gasket style from a given category and is a summary of each category including typical application parameters where each is utilized, gasket characteristics, and features.

Tips:

- A word of caution; despite the similarity of many materials, the properties of the seal and performance achieved will vary from one manufacturer to another. Always consult the manufacturer for detailed guidance on specific products.
- It is important to always use a good quality gasket from a reputable supplier, because the cost of a gasket is insignificant when compared to the cost of downtime or safety considerations.

A. Non-metallic (soft) Gaskets

Non-metallic materials are suitable for a wide range of general and corrosive chemical applications. These gaskets are suitable for low and high temperature applications depending on materials. Their use is generally limited from low to medium fluid pressure applications. Non-metallic gaskets are also typically the least expensive of the three (3) gasket categories, however, specialty materials used in them can be an exception. Types include: compressed elastomer-based fiber materials ("CNF"), flexible graphite, polytetrafluoroethylene (PTFE), and mineral based (i.e. vermiculite, mica).

Non-metallic (soft) gaskets are available as "ring type" (ID/OD gaskets), full face (ID/OD with bolt holes) and can be supplied in custom shapes for specialty flanges (square, rectangular, etc...with and without bolt holes). Technology today has given rise to various automated means of cutting non-metallic (soft) gasket material such as automated knife cutters, laser cutters and punches in just about any shape required. Typical material sheet width is sixty inches (60"), while the sheet length varies by manufacturer. It is not uncommon for non-metallic (soft) gaskets to be segmented for sizes larger than available sheet dimensions.

There are typical tests to help define and compare characteristics of non-metallic (soft) gasket materials. This may be found listed on data sheets from the manufacturers for the product, to help guide in selection of material(s) for a particular application. These standardized tests are defined by ASTM International (United States), CEN (European), and DIN (German), BSI (British), AFNOR (French), JIS (Japan), ISO (Global), among others and are summarized in [Appendix A](#).

Another consideration when selecting soft gasket material(s) is the gasket thickness. Typically nominal non-metallic (soft) gasket thicknesses are, in North America, 1/32", 1/16", 1/8" and, in Europe and Asia, 0.75mm, 1.0mm, 1.5mm, 2.0mm, and 3.0mm. Thicker and thinner gaskets are also available. Contact the manufacturer for specific tolerances on their gasket thickness and thickness variations within a sheet. It should be noted that thickness can affect the pressure/temperature rating of a gasket (refer to Chapter 3 Section A). Gasket thickness should also be noted by the end user when reviewing standardized test data and what particular material thickness was utilized to perform the test compared to the thickness being considered for an application.

For gaskets cut from sheets, it is recommended to use the thinnest material that the flange arrangement will allow. But thick enough to compensate for unevenness of flange surfaces, their parallelism, surface finish, rigidity, etc. The thinner the gasket, the higher the bolt load the gasket can withstand and the less loss of bolt stress, due to relaxation. Also, the thinner the gasket material, the lower the gasket area which will be exposed to attack from the internal pressure and aggressive fluid.

Non-metallic (soft) gaskets are typically either homogeneous (i.e. flexible graphite sheet, virgin PTFE) or they are a composite of several materials each serving a specific purpose (i.e. CNF, mineral based, filled PTFE). Of course, for each material within a gasket, consideration has to be given in terms of compatibility with fluid and temperature.

Generally, a composite gasket has the following main components:

- Fiber - added for increased mechanical properties such as tensile and compression (i.e. aramid, cellulose, ceramic, glass)

- Binder - added to increase flexibility and act as a binding agent for the other materials utilized (i.e. NBR, SBR, EPDM)
- Filler - added for various reasons such as reducing cold flow, creep and cost reduction (i.e. silica, clay, mica, powdered graphite, barium sulfate)
- Coatings - added to both faces to facilitate easy release of gasket from flange face. (i.e. PTFE, silicone)

Current non-metallic (soft) gaskets encompass a broad spectrum of materials with a wide range of physical properties, which are suitable for various temperature and pressure ranges. New materials continue to appear in the market, as do variations of conventional products. The total number of materials on the market is extensive and arduous to list. A practical approach is to comment generally on materials commonly in use, which for the most part offer the gasket user a complete enough range to make a proper selection. The user should consult the manufacturer's literature for proper material selection.

ASTM F104 provides one framework for characterizing gasket material properties. The F104 call-out is an alphanumeric sequence which defines specific properties of the material. An end user may use a call-out to specify a gasket material for a particular application. The call-out may not be comprehensive, therefore, for critical applications it is recommended that further investigation of the material properties and suitability take place.

See the materials section below for a brief review of non-metallic (soft) gasket materials and types.

Please note that in the listings which follow, operating limits are indicative only. Many of the gasket materials are composites, containing a variety of binders, fillers, etc., the inclusion of which will modify the performance envelope of the gasket. Operating limits

and suitability may vary significantly, dependent upon material constituents and specific operating conditions; under these circumstances, the advice of the gasket manufacturer is vital! Always consult the gasket manufacturer for guidance on suitability for specific applications and limits which may be achieved under specific operating conditions. Whichever gasket material or type is selected, ensure it is correct for the application!

1. Gasket Materials

Beater Addition Elastomer-Based Fiber Sheet Gasketing

The Beater Addition process incorporates a range of natural or synthetic fiber (i.e. cellulose, aramid, etc.) for strength. Additionally, binders (i.e. NBR, SBR, etc.) and resins are added for flexibility, strength, heat or chemical resistance. Gaskets manufactured per this method can also be laminated to support materials such as stainless steel for increased strength. Fluid compatibility and acceptable application temperature range will be a function of the material utilized and material thickness. The manufacturing process is outlined in [Appendix B](#).

Compressed Elastomer-Based Fiber Sheet Gasketing

Compressed sheets have been around since the 1890's. It is a composition of fibers, elastomers and fillers that is formed into sheets of finite dimensions with the process dictating maximum sheet width and maximum sheet length. This manufacturing method is outlined in detail in [Appendix B](#).

Fluid compatibility and acceptable application temperature range will be a function of the material utilized and material thickness. Different compressed sheets are available that can function over an extensive range of fluids, temperatures and pressures. End users should ensure they provide complete application service conditions to optimize in-service effectiveness and life.



Figure 9: Scan this QR Code to access the FSA Gasketed Joint Questionnaire from the FSA website

Cork Gaskets

Although there are many new materials available today, cork gaskets may continue to be used in some applications where minimal bolt load is available such as stamped metal flanges or easily damaged materials (i.e. glass or ceramics). Cork is impervious to water, lubricating oil and other petroleum derivatives.

Cork gaskets are primarily used for low internal pressures up to 345 kPa (50 psi), where sustained fluid temperature does not exceed 120°C (250°F). Cork has a tendency to stick to flanges and also has limited shelf life due to humidity. It should not be used to seal inorganic acids, alkalis or oxidizing solutions. See [Appendix B](#) for additional information.

Flexible Graphite

Flexible graphite refers to natural graphite flake that has been expanded and then compressed. It is a material with the essential characteristics of graphite and complementary properties of flexibility and resilience, as well as an ability to compress and conform. The manufacturing process is described in [Appendix B](#).

A sheet density of 1.12 g/cm³ (70 lbs/ft³) is often typical of the processed material in the US, while a density of 1.0 g/cm³ (62.4 lbs./ft³) is typical in Europe and is widely used for the majority of industrial gasket applications. While this density is approximately fifty percent (50%) of the theoretical maximum density of graphite, the through-thickness sheet permeability to fluids, as measured by the helium admittance test, is extremely low. Characteristics of the flexible graphite can be tailored for specific gasket applications simply by changing the starting density of the sheet. Additional details related to flexible graphite are described in [Appendix B](#).

Effective sealability is inherent in the flexible graphite by virtue of its conformability to the flange surfaces under load and once in place because of its low creep relaxation and stability under a wide range of compressive load/temperature conditions. Since the tensile strength of flexible graphite is significantly lower than that of binder containing products, a reinforcement material is commonly employed to improve handleability of the flexible graphite for many applications. Gasket reinforcement can be either metallic or non-metallic material. There are many variables and options for consideration when selecting the gasket reinforcement and construction of flexible graphite gaskets.

Considerations for Reinforcements:

- Non-metallic materials, such as fiberglass cloth and polyester film, can be used to produce the laminate or composite gasket material. The benefits of these inserts are chemical resistance and ease of cutting.
- Metallic materials, such as stainless steels, carbon steels and other alloys, can be used to reinforce the laminate or composite gasket material. The insert material can be in the form of flat sheet (foil), woven wire screen, perforated foil or tang. Generally tang and wire screen inserts require higher compressive loads to achieve the same level of sealability as the unreinforced or flat metal laminates. The benefits of these inserts are increased handling robustness and the metallic reinforcing layers can be selected to address specific chemical resistance requirements for special applications.

Considerations for Construction:

- Flexible graphite gaskets can be composed of multiple layers of flexible graphite sheet and reinforcements, in order to achieve the desired thickness or application requirements.
- Adhesive is used to bond polyester to flexible graphite. The polyester film itself, is the non-metallic reinforcement. Joining the materials occurs by applying a double-sided adhesive polyester tape to the flexible graphite. This bonding technique provides enhanced tensile strength and toughness for handling robustness. Plastic layers can also be thermally bonded by heating the thermoplastic material to its softening point and adhering the softened material directly to the flexible graphite.
- Chemical Bonding is used to join metallic reinforcements to the flexible graphite. The use of thermally activated contact adhesives is an effective method of construction that minimizes the glue layer thickness. The benefit of this technique is improved gasket

sealability under low gasket loads and sheet cutting ease, compared to gaskets and sheet constructed via tanging.

- Tanging is a process of perforating the metal reinforcement and creating tangs (hooks) in the metal. The finished laminate is then made by clinching the flexible graphite facing material onto the tanged metal. One benefit of this technique is high shear strength between layers which provides enhanced blowout resistance. Another benefit is the absence of adhesive, which eliminates related concerns of creep relaxation and outgassing of the adhesive layer, chemical compatibility and process contamination.
- When using woven wire mesh the flexible graphite sheet is bonded to the mesh with adhesives.

Phyllosilicates (Mica & Vermiculite)

The main drawback with graphite gaskets is that they can oxidize at high temperatures/ when in the presence of oxygen or other oxidizing agents. Phyllosilicates are a group of minerals based on the mica family which can be used to make non-oxidizing, high temperature gasket materials like sheet, tanged metal reinforced, flat foil reinforced, perforated reinforced, spiral wound and kammprofile gaskets. The two (2) main phyllosilicates used are mica and vermiculite; both have the same temperature and chemical resistance properties. Vermiculite is different from mica, in that it can be exfoliated due to “water” being between the layers.

Polytetrafluoroethylene (PTFE) Gasketing

Polytetrafluoroethylene (PTFE) Gasketing is a material with unique chemical resistance and physical properties. PTFE is chemically inert to most chemicals, with the exception of molten alkali metals and free fluorine and can withstand a wide temperature range. PTFE also has excellent anti-stick, dielectric and impact resistance properties.

However, most PTFE gaskets are subject to cold flow or creep relaxation under compression, which means that gaskets lose thickness, expand in width and length under applied loads. Creep results in the loss of bolt load and ultimately gasket stress in an application. And frequently requires additional efforts to regain that lost stress in the field, which results in increased maintenance costs. Generally, initial seating stress decreases

significantly in the first 4 to 24 hours after installation. Also creep increases as temperatures increase.

While the property of creep is inherent in this material, the degree of creep in the PTFE material differs significantly amongst the three (3) largest types of PTFE gaskets; virgin, filled, and expanded. There are other, less common, PTFE variations commercially available such as envelope, microcellular, and filled biaxial sheets.

Virgin PTFE:

Virgin PTFE gaskets are made from unaltered PTFE, which preserves the full chemical compatibility of PTFE but has the inherent high cold flow characteristic of PTFE. Virgin PTFE provides the basis for improvement of creep relaxation for other PTFE variations. As a result, this product is generally used in low temperature non-critical applications.

Filled PTFE:

With the addition of a filler material to virgin PTFE, filled PTFE gaskets reduce the cold flow; thereby improving the creep relaxation performance. The fillers act as “speed bumps” slowing the cold flow. However, the addition of a filler reduces the range of media for which the gasket may be suitable. For example, the addition of Silica or Barium Sulfate filler would limit the use of the gasket to either acid or caustic service. Multiple fillers are available to ensure the product is chemical compatible for a particular application.

The most common filler materials for PTFE gaskets are:

- Silica
- Glass
- Fibers
- Carbon
- Aluminum
- Oxide
- Barium
- Sulfate
- Bronze

Expanded PTFE (ePTFE)

Cold flow is most effectively reduced in expanded PTFE gaskets (ePTFE) by physically altering the PTFE microstructure. Because no fillers are used, the complete chemical compatibility of the virgin PTFE is retained.

The ePTFE microstructure is a network of interconnected nodes and fibrils that increases the tensile strength of the material, decreases the density of the material and increases the compressibility of the material. Because of the high compressibility, ePTFE gaskets conform well to surface irregularities. Unlike virgin and filled PTFE gaskets, ePTFE materials are more easily applied in glass-lined steel, fragile plastic flanges and other fragile flanges. In addition, ePTFE is available in sheet, tape or cord (joint sealant) form. The tape and cord forms are solid form-in-place products.

Rubber (Elastomers)

Because of rubber's many beneficial features and advantages as a sealing material, it has become a primary material used in the production of gaskets.

Today, a wide variety of rubber polymers and compounds, each possessing unique features and advantages, have been developed to produce the highest quality gaskets and sealing materials for many industries.

Basic Features of Rubber:

There are seven (7) basic features of rubber which establish its advantages as an ideal gasket and sealing material.

1. Rubber is a naturally resilient material. It is elastic and squeezes into joint imperfections under relatively light bolt loading. As such, it provides effective sealing properties even under difficult conditions.
2. The availability of various rubber polymers provides a wide range of physical properties:
 - Durometer
 - Tensile strength
 - Elongation
 - Compressive Modulus
 - Compression Set
3. A variety of desired properties can be combined into a single compound to meet specific application needs.
4. Rubber can be reinforced with fabric or steel inserts to add strength and prevent creep, rupture or blowout.
5. Rubber can be compounded to resist the effects of temperature, oil, chemicals, ozone, weathering, aging and abrasion. The result is longer gasket life and reduced maintenance.

6. Rubber sheeting can be produced in an infinite variety of thicknesses, widths, lengths, surface finishes and colors to meet user needs and requirements.
7. Rubber can be specially formulated to meet specific requirements. For example, some Natural Rubber compounds are Food & Drug Administration (FDA) approved, using only ingredients generally recognized as safe and listed in the FDA Federal Register for Food Handling Materials.

Rubber gasket and sealing material applications involve all types of gases, liquids and solids. In sealing or separating these materials, a wide range of service conditions, such as temperature and chemical exposure may be encountered. It is, therefore, essential that all factors carefully be considered to ensure selection of the grade and type of rubber gasket or sealing material, which will deliver optimum performance as well as economy.

As a result of rubber's excellent features and advantages, the actual uses of rubber sealing devices can range dramatically from very general, non-critical applications, such as plumbing; to very demanding and critical high technology service, as encountered in the aircraft industry. Rubber gaskets and sealing materials provide equally optimum results.

Impregnated Textiles

Woven and Folded Impregnated Cloth

Fabrics such as glass fiber fabrics are woven in such a manner as to allow sufficient impregnation of elastomers or PTFE, whereby all voids are filled and fibers are properly coated to prevent or minimize wicking.

Fabrics measure 0.8mm (1/32") or 1.5mm (1/16") in thickness. Thickness over 1.5mm (1/16") are obtained by plying additional layers.

Where additional reinforcement is required, wire strands of brass, high nickel alloys and occasionally, stainless steel are used. Such fabrics are able to withstand higher pressures

and temperatures. The wires are tightly interwoven into the yarns with no looping of the wire observed. A uniform coating of the impregnating material is necessary for optimizing properties in the final product.

Folded Cloth Gaskets

Texturized or blended fiberglass cloth gaskets are folded to form endless seals, used for hand hole and manhole gaskets. They can be round, oval, square or rectangular and may also be die cut into various configurations.

Woven Tape

Tape is formed by slitting and folding cloth. It can be made in widths of 6mm (1/4") to 254mm (10") and in thicknesses of 1.5mm (1/16") to 13mm (1/2").

Groove or Door Packing

Any of the rubberized fabrics can be rolled or folded to form round, square or rectangular cross sections.

Tadpole Tape

This tapes consists of fabrics wrapped around various core materials which include:

- Glass or ceramic rope
- Rubber cords - silicone, chlorosulfunated polyethylene (CSM), Chlororoprene (CR)
- Wire mesh cables - high nickel alloys, stainless steel

The selection of core and cover materials is based on heat resistance, pressure, environment and compressibility. The cloth extends beyond the core to form a flat lip. This lip can be punched or drilled to accept bolts and the extension or "tail" is then bolted to the mating surface. This allows the bulb portion to be compressed and provides a good seal for irregular surfaces that must be subjected to opening and closing.

Non-impregnated cloth with various cores may also be used and the tadpole shape is formed by using a high temperature thread.

Liquid Formed-in-Place

A popular product in less severe service, is the liquid form-in-place (F.I.P.) gasket made of silicone, polyester-urethane or other polymer based substance. On assembly of the flange a ribbon of paste-like polymer is applied to the flange area. Then the F.I.P. material is compressed between the mating surfaces to conform to all the surface irregularities.

Application of the liquid F.I.P. gasket can be done manually from a tube, caulking gun or automatically using a high speed programmed machine which is commonly used in automotive assembly plants. See [Appendix A](#) for applicable standards.

Solid Formed-in-Place

Gaskets of flexible graphite tape; PTFE rope; folded cloth or tape, can be formed-in-place to create a gasket. It is an ideal do-it-yourself gasket material for easy field installation.

The solid F.I.P. is furnished on a roll with adhesive backing in various sizes. The material is rolled out onto the flange mating surfaces, cut off, overlapped and compressed between the flanges.

B. Semi-Metallic Gaskets

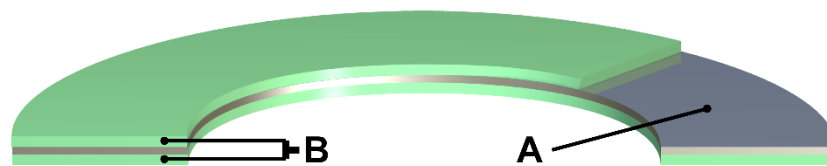
Semi-metallic gaskets are made by combining soft materials such as fillers, facings or insertions together with a metallic component to optimize the characteristics of the composite material as a gasket. In a composite or semi-metallic gasket, the metal generally provides the strength structural requirements and, depending upon configuration, increased resilience. Non-metallic material may also provide resilience and enhanced sealing characteristics. Many synthetic composites and/or mineral-based materials are used as well as elastomer based compounds. These soft materials may be inserted in a specifically designed metallic profile, may be applied to a metallic face or carrier, or may be partially or completely encapsulated by metal. Semi-metallic gaskets can be suitable for both low and high temperature and pressure applications, depending on the materials and configuration used. Types include: grooved metal gaskets with

covering layers, metal eyelet, metal jacketed, metal reinforced non-metallic (soft) gaskets (including tanged metal or wire reinforced “sheet” materials), corrugated metallic and spiral wound gaskets among others. Each gasket style has a particular set of materials which must be defined based upon the components making up the gasket. The following is a brief description of the more popular semi-metallic styles and the components involved and considerations when choosing a material for each component.

1. Gasket Styles

Metal Reinforced Non-metallic Gaskets

Typically made with a thin stainless, alloy core or wire mesh approximately .002"/.004" thick, it acts as a carrier and support for the soft sealing material. The material used is typically 316L stainless, however, nickel and other materials are also utilized.



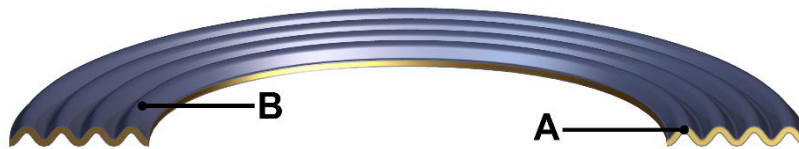
A=Metal Insert; B=Non-metallic sheet material

Figure 10: Metal Reinforced Non-metallic Gasket (cross section)

Concerning the .002" / .004" thick cores, they can be either flat metal, perforated or tanged cores. If the core is flat metal, the soft sealing material is usually adhesively attached to the core, while if the core is perforated or tanged, the soft sealing material is mechanically pressed and clinched onto the core. Soft sealing materials such as flexible graphite, PTFE and mineral-based materials (i.e. vermiculite) are often used. Both the soft sealing material and metallic core material should be considered when looking at operating temperature, pressure and fluid.

Corrugated Gaskets

These gaskets consist of a thin metal that is corrugated or embossed with concentric rings and faced with a soft material such as flexible graphite.



A=Metal Corrugations; B=Soft Facing Material

Figure 11: Corrugated Gasket

Corrugated gaskets utilize the substrate's geometry to achieve conformability to flange irregularities and promote recovery over the life of the seal, they are essentially a line contact seal. Multiple concentric corrugations provide a labyrinth effect, along with mechanical support for the facing material.

Corrugations provide resilience, depending on pitch and depth as well as the type and thickness of the metal used. Again, both the thin metal and the facing material must be considered and be suitable for the fluid and operating conditions.

Jacketed Gaskets

Jacketed gaskets consist of a soft compressible filler, partially or wholly encased in a metal jacket. In some instances, corrugated metal is used in place of soft filler material and also may have a soft surface layer of material such as flexible graphite. The primary seal against leakage is the inner metal overlap, where the density of the gasket is the greatest when compressed.



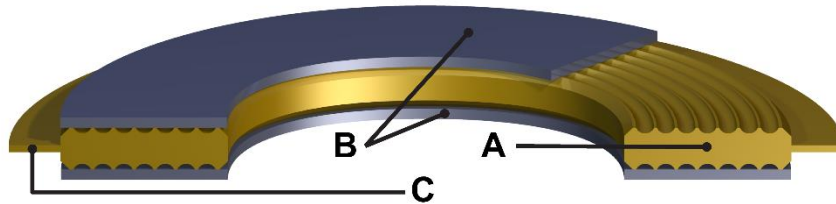
A=Metal Jacket (Outer Layer); B= Filler Material

Figure 12: Metal Jacketed Gasket

This area cold flows it creates a seal. The entire outer lap, if any, provides a secondary seal between the flanges when compressed. Any intermediate corrugations, if they exist, may contribute to the labyrinth effect. These gaskets are used for circular as well as non-circular applications and for applications at temperatures up to those which limit the filler and metal endurance. These gaskets are normally specified in thicknesses of 2mm (3/32") or 3mm (1/8") nominal. The thickness of jacketed gaskets cannot be held to as precise dimensions as non-metallic (soft) gaskets, due to accumulated tolerances of the metal, filler and the metal spring back when it is formed. Because of limited resilience, they should not be used in joints requiring close maintenance of the compressed thickness. They can be made with or without pass bars for use in heat exchangers. If pass bars are utilized, the pass bars can be integral (not welded but formed from the same piece of material as the outer ring) or welded (pass bars are separate pieces and welded into the ID of the outer ring). Materials which must be considered are the metal jacket, material used and the filler material.

Grooved Metal Gaskets with Covering Layers (Kammprofile/Camprofile)

Kammprofile gaskets are a solid metal ring with grooved faces and a soft facing material is usually present on the grooved faces to improve sealability. Typical facing materials are flexible graphite, phyllosilicates (mica and vermiculite), or PTFE.



A=Metal Core; B=Soft Facing Material; C=Metal Outer Ring

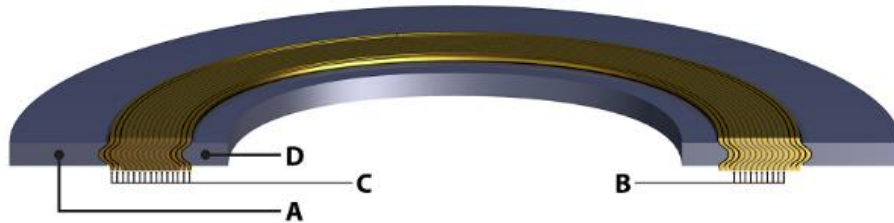
Figure 13: Kammprofile Gasket

When the gasket is compressed the serrated faces create concentric rings of high stress, enhancing the sealing capabilities of the gasket. Typical configurations include a grooved sealing section or core with soft facing material, a serrated sealing section or core with an independent outer ring (outer ring made with separate piece of material) and a serrated sealing section or core with an integral outer ring. The function of the outer ring is to locate or center the sealing core onto the sealing face (i.e. flange raised face) utilizing the bolts in much the same way an outer ring on a spiral wound gasket would on a raised face flange. However, the outer ring on a kammprofile is not typically used as a torque stop and is thinner than the serrated sealing section of the gasket to ensure the bolt load is concentrated on the sealing section or core and soft facing material. Materials which must be considered are the metal core and soft facing materials used.

Spiral Wound Gaskets

These gaskets are comprised of a preformed “V” or chevron shaped metal strips alternately wound with a conformable filler material. The metal windings provide strength and resilience, while the non-metallic filler portion conforms to the irregularities of the flanges aiding in the joint seal. These gaskets can be constructed in a variety of densities accommodating available bolting and pressure conditions.

Sealing is achieved through a combination of yielding and flowing of the “V” shaped metal material and conformable fillers during the compression phase. They can be made in several configurations, to accommodate various flange facing shapes. This gasket can be made with windings to include a solid metal outer ring, solid metal inner ring or both.



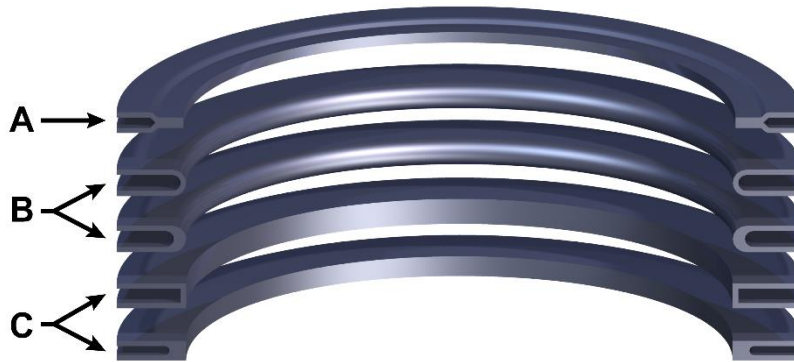
A=Outer Ring; B=Filler Material; C=Metal “V” Windings; D=Inner Ring

Figure 14: Spiral Wound Gasket

The solid metal inner and outer rings serve various functions. The outer ring serves to center the windings onto the sealing face, utilizing the inner edge of the bolts. The inner ring acts to help support the ID of the windings/ to help prevent inward buckling of the windings. Both inner and outer rings are typically made of a thickness that is within the optimal compression thickness range of the windings. Materials which need to be considered for the manufacture of such gaskets includes the inner ring metal, metal winding strip, filler material and outer ring. If an inner ring is present, it should be compatible with the fluid being contained and be able to withstand the temperatures encountered in the application. The metal winding strip has the same considerations as the inner ring, and is often made utilizing the same material type. The filler material utilized should be compatible with the fluid and again, be suitable for the temperatures to be encountered in the application. The outer ring should also be suitable for the temperatures encountered, but its material selection is less critical than the winding strip and inner ring material, as it is not exposed to the process fluid.

Envelope Gaskets

An envelope type gasket is a composite consisting of two parts; envelope (shield) and insert (filler). These gaskets are primarily used in conjunction with corrosive resistant equipment constructed of stoneware, glass, glass-lined metal, etc. The envelope serves as the corrosion resistant part of the gasket and is usually PTFE.



A=Slit Type; B=Folded Type; C= Machined/Square Type

Figure 15: Envelope Gaskets

There are basically three (3) designs of envelopes which are "Slit", "Machined" and the "Square" cut (inside diameter, flat) or "Folded" type (inside diameter, round). The "Slit" type is most commonly used with inside diameters of 24" and under. The "Machined" type is used where close tolerances, narrow flange widths or a reduction in the dead space is desirable. The "Folded" shield gasket is used on larger than 24" I.D. gaskets. "Slit" and "Machined" gaskets are lathe cut from billets or sleeves; the "Folded" shield is made from tape, which produces a continuous jacket or shield. The insert material may be selected for a particular environment or designed to cover a wide variety of conditions. It provides the gasket with good compressibility and recovery to allow the minimum seating stress and proper conformability that is required for this type of service. The insert may be made of any recognized gasket material, with or without metal reinforcing, taking into consideration temperature, pressure and corrosive conditions. The most popular insert materials are compressed and beater add products. Elastomeric materials have a

tendency to flow and cause envelope splitting; whereas extremely hard materials require excessive bolt loading.

2. Filler and Facing Materials

The following is a listing of typical materials that can be used in semi-metallic gaskets, either as facing (jacketed gaskets, kammprofile gaskets, corrugated gaskets) or filler materials (jacketed gaskets, spiral wound gaskets). A listing of metals commonly used in the construction of semi-metallic gaskets is covered at the end of the discussion concerning metallic gaskets, as they are typically available for both metallic and semi-metallic gaskets.

Flexible Graphite

This material has excellent chemical resistance and very low creep relaxation. The recommended operating temperature is from cryogenic to a maximum in oxidizing conditions of 454°C (850°F) for facing material and spiral wound gaskets. These limits are dependent on the application and grade of flexible graphite used. In some cases, the maximum service temperature may exceed these limits. Avoid use with strong oxidizing fluids such as concentrated sulfuric acid. Contact the manufacturer for specific applications.

Mica Graphite

A phyllosilicate (specifically, chlorite), graphite and cellulose-based paper with a rubber latex binder, has been used as an asbestos substitute. When subjected to temperatures over 230°C (450°F), this product starts to lose volume, which has an adverse effect on performance.

PTFE, Filled PTFE and Expanded PTFE

Typically used in tape form, these materials are used for high chemical resistance. The temperature limits are cryogenics to 260° (500°F). Maximum temperature shown does not account for all operating conditions.

Ceramic

Aluminum oxide materials, commonly referred to as ceramic, are used in some corrosive environments. There is a wide variety of compositions that can be classified as ceramic materials.

Phyllosilicates

Phyllosilicates are a group of minerals based on the mica family which can be used to make non-oxidizing, high temperature gasket materials. Sheet, spiral wound and kammprofile gaskets can be made from phyllosilicates. The two main phyllosilicates used are mica and vermiculite.

C. Metallic Gaskets

Metallic gaskets can be fabricated from a single metal or a combination of metallic materials, in a variety of shapes and sizes. Metallic gaskets are suitable for high temperature and pressure applications. Higher loads are required to seat the gaskets. Types include flat, grooved, round cross-section solid metal, lens rings, ring type joints (RTJ's) and welded gaskets. A brief description of the more popular styles are described below.

1. Metallic Gasket Styles

Flat Metal Gaskets



Figure 16: Flat Metal Gasket

These are defined as gaskets that are relatively thin compared to their width. They are cut from sheet metal and typically have a reduced area to increase unit load and improve sealability. Plain metal, washer shaped gaskets are relatively inexpensive to produce and can perform satisfactorily in simple applications. Surface finish on the gasket and flange facing is critical.

Serrated or Grooved Flat Metal Gaskets



Figure 17: Grooved Flat Metal Gasket

This is a flat metal gasket with concentric serrations or grooves, which reduce surface contact area between the gasket and flange face. Thus creating concentric rings of high stress when loaded.

Round Cross-Section Solid Metal Gaskets



Figure 18: Round Cross-Section Solid Metal Gasket

These gaskets are generally made from round wire of the desired diameter cut to the length of the gasket mean circumference, then formed into a circle and welded. They provide positive, gas tight seals at relatively low flange pressures. Since only line contact occurs, they have high local seating stress at low bolt loads. The contact faces increase in width as the gasket is compressed, effectively flowing into the flange faces. Round solid gaskets are used on equipment designed specifically for them. Flanges are usually grooved or otherwise faced to accurately locate the gasket during assembly. However, there are some applications in which they are used between flat faces.

Corrugated Metal (No Filler or Facing)

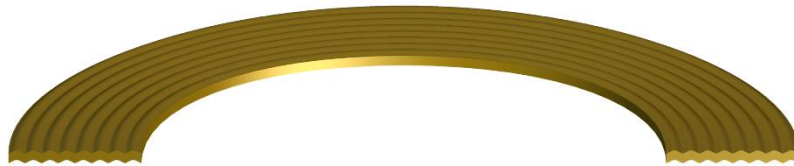


Figure 19: Corrugated Metal Gasket No Filler or Facing

Corrugated metal gaskets are plain metal with concentric corrugations. For low pressure 34.5 bar (500 psi) applications such as valve bonnets, gas turbines and combustion lines.

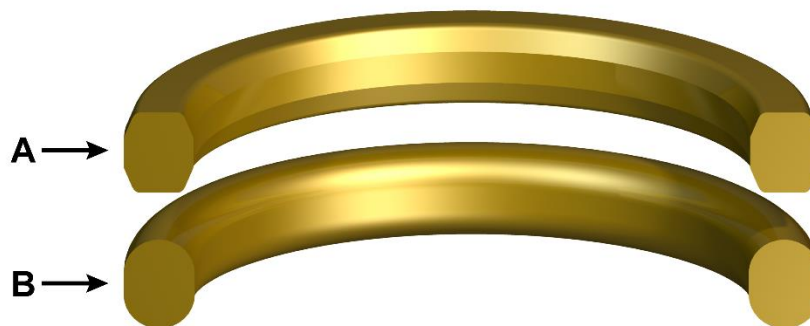
Solid Metal-Heavy Cross Section Gaskets

These gaskets are machined from solid metal and are designed for high pressure, high temperature service where conditions require a special joint design. Solid metal-heavy cross-section gaskets may seal by initial line contact or wedging and coining action, causing high unit stresses and the metal surface to flow at this line contact. Surface finish and dimensional accuracy is critical on both elements. Another type of solid metal-heavy cross-section gaskets includes welded gaskets (i.e. weld rings and weld membrane gaskets). The more common solid metal-heavy cross-section gaskets are described below:

Ring Type Joints (RTJ)

- Style R, Oval and Octagonal

The oval cross-section is the original ring joint design.



A=Octagonal Style; B=Oval Style

Figure 20: Style R Gaskets

The octagonal cross-section is an evolution of the oval design. Both oval and octagonal rings can be used with flanges having the standard ring joint flat bottom groove.

The former round bottom groove is no longer shown in the flange specifications and can only be used with an oval gasket. Standard sizes of these gaskets are manufactured to ASME B26.20 and API 6A specifications.

- Style RX

The RX style ring joint has a unique self-sealing action. The outside bevels of the ring make the initial contact with the groove as the flanges are brought together with the flange bolting.

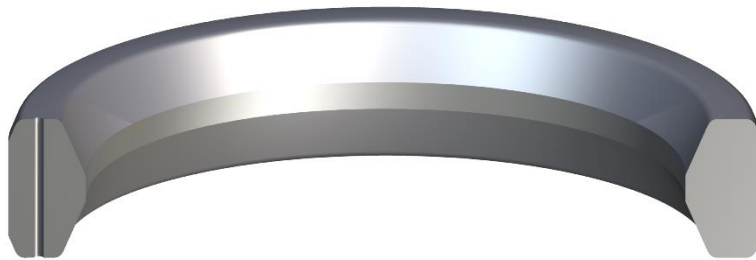


Figure 21: Style RX Gasket

This provides initial sealing of the joint with the gasket seating against the groove surfaces. During pressurization the gasket loading increases against the groove. Style RX ring joint gaskets as specified in ASME B16.20 and API 6A are completely interchangeable with the oval and octagonal series of identical reference numbers and are used in the same flange grooves.

- Style BX

The BX style ring is designed to specifications shown in ASME B126.20 or API 6A, for use with grooved flanges on special applications involving high pressures from 344 bar (5,000 psi) to 1,034 bar (15,000 psi).

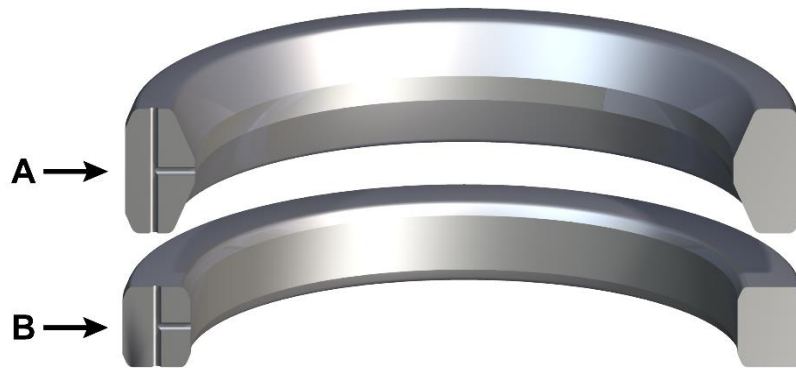


Figure 22: Style BX Gasket

The pitch diameter of the ring is slightly larger than the pitch diameter of the groove, thus initial contact is made on the outside of the ring, pre-loading the gasket and creating a pressure-energized seal. Connections utilizing Style BX have a limited amount of positive interference, ensuring that the gasket will be “coined” in the flange grooves. Style BX ring joint gaskets can only be used with API BX flanges and are not interchangeable with the Style RX series.

- Style SRX/SBX for Subsea Type

Style SRX and SBX ring joint gaskets are made per API 17D for subsea wellhead and tree equipment. These ring joint gaskets with "S" suffix designations, indicate that these gaskets have cross-drilled holes which connects fluid volume located between the flange joint groove, the ring joint gasket and the bore or ID. This hole prevents fluid located between the joint groove and the ring joint gasket from interfering with proper seating of the gasket. During installation, the gasket is compressed into the flange groove and fluid is allowed to vent into the bore or ID.



A=SRX Style; B=SBX Style

Figure 23: Style SRX and SBX Gaskets

The SRX and SBX gaskets have identical overall measurements to the RX and BX ring joint gaskets with the same number designation. These additional vent holes are typically installed in one of two different patterns.

NOTE: The use of vent holes can also reduce the possibility of trapping pressure between one side of the ring joint gasket and the groove, creating a potentially dangerous situation during disassembly.

- Lens Ring

These are for high temperature, high pressure applications on pipework, valves and pressure vessels.

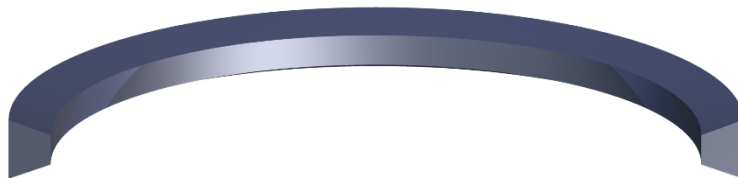


Figure 24: Lens Ring

Lens rings have two (2) spherical faces and are used between flanges with straight tapered twenty degree (20°) faces. Providing a line contact seal approximately one-third across the gasket face, the specially designed cross-section affects a pressure-energized seal.

- Bridgeman

This pressure-activated design is used for pressure vessel and valve bonnet gaskets, at pressures 103 bar (1500 psi) and higher.

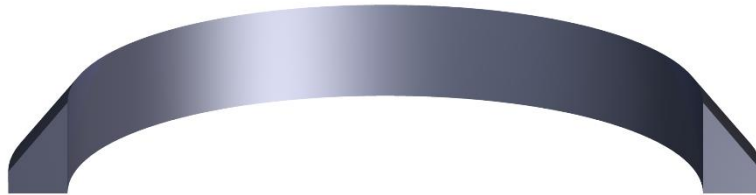


Figure 25: Bridgeman

This design has also been adapted to pipe joints which are subject to extreme thermal shock conditions.

- Delta

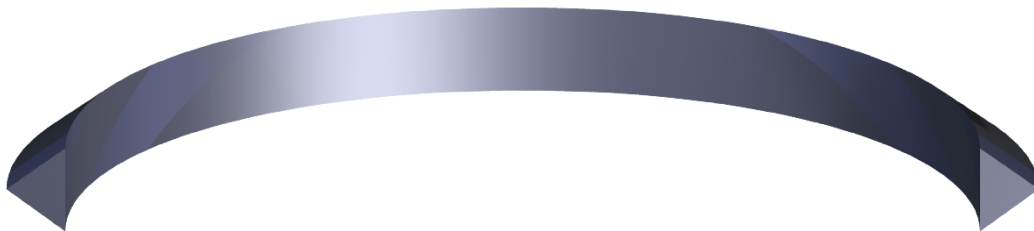


Figure 26: Delta

The pressure-activated Delta cross-section is a pressure vessel or valve bonnet gasket, useful for pressure ranges of 344 bar (5000 psi) and higher.

Welded Gasket

Welded Gaskets have originally come from the German industrial market. There are two (2) typical variations; Weld Membrane Gaskets, in accordance with DIN 2695 and Weld Ring Gaskets. Welded gaskets are typically used where a welded joint is required and limited disassembly will occur. Typically, Welded Gaskets can be reused/rewelded up to approximately five (5) times. It is important to note that when utilizing Welded Gaskets in bolted flange joints, the bolting is still relied upon to carry the hydrostatic end loads on the joint. Also, Welded Gaskets are sometimes utilized in conjunction with machined face profiles to accept installation of other auxiliary gasket types, such as spiral wound or kammprofile gaskets. In these cases, the Welded Gasket may be utilized and welded on the OD in the event of failure of the auxiliary gasket. Or the auxiliary gasket may be utilized to perform hydro tests or other functions, thereby not requiring welding of the OD of the Welded Gasket set until final assembly

- Weld Membrane Gaskets

Weld Membrane Gaskets are used in pairs, one welded to each flange.

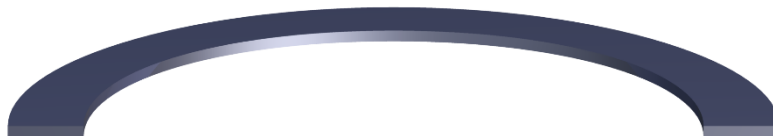


Figure 27A: Weld Membrane Gasket

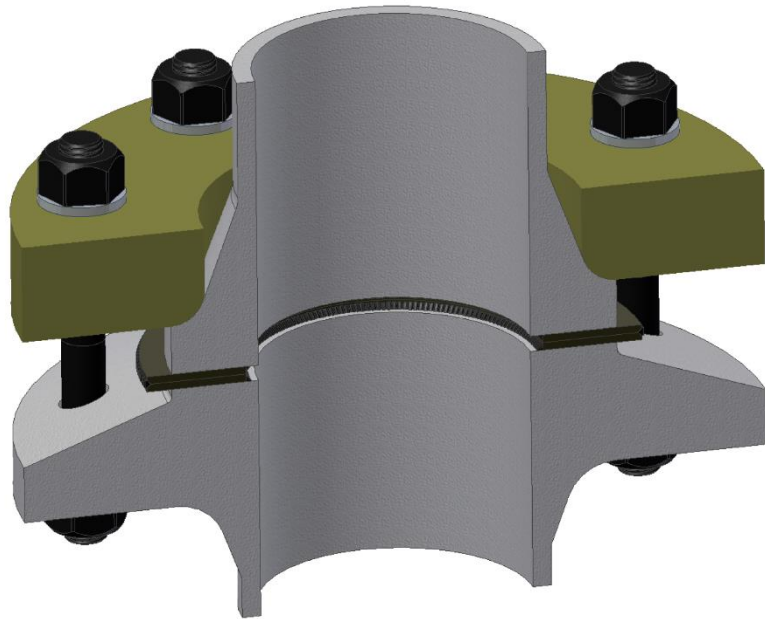


Figure 27B: Weld Membrane Gasket in a Flange Assembly

Weld Membrane Gaskets made to DIN 2695 are 4mm thick. They are typically made of material the same or similar to the flange material/ in terms of weld compatibility, thermal characteristics and corrosion characteristics. Each ring is seal welded to its mating flange on the ID. Then upon flange assembly, the two Weld Membrane Gaskets are seal welded to each other at their outer diameter, providing a fully welded joint. Special flanges made to DIN 2526 Type M are utilized in conjunction with Weld Membrane Gaskets, to ensure that there is adequate room to perform the OD seal weld.

- Weld Ring Gaskets

Similar to Weld Membrane Gaskets in that Weld Ring Gaskets are also used in pairs.

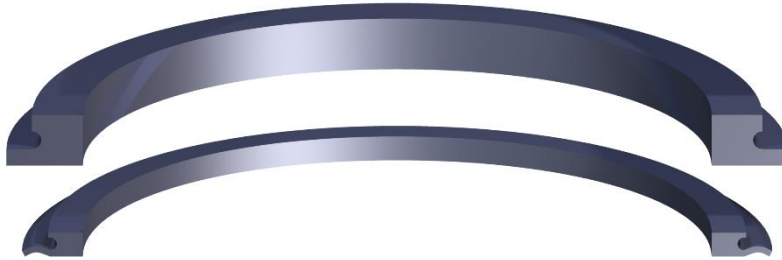


Figure 28A: Style SR Welded Ring
Figure 28B: Style SRL Welded Ring

Materials utilized should be similar to the flange material as noted above for Weld Membrane

Gaskets.

Each ring is seal welded to its mating flange on ID or OD (depending upon style utilized).

Then upon flange assembly the two Weld Ring Gaskets are seal welded to each other at their outer diameter.

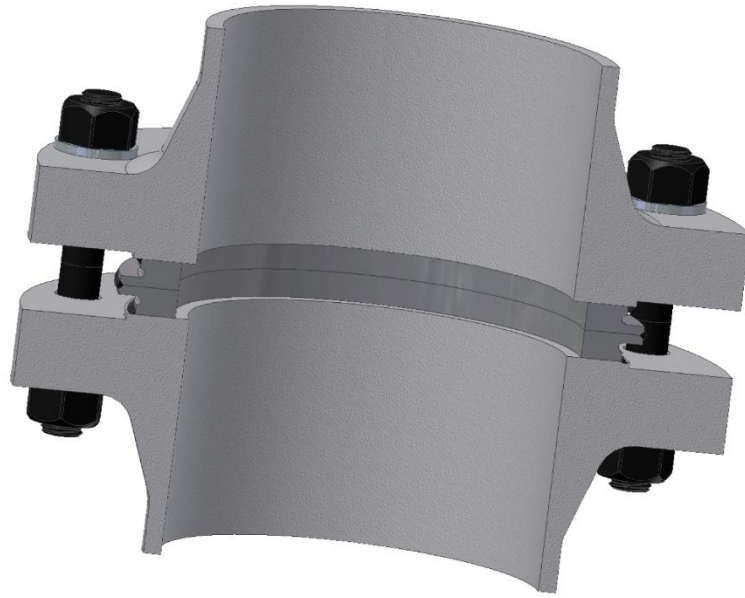


Figure 28C: Weld Ring Gasket in Flange Assembly

2. Common Metallic Gasket Materials

The following is a listing of the more common metals used in manufacturing both semi-metallic and metallic gaskets. It is not intended to be a list of all available materials, only the typical materials. For a more complete listing, contact your gasket supplier or manufacturer to discuss all the materials which they may have available. Refer to EN 10027-1 and EN 10027-2 Designations Systems for Steel Part 1: Steel Names and Part 2: Steel Numbers and The Unified Numbering System (UNS) for Metals and Alloys for complete list of metal standards.

Aluminum

Has excellent corrosion resistance to organic acids except nitric acids.

Brass

Copper alloys are generally used with non-oxidizing acids, alkaline and neutral salt solutions.

Carbon Steel

The most commonly used material for manufacturing double jacketed gaskets. It has poor resistance to corrosion and should be used with caution when in contact with water or diluted acids.

Copper

Used successfully in acetic acids, nitrates and many organic chemicals

Hastelloy® B

This is a corrosion resistant alloy resists corrosion of hydrochloric acid under most conditions, as well as, other halogen acids. It is also resistant to phosphoric acid and reducing conditions.

Hastelloy® C

Offers exceptional resistance to severe oxidizing conditions encountered with nitric acid, free chlorine as well as strong aqueous and acid solutions.

Inconel®

Withstands high temperatures and has excellent resistance to corrosion by halogen gases and compounds.

Lead

Good resistance to sulfuric, chromic and phosphoric acids. It is soft and malleable.

Monel®

Excellent resistance to most acids and alkalis except extremely oxidant acids.

Nickel

Excellent resistance to caustic substances. Has a high degree of corrosion resistance to neutral and distilled water.

Titanium

Has a good resistance to wet chlorine and chlorine dioxide.

Type 304 Stainless Steel (1.4362)

This material is widely used in the manufacture of industrial gasketing, due to its low cost and excellent resistance to corrosion.

Type 316 (1.4401) /316L (1.4404) Stainless Steel

This material generally offers a higher resistance to corrosion than type 304SS.

Type 321 Stainless Steel (1.4541)

This alloy is similar to 304SS but titanium is added. It is widely used in high temperature corrosive applications.

Type 347 Stainless Steel (1.4550)

This alloy is similar to 304SS but columbium and titanium are added. It has good performance in high temperature corrosive applications.

Type 410 Stainless Steel (1.4006)

This stainless steel is a heat treatable 12% chromium steel, which combines good general corrosion resistance with high strength.

Chapter 3: How to Select a Gasket

Gasket selection can be complex or it can be as simple as selecting the right color from a shelf in the stockroom. However, selecting the right gasket for a leak-free seal requires much more thought and consideration. Though the best practice for gasket selection occurs during the system and piping design phase. The majority of the context which follows is focused on existing bolted flange connections.

There are four major categories for consideration when selecting the right gasket: gasket related, flange related, fastener related and the gasket-flange-fastener system as a whole. Specific gasket related considerations include the temperature, pressure and fluid interactions against the gasket; as well as the gaskets thickness required stress to seal and storage of the actual gaskets. Of course, there are also special critical applications which require additional industry regulated recommendations, such as oxygen, chlorine services and heat exchanger applications. Flange related considerations include the type of flange in use, its surface finish, flange compatibility with semi-metallic and metallic gaskets due to electrochemical (or “galvanic”) corrosion and flange strength and deformation. Considerations related to the fasteners include material properties of bolts/studs, nuts and washers. When you begin to put these three targeted categories together you must have more holistic considerations such as gasket size, overall joint “tightness”, gasket factors (design) and torque to control joint integrity.

It is imperative to understand that even on an independent level, the complexity of gasket selection is high and when you begin to evaluate the system on multiple levels, the complexity grows exponentially. The following sections will explore the main criteria to ultimately select the right gasket for your application, but it is always advisable to consult your gasket manufacturer for their recommendations on your application as a whole system. Complete an FSA gasket application questionnaire and send it to your preferred manufacturer for a detailed analysis and recommendation.



Figure 2: FSA Gasket Application Questionnaire (QR Code)

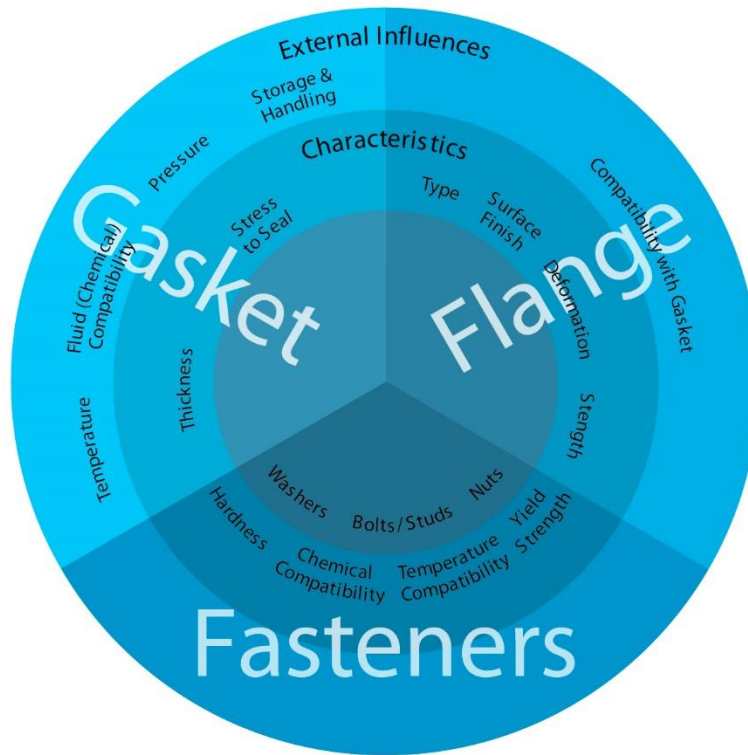


Figure 30: Considerations of Bolted Flange Joint Connections

A. Gasket Related Considerations

When trying to understand the influences upon gasket selection we must break it down into specific factors which are the most influential: temperature, pressure, fluid (chemical compatibility), gasket thickness, stress to seal, storage and handling. Additional factors are influential in some unique applications and specialty equipment. The following sections look at these factors independently, however, they must all eventually be balanced and evaluated as a whole in order to make a recommendation. It very important to involve your gasket manufacturer for detailed analysis.

1. Temperature

In general, the temperature of the application fluid is assumed to be the temperature of the gasket. While that is mostly assumed negligible, there are other variables that may be significant in specific applications such as insulation, extreme weather conditions and external heat sources, etc.

Gaskets are affected by temperature in three ways: gross physical characteristics, mechanical and chemical resistance properties. General temperature limits of both gasketing products and components are provided in the Table 1 below

- Gross physical characteristics of a gasket and/or its individual components include the material state, oxidation point and general resilience
- Mechanical properties include creep relaxation (sometimes referred to as stress relaxation) and the resulting torque retention capabilities. Under ambient conditions, most gasket materials will not show any significant torque loss. As temperature rises above 90°C (194°F), torque loss becomes a serious consideration and requires a gasket material which will be minimally affected by material degradation or creep relaxation. If the gasket material is suitable for the temperature, re-torquing at an ambient temperature may compensate for torque loss. At temperatures above 90°C (194°F), the majority of applications lose the most torque within the first 24 hours of operation. Refer to Chapter 3D4 for more information on torque & re-torque Torque retention also decreases as material thickness increases. Refer to Chapter 3 Section A4 for more information on gasket thickness
- Chemical resistance properties can be more difficult to assess on multi-component gasketing products. It is always important to consult with the manufacturer in order to gain specific information on their unique formulations as it pertains to the temperature requirements for your given application

Table 1 outlines the approximate minimum and maximum temperature limits for common gasketing materials and individual components, based on generally accepted application parameters. While every attempt has been made to provide reasonably accurate values, the data contained herein is considered to be a guide and should not be used as a sole source of information for any given product group or type. Variations within the category descriptions between manufacturers, manufacturing methods and material combinations, can significantly affect the listed limits and care must be exercised when such circumstances arise. Please consult the specific manufacturer of the product in question for specific information as it relates to the application.

Consideration should be given regarding the continuous operating temperature of the system. The general temperature limits listed above are generally considered upper and lower limits to the given material or material type under continuous operating conditions. Many manufacturers publish specific pressure-temperature curves for their various non-metallic products as these products are most susceptible to pressure and temperature fluctuations. It should be noted that a given continuous operating temperature limit provided by a manufacturer does not necessarily coincide with a constant continuous operating pressure; rather the relationship is dynamic and should be considered as such. Consult with the manufacturer's specific information as it pertains to individual operating conditions within the system.

Table 1: Material Application Temperature Limits

Material	Minimum Temperature	Maximum Temperature
Flexible Graphite ¹		
Non-Oxidation Inhibited	-240°C (-400°F)	400°C to 450°C (752°F to 842°F)
Oxidation Inhibited	-240°C (-400°F)	500°C to 525°C (932°F to 977°F)
Compressed Elastomer- Based Fiber ²	-40°C to -30°C (-40°F to -22°F)	204°C to 400°C (400°F to 750°F)
Beater Addition Elastomer-Based Fiber ²	-40°C to -30°C (-40°F to -22°F)	180°C to 400°C (350°F to 750°F)
Polytetrafluoroethylene (PTFE) ⁶		
Virgin PTFE	-210°C (-346°F)	260°C (500°F)
Expanded PTFE	-210°C (-346°F)	260°C (500°F)
Filled PTFE	-210°C (-346°F)	260°C (500°F)
Phyllosilicate ⁸	-240°C (-400°F)	454°C to 982°C (850°F to 1800°F)
Vegetable Fiber	-30°C (-22°F)	121°C (250°F)
Rubbers/Elastomers ^{4 and 7}		
Natural (NR)	-51°C (-60°F)	104°C (220°F)
Nitrile (NBR)	-30°C (-22°F)	100°C (212°F)
Hydrogenated Nitrile (HNBR)	-30°C (-22°F)	149°C (300°F)
Ethylene-Propylene (EPDM)	-51°C (-60°F)	149°C (300°F)
Fluorocarbon	-15°C (-5°F)	199°C (390°F)
Chloroprene (CR)	-40°C (-40°F)	121°C (250°F)
Silicone (VMQ)	-59°C (-75°F)	232°C (450°F)
Fluorosilicone (FVMQ)	-59°C (-75°F)	232°C (450°F)
Styrene-butadiene (SBR)	-46°C (-50°F)	100°C (212°F)
Cork Composition	-30°C (-22°F)	121°C (250°F)
Metals ⁵		

Common Brasses	-269°C (-452°F)	260°C (500°F)
Copper	-269°C (-452°F)	316°C (600°F)
Aluminum	-269°C (-452°F)	427°C (800°F)
Stainless Steel, Type 304	-254°C (-425°F)	760°C (1400°F)
Stainless Steel, Type 316	-254°C (-425°F)	760°C (1400°F)
Stainless Steel, Type 317	-198°C (-325°F)	760°C (1400°F)
Stainless Steel, Type 321	-254°C (-325°F)	760°C (1400°F)
Stainless Steel, Type 347	-254°C (-325°F)	871°C (1600°F)
Soft Iron, Carbon Steel	-29°C (-20°F)	538°C (1000°F)
Alloy 20 (UNS N08020)	-198°C (-325°F)	871°C (1600°F)
Titanium	-59°C (-75°F)	1093°C (2000°F)
Nickel	-198°C (-325°F)	760°C (1400°F)
Monel® 400 (UNS N04400)	-198°C (-325°F)	816°C (1500°F)
Inconel® 625 (UNS N06625)	-254°C (-325°F)	1093°C (2000°F)
Hastelloy® (UNS N10276)	-254°C (-325°F)	1093°C (2000°F)

1 Categories of flexible graphite styles and limits in this chart are referenced from PVRC-SRC.

2 Limits vary depending on the configuration of the binder and fiber-reinforcing system. The minimum range provided is based upon the glass transition temperature (ASTM STP 1249) of the elastomer binder in these types of products. Manufacturers and manufacturing methods vary; when combined with other materials, the minimum temperature limit published by the manufacturer will take into consideration their unique formulation and experiences in static seal applications which may allow for lower limits than those published here. The maximum range provided generally takes into account the various typical configurations offered by major manufacturers.

3 Maximum temperature limit provided is generally based upon manufacturers agreed maximum continuous operating limits.

4 The maximum temperature limit of rubbers/elastomers can be highly dependent on the operating pressure of the application. Generally a PxT limit is set at <20,000 (psig x oF) for this product group. Consult the manufacturer for specifics based on the application.

5 Minimum temperature limits used in this table for metals are referenced from ASME B31.3 Process Piping as it is considered that the metallic gasket and/or the metallic gasketing components will be limited to the minimum temperatures of the process piping design. Please note that the allowable stress values for metals are greatly reduced at elevated temperatures. Please consult with the manufacturer for specific details based on the application. Additionally, the limits provided are based on the specific material identified: do not use these values for all sub-styles of a particular metal i.e. 304H is different than 304 and 316L is different than 316.

6 The minimum temperature limit for PTFE products has been listed at the temperature just below the points where liquid nitrogen and liquid oxygen will become a solid. This reference point is used in the publication due to the fact that these two substances are the most common cryogenic liquids used in industry. The maximum temperature limit for PTFE products is based on manufacturer's experience of maximum continuous operating temperature.

7 The minimum temperature limit of rubbers/elastomers has been set to approximately the glass transition temperature (ASTM STP 1249) of the specific material as this change of state from flexible to "glass-like" is considered the limiting factor when using them on any given application.

8 Phyllosilicates come in various types from virtually pure to mixtures with various fillers and binders (for sheet processing and handleability). The maximum temperature range provided in this table is based on published maximums by major manufacturers of this product type.

2. Pressure

In flanged applications, there are four types of pressures that could be considered in gasket selection: working pressure, system design pressure, operating pressure and hydro test pressure.

- Working pressure refers to the flange pressure rating for a given material and operating temperature. Working pressures are provided in commonly recognized codes and standards such as those specified by ASME, CEN, JIS, DIN, etc. For practical purposes related to gasket selection, these codes prescribe the temperature and pressure rating (limits) as well as associated flange dimensions. The higher the pressure class, the more robust the flanges become, providing greater load capability
- System design pressure is the pressure limit specific to a process or equipment and is generally the same as the settings for relief devices. These system design pressures take into consideration system upsets, excursions and pressure spikes
- Operating pressure is the pressure at which the process typically operates under normal conditions. This pressure is lower than system design pressure, to allow for system change/growth, safety and pressure fluctuation, caused by process controls. It is important to distinguish between the two limits, because a particular gasket material that may be suitable for a given operating pressure, may not be suitable for the system design pressure
- Hydro test pressure is pressure used as a safety check to verify equipment integrity prior to system start-up. A hydro test is generally performed at a given factor (commonly 1.5x) above the working pressure. A gasket must be selected to withstand this hydro test pressure. In some cases, it may be necessary to choose one gasket for the system hydro test and then install a different gasket for operating conditions afterwards

For non-metallic (soft) gaskets, manufactures have defined the maximum pressure limit of the gasket, which is dependent on the compressive load and the operating temperature. In general, high operating temperatures reduce the pressure capability of the gasket. Therefore, care must be taken to ensure that the compressive load, operating temperature, and pressure limit are considered when selecting a gasket for an application. Avoid selecting a gasket by matching the gasket pressure rating to the system pressure alone. Please consult with the manufacturer of the selected gasket material regarding the pressure and temperature ratings of their product.

Examples:

A gasket may have a maximum pressure rating of 103 bar (1500 psi) but may not be used in ASME Class 900 flanges because the application would exceed the maximum compressive load of the gasket.

A gasket may have a maximum pressure rating at ambient temperature of 103 bar (1500 psi) but may be restricted to a 50 bar (725 psi) pressure if the application temperature is 250°C (482°F).

For metallic and semi-metallic gaskets, maximum pressure limits are mostly dictated by the available flange load and flange working pressure. Therefore, metallic and semi-metallic gasket pressure ratings are not directly influenced by temperature.

3. Fluid

The primary purpose of a gasket is to contain a fluid in a mechanical joint. The contained fluid or media can be either gas or liquid. The fluid can range from hot to cold, high to low pH, corrosive to benign, flammable to non-flammable and everything in between. The gasket must be chemically compatible with the contained process fluids and with any fluids used for pressure testing or washdowns. Each gasket material has a different range of chemical compatibility which can change with the process temperature, fluid composition and fluid concentration.

Compatibility is determined by whether the gasket's physical and chemical properties are adversely affected by exposure to the fluid. Such adverse effects are color change, shrinking and/or weight loss and swelling or softening of the materials. These affects are a result of direct chemical attack, specifically oxidation and corrosion. Direct chemical attack is a very complex subject and can be influenced by many different variables, such as temperature, concentration and duration of exposure. As a rule, the selection of a gasket becomes more critical with increasing temperature, since the rate of chemical attacks generally increases with temperature.

Since some gasket types are made from multiple materials it is critical to ensure that all the materials in the gasket are chemically compatible with the process fluid. We recommend checking with the gasket manufacturer for specifics on chemical compatibility of their specific gasket materials. For fluids or conditions that are not listed in the manufacturer's tables, the user should seek additional technical assistance for his/her application. It may require an independent study to determine the compatibility of the gasket material with the fluid at the specific operational conditions.

4. Gasket Thickness

Metallic and semi-metallic gasket thickness generally does not alter the gasket pressure and temperature (PT) rating. Therefore, gasket thickness is not a critical factor in gasket selection for metallic and semi-metallic gaskets. Gasket thickness is typically dependent only on gasket construction due to constraints in manufacturing or handling. For example, spiral wound gaskets are generally 3.2mm (1/8") thick for smaller diameters and up to 7.2mm (0.285") for larger diameters.

In contrast, the thickness of non-metallic (soft) gaskets affects the gasket pressure and temperature (PT) rating. In general, thicker gaskets will have both a lower pressure rating and a lower temperature rating. This reduction may be compensated with additional compressive load (up to the maximum for the gasket at the given thickness). The maximum compressive load may decrease with increasing gasket thickness.

For non-metallic (soft) gaskets, selecting a gasket thickness can be based on the flange material and/or the flange condition. For metallic flanges, the flange condition may determine the selection of gasket thickness. For special flange materials, such as fiber-reinforced plastic (FRP) and glass-lined steel, other factors, such as flange strength, flange cracking drive and gasket thickness selection.

For non-metallic (soft) gaskets, the goal is to select the thinnest material able to compensate for flange irregularities. (i.e. flange damage, flange warping, uneven flange surfaces, lack of flange parallelism, etc.). Unless the flanges are new, assessing the flange condition can only be done when a bolted flange connection is disassembled. Therefore, it is often difficult to plan for which gasket thickness is best for your particular flange connection. Some general guidance is provided below with respect to the advantages of thin and thick gaskets.

Advantages of a Thin Gasket

Generally thin gaskets are 1.5mm (1/16") or thinner. A thinner in-service gasket provides the following benefits:

- Higher blowout resistance due to the smaller surface area (at the bore) exposed to the internal pressure
- Lower leak rate due to through-gasket permeation. Smaller surface area exposed to the fluid provides less opportunity for the fluid to permeate through the material
- Better torque retention in the fasteners due to better creep relaxation resistance. For a given material, creep relaxation resistance improves as the thickness decreases

Advantages of a Thick Gasket

Generally, thick gaskets are 3.2mm (1/8") or thicker. Typically a thicker gasket can "travel" more upon installation, allowing the gasket to fill in flange irregularities. The amount of "travel" is dependent on both the gasket compressibility and gasket thickness. To illustrate this concept, a 3.2mm (1/8") gasket compressed 10%, will "travel" 0.32mm (0.0125"); while, a 6.4mm (1/4") gasket compressed 10%, will "travel" 0.64mm (0.025"). Therefore, the 6.4mm (1/4") can accommodate twice the amount of flange irregularities. Compressibility is a term often used to describe the gasket's ability to compress and takes into account compressive load and gasket type.

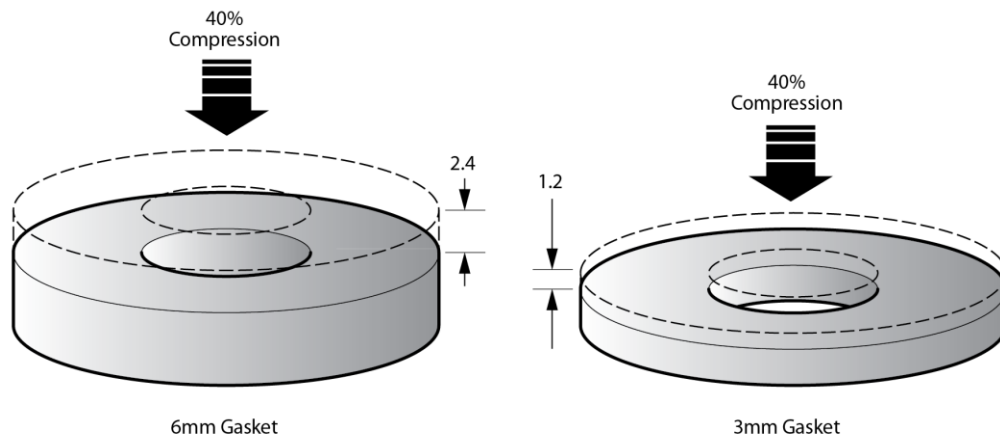


Figure 41A: Accommodating Flange Deviation: Compressibility & Gasket Thickness

The thicker in-service gasket provides the following benefits:

- More “travel” to fill in flange face irregularities
- Lower leak rates by closing off leak paths between the gasket and the flange surface
- More tolerant to flange misalignment

In general, gasket manufacturers have found the following to be true:

- Standard Raised Face flanges in as-new condition will typically utilize 1.5mm (1/16") gaskets, up to 600mm (24") nominal diameter. 3.2mm (1/8") gaskets are used for flanges greater than 600mm (24") nominal diameter
- Standard Flat Face flanges often utilize 3.2mm (1/8"), since the flange designs utilize thinner flanges with less rigidity
- Non-Standard pipe flanges, made of glass-lined steel or plastic, will typically utilize 3.2mm (1/8") gaskets
- Large equipment flanges will typically utilize 6.4mm (1/4") gaskets to accommodate their typical uneven flange surfaces

5. Gasket Stress

Gasket stress is a term commonly used to describe the unit load on its surface. It is one of the most important parameters of a bolted joint because it directly impacts the ability of the gasket to seal. Since the conditions under which a bolted joint operates during its life can be complex; compressive stress definitions have been established to describe conditions throughout this life cycle. Gasket types respond differently to a given stress

range, so employing the guidance provided by the gasket manufacturers regarding how their materials react is important. A soft and conformable gasket may seal at a relatively low gasket stress, while a hard metal gasket may require much higher stress.

Four Aspects of Gasket Stress

The compressive stress required on a gasket can be viewed in four ways:

- **Conform to the Flange Surfaces**
A minimum amount of compression is needed to seat the gasket on the flange surfaces. The gasket must conform to the flange's irregularities to function effectively. If the flanges were perfectly flat and smooth, a gasket might not be needed. With greater imperfections, more compression is needed to form the gasket into that shape
- **Block the Gasket Material's Permeability**
Once the gasket has conformed to the flange surface, additional compression may be needed to block any permeability in the gasket body. Permeability through gaskets varies greatly for different types of material, but in almost all cases, leak rates decrease as the compressive load increases. Required stresses, especially in gaseous services, will increase depending on how tight the seal needs to be. These stresses are higher than the minimum stresses that are necessary to make the gasket conform to the flanges. Refer to Chapter 3 Section D.2 for information on joint tightness
- **Withstand Internal Pressure**
When using non-metallic gaskets, the ability of a bolted joint to hold internal pressure depends on friction, which is related to the compressive load on the gasket. The minimum compressive stress will need to be high enough to maintain the friction needed to keep the gasket from blowing out from the internal pressure
- **Temperature**
The fourth consideration for determining an installation stress is temperature. Elevated temperature will create gasket relaxation and subsequent relaxation in the bolt load. Some load losses can be as high as 50 percent of the initial gasket stress. The initial installation stresses need to be high enough to compensate for this effect. This is the reason that some gasket manufacturers recommend a re-torque after the first heat cycle depending on the gasket type (of course, observing the appropriate lock-out and tag-out safety procedures)

Characterization of Stresses

The minimum seating stress, ideal operating stress, minimum operating stress (considering internal pressure of the system) and maximum operating stress specific to a given gasket material, need to be understood and taken into consideration. While many references to values for these stresses have been published, the most updated reference

is found in an appendix to recently published ASME PCC-1-2010 Guidelines for Pressure Boundary Bolted Flange Joint Assembly. EN1591 *Flanges and their joints – Design rules for gasketed circular flange connections* also provides terminology and an approach for characterization of gasket stresses and for selecting a target assembly stress.



Figure 52: Relative Gasket Stresses

References to gasket stress in this document are shown, but further explanations are needed. Below are the terms and references used in the text and some suggested guidance agreed upon by gasket material manufacturers.

- Minimum gasket seating stress (S_{gmin-S}) is basically the absolute minimum stress needed to conform to the flanges, assuming that there is little or no internal pressure. Most gasket manufacturers can provide these values on their gasket materials. Often, these values are determined with low-pressure leakage tests on each gasket material. This minimum stress value will normally be used only in flange design calculations
- Minimum gasket operating stress (S_{gmin-O}) will normally depend on the design pressure of the assembly. It will be higher than the seating stress or Y value, of the gasket. Most gasket suppliers can provide the minimum operating stress with consideration of the pressure. It is not uncommon for these values to increase with increasing gasket thickness. The minimum operating stress is always lower than the minimum seating stress, however, manufacturers recommend installation stresses higher than both
- Maximum assembly gasket stress (S_{gmax}) is the stress that could damage the integrity of the gasket and detrimentally affect its ability to maintain a seal. Many gasket manufacturers will perform laboratory tests to determine the maximum stress on a gasket. Many variables are involved when considering the maximum stress or crush strength of a material, including surface finish, gasket width, thickness, material type and temperature. Most manufacturers will test with smooth surfaces as well as standard ASME/EN serrated flange finishes. Thicker gaskets are usually less resistant to over compression and crushing. Also, serrated flanges tend to allow for higher compressive loads, because the rougher surface will grab or hold the gasket better. Smooth surfaces allow the gasket to slip sideways and split at lower stresses

Because there is a natural variation in any assembly method between calculated and actual compressive stress, most gasket manufacturers will supply a maximum recommended stress that is safely below the actual crush test results. For

example, if laboratory tests show damage to a gasket at 172.4 MPa (25,000 psi) stress, the recommended maximum stress might be limited to 103.4 MPa (15,000 psi).

- Target gasket stress (SgT) is the load that allows the gasket, as well as the entire joint, to operate at optimal performance and sealability. Additionally, the installation stress creates a preload in the joint that compensates for overall bolted joint relaxation after installation and during operation for the service life of the joint (with consideration given to joint integrity). ASME PCC-1-2010 recommends that the target stress should be as high as possible; “The target gasket stress should be selected to be towards the upper end of the acceptable gasket stress range, as this will give the most amount of buffer against joint leakage.”

Many reasons exist for using a high-target gasket stress. In assemblies running at high pressures or flanges with large internal diameters, there will be significant unloading of the joint when pressurized. Studies conducted by the Pressure Vessel Research Council (PVRC) on pipe bending stresses showed that the bolt stress in the joint was a major factor in keeping the gasket from leaking. The higher the bolt stress, the more bending force the joint could potentially handle.

System fluctuations in pressure and temperature will affect the retained bolt load in a joint. Since these factors may reduce the load in the bolts, it is good practice to install the bolts at higher initial stresses, as long as the components are not damaged and bolt material yield is taken into account. Stresses in the bolts will have a direct impact on the stresses in the flanges, so these factors must all be considered when selecting the target gasket stress.

Selecting an Installation Gasket Stress

Choosing an appropriate gasket installation stress, takes into consideration many factors:

- With equipment such as pumps, valves, actuators, sight glass assemblies, etc., the manufacturer of those components should be consulted. For standard plant piping, the designer or plant engineer will typically define the maximum bolt stress based on the bolt grade, operating temperature and flange design stresses

NOTE: This maximum bolt stress is NOT the same as the allowable stress in ASME design calculations, which is typically only 25 percent of yield. This stress limit is much higher because the ASME Code calculations are meant to force the design to have a significant safety factor, and the design stresses are therefore low.

- Once the maximum bolt installation stress is known, the gasket supplier can provide the recommended gasket stress. They will need to know the service

conditions for the assembly to select the correct gasket stress

NOTE: The Y value from the ASME Code calculations should only be used to design the flanges.

The minimum gasket operating stress might be used if the system is going to run at very low pressures. For example, assemblies using pipe and flange materials with low compressive strengths, might need to use the lowest possible gasket stress to affect a seal and avoid damage to the flanges. Flanges running at higher pressures and temperatures will use a stress higher than the minimum operating stress.

The simplest method of selecting the target gasket stress for installation is to calculate the available compressive stress at the maximum bolt stress. This maximum bolt stress is typically determined by the plant engineer, and could vary from 40 percent of bolt yield to over 75 percent at some plants. As long as the available gasket stress at maximum bolt stress is below the maximum gasket stress (or crush strength of the gasket) and above the minimum recommended gasket stress for the operating conditions that can be the target stress.

6. Gasket Storage and Handling

Although many gasket materials can be used safely after storage for many years, the performance of some gaskets may be compromised due to ageing. Chemical degradation will occur over time as some gaskets are exposed to temperature, humidity, ozone (generated from high voltage electrical sources) and UV exposure.

Compressed elastomer-based sheets, as well as finished gaskets, should not be stored for long periods of time. The elastomer used as a binder can age causing degradation of physical characteristics, important to sealing performance. Even aging at ambient temperatures for long periods will have a distinct effect on properties of certain types of gasket materials. This occurs over time primarily because of the chemical degradation of the rubber binder. Figure 34 shows a typical curve of a decrease in compressed elastomer-based fiber gasket material compressibility as a function of time at 25°C (77°F). Primarily, aging is a concern for materials bonded with most elastomers. In general, these gaskets should not be used after about 4 years from the date of manufacture. Those materials with elastomeric binders will inevitably deteriorate over time and even more quickly at higher ambient temperatures. Degradation is also accelerated by intense sunlight and naturally occurring ozone. All of these factors can cause extensive physical damage to the gasket material which will typically result in leakage over time.

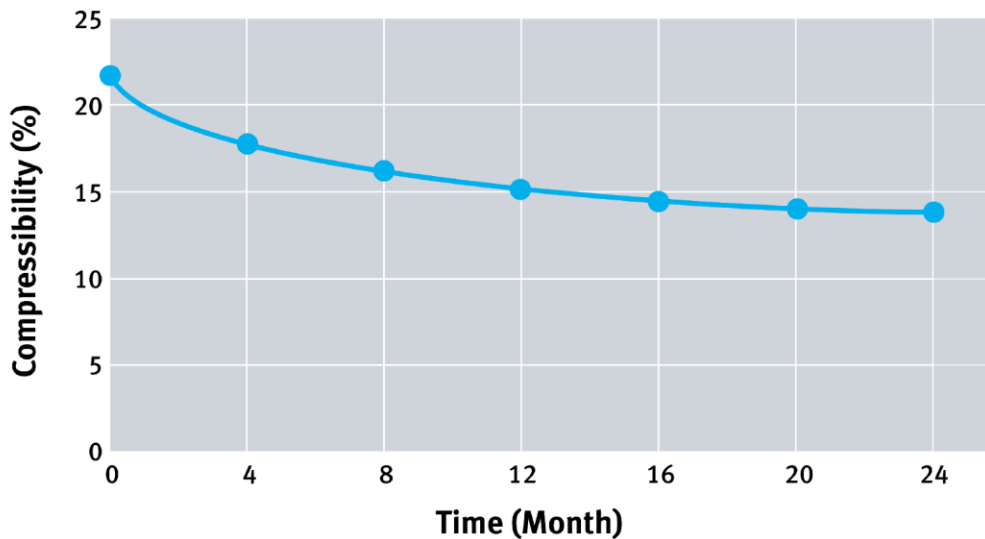


Figure 63: Compressibility Change after Aging

Since the mechanical properties of the gasket material play an important role in performance, it is important to control those conditions that accelerate deterioration from aging. The natural aging of the compressed non-asbestos gasket will depend upon the material composition, degree of rubber cure and the manner in which the gasket was fabricated. It is important that the manufacturer recommendations for storage and handling be followed to ensure the longest shelf life for the material.

For metallic gaskets, performance degradation is of little concern; however, it may have an effect on semi-metallic gaskets (specifically, those which are combined with elastomer-bound materials and which may incorporate adhesives to bond substrates). Since homogeneous flexible graphite and PTFE materials contain no binders and are generally considered inert, sheets and gaskets of these materials have virtually an indefinite shelf life.

General guidance from most gasket manufacturers is to store gaskets and gasket materials in a cool, dry location away from heat, excessive humidity, direct sunlight, and chemicals. The optimum storage conditions are defined as 4°C to 27°C (40°F to 80°F) with 40% to 75% relative humidity, in a room with no windows and non-UV or low-UV producing lights, minimal dust and no chemical storage or high voltage electrical sources nearby.

Overall storage recommendations:

- Store in a cool, dry place, away from direct sunlight, UV light, water, oil, chemicals, and chemical vapors

- Do not expose gaskets to excessive heat and humidity or extreme fluctuations of heat and humidity
- Keep gaskets clean and free from mechanical damage (for maximum protection, store in sealed poly bags)
- Avoid accumulation of dust and particulate on gasket faces and edges which may cause compatibility issues with the fluid being sealed
- Store most sheet materials flat where practical and wrapped and/or covered
- Store non-metallic (soft) gaskets flat in stacks and avoid hanging them as they may deform



Figure 74: Gasket Storage by Peg Board (A) vs Flat (B)

- For spiral wound gaskets, store them in their original packaging with spacer clips intact. Commonly, gaskets up to 150mm (6") are stacked in 5 or 10 pieces per bundle and gaskets between 150mm (6") and 500mm (20") are stacked in 2 or 5 pieces per bundle using plastic spacer clips to avoid damage to the sealing elements

- For large diameter spiral wound gaskets (>500mm (20")), keep them on their mounting board and in original packaging
- For metallic gaskets, high humidity and moisture can cause oxidation. Typically these gaskets are treated to prevent oxidation. Consult your gasket manufacturer

The effect of storage and ageing will depend upon the material. Consequently, always consult the manufacturer for advice about storage of specific products.

Gaskets and their packaging should always be handled with care in order to avoid deterioration and damage and extra care should be taken when handling large gaskets greater than 500mm (20") in diameter. Whenever gaskets are being transported; individually or in groups; it is preferred that they be kept flat, however, when this is not practical, always make sure that the gasket(s) are adequately supported to avoid any distortion. Typically, transporting gaskets in their original packaging will provide the best protection against distortion until they are ready to be installed.

For individual gaskets; sizes up to 800mm (32") in diameter, can often be handled by one individual. However, it is recommended to use additional people for larger size gaskets in order to properly support the gasket and avoid twisting, distortion and breakage.

- 800 - 1000mm (32" - 40") 3 people
- 1000 - 2000mm (40" - 80") 4 people
- 2000mm (80") and larger 6 - 8 people

When handling spiral wound gaskets, wear gloves and do not hold the gasket by the outer ring only. Failure to adequately support the sealing element and/or inner ring may cause it to dislodge from the outer ring under its own weight, or through flexing and become damaged. Always ensure to support all of the components of spiral wound gaskets through to final installation. It is recommended to keep the mounting board in place for large diameter gaskets until the gasket is situated between the flanges.

Proper handling of gaskets will ensure its integrity is withheld through the transportation and installation stages. Special sizes and gasket configurations usually require special handling on their own. Always consult the manufacturer for recommendations and best practices for your unique conditions.

7. Unique Applications / Specialty Equipment

As with most industrial products, there are many unique applications and pieces of specialty equipment. They often have their own product, material, and specification requirements in combination and in addition to those referenced in 1-6 above. Though it is impossible to consider all the unique applications and specialty equipment, several common ones are briefly discussed below in order to highlight their specific gasketing requirements.

Oxygen Service

All organic and inorganic materials react with both gaseous and liquid oxygen at certain pressures and temperatures. This can cause serious fires and/or explosions. Because of this inherent danger, it is important to select gasket materials which have been tested and certified for use under these severe conditions. Perhaps the most recognized testing and certifying body in the gasket industry is the Federal Institute for Materials Testing & Research (BAM) located in Berlin, Germany. There are many sub-handling requirements for all products in oxygen service, but most applications require the base gasket material to be BAM certified. ASTM publishes two guides (G63, G94) which establish a system for evaluating non-metallic and metallic materials for oxygen service. Table X1.1 in G63, lists several materials commonly used as gaskets in oxygen service, such as PTFE, graphite, and sponge chloroprene (CR) elastomer. Guide G94 tends to not list accepted metals as the determination of such is a very complex process, however, the listed best practice by ASTM for metal selection is to use the least reactive material available with the highest oxygen indices.

Chlorine Service

Chlorine is an aggressive oxidizer that reacts with many metals and organic materials. Service conditions, including contact with dry or wet chlorine, must be taken into account when assessing proper gasket selection. The Chlorine Institute (CI) *Pamphlet 95 – Gaskets for Chlorine Service* and Euro Chlor in Europe list several gasketing products which have been found as acceptable for use. The Chlorine Institute and Euro Chlor do not endorse any of the listed products; rather the publication reflects information obtained from CI companies in their use and/or evaluation of the gasket or gasket material.

Ethylene Oxide

Ethylene Oxide (EO) is considered very reactive and must be given special attention when selecting proper sealing products. The reactive process is referred to as polymerization and occurs naturally with many products. EO rapidly attacks and breaks down many of the organic polymers and elastomers used to make gaskets and one of the most important points to consider is the rate of deterioration of any selected material. The most visible organization making suggestions on safe products for use with EO is the American Chemistry Council and their publication *Ethylene Oxide*. Through the American Chemistry Council's Ethylene Oxide/Ethylene Glycols Panel membership experience, it has been found that the preferred gasket type is a spiral wound gasket with 304SS outer/inner rings, 304SS windings and pure (98% min.) flexible graphite filler. Where spiral wound gaskets are not practical or possible for use, the next choice is often flexible graphite sheets laminated onto a tanged metal core insert. Virgin PTFE has been found to be an acceptable material where the gasket can be captured to minimize creep, however, filled PTFE products are often unsuitable due to effects caused by polymerization of the EO with the filler material (such as glass and barium sulfate).

Fire Safe Requirements

In many refinery and power plants there is the requirement for gaskets to be rated as "fire safe". One of the more common gasket industry fire test procedures is known as the API

607 Modified Fire Test, which is an adaptation of a fire test for valves. It is common that most metallic and semi-metallic gaskets are accepted as being “fire rated”. There are non-metallic gasketing products such as flexible graphite gaskets which have passed fire tests. In addition, there are a few compressed elastomer-based fiber and PTFE gaskets that have also passed fire tests. Consultation with your gasket manufacturer is important when requiring a fire safe gasket, as they may have many styles for you to choose from to suit your budget and performance criteria.

Nuclear Applications

There are many traditional applications found in the nuclear industry which can use common gasketing types, however, gasket requirements located on the reactor side of the process have very different requirements which must always be carefully scrutinized for safety reasons. Perhaps the most common gasket type used in the nuclear industry is some combination of stainless steel and flexible graphite. Typically there are high purity requirements for the flexible graphite component of the gasket and often special oxidation inhibitors are also required. The nuclear industry has its own regulating bodies and gasket standards can vary depending on operator, reactor type, and region/country. It is important to verify local plant standards and coordinate suitable materials from your gasket manufacturer for these applications.

Food and Pharmaceutical Application

Though these industries are very distinguishable, gasketing specifications and requirements for these two industries are often based upon toxicological tests and component “leaching” tests. The common standards used in these industries include, but are not limited to:

- The Food and Drug Administration (FDA) in the USA has been the primary reference for gasket usage for many years and design specifications often have a requirement for gasketing products to be ‘FDA Approved.’ In virtually all cases, gasket products themselves are not “approved” and only carry a statement of “FDA Compliant”
- The US Pharmacopeia Convention (USP) has developed gasketing standards (USP Class VI <87> and <88>) specifically to the pharmaceutical industry. These new USP standards sometimes requires certification of a manufacturer for a given product in order to verify all of the components, systems and equipment used in the manufacture of the gasket
- ASME has a bioprocessing standard (BPE-2005) which specifically addresses the “materials of construction of seals in equipment used in the bioprocessing, pharmaceutical and personal care products industries.” BPE-2005 defines 4 classes of seals: Class I, II, III, and Hygienic Fitting Seals
- The 3-A Sanitary Standards Inc. is largely a USA-based organization focusing on “equipment design for the food, beverage and pharmaceutical industries. 3-A has

standards in place to address rubber, rubber-like materials (Standard 18) and plastic materials (Standard 20)

- The European Hygienic Engineering & Design Group (EHEDG) is generally considered Europe's equivalent to 3-A and has several guidelines which address gasket material selection in various designs of pumps, homogenizers, dampening devices and piping. EHEDG has a harmonization effort underway with 3-A in order to ensure consistency in food safety hygiene practices

There are many gasket products which meet the codes and standards mentioned above and the user should consult their operations standards, local regulatory bodies and gasket manufacturer for assistance.

Clean/Ultra-Pure Water

Due to the requirement of this industry for ultra-clean equipment (piping, valves, fittings and gaskets), most gaskets can be used in these pure water applications providing they have been cleaned to some specific level as required by the end-user. In many circumstances cleaning procedures similar to those for oxygen service can be employed and will meet the local requirements, however, always consult with the manufacturer and verify that the gasket supplier's cleaning procedures meets end-user requirements. Typically end-users will perform additional cleaning procedures before placing equipment in service.

Heat Exchangers

Shell and tube heat exchangers pose a unique challenge, due to the relatively low allowable gasket stress designed into the equipment, combined with the temperature cycles and temperature changes (creating a condition called radial shear) from chamber to chamber. Research indicates that there can be a net loss of 20% or more in initial bolt load during the increase in operational temperature of the joint. Care needs to be exercised when making gasket changes in these types of systems.

Many shell and tube heat exchangers come from the factory equipped (OEM) with metal jacketed gaskets, mostly for costs, which usually do not give optimum performance over an extended period of time. Kammprofile, expanded PTFE (ePTFE) and flexible graphite gaskets, can be suitable alternatives to these OEM gaskets.

Kammprofile gaskets (stainless steel serrated cores with flexible graphite covering layers) offer significantly lower required seating stress, resiliency to temperature fluctuations and radial shear inherent in the application. With the varying designs of shell and tube heat exchangers and required partition bars, it is important to communicate measurements and drawings to your gasket manufacturer in order to ensure precision alignment with your equipment.

ePTFE gaskets can be a gasketing option for heat exchanger design that does not require a metal component to the gasket. ePTFE gaskets offer the benefit of conformability and chemical compatibility. Heat exchanger gaskets can be cut from ePTFE sheets. In addition, the use of ePTFE tapes can be a practical solution as the gasket can be formed-in-place around the outside diameter and across the cross-bar(s).

Often in the field, heat exchanger surfaces get damaged, causing difficulty in sealing the metal gasket specified in the original heat exchanger design. When heat exchanger surface re-surfacing is not possible during an outage, graphite joint sealant and ePTFE can be an effective repair method.

B: Flange Related Considerations

The previous section discussed gasket selection in terms of the properties of the gasket itself. The effects of flange and gasket interaction on the resulting joint need to be considered. Certain aspects of flange construction may become the determining factor(s) in the selection of the gasket to produce the desired seal. Below is a review of flange type, flange surface finish and compatibility of the gasket material with that of the flange.

1. Flange Type

There are many types of flanges and associated gaskets in common use. While detailed discussion of flange design is beyond the scope of this document, it is valuable to at least outline some of the common types which are to be found in industrial installations.

While the majority of flange materials are metallic, some applications call for non-metallic flanges, such as reinforced plastic, glass or glass-lined steel. Non-metallic flanges tend to be used for applications which require a greater chemical resistance. Generally, these flanges are less robust and often require gaskets that can be seated under lower gasket stress. Operating temperatures and pressures are usually less severe. It is important to work directly with the gasket manufacturer for non-metallic and lined flanges as the intricacies of creating a tight seal are more complex than standard metallic flanges.

Common Flange Types

Raised face flanges

Raised face flanges are probably the most common flange type. The flange contact surfaces are raised and the gasket is non-confined.

The outside diameter of the gasket is centered inside the bolt circle. This is often called a “ring” gasket (also sometimes referred to as an inside bolt circle (IBC) gasket). This allows easy installation and removal of the gasket, without having to separate the complete flange system.

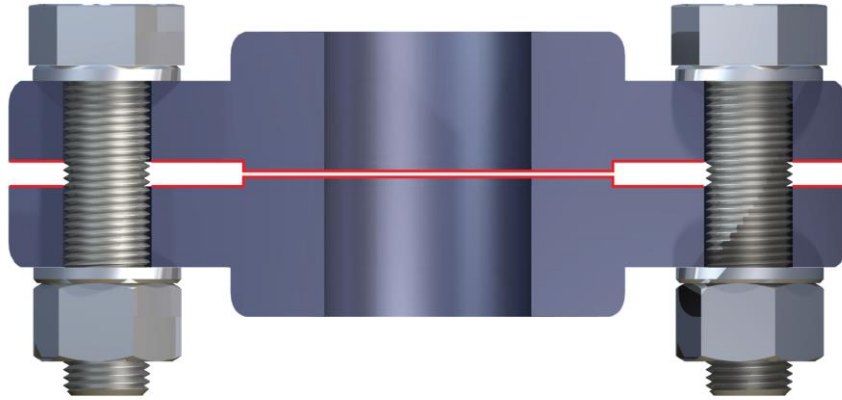


Figure 35: Raised Face Flange

Flat face flanges

Flat face flanges are normally used where the flange material is made of relatively fragile materials, such as cast iron or plastic. In this case, the gasket is non-confined and is relatively easy to install and remove.

The gasket is in full contact with the flange surface from inside to outside diameters with cut-outs for the bolts to pass through. These are commonly referred to as full face gaskets though several variations are available to meet specific flange load limitations. Ring gaskets can also be used with these flanges, though caution should be taken to avoid flange rotation.

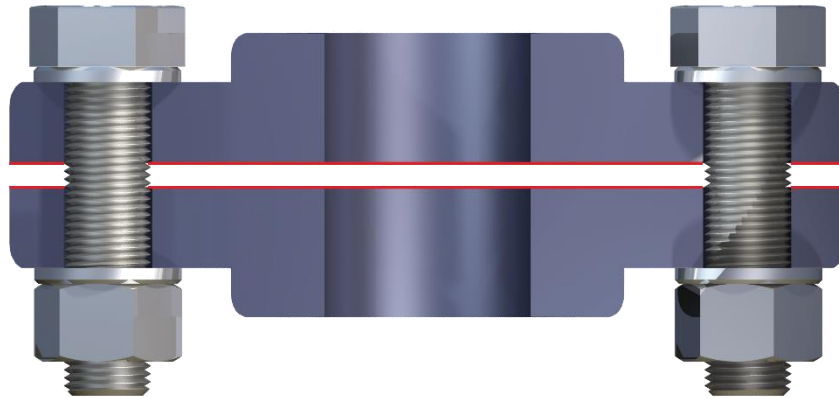


Figure 36: Flat Face Flange

Tongue and groove flanges

Tongue and groove flanges use a gasket which becomes totally confined on the groove side. The groove depth is equal to, or greater than, the tongue height and normally the gasket has the same width as the tongue.

In this arrangement it is necessary to separate the flanges completely in order to change the gasket. This flange system exerts high seating pressure on the gasket and is not usually recommended for non-metallic (soft) gasket types.

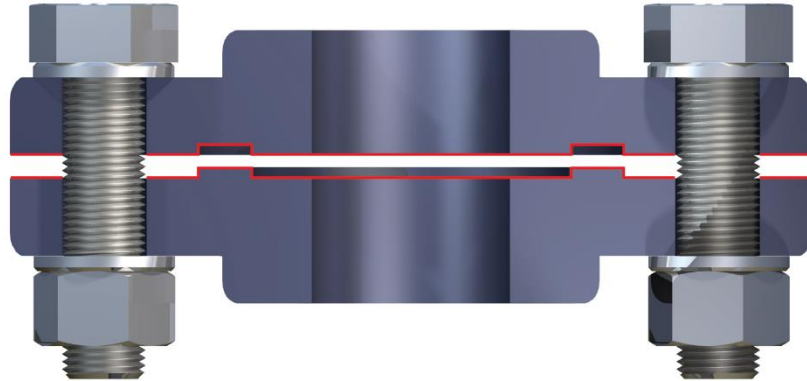


Figure 37: Tongue and Groove Flange

Male and female flanges (also known as spigot flanges)

Male and female flanges contain a semi-confined gasket and are available in a variety of styles. The depth of the female flange is equal to or less than the height of the male flange in order to avoid the possibility of direct contact between the flange faces. Also allows for the proper gasket seating stress when the gasket is compressed. The flange system must be separated in order to change the gasket.

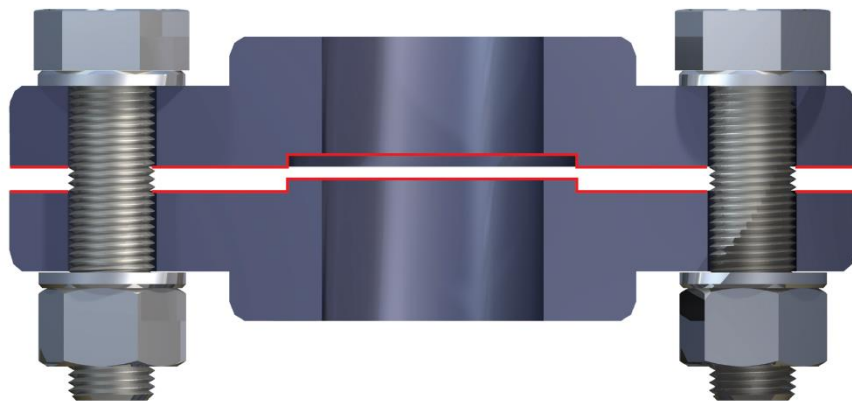


Figure 38: Male and Female Flange (spigot)

Flat face and groove flanges

Flat face and groove flanges use a gasket that is totally confined in the groove. The external face of one of the flanges is plain (flat) and the other has a groove where the gasket is installed. These designs are used in applications where the distance between the flanges must be precise and controlled. When the gasket is seated, the flanges are usually in contact with each other. Only resilient gaskets should be used in this system.

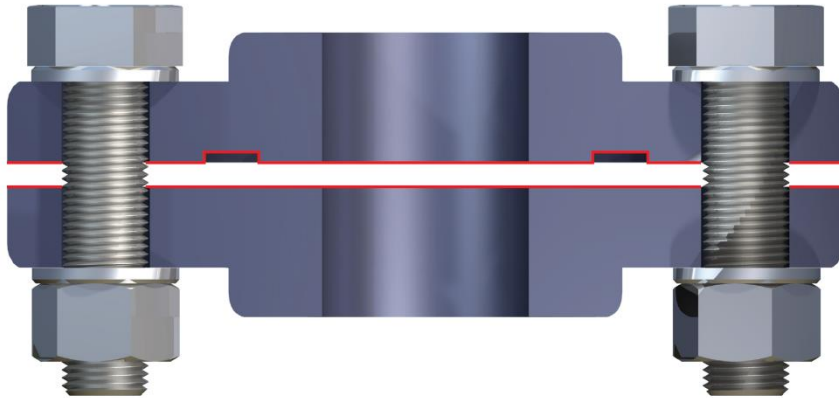


Figure 39: Flat Face and Groove Flange

Ring joint flanges (also known as API Ring)

Ring joint flanges have matching channels in both faces of the mating flanges to accept the ring joint gasket, which is usually made of solid metal. The channels are flat bottomed with sides tapered from vertical with angles of 23 degrees. The gaskets involved are often referred to as RTJ or ring type joint gaskets and are precision machined with specific hardness values.

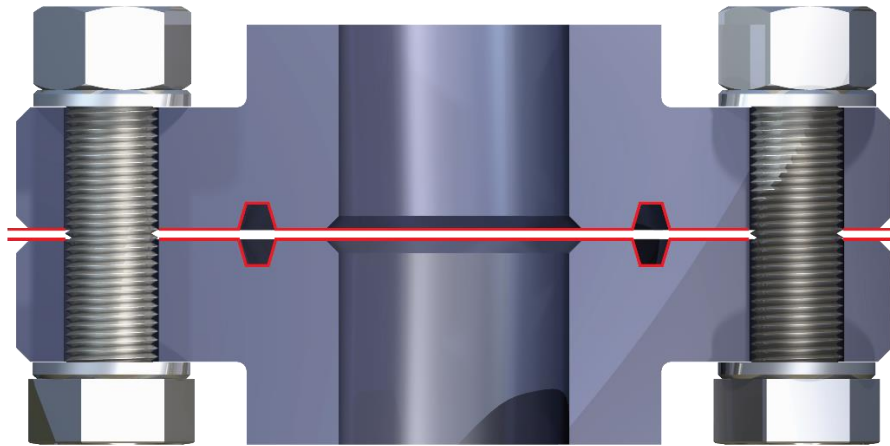


Figure 40: Ring Joint Flange (API Ring)

2. Flange Surface Finish

It is common practice for new flanges to be supplied with a coating to protect the flanges prior to use. Such coatings should be removed from the area to be contacted by the gasket because, when hot, the coatings become soft and reduce the friction between the gasket and flange surfaces. When non-metallic (soft) gaskets are being used this can cause joint failure due to excessive creep induced by the low level of friction.

Metallic flange surfaces may range from a rough casting to that produced by machine lapping and each type of surface influences sealing effectiveness. Surface roughness is usually measured in micro-meters (micro-inches) as an Arithmetic Average Roughness Height (AARH) or Root Mean Square (RMS). The former method is currently preferred. The ideal finish for any particular type of gasket has been a hotly debated subject. There have been studies on the effect of flange surface finish and, in general, most manufacturers provide recommendations about appropriate flange surface finishes for their particular gasket materials.

Commonly used finishes for pipe flanges with non-metallic gaskets are the serrated concentric and serrated spiral (phonograph) finishes. Both finishes are usually made with tools of similar shape and the flange faces are cut to various depths, depending upon the metal. Both serrated finishes consist of a series of cuts, whose width also varies with the type of metal. The serrated spiral finish is a continuous spiral groove, extending from the bore of the flange to the outer perimeter. The serrated concentric finish has definite "hills and valleys", each endless.

"Smooth" finishes which appear to have no perceptible surface irregularities are also quite common. However, when microscopically viewed, the face presents a different picture. The "smooth" finish has wavy contours and slight surface irregularities, which cannot be sealed by naked face-to-face flange contact and a gasket is an essential requirement.

Refer to ASME PCC-1 for additional details on recommended contact surface finish for various gasket types.

There are general rules applicable to surface finishes:

- The flange surface finish has a definite effect on sealing effectiveness
- A minimum seating stress must be reached in order to flow the gasket material into the irregularities of the gasket surface. A more compressible gasket requires less seating stress than a denser gasket. The total force required to flow the material is proportional to the area of the gasket
- Bolting force may be lowered by reducing the gasket area or the flange contact area. The difference is primarily a relationship of force to area
- The closer together the ridge surfaces of a serrated concentric finish and the shallower the grooves, the more the flange area begins to resemble a smooth face flange and hence there is greater contact area. Higher bolt loading is thus required to seat the gasket. The opposite effect occurs as the ridges span wider
- A serrated spiral finish is more difficult to seal than a serrated concentric finish. Complete flow of gasket material must reach the "valley" surface in a spiral finish, otherwise, a leak path will exist from one end of the spiral to the other end
- Since gasket materials vary in hardness or resistance to flow, selection of the proper materials and thickness is important in relationship to the flange finish. For example; high temperature and /or pressure applications can use a rough (but controlled) surface finish and gaskets with high resistance to flow; low temperature and / or pressure applications can use a smooth finish, especially with non-metallic(soft) gaskets; and for weak or fragile flanges, non-metallic(soft) gaskets should be used
- Serrated finishes are generally associated with pipe flange assemblies, whereas "smooth" finishes are likely to be found in flanged joints other than pipe flange assemblies

3. Flange Compatibility with the Gasket

While all gaskets must be compatible with the fluid, metallic and semi-metallic gaskets must also be compatible with the flange material. Electrochemical (or galvanic) corrosion is an electrochemical process between dissimilar metals that occurs in the presence of a conductive fluid. Electrochemical corrosion can be minimized by selecting gasket and flange metals which are close together on the electrochemical series. Alternatively, the gasket can be sacrificial to minimize damage to the flange.

4. Flange Strength and Deformation

While not necessarily a frequent occurrence, recognizing the flanges' stress limits of a given bolted flange connection is an important consideration that must be made to ensure integrity of the seal.

Metallic flanges

Metallic flanges are employed most extensively because of their robustness and wide range of suitable mechanical, thermal and chemical resistance properties. Proper function of a bolted flange connection must also take into consideration the mechanical limits of metallic flanges. If these are exceeded through overstressing it can lead to various forms of damage from excessive flange rotation to failure by Gross Plastic Deformation (GPD) causing the loss of the integrity of the seal. This can occur if flanges are assembled at bolt loads beyond the limits of the flange. In that case, the flanges become the limiting factor for sealing performance. A discussion of the various stresses and the point at which they affect flange damage is beyond the scope of this publication but have been documented in a number of publications as noted below.

Until relatively recently^{1,2} an established method for practical determination of the limiting stresses for flanges had not been addressed. Earlier research was focused only on bolt and gasket stress limits. The publication of ASME PCC-1 now includes a comprehensive methodology that enables the determination of bolt stress limits taking into consideration pipe flange limits as well. This is included in Appendix O of the PCC-1 document which takes into account not only the type of flange but also the composition of the metal. An example is provided to show what conditions of bolt stress exceed maximum flange stress limits for NPS steel Weldneck Flanges.

Non-metallic Flanges

Fiberglass reinforced plastic (FRP), plastic and other non-metallic piping and flanges are often used in the Chemical Process Industry (CPI). Application of these types of flanges is usually driven by chemical resistance and lower cost compared with the more exotic metals. Design practices for FRP flanges are described in ASME Standard RTP-1-2011³ and are beyond the scope of this publication. Appendix NM-9 Installation of RTP Vessels provides guidelines for gaskets, fasteners, torque, lubrication and other factors related to the bolted flange connection. Mechanical properties of these materials differ substantially from those of metals and none approach the strength, stiffness, resistance to impact damage, temperature capability and robustness of metals. As a result flange strength

¹ Brown, W., 2004, "Efficient Assembly of Pressure Vessel Bolted Joints" Proceedings of the ASME PVP 2004, ASME, San Diego, USA

² Brown, W., Reeves, D., 2006, "Considerations for Selecting the Optimum Bolt Assembly Stress For Piping Flanges", Proceedings of the ASME PVP 2006, ASME, Vancouver, Canada, PVP2006-ICPVT11-93094

³ ASME. 2011, ASME Standard RTP-1-2011 "Reinforced Thermoset Plastic Corrosion-Resistant Equipment"

limits bolt torque and consequent gasket stress. Failure modes differ from those of metals because creep and fatigue can result in failure at much lower stresses⁴.

Elastomeric gaskets historically have been applied to these flanges because of their low sealing stress. PTFE is being applied where superior chemical resistance is required but requires a higher sealing stress contributing to some sealing problems with current flange designs⁵. These are being addressed through revisions in flange design methodology.

C. Fastener Related Considerations

The reliability of a bolted flange connection depends largely on the threaded fasteners that are both one of the key and most neglected components in the connection. They work like a spring controlling the internal as well as the external forces to keep the required sealing stress on the gasket. Although threaded fasteners are generally considered a mature technology, significant problems continue to exist with their use. Problems with threaded fasteners arise from insufficient preload, self-loosening, tensile overload, fatigue, galling and thread stripping. While design of a bolted connection provides for a reliable connection; in practice, fastener related failures are not uncommon. Uncertainties about the applied forces, the magnitude of the preload achieved by the tightening process, inappropriate materials being specified and most notably, human error, often results in joint problems in practice. Any problems related to the fasteners can result in serious consequences. On occasion, such failures can have disastrous consequences.

Often the bolts/studs and nuts are considered the principal fastener components; however, washers are also an important part of the system. This fastener system is discussed below.

1. Bolts/Studs

To avoid failure, and at a minimum, compliance with the following must be verified for the fastener:

- Material specification
- Correct thread type and finish
- Sound physical condition
- Correct surface lubrication (See Chapter 4, Section B.4 for more detailed information)

⁴ IMechE, 1985, *Pipe Joints, A state of the Art Review, Part 2: Non-Metallic Pipe Joints*

⁵ Sealing Sense February 2012 *Why don't my PTFE gaskets seal FRP, plastic and other light load flanges?*

A bolt standard must define a series of properties that are required to meet the application needs. The most important properties are:

- Yield strength
- Temperature capability
- Chemical compatibility
- Hardness

The choice of appropriate material standard depends on the industry and application requirements. Many standards are available each of which specifies the chemical composition and the associated mechanical properties.

For pressure vessel and industrial piping applications, ASTM International standards are the major industry reference for North America. Among them, the most representative are:

- ASTM A193/A193M - Specification for Alloy-Steel and Stainless Steel Bolting for High Temperature or High Pressure Service
- ASTM A320/A320M - Specification for Alloy-Steel and Stainless Steel Bolting for Low Temperature Service
- ASTM A453 / A453M - Standard Specification for High-Temperature Bolting, with Expansion Coefficients Comparable to Austenitic Stainless Steel

For Europe, EN and ISO standards are the predominant ones, the most representative being:

- EN 10269 - Steels and nickel alloys for fasteners with specified elevated and/or low temperature properties;
- EN ISO 3506-1 - Mechanical properties of corrosion-resistant stainless steel fasteners Bolts, screws and studs.
- EN ISO 898-1 – Mechanical properties of fasteners made of carbon steel and alloy steel Bolts, screws and studs with specified property classes. Coarse thread and fine pitch thread.

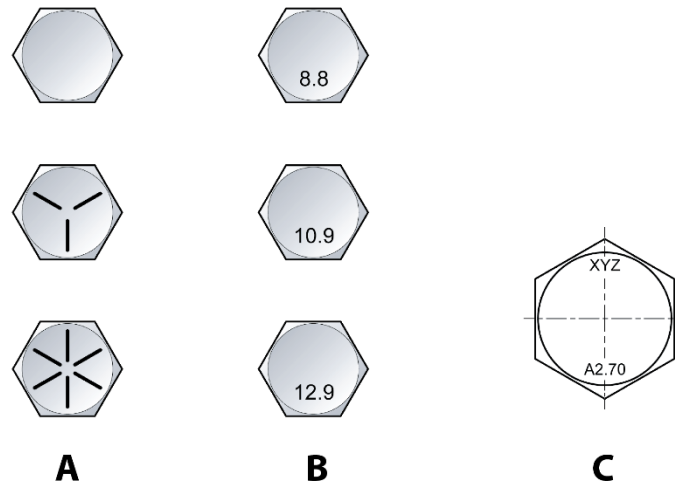


Figure 41B: Material Identification on Bolt Head

Yield Strength

For the bolt to operate like a spring, the yield strength must be in balance with the joint. Bolts that apply loads higher than necessary are harmful for the system, as are those that apply insufficient load. The applied load must be sufficient to guarantee the correct gasket seating stress and lower than the flange strength and gasket limit.

When fasteners and joint components are put under tension by tightening the nut (thus inducing a load on the gasket), the fastener and joint components will deform. The fastener will increase in length as the tension in it increases.

The initial stretch of the bolt/stud is the elastic region, within which permanent deformation of the fastener will not occur, even with repeated loading and unloading. The highest tensile force which can be withstood without permanent deformation is known as the elastic limit (also called proof load or yield strength). Fasteners perform most effectively within their elastic region.

Tension loads above the elastic limit will produce some permanent deformation; the fastener will not return to its original length and its effectiveness as a spring clamp will be impaired. At the maximum limit, the ultimate strength of the fastener is also known as the tensile strength.

The mechanical properties of bolts are sometimes expressed in terms of property class. For carbon and alloy steel, it consists of two figures (Cf EN ISO 898-1)

- The first figure indicates 1/100 of the nominal tensile strength in MPa.

- The second figure indicates 10 times the ratio between lower yield stress R_{eL} (or stress at 0,2 % non-proportional elongation $R_{p0,2}$) and nominal tensile strength R_m , nom (yield stress ratio).

The multiplication of these two figures will give 1/10 of the yield stress in MPa

For stainless steel, it consists of the combination of a letter and a number (Cf En ISO 3506-1)

- The letter indicate the type of steel (A for austenitic, C for martensitic and F for ferritic)
- The number, the property class, indicate 1/10 of the nominal tensile strength in MPa

Temperature Capability

A correlation exists between the metallurgical and chemical properties of the bolt material and its temperature capability (i.e. in-use temperature range). The bolt material selection must be based on the yield strength needed as well as the design temperature and flange material. It is crucial to have both bolts and flanges made of materials with similar thermal expansion for proper performance of the fasteners.

Chemical Compatibility

The compatibility of the bolt material with the process fluid and the environment must be considered. Bolts can be subject to chemical corrosion which over time can limit the performance of the fastener and cause problems with disassembly. Bolts can also be subject to electrochemical corrosion and as such, materials should be selected accordingly.

Hardness

Though hardness is not often verified, it is an important consideration for critical applications in nuclear, oil rigs and aerospace. Hardness is an important indicator of whether the required metallurgical processes were followed during manufacture of the fastener. This is an important property check because determination of the fastener material's chemical composition alone is insufficient to ensure that material properties requirements, such as yield strength, are met. It also ensures the fastener will not be prone to failure, particularly due to Stress Corrosion Cracking (SCC) or brittle fracture at its operating conditions.

2. Nuts

For each bolt/stud specification, there is an associated nut specification. Since both parts interact, it is important to refer to the nut standard as well. The ASTM standard for nuts related to the above for bolts and studs is:

- ASTM A194/A194M - Specification for Carbon and Alloy Steel Nuts for Bolts for High Temperature or High Pressure Services, or Both. While this standard is indicated for high temperature services, it is also applied to low temperature services

The EN/ISO standards for nuts related to the above for bolts and studs are:

- EN ISO 898-2 – Mechanical properties of fasteners made of carbon steel and alloy steel Nuts with specified property classes. Coarse thread and fine pitch thread
- EN ISO 3506-2 - Mechanical properties of corrosion-resistant stainless steel fasteners Nuts

The tension in the fastener (and hence the compressive pressure on the gasket) is generated by tightening nuts along the threads of the bolt. The threads therefore play a major role in the clamping operation and care must be exercised to maintain their integrity. Threads will strip when the axial forces on the fastener exceed the shear strength of the threads. The main factors which determine stripping strength are:

- the size of the fastener
- the length of engagement of the threads
- the strength of the materials from which the bolt/stud and nut are made

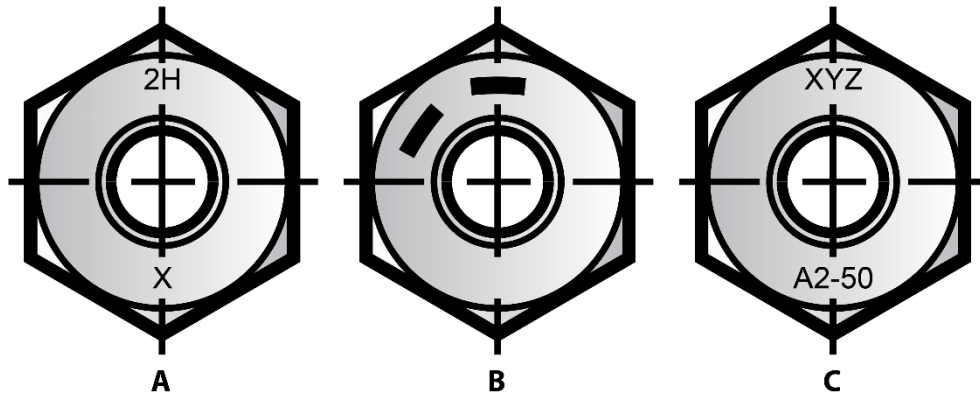
The threads on a larger bolt/stud are “longer” per turn and have thicker roots than the threads of a smaller bolt/stud. This means that the per-thread area which must be sheared to strip the threads is greater on a larger bolt/stud, which means greater stripping strength. Increasing the length of engagement between threads increases the cross-sectional area of the material which must be sheared to strip the threads.

Threads strip more readily when bolt/stud and nut materials are of the equal strength. For optimum safety, use a nut which has a specified proof load 20% greater than the ultimate strength of the bolts/studs. When done this way, the bolts/studs will break before the nut threads will strip. Remember, a break is easier to detect than a stripped thread!

Also note the effect of “galling”, which is the cold welding (partial or full) of one heavily loaded surface against another. It is encountered when the surfaces are brought together so intimately that molecular bonds form between mating parts, for example, between a nut and a bolt. This occurs when surfaces are highly loaded, when threads are a tight fit, when lubricants have migrated or dried out and when threads are damaged. This is compounded at high operating temperatures or when corrosion has occurred. It is difficult to eliminate galling, but the following may help:

- use coarse threads, rather than fine
- use the correct lubricant
- select materials for bolts/studs and nuts which in combination are resistant to galling, such as cold drawn 316 stainless steel on cold drawn 316 stainless steel, 400 steel nuts and 316 fasteners, etc.

Finished hex nuts are the most common type. Heavy hex nuts are used in high temperature and high pressure applications. This is the most common type of nut for flanged joints. Heavy hex nuts are slightly larger and thicker than finished hex nuts.



A=Americas; B=Europe; C=Stainless Steel

Figure 42: Material Identification on Nuts

3. Washers

Addition of steel washers to a fastener system is recommended to improve translation of torque input into bolt preload. Washers protect the contact surface of the flange from the turning nut and also provide a smooth bearing surface, reducing friction between nut and flange. This effect is greatest when washers are through-hardened (as distinct from “case hardened”) and washers should be specified as through-hardened.

Washers can:

- reduce significantly the friction between a turning nut and the joint components. This improves the consistency of the torqueing operation, so improving accuracy and repeatability, while reducing the torque required
- reduce problems of fatigue by spreading the load placed by the fastener on the joint
- make the interface forces between joint components more uniform, which will improve gasket performance
- bridge slotted or oversize holes, facilitating assembly of poorly mated components
- prevent damage to joint surfaces
- reduce the amount of embedment amongst joint components, thus reducing relaxation after tightening

Reference ASME PCC-1 for guidance on washer usage and purchase specification.

4. Stainless Steel

In ASTM standards, stainless steel bolts are identified in A193/193M, A320/320M as the B8-grade of alloys. The most popular grades are B8 (304SS) and B8M (316SS). For applications in which chemical resistance properties superior to those of 304SS are needed, 316SS is a next step. Its additional molybdenum content provides improved

pitting and corrosion resistance. Other grades with even higher molybdenum and other element content can be considered for more aggressive environments.

What is not always recognized is that every grade has two classes. The difference between the two classes lies in the strain hardening process. While this process will not affect chemical properties, it will have a significant impact on mechanical properties. For example, bolt grade B8 Class 1 material which is carbide solution treated, has a single yield strength for all diameters; while B8 Class 2 which is carbide solution treated and strain hardened, has yield strength dependent on nominal diameter. Typically, strain hardened Class 2 stainless steel fasteners will provide better results because of their higher yield strength properties; especially when significant assembly load is required to generate a required gasket stress.

In European standard EN10269, stainless steel bolts can also be supplied as annealed solution (AT) or cold work solution (C).

For example, grade X5CrNi18-10 - 1.4301 has:

- When supplied as annealed solution a 0.2% offset yield strength of 190MPa (27.6 ksi) and a tensile strength of 500MPa (72.5 ksi)
- When supplied as cold work solution a 0.2% offset yield strength of 350MPa (50.8 ksi) and a tensile strength of 700MPa (102 ksi)

Thermal effects can significantly change the stability of the initial load. After a pre-stress is applied to a fastener and the service is brought up to an elevated operating temperature, the bolt could elongate further, causing a reduction in load. ASTM A453 Grade 660 bolts are a good option in applications where corrosion resistance, higher yield strength potential and retention of yield strength at elevated temperatures are all important.

While preventing galling is a concern for all bolt materials, it can be a particular problem with stainless steel fasteners if not properly addressed. Oxide build up between the threads can lead to fusion of the mating pieces and prevent torque transfer to the assembly.



Figure 43: Galled Stainless Steel Bolt

The table below shows the designations for bolt and nut grades shown in ASTM specifications that are frequently used in bolted flange assemblies.

Note, washers should be made in accordance with ASTM F436 with modification to fit the dimensions of bolted flange connections.

Table 2: Typical ASTM Bolts/Nut Materials used in Bolted Flanged Connections

Bolt Grade Designation	Nut Grade Designation	Bolt Yield Strength (1)	Applications
A 193 B7 / L7	A 194 2H	517 to 724 MPa (75 to 105 ksi)	General Use
A 193 B16	A 194 7	586 to 724 MPa (85 to 105 ksi)	Higher Temperatures
A 193 B8 cl. 2 (2)	A 194 8	345 to 689 MPa (50 to 100 ksi)	Higher temperatures and stainless steel flanges
A 193 B8M cl. 2 (2)	A 194 8M	345 to 655 MPa (50 to 95 ksi)	Higher temperatures and stainless steel flanges
A 320 L7	A 194 4 or 7	517 to 724 MPa (75 to 105 ksi)	Cryogenic and low temperature

1 - Yield strength at room temperature varies with bolt/stud nominal diameter.

2 – Bolt/stud A 193 B8 cl. 1 and A 193 B8M cl. 1 have lower yield strength than the cl. 2 listed in the table. This difference frequently is not recognized and has been the cause of failures.

Selection of the suitable bolt/stud and nut is a fundamental step toward a reliable flange connection assembly. Most industrial flange connections are designed in accordance with ASME/PED Codes that reference bolts/nuts following ASTM/EN standards. This association leads to safer flange connections. It is always important to check to ensure that fasteners with the correct specification are used before assembling the joint. To confirm that the bolts and nuts are correct, check their grade identification mark, as noted in Figures 43 and 44. All bolts and nuts must have a grade identification mark on one face.

The table below illustrates the “equivalence” between ASTM and EN standards which means that some differences do exist between them. Material characteristics should be verified according to the proposed standard used.

Table 3: Some ASTM / EN Standard Equivalents

ASTM Designation	EN Designation	
	Material n°	Symbol
A193 B7	1.7225	42 CrMO4
A193 B8 Cl 1 & 2	1.4301	X5CrNi18-10 (*)
A193 B8M Cl 1 & 2	1.4401	X5CrNiMo17-12-2 (*)
A193 B8T	1.4541	X6CrNiTi18-10
A193 B16	1.7711	40CrMoV4-6
A320 B8 Cl 1 & 2	1.4301	X5CrNi18-10 –(*)
A320 B8M Cl 1 & 2	1.4401	X5CrNiMo17-12-2 (*)
A453 Gr.660	1.4980	X6NiCrTiMoVB25-15-2

(*) class 1 is equivalent to annealed solution, class 2 to cold work solution.

D: Gasket, Flange, Fastener as a System

In order for a bolted flanged joint to perform satisfactorily, individual components must be suitable for the design operating conditions (chemical compatibility, temperature, pressure, etc.). These same components must be well suited to maintain a seal as an assembly. More specifically, the fasteners (size, quantity, material, etc.) must be capable of applying adequate load to the gasket to achieve the desired tightness under designed operating conditions. The gasket must be capable of operation within the design operating conditions and achieve the seal, given the available bolt load. The flange must be rated for the design operating conditions and of adequate stiffness to ensure loading on the

gasket is maintained to expected levels. These are just a few of the items to consider when taking the entire system into consideration. The following is a review of relevant topics when considering the bolted joint as a system.

1. Specifying a Gasket Size for the Flange System

Industry standards provide nomenclature for gaskets for standard flanges.

ASME

Nominal Pipe Size (NPS)

Pressure Class (Class)

Ring or Full Face Gaskets

Example: NPS 2, Class 150 Full Face Gasket

EN

Nominal Diameter (DN)

Nominal Pressure (PN)

Inner Bolt Circle (IBC) or Full Face Gaskets

Example: DN10 PN40 IBC gasket

ASME provides two standards to consider when specifying standard gaskets for standard flanges made to ASME B16.5 and ASME B16.47 (Series A and B)

- ASME B16.21 *Nonmetallic flat gaskets for Pipe Flanges*
- ASME B16.20 *Metallic gaskets for Pipe Flanges: Ring Joint, Spiral Wound, Jacketed*

CEN provides a standard to consider when specifying standard gaskets for standard flanges made to EN 1092 *Flanges and Their Joints – Circular Flanges for Pipes, Valves, Fittings and Accessories, PN Designated* and made to EN 1759 *Flanges and Their Joints – Circular Flanges for Pipes, Valves, Fittings, and Accessories, Class Designated*

- CEN EN 1514 *Flanges and Their Joints – Dimensions of Gaskets for PN-Designated Flanges*
 - Part 1: *Non-Metallic Flat Gaskets With or Without Inserts*
 - Part 2: *Spiral Wound Gaskets for Use with Steel Flanges*
 - Part 3: *Non-Metallic PTFE Envelope Gaskets*
 - Part 4: *Corrugated, Flat or Grooved Metallic and Filled Metallic Gaskets for use with Steel Flanges*
 - Part 6: *Covered Serrated Metal Gaskets for Use with Steel Flanges*
 - Part 7: *Covered Metal Jacketed Gaskets for Use with Steel Flanges*

- Part 8: *Polymeric O-Ring Gaskets for Grooved Flanges*
- CEN EN 12560 *Flanges and Their Joints – Gaskets for Class-Designated Flanges*
 - Part 1: *Non-Metallic Flat Gaskets With or Without Inserts*
 - Part 2: *Spiral Wound Gaskets for Use with Steel Flanges*
 - Part 3: *Non-Metallic PTFE Envelope Gaskets*
 - Part 4: *Corrugated, Flat or Grooved Metallic and Filled Metallic Gaskets for use with Steel Flanges*
 - Part 5: *Metallic Ring Joint Gaskets for Use with Steel Flanges*
 - Part 6: *Covered Serrated Metal Gaskets for Use with Steel Flanges*
 - Part 7: *Covered Metal Jacketed Gaskets for Use with Steel Flanges*

Concerning pressure class designation, it is a frequent misconception that the pressure class is the gasket rating. Class 300 simply refers to a Class 300 flange design and does not necessarily mean the gasket is good up to 300 psi in the actual application. Similarly, PN40 simply refers to a PN40 flange design and does not necessarily indicate the gasket is good for use up to 40 bar. The allowable application pressure of the flange is dependent on temperature and material, which is typically provided in the associated flange standard (such as ASME B16.5). A rule of thumb, for ASME flanges, the maximum pressure at ambient temperature specified for Class 150 is 290 psi and for all the other pressure classes it is 2.5 times the class designation (i.e. Class 300 is 750psi).

2. Joint Tightness

All joints leak at some low but measurable rate. Therefore, the acceptable leak rate for a joint design should be defined by the type of fluid contained, the hazardous nature of the contained fluid, the laws controlling emissions where the joint is installed, the value of the leaking product and other factors.

Tightness Classes

Tightness classes were developed to define the leak rates. These tightness classes are generally defined in the Americas as class T1 through T5 as proposed in the Room Temperature Tightness (ROTT) test procedure. A T2 leak rate is called a standard tightness class and has a helium leak rate of 0.002 mg/sec mm of the gasket outside diameter. The higher the tightness class, the lower the mass leak rate. With each full level of tightness (going from T2 to T3 for example) reducing the leak rate by 2 orders of magnitude, so a T3 tightness class joint would have a leak rate of 0.00002 mg/sec mm.

Gasket tightness is a measure of a gasket's ability to control leak rate in a joint at a given load. Given all other variables are equal a tighter gasket requires higher internal pressure to drive the same rate of fluid through the joint. Tightness also may be considered as the internal pressure needed to cause a small leak rate in a joint.

Tightness class is defined differently in Europe. Per EN-1591-1, the leak rate is defined by L with a subscript indicating the mass leak rate. For example L_{1.0} would be a helium mass leak rate of 1 mg/ (sec m) of the mean gasket circumference. The chart below shows the relative correlation between the American “T” tightness class and the European “L” tightness class.

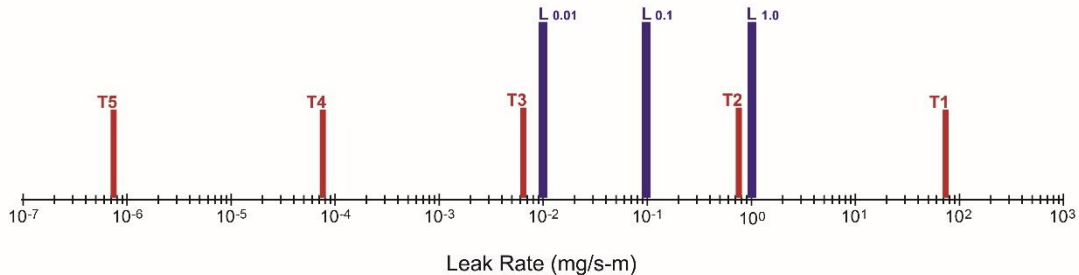


Figure 44: Comparing “T” and “L” Tightness Class

Common Concepts

The initial tightness behavior of a bolted flange joint is determined by the material type and geometry of the gasket, the seating gasket stress, the operating gasket stress level and operating internal pressure. Below are some general considerations to keep in mind when thinking about tightness:

- The tightness can change over time, since the operating stress is susceptible to change during service life of the joint. This is due to joint relaxation from creep of bolts, flanges and gasket and from other load losses caused by variation in service conditions of pressure, temperature and fluid type
- Leakage at the flange/gasket interface is usually low (except for solid metal gaskets)
- For porous gasket materials, most leakage occurs through the body of the gasket
- Within the bounds of industry practice, flange surface finish plays a relatively minor role in leakage for most gasket types, other than metal gaskets
- Leak rates are proportional to gasket diameter as a first approximation for a given gas
- The ratio of mass leak rates for two different gases is inversely proportional to their respective dynamic viscosities, again as a first level of approximation

3. Design Gasket Factors

Design Codes/Standards are used to design bolted flange connections. In general, these codes/standards provide guidance on design and selection of flanges, bolts and gaskets to ensure adequate performance of the joint. Some codes/standards have implemented the concept of joint tightness. Below is a discussion of two main design codes/standards and their respective design gasket factors. Other concepts used in industry are also briefly discussed.

ASME Boiler and Pressure Vessel Code

ASME Boiler and Pressure Vessel Code, Section VIII, Division 1 and 2 contain rules for the design and construction of unfired pressure vessels. The design of bolted flanges requires that gasket constants referred to as maintenance (m) factor and seating (y) stress be used in the calculation. The recommended values given for the gaskets listed in the code are non-mandatory. However, these constants, m and y, must be used in the code formulas unless the designer can justify the use of other values for these constants. Values for constants of specific gaskets are included in Division 1, Table 2-5.1. Additionally, gasket manufacturers publish m and y values for their own specific gasket materials and styles.

NOTE: There is currently no industry standard test to determine the m and y gasket constants, so many gasket manufacturers have developed individual test procedures based on the withdrawn ASTM F586 test method. There is no approved ASME alternative to the code that requires use of these constants.

Bolted Flange Design Methodology

This methodology is based on the Taylor-Forge approach to flange design, which did not include the concept of tightness.

A flange must be designed to create sufficient compressive load on the gasket contact area, to create an initial seal with essentially no pressure in the vessel. The gasket must conform to the flange surface and be sufficiently compressed to compensate for internal voids or spaces that could be detrimental to a seal. The gasket stress required to achieve this initial seal is considered the y constant.

The m value allows the flange designer to determine the compressive load on the gasket required to maintain tightness when the vessel is pressurized. This value is considered a multiplier or maintenance factor. This constant is intended to ensure that the flange has adequate strength and available bolt load to hold the joint together, while withstanding the effects of hydrostatic end force or internal pressure. The design intent is that the flange and bolting will hold the flanges together under pressure and exert an additional stress on the gasket of m multiplied by the internal pressure.

The designer calculates the load required to seat the gasket (Wm_2) using y, and calculates load required during operation (Wm_1) using m and the design internal pressure. The flange design is then based on the larger of the two calculated values.

Critical Considerations

There are some critical considerations when using the m and y in the two design equations (W_{m1} and W_{m2}); including the fact that they:

- Were originally derived to assist in the design of flanged joint
- Do not specifically address joint tightness
- Are often used to determine minimum required bolt loads for assembly purposes
- Do not take into account potential joint relaxation due to temperature effects, torque scatter and the inherent inaccuracies involved in assembly
- Are more of an indication of minimum load required, when used for assembly purposes and may not correspond to a bolt load required to achieve a certain tightness level under a given set of operating conditions
- Gasket stress is calculated using an estimated effective contact area, not what may actually occur with each size and pressure class of flange

ROTT TEST PROCEDURE

While there are no design codes or standards that are based on gasket factors derived from ROTT, ROTT is often referenced/used to describe gasket sealing performance relative to tightness class in the Americas.

Test Methodology

The ROTT test is performed on a 4-inch NPS gasket using a ROTT test rig with helium gas as the pressurized medium. The test includes two parts.

Part-A represents initial joint tightening and gasket seating. The test includes 5 main gasket stress levels in psi; 1025 (S1), 3040 (S2), 5390 (S3), 7750 (S4), and 10110 (S5) psi, respectively. At each stress level, leakage is measured at 400 psig and 800 psig.

Part-B simulates the operating conditions by performing leakage rate measurements during unload-reload cycles, which are described below

- Part B1 S3-S2-S1-S3
- Part B2 S4-S3-S1-S4
- Part B3 S5-S4-S1

Key Outputs

There are four key outputs from the ROTT test procedure:

- gasket stress vs. leakage rate
- gasket stress vs. gasket deflection
- maximum tightness parameter (T_{pmax})

Upon initial seating, gasket tightness normally increases with increasing gasket stress. The maximum tightness parameter, T_{pmax} , is simply the highest level of tightness achieved during the ROTT test. Normally, the T_{pmax} value corresponds to the maximum gasket stress level, S5. A high T_{pmax} is favorable.

- Gasket constants (G_b , a and G_s)

“ G_b ” and “ a ” are obtained from the seating load sequence (Part-A) of the ROTT test. “ G_b ” represents the loading of the gasket at $T_p = 1$, where T_p is the Tightness Parameter. “ a ” describes the rate at which the gasket develops tightness with increasing stress. For a given gasket material the “ G_b ” and “ a ” values are interdependent to determine the gasket stress. Low values of both “ G_b ” and “ a ” are a favorable and they indicate that the gasket requires a lower gasket stress to achieve a given tightness level.

“ G_s ” is obtained from the load-unload cycles (Part-B) and is related to the operating conditions of the gaskets. “ G_s ” shows how sensitive the gasket is to the normal operating conditions such as vibration, shock load, pressure changes and other acts that try to reduce the gasket load and allow more leakage. A lower value of “ G_s ” is favorable, which indicates that the gasket is less sensitive to unloading.

CEN EN 1591

CEN has published EN1591 *Flanges and Their Joint – Design Rules for Gasketed Circular Flange Connections* which provides the European standard requirements for designing flanges. This document consists of four parts:

- Part 1: *Calculation*
- Part 2: *Gasket Parameters*
- Part 3: *Calculation Method for Metal to Metal Contact Type Flanged Joint*
- Part 4: *Qualification of Personnel Competency in the Assembly of Bolted Joints Fitted to Equipment*
- Part 5: *Calculation Method for Full Face Gasketed Joints*

Design Methodology

The flange calculation described in CEN EN 1591 is a complex calculation that considers flange tightness. As a result, the gasket design parameters also incorporate tightness, L . Gasket manufacturers are responsible for publishing the parameters for their gaskets at the relevant test conditions.

The gasket parameters and associated test method are described in EN 13555 *Flanges and Their Joints – Gasket Parameters and Test Procedures Relevant to the Design Rules for Gasketed Circular Flange Connections*.

Note: the CEN EN 13555 gasket parameters only apply to Ring (IBC) gaskets, as a DN40 PN40 is the test specimen size.

- P_{QR} – creep relaxation factor, the ratio of the residual and initial surface pressures.

Definition: this factor allows for the effect of the imposed load on the relaxation of the gasket between the completion of bolt-up and long term experience at the service temperature

- $Q_{\min(L)}$ – the minimum level of surface pressure required for leakage rate class L on assembly

Definition: the minimum gasket surface pressure on assembly required at ambient temperature in order to seat the gasket into the flange facing roughness and close the internal leakage channels so that the tightness class is to the required level L for the internal test pressure

- $Q_{\min(L)}$ - the minimum level of surface pressure required for leakage rate class L after off-loading

Definition: the minimum gasket surface pressure required under the service pressure conditions, (i.e.) after off-loading and at the service temperature, so that the required tightness class L is maintained for the internal test pressure

- Q_{\max} – the maximum surface pressure that can be safely imposed upon the gasket at the service temperature without damage

Definition: the maximum surface pressure that may be imposed on the gasket at the indicated temperature without collapse or “crush”, compressive failure, unacceptable intrusion into the bore or damage of the stressed area of the gasket such that failure was imminent

- E_G – unloading modulus of elasticity of the gasket

Definition: this is the additional change in thickness of the gasket or sealing element due to creep between the completion of the loading and the end of the test period

4. Torque

Torque and bolt stretch are two units of measure used to determine the amount of tensile load that is applied to a bolt during installation. Torque wrenches and other tightening devices utilize torque. Tension control fasteners, hydraulic tensioning devices and

ultrasonic fastener analysis, utilize bolt stretch giving improved reproducibility and greater precision of fastening flanged joints.

There are several factors to consider when assembling a bolted joint utilizing torque as a means of proper assembly. Some of these factors are universal in that they should be considered regardless of assembly method.

- **Minimum Torque Considerations:** Minimum torque may be affected or limited by several factors. They include, among others, obtaining minimum gasket assembly stress, minimum gasket service stress and minimum amount of bolt load (% yield strength)
- **Maximum Torque Considerations:** Maximum torque may be affected or limited by several factors. They include, among others, maximum flange strength, maximum gasket load and maximum bolt material strength (% yield strength)
- **Personnel Considerations:** Personnel who are properly trained on proper installation practices greatly increase the likelihood for a successful installation on any given application

Refer to ASME PCC-1 for more discussion on calculating torque, applying torque, and training personnel.

E. Summary...Putting it all together

Unless the bolted joint is properly designed for all the operating conditions in a process, including system upsets, sealing reliability cannot be ensured. Historically, design codes for bolted joints have been successfully based on experimental methodology, while tightness based approaches were introduced more recently. Both have proven to provide the required system reliability. The more practical and prevalent problem encountered in practice is ensuring the integrity of bolted joints with standard flanges, such as ASME or EN. Standards for the material, dimensions and identification of gaskets employed in these flanges enable proper selection. The proper selection and condition of each component, including the gasket, their correct assembly and installation are fundamentally important to preventing leakage and joint failure. The proper training and qualification of personnel safely employing the appropriate tools, also is essential to joint integrity.

To avoid leakage, the joint must be assembled to a bolt stress level that provides adequate stress to seat the gasket, adequate stress to provide sufficient residual stress on the gasket during operation and also be sufficiently low such that no damage occurs to any of the joint components during assembly or operation. For most joints, this concept results in a band of acceptable assembly bolt stressⁱ values that can be depicted as shown in

Figure 45. Several gasket properties must be known to determine the lower limits of assembly bolt stress levels. These include minimum seating stress, percentage gasket relaxation and minimum stress during operation. To establish the upper limits on assembly bolt stress the maximum acceptable gasket stress and the maximum allowable assembly bolt stress that the flange will withstand must be known. A detailed analysis of this concept can be found in PVRC Bulletin WRC-538 Determination of Pressure Boundary Joint Assembly Loads. Such information can also be found in EN1591 *Flanges and their joints – Design rules for gasketed circular flange connections*.

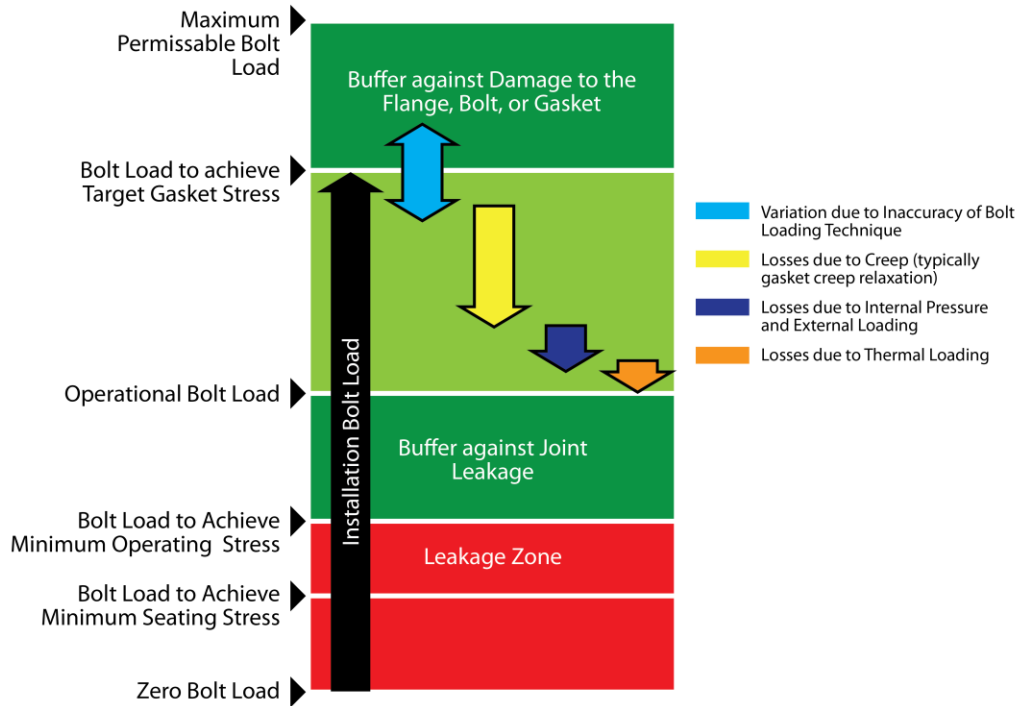


Figure 45: Acceptable Assembly Bolt Stress

Chapter 4: Installing Gaskets

A. Introduction

Often when there are leaks at a flange joint, it is assumed to be a “gasket failure”. The FSA and the ESA both have Gasket Divisions whose membership consists of many of the gasket material manufacturers in the world; report that a high percentage of reported “gasket failures” are actually Bolted Flange Joint Assemblies (BFJA) that have been poorly designed, installed and/or assembled.

Industry reports less than desirable leak-free results despite all the effort and time to properly design a BFJA that will confine the target media at the target pressure and at the target temperature. Over the past several years, industry awareness of leakage from emissions has created a focus on improved assembly and installation practices as a primary target for corrective action to lead end users towards achieving a leak-free environment.

Of all of the considerations that go into designing a successful bolted joint, proper gasket selection and installation are two of the most critical components to creating a leak free BFJA. For more information on selecting a proper gasket, please refer to Chapter 3. Often the skill and knowledge needed to correctly install a gasket are taken for granted. In fact, considerable skill and knowledge are needed to appreciate the conditions and procedures necessary to achieve a reliable (leak-free) bolted joint.

The FSA and ESA recognizes PCC-1 (Guidelines for Pressure Boundary Bolted Flange Joint Assembly) as the industry guideline in the Americas and EN 1591-4 (Flanges and their joints. Qualification of personnel competency in the assembly of the bolted connections of critical service pressurized systems) in Europe for installation of gaskets. These documents represent generally accepted good practices that can be used in conjunction with existing codes.

The FSA and ESA urges the reader to have on hand the most current PCC-1 document including it’s Appendices. For convenience, we list below bulleted and paraphrased highlights from this document and referenced PCC-1 Appendices where appropriate. PCC-1 focuses primarily on inside the bolt circle flanged joints but the fundamental principles noted in this document apply to all flange and gasket styles.

The guidelines outlined in PCC-1 cover the assembly elements essential for a high level of leak-tightness integrity of otherwise properly designed/constructed BFJAs. The following table represents the key topics covered in PCC-1 to illustrate the detail required to properly install a BFJA.

Table 4: ASME PCC-1-2013 Chapter Listing

Chapter	Title
1	Scope
2	Introduction
3	Training and Qualification of Bolted Joint Assembly Personnel
4	Cleaning and Examination of Flange and Fastener Contact Surfaces
5	Alignment of Flanged Joints
6	Installation of Gasket
7	Lubrication of “Working” Surfaces
8	Installation of Bolts
9	Number of Bolts
10	Tightening of Bolts
11	Tightening Sequence
12	Target Torque Determination
13	Joint Pressure and Tightness Testing
14	Records
15	Joint Disassembly
16	References

ASME PCC-1 also contains a number of appendices which provide helpful information for the installation process. It is recommended that the reader become familiar with the information provided in these appendices in order to improve the integrity of the BFJA. Though a detailed description of each appendix is outside the scope of this document, the FSA and ESA would like to bring to the reader’s attention the contents of Appendix A (Training and Qualification of Bolted Joint Assembly Personnel).

Appendix A describes thoroughly a new certification system for three classes of assembly personnel, including Bolting Specialists, Senior Bolting Specialists and Certified Bolting Specialist Instructors. Appendix A clearly defines the requirements for qualification, certification, duties and responsibilities of each of these three classes when engaged in the assembly and disassembly. This includes inspection and quality assurance of: pressure vessel pressure boundary bolted joint, piping pressure boundary bolted joints and storage tank pressure boundary bolted joints manufacturers.

Additional endorsements may be obtained on the basic training to extend the qualifications, duties and responsibilities to include: powered equipment, heat exchanger pressure boundary bolted joints and special pressure boundary bolted joints.

Table 5: ASME PCC-1-2013 Appendix Listing

Appendices	Title
A	Training and Qualification of Bolted Joint Assembly Personnel
B	Description of Common Terms
C	Recommended Gasket Contact Surface Finish for Various Gasket Types
D	Guidelines for Allowable Gasket Contact Surface Flatness and Defect Depth
E	Flange Joint Alignment Guidelines
F	Alternatives to Legacy Tightening Sequence/Pattern
G	Use of Contractors to Specializing in Bolting Services
H	Bolt Root and Tensile Stress Areas
I	Interaction During Tightening
J	Calculation of Target Torque
K	Nut Factor Calculation of Target Torque
L	ASME B16.5 Flange Information
M	Washer Usage Guideline and Purchase Specification for Through-Hardened Washers
N	Definitions, Commentary and Guidelines on the Reuse of Bolts
O	Assembly Bolt Stress Determination
P	Guidance on Troubleshooting Flanged Joint Leakage Incidents

EN 1591-4 highlights key factors in the safe operation of pressure-stressed systems, for the protection of human health and the environment.

It requires the installer to have the ability to disassemble, assemble and tighten bolted flange connections correctly and safely. This knowledge can only be acquired according to the standard through theory and practical experience. These capabilities must be tested and confirmed by a certified expert assessor. This evaluation of the training course is carried out in two steps - a theoretical and practical assessment.

The standard provides different modular training curriculums and is very thorough with its technical content. The course content requires each participant to first attain a basic qualification, which can be extended by specific modules such as heat exchangers, pressure vessels, special flanges, etc.

It is important to note that the curriculums exist not only for the training of pipe fitters, but also for the staff which supervise them, such as the engineers and technicians. They too are also required to confirm/reconfirm their skills.

Within the group being trained, it will also be distinguished if any trained mechanics, engineers and professional installers are present, because the participation in the theoretical training is optional for participants who have the necessary knowledge. If they have proven prior knowledge, the assessment can be carried out immediately with no training. Only if they fail the assessment must a training course be taken. For employees without specialized training or qualifications, an approved training course must be taken before any assessment can be performed.

Finally, upon successfully proving their abilities, the training participant will receive a certificate with all the relevant information about the course content, skill levels, additional qualifications, etc. This certificate has a validity of 5 years, although they must be able to

prove that they have worked with bolted flange connections during that time, with no longer than a 6-month gap. An extension for another 5 years is possible after a re-assessment only.

The following table represents the key topics covered in EN1591-4.

Table 6: EN 1991-4 Section Contents

Section	Title
1	Scope
2	Normative references
3	Terms and definitions
4	Qualification of trainer
5	Qualification of assessor
6	Personnel with work-based learning
7	Training location
8	Training syllabi
8.1	Syllabi content
8.2	Qualification level
8.3	Responsible engineer
8.4	Technical authority
9	Effectiveness of training
10	Competence assessment
10.1	General
10.2	Method of assessment
10.3	Certificate
11	Competence management
11.1	Record keeping by the manufacturer, operator or constructor
11.2	Record keeping by the assessor
11.3	Information to be supplied by the competent person
12	Period of validity of certification
12.1	Initial certification
12.2	Prolongation

B. Consideration of Torque & Frictional Losses

When using, torque tightening methods, there are 3 main factors to take into account in order to ensure that the required forces are produced to overcome fastener friction losses:

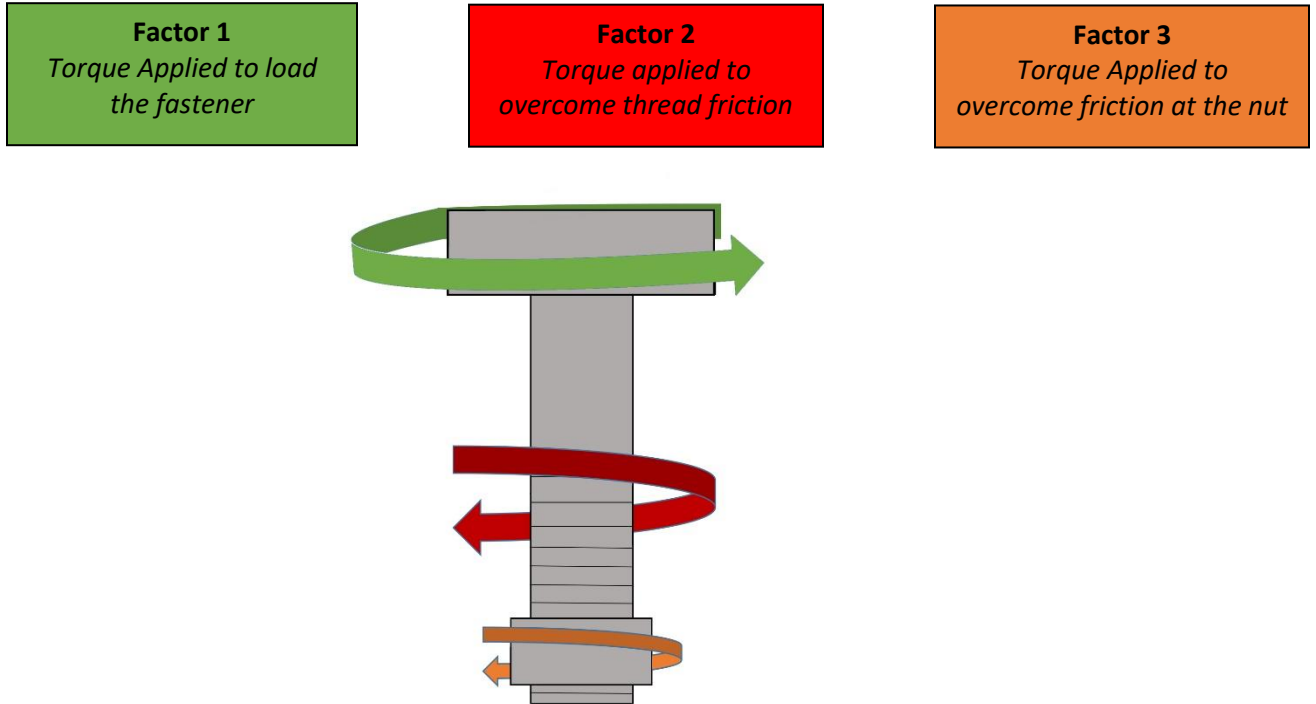


Figure 46: Torque & Friction Loss Illustration

These factors include the assembly load on the fastener spot face (contact surface), the dimensions of the thread and nut and the coefficient of friction between these surfaces. The coefficient of friction is dependent upon the type of lubricant used. The lubricant must have sufficient film strength to prevent direct surface to surface contact which will occur if the lubricant breaks down. There are many types of compositions of lubricants such as aluminum, molybdenum, nickel, copper, ceramic, PTFE and graphite. The composition of the lubricant must be considered when choosing the proper lubricant for things such as the operational temperature range it will be used in, the bolting material (galvanic corrosion) and the chemical environment that the lubricant is being used in (oxidation corrosion). All of these considerations must be taken into account for the entire service life of the component. Regardless of which type of tensioning method being used (stud tensioner, torque wrench, hammer and wrench), the lubricant needs to function during both installation and disassembly of the BFJA.

It must be emphasized that friction makes a significant contribution to the recommended torque which must be applied, and hence the use of specified lubricants is crucial for consistent torque control. A change from 0.1 to 0.3 does not result in a 20% change in torque, but a 200% change.

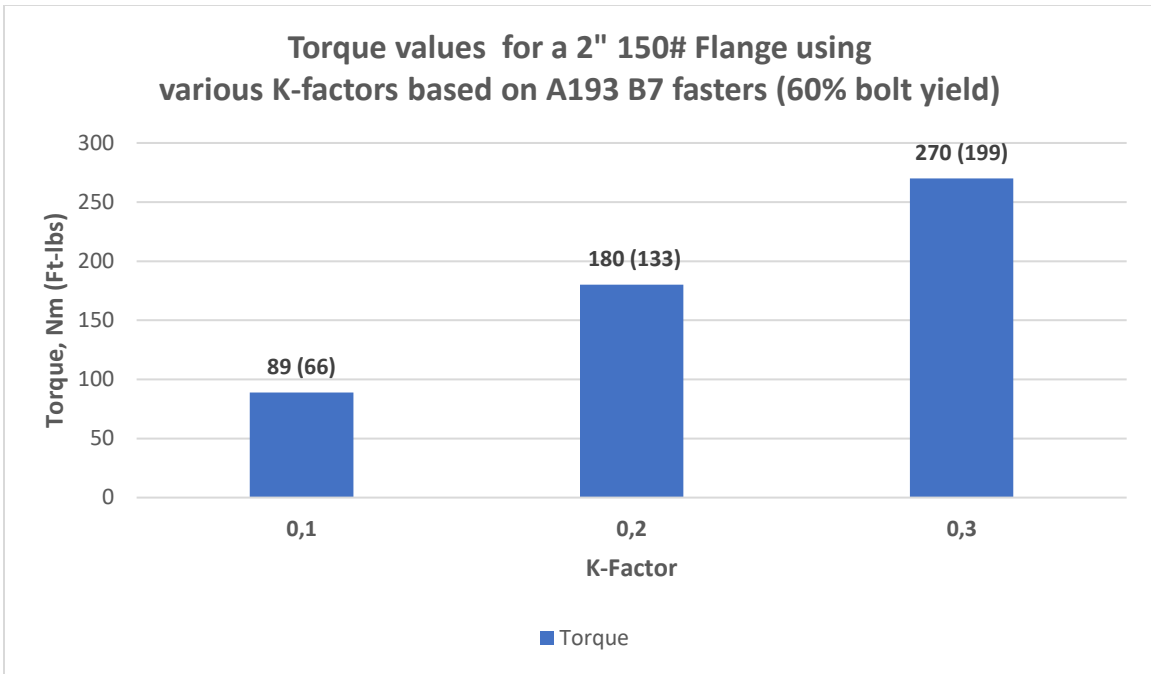


Figure 47: Required Torque vs. K Factor

Values for the coefficient of friction provided by the manufacturer of the lubricant must be known in order to establish accurate fastener load. The “Nut factor K” is used to determine the axial load from the torque applied. It should be advised that “K” is an experimentally derived dimensionless constant related to the coefficient of friction among many parameters such as the lubricant used, bolt sizes, their condition, thread pitch, and other. This dimensionless constant can be either experimentally derived using ISO 16047:2005 or can be calculated using a formula that incorporates thread friction, nut on the face friction, thread pitch, and bolt diameter. It is recommended that end users perform their own onsite testing with the bolts, nuts, washers & lubricant that are being used in the installation. This can be done by using a method such as the Skidmore Wilhelm method where it can be performed at the installation site and will allow the end user to get real world values based on the installer, tightening method and application conditions.

Table 7: Bolt Conditions and Resulting K Factors

Conditions of Bolts and Materials	K Factor
New steel bolts and nuts, through hardened steel washers under nuts, all mating surfaces coated with moly paste containing 70% solids; bolt and nut temperature of 93-121°C (200-250°F)	0.08 – 0.10
New steel bolts and nuts, through hardened steel washers under nuts, all mating surfaces coated with moly paste containing 70% solids; bolt and nut temperature of 21-32°C (70-90°F)	0.16 – 0.18
Used steel bolts and nuts with cleaned threads and not washers but lubricated on all mating surfaces with moly paste containing 70% solids	0.20 – 0.30
Used steel bolts and nuts with cleaned threads but with no washers and lubrication	0.40 – 0.50

Additional information on nut factors can be found in ASME PCC-1, appendix K

The example calculations below utilizing the above factors will illustrate the importance of accurate K factors.

Table 8: Sample Torque Calculation with varying K Factor

Sample torque calculation using various friction factors – 3” 150# Ring gasket with new A193 B-7 studs, 2H heavy hex nuts and hardened washers applying 434 MPa (63,000psi) bolt stress	
K Factor	Recommended Torque, Nm (Ft-lbs)
0.16	144 (106)
0.19	171 (126)
0.40	359 (265)

For final consideration with choosing a lubricant for the installation of a BFJA, the K nut factor provided from the manufacturer must be reliable. It is as important as other engineering components in the system. The manufacturer should be able to advise the percentage of variance for scatter, the particle size and distribution as well as the pressure load resistance otherwise known as the load wear index (LWI) of the lubricant selected.

The performance of the seal is largely dependent upon the correct level of tension in the fastener as described in Chapter 1. Remember that for maximum effectiveness, the load on the fastener should be kept within its elastic region. The fastener should be loaded to ensure that a minimum stretch or strain is applied to the bolting. It is common practice to recommend a bolt stress at assembly that ranges from 40% to 70% of the minimum yield strength of the bolt material. At low stress levels the relationship of torque to axial load will be inaccurate. It is typical to see minimum bolt stress levels above 103.4MPa (15,000 psi) tensile stress up to 70% of maximum yield for assembly stresses in order to reduce torque scatter and inaccuracy.

Joining bolted flange joints is full of inaccuracies & real world scenarios that must be overcome to achieve the initial gasket seating stress and to achieve a longer term gasket seal (bolt stretch).

C. Outline of Installation, Re-Torque, and Disassembly of Bolted Flange Joints

Using a proven tightening pattern is very important when installing a gasket in a BJFA.

NOTE: All suggested procedures that follow should be performed within the plant guidelines for safety and proper protection of all employees engaged in these activities

These tightening patterns range from the common Legacy Method (Star Pattern) to very intricate installation methods such as the Quadrant Pattern or the Circular Sequence tightening method.

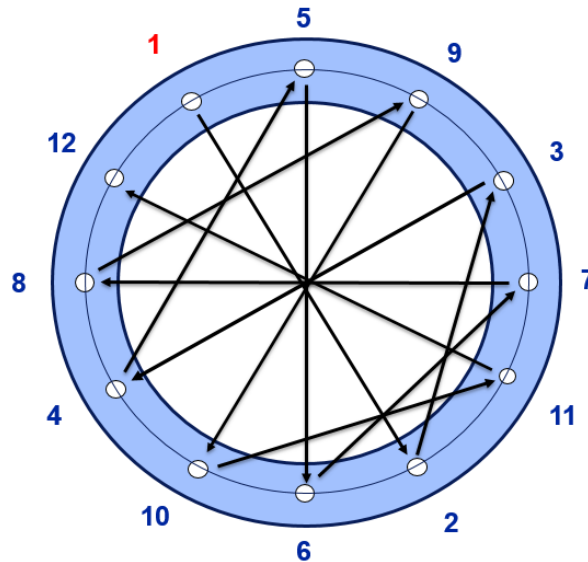


Figure 48: Legacy Method Bolt Tightening Pattern

*Please note that the tightening pattern above may be numbered differently than shown in PCC-1; however, this is for illustration purposes only as the tightening pattern remains the same.

All of these methods can be found in Section 11 of ASME PCC-1. Regardless of the method chosen for your gasket installation, the main common goal is to bring the flanges together in parallel as best as possible. Not bringing the flanges together in parallel can create uneven seating stresses on the gasket which can result in crushing the gasket or even a gasket blowout which can occur in areas of non-uniform lower seating stresses.

D. Pre-installation

Before installing a gasket, it should be inspected to ensure that it is in good condition. Check to insure proper OD, ID and thickness of the gasket are compatible to all operating parameters to which it will be subjected. Many gaskets are fragile and require special handling care to prevent damage, such as large diameter gaskets. A visual inspection of the flange sealing surfaces should be done to make sure that they are free of debris, lubricants and defects. It is not recommended to use grease or any type of lubricant to

temporarily hold the gasket in place nor for ease of gasket removal on disassembly. Verify all fasteners meet all specifications including material, length, thread pitch, and nut thickness. Previously used fasteners need to be inspected for defects such as burrs, galling, corrosion and fatigue. It is accepted practice to check all fasteners to be sure the nuts run freely up and down the length of the threads. If they do not, determine the cause and correct the condition before continuing.

E. Installation of the Gasket and Assembly of the BJFA

With the exception of grooved metal gaskets with covering layers, do not reuse gaskets under any circumstances. Align the new gasket properly to be concentric with flange ID and avoid protrusion into piping flow path. Ensure the gasket remains in proper place during assembly but do not apply lubricant or grease on the gasket or contact surfaces as mentioned above (this does not typically apply to o-rings). Also ensure that flanges are properly aligned and parallel to each other (refer to PCC-1 for information on the allowable tolerances of alignment, rotation and parallelism).

Lubricate load bearing surfaces such as bolt threads, under-head contact area, nut facings and washers, as per the lubricant manufacturer's recommendations. Do not lubricate coated bolts for first time use.

Initially install bolts and nuts so they are hand tight in the BFJA but not exceeding 20% of the recommended target torque. It is also good practice to number each bolt to assist in proper assembly.

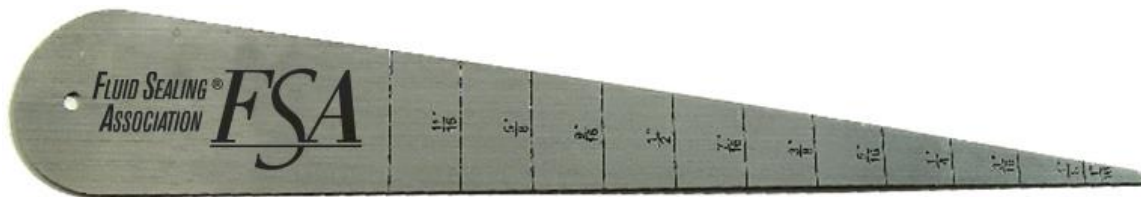
F. Tightening the Bolts

Bolts must be tightened in incremental steps to arrive at the target stress level using a properly calibrated load control device such as a torque wrench, a stud tensioner or similar device. PCC-1 provides many different methods for tightening of the bolts in combination with many different load control devices. Use of any of these combinations are designed to assure proper and even load distribution over the entire area of the gasket contact surface. The reader is encouraged to reference FSA/ESA document **(FSA0009) FSA/ESA Gasket Installation Procedures – Assuring Joint Integrity and Maximum Safety which is adapted from PCC-1.**



Figure 49: FSA Gasket Installation Brochure

During the incremental torquing steps, it is good practice to measure the flange gap at a minimum of four points at 90 degrees to each other around the flange OD at each step to assure even loading. When possible it is recommended to use more than four measurement points for flanges larger than 8” in diameter. This can be done easily by using a gap measurement tool or Vernier calipers.



Flange gap measurement tool

Figure 50: Flange Gap Measurement Tool

It should be noted that over the years there have been many new methods developed where installation time (especially on flanges over 20” in diameter) can be reduced while the final torque accuracy is maintained at an equal or higher level. PCC-1 provides the installer with many of these alternatives with in-depth instruction as to how to properly implement such procedures.

It must be recognized by users and planners that all BFJA's (flanges, bolts and gasket materials) relax after initial stress is applied. Experience shows that a large percentage of BFJA relaxation happens within the first four hours. It is therefore recommended that before the plant process is energized, a four hour wait period is observed after the initial assembly is completed and a final rotational torque is performed to return the assembly to the target stress level.

G. Re-Torquing the BJFA after initial installation

For the majority of materials in the flange system (including gaskets, fasteners, nuts, washers), relaxation sets in after a fairly short time. For soft gasket materials, one of the major factors is the creep relaxation of the gasket. Creep effects are accentuated at elevated temperatures, with the net result that the compressive load on the gasket is reduced, thus increasing the possibility of a leak. Consequently, gasket manufacturers recommend that fasteners should be re-torqued (to the recommended torque at ambient temperature before the process is energized) 24 hours after the initial assembly. Re-torquing adjustments are not always feasible nor desirable, thus the gasket material with the most suitable torque retention characteristics becomes a higher priority in the gasket selection process. For more complete guidance on re-torquing, please refer to ASME PCC-1 or the gasket manufacturer for application specific procedures.

Care must be exercised with repeated re-torquing in order to avoid damage to the gasket. This is especially important in the case of soft gaskets with a relatively small sealing area, such as ring gaskets, as the stress on the gasket often approaches the maximum allowable seating stress of the material. With larger area gaskets, such as full face gaskets, the maximum seating stress is typically never reached, thus allowing for more opportunities for re-torquing before gasket damage will occur.

Elastomeric gaskets and fiber reinforced elastomer bound gasket materials continue to cure in service from start-up as the system reaches final operating temperature. Once fully cured, these gasket materials become hard and brittle and may crack under excessive load. Always consult the gasket manufacturer for advice about re-torquing, but as a general rule do not re-torque an elastomer-based fiber gasket after it has been exposed to elevated temperatures (121°C/250°F).

In many applications, system designs are subject to thermal cycling which can vary from tens of degrees, to hundreds of degrees. Special consideration must be taken in the gasket selection process where thermal cycles can be significant as bolt torque retention is reduced with each subsequent cycle. There are many available solutions to combat these conditions and it is best to consult with the gasket manufacturer for optimum material selection.

H. Hot Re-Torquing

With respect to hot re-torque, studies have been conducted on the feasibility of re-torquing at elevated temperatures. In general, such practices are not recommended, nor are they safe; however, as the complexity of modern gasket materials varies significantly, it is imperative to consult with the gasket manufacturer on their specific recommendations for hot re-torquing.

I. Joint Disassembly

Prior to any joint disassembly, it is essential that plant procedures (lock-out and tag-out procedures) have been followed to depressurize and de-energize the system, including the removal of liquid head from the system, to ensure that the BFJA may be safely opened.

After reaffirming that all pressure on the joint has been released and the joint has been separated, proceed with bolt loosening and nut removal. Good general practice is to loosen the side of the joint away from yourself first to ensure in case of an accidental release that it is directed away from yourself. Disassembly of a BFJA should be conducted in a similar fashion as the initial assembly. Bolts should be loosened in increments and also in a crisscrossed pattern to ensure an even unload. The first loosening should be done at approximately 50% of the original recommended torque. Once joint separation is achieved, proceed with the balance of the bolt loosening and nut removal. An aid such as a hydraulic or manual flange spreader may be used if necessary to separate the joint.

J. Special considerations for Large Diameter Flange Gasket Options

Spiral Wound and other Semi-Metallic Gaskets - For large diameter spiral wound gaskets, seat the gasket in its mounting on the flange, remove securing straps, then slide the gasket from its mounting onto the flange using an appropriate number of persons to avoid damage to the gasket. Making sure not to grab or handle the gasket by the inner ring and or winding to avoid possibly damaging the gasket.

Form in place gasketing products are typically produced as tapes or “cords” and may be considered for large and/or non-standard flanges. Form in place products are available in a wide variety of widths, and care must be taken to calculate gasket stress in terms of the final *compressed* width of the product at installation. Consult the manufacturer for help in making this determination. Many form in place products have an adhesive strip on one side to aid in holding the tape in place during installation particularly on vertically oriented flanges. All form in place gasket products require the creation of a joint where the ends of the product meet. There are a number of methods to create joints that vary by the particular product form and material. To best ensure a stable joint, installation should be done such that the joint is located at a bolt hole so that there is a maximum amount of load available to ensure that the joint is adequately compressed. Consult the product manufacturer for specific advice on techniques for making the joint.

For flexible graphite gaskets with large diameters, great care must be taken when handling and moving gaskets into place during the installation process. Wrinkling or creasing of the gasket can create a site for a leakage path to develop. For improved handling, using flexible graphite with a laminated or tanged insert such as 316SS greatly increases the handling ability of the gasket and reduces the risk of damage prior to installation. For large diameter gaskets >20” (500mm) graphite tape can also be used to make a gasket onsite for leaking flanges or emergency repairs. For gaskets with a diameter <20” (500mm) crinkle gasket tape should be used to prevent the gasket material from wrinkling or creasing during installation.

Chapter 5: Diagnosing Gasket Failures

The gasket is but one of many reasons a bolted flange joint connection can leak. Even when all the complex inter-related components of a bolted joint flange connection work in perfect harmony, the single most important factor leading to success or failure of that bolted flange connection, will be giving attention to the proper installation and assembly procedures by the person installing the gasket. If done properly, the assembly will remain leak-free for the target life expectancy.

Seal failures can occur when any component of the flange, fastener or gasket system, is not performing correctly. The normal result is leakage from the joint, which may be virtually undetectable at first, and then build-up over time, or may be a sudden catastrophic failure. Leakage is mainly observed when the fasteners fail to maintain their clamping function, usually when they provide too little force – but occasionally when they exert too much force.

The experience of most gasket manufacturers suggests that a very high percentage of bolted flange connections that leak (approximately 75 percent, **1992 NPRA #36 WRC 391**) do so as a result of non-gasket related factors. These factors usually relate to installation and assembly problems and limitations.

One important factor in diagnosing gasket failures is to look for the root causes of the failure. This process of “failure analysis” is extremely helpful to identify the root cause of premature failure. This process can also offer some alternatives to fix the underlying issue(s). Without examining the gasket, the bolted component and the maintenance practices, often the same type of failure can happen again.

Some of the most frequent issues dealing with the installation of a gasket and the assembly of a flange include:

A. Under Loading of the Gasket

Under loading of the gasket is the most common reason for a leak in a BFJA. In most cases, it is caused when the joint is not able to generate enough gasket seating stress on the gasket material and also maintaining this stress throughout the temperature and pressure conditions of the application. Low gasket seating stresses can occur from poorly applying the correct load to the gasket. It can also be caused due to the condition of the bolted connection; such as not being able to transfer the correct load to the gasket from the bolts because of misaligned flanges.

All gasket materials are somewhat porous, which can be a pathway for leakage to occur. Manufacturers will recommend a minimum seating stress that will allow the gasket to do two things: properly fill into the flange serrations and voids and by compressing the gasket in between two flanges, eliminating pores by removing the pockets or voids.

Signs of under loading of a gasket:

- Gasket compression pattern has little or no flange serration marks on the gasket face, or little change in gasket thickness after being compressed

Poor bolting procedures including:

- Torque not used to apply gasket seating stress
- Corroded bolting or bolting in poor condition. Bolts should be in new condition to reduce the risk of an improperly applied bolt load. Re-use of bolts will cause less load transfer than new bolts, due to the deformation of bolt threads and corrosion. Fasteners in the field tend to corrode unevenly, resulting in the inability to create even loads the next time they are tightened
- Not using the proper anti-seize on bolt threads, nuts and flat washers. Poor anti-seize usage can cause a 50% increase in the loss of load applied to the BFJA
- Not using a hardened flat washer. Having the nut surface on rough surfaces can result in poor bolt load transfer
- Over-stretching of bolting can cause a yielded bolt that does not apply bolt load and can result in possible rupture
- Torque does not equal bolt load and can be deceiving if not following the proper bolting procedures. The applied torque is reduced significantly, resulting in insufficient bolt load or stress on the gasket
- Not calculating torque based on gasket manufacturer's minimum seating stresses
- Excessive pipe strain and flange misalignment (whether axial, angular or radial)
- Poorly designed flanges (gasket area and total bolt load) not providing enough bolt load during thermal cycling. These are usually custom flanges (not designed to any standard) and from their actual dimensions. They do not provide adequate seating stresses to compensate for thermal growth while the bolts are heated

Changes that can remedy these issues:

- Having a plant wide bolting procedure that takes into effect good bolting procedures as referenced in ASME PCC-1
- Adding more expansion joints to handle pipe strain
- Have engineering review the flange design issues and change gasket dimensions and/or possible use of bolt load retaining devices (stretch bolts, collars or flange springs)

B. Uneven Compression of the Gasket

Uneven compression of the gasket frequently results from not using the proper torque pattern and too few passes when initially assembling the bolted flange connection. Gaskets are often fully compressed on one side, while the other side has low-to-moderate compression, indicating the bolts were tightened on one side of the flange first and then tightened on the other side. Since gaskets rely on both friction and compressive force (seating stress) to prevent gasket blowouts from occurring, this can become a severe safety issue.

Signs of uneven compression of a gasket:

- Measured differences in compression from side to side on the gasket
- Flange serration impression differences around the gasket
- Stress cracks on one side or the other



Figure 51: Uneven Gasket Compression

Changes that can remedy these issues:

- Having a plant wide bolting procedure that takes into effect good bolting procedures as referenced in ASME PCC-1, which includes a bolting pattern. This would ideally include 20 to 30%, 50 to 70% and 100% of the target torque. Followed by one final rotational round of tightening at 100% of the final target torque. During these rounds of tightening, it should be noted that using a gap tool or gauge, helps the installer identify uneven areas of compression, before it is too late; it is not correctable during the gasket installation process
- Dealing with pipe strain in the plant to handle flange misalignment

C. Over Compression of the Gasket

Over compression of gaskets, especially soft gaskets, will crush the gasket causing premature failure. It is generally not recommended to exceed 15,000 psi (103.4 MPa) for soft gasket materials, such as compressed non-asbestos, PTFE and flexible graphite. Metallic gaskets, such as grooved metal gaskets with covering layers and spiral wound gaskets have a much higher compressive strength up to 30,000 psi (206.8 MPa). However, for spiral wound gaskets, there can be some misinterpretation in regards to the centering ring acting as a compression stop. It should be noted that ASME B16.20 recommends the maximum thickness compression allowable for spiral wound gaskets with and without inner rings. The stress required to compress the gasket winding to the

centering ring is typically more than the maximum recommended value; therefore, it can cause inwards buckling.

Signs of over compression of a gasket:

Soft gaskets

Gasket damage due to crushing, which includes cracking and ripping

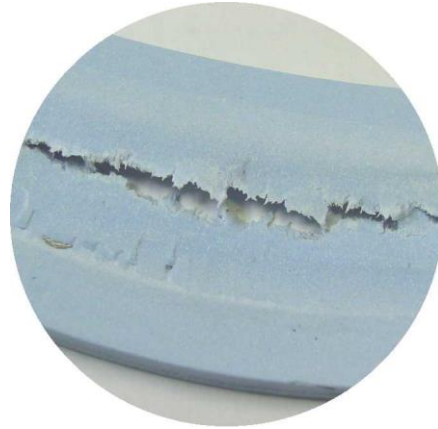


Figure 52: Gasket Over Compression

- Gasket appears to extrude out of the flange or appears to be an irregular shape.

Metallic gaskets

- Inward buckling of spiral wound gaskets without inner ring. Over tightening of spiral wound gaskets can also decrease the “spring-like” properties of the metal windings against the flange. That can also increase the probability of leaks within the flange



Figure 53: Spiral Wound Gasket – Inwards Buckling

- Imprint of flange on the guide ring

Changes that can remedy these issues:

- Having a plant wide bolting procedure that takes into effect good bolting procedures as referenced in ASME PCC-1, including calculating torques based on the gasket material

D. Re-use/Double Compression

Important characteristics when choosing a gasket involve both compression and recovery properties of the material. When the gasket is compressed, it fills the voids, serrations and irregularities in the flange. Since most soft gaskets have rubber used in the product formulation, this decreases the product's ability to rebound or recover once being compressed. Especially as the service temperature in which the gasket is used, becomes elevated. Gasket materials do not recover to 100% of their original thickness and the rebound or recovery rate drastically decreases each time the material is compressed.

Signs of re-use of a gasket:

- Gaskets with multiple compression lines/double patterns



Figure 54: Gasket with Multiple Compressions

Changes that can remedy this issue:

- Stop the re-use of gaskets

E. Not Enough Conformability/Compressibility to Fill Flange Irregularities

It is recommended using the thinnest gasket possible that will allow maintaining a proper seal. This is extremely important for smooth or machined surfaces, as there are no serrations for the gasket to fill. This enables the gasket to resist being pushed out by occurring forces. Due to these forces, it should be noted, for thinner gaskets higher seating stresses must be used to prevent blowouts from occurring. However, in some cases, a thicker gasket may be necessary due to surface finish or irregularities. These can be pits, scores or marks (see Figure 5 and 6, Chapter 1) and this can occur during a flange's lifespan from gasket installation to removal. Softer materials can also be good choices; however, again it may be necessary to apply higher seating stresses to achieve a good seal and resist the possibility of a gasket blowout. Another important factor is gasket creep relaxation, which is determined by a percentage of overall gasket thickness. The thicker the gasket material, the greater the creep relaxation in that material. What this means is that as the gasket relaxes, the gasket thickness decreases which can result in a loss of gasket seating stress.

Signs of poor conformability/compressibility of a gasket:

- Very little change in overall gasket thickness after being installed in between the flanges
- Very faint or no sign at all of flange serrations imprinted on the gasket

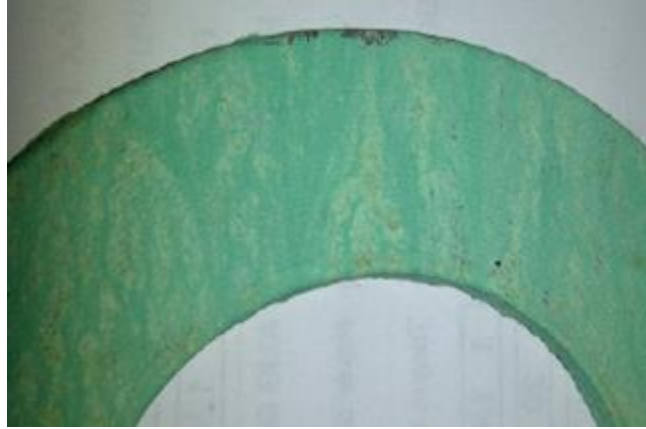


Figure 55: Poor Gasket Conformability

Changes that can remedy this issue:

- Decrease the gasket area to increase the gasket seating load
- Choose a softer material; if applicable i.e. chemical resistance and temperature.
- Choose thicker material; however it should be noted that gasket creep increases with material thickness.

F. Chemical Attack of the Gasket

Gasket selection must be made with all service conditions in mind, including temperature, pressure and media. Misapplication of gaskets can also be an issue, as it is often caused by confusion in the storeroom about which gasket to use. However, not all gaskets are made entirely from a single material and it is very important that the chemical resistance and all of the components, such as the binder or filler that the product is composed of, be verified. Some of the more common materials used in chemical service can include rubber, elastomers, compressed elastomer-based fiber sheet gasketing, PTFE, flexible graphite, metals and other semi-metallic composites. Chemical resistance of materials can also change with increasing temperature, so it is very important to know the application details and to consult with the gasket manufacturer if unsure. For further information please check out the full FSA Sealing Sense article – “How do I choose the right gasket for pumps in chemical service?”

This can be found at <http://www.fluidsealing.com/sealingsense/Nov06.pdf>

Signs of a gasket chemical attack:

- Gasket cracking (becoming brittle),
- Softening of material
- Tearing, missing or erosion of material
- Material discoloration



Figure 56: Gasket Chemical Attack

Changes that can remedy this issue:

- Review all chemical compatibility of gaskets being used in chemical service
- Use visual aids in storeroom to highlight what gaskets should be used in what service
- Consolidation of materials and reduce the amount of sheets in inventory to eliminate the risk of choosing the incorrect material.

G. Hardening of Elastomers

Elastomers, such as rubber, that are found in the binder for soft gasket material, will harden over time. Proper storage conditions are very important elements, such as UV lighting, humidity, steam and temperature which can accelerate the hardening process. Steam is a powerful hydrolyser and it has a very powerful effect on polymers and fibers. This can change the state of these products and even in some cases cause the polymers to become very brittle.

Signs of hardening of elastomers:

- Gaskets cracking (becoming brittle)

Changes that can remedy this issue:

- Review chemical compatibility of gaskets used in specific service
- Use visual aids in storeroom to highlight what gaskets should be used in what service
- Review storage requirements from Gasket Manufacturers

H. Lubrication Used on a Gasket's Surface

A poor installation practice involves putting anti-seize or other lubricants on gasket surfaces. Lubricants are used to make flat gaskets easier to remove or hold in place during

assembly. The use of lubricants on gaskets interferes with the sealing ability, by creating a barrier. Also the lubricant can breakdown the gasket material, causing gasket failure by a chemical attack. On flexible graphite, it can alter the compressive strength of the gasket. Lubricants on gaskets should never be used since they hinder long term flange sealability.

Signs of lubricants used during installation:

- Powder or residue on gasket surface
- Pits on gasket surface

Changes that can remedy these issues:

- Having a plant wide bolting procedure, which includes good bolting procedures as referenced in ASME PCC-1, which includes the recommendation to never use lubricants on gasketing surfaces

Chapter 6: Frequently Asked Questions

Table 9: FAQ

FAQ	Answer
Is the "XX" material suitable for sealing gas?	You will need to specify the type of gas, working pressure and temperature. Flange dimension is also important when recommending a gasket material.
Can you give us a bolt torque value for gasket material "Y" and flange PN 40, DN 100?	You will need to specify media, working pressure, temperature, gasket thickness, bolt material grade, bolt diameter, lubricant (K Factor) and tightness class or leakage requirements.
Material equivalent questions – e.g. what is the UK equivalent to a particular Werkstoff number?	Check the website relating to the equivalent you want to have. E.g. UK = British Stainless Steel Association at http://www.bssa.org.uk/
Can you provide the M & Y values for a particular material? Could we use M & Y values to calculate bolt torque?	M & Y values are not recommended for torque calculation as actual leak requirements are not taken into consideration with these values. Consult with the manufacturer.
How can we request bolt torque information?	Contact the gasket manufacturer for the recommended gasket stress for your application. Use the FSA Gasketed Joint Application Form to assist with gathering necessary information.
Chemical compatibility – "What material do you recommend for chemical 'X'?"	It's very important to know the chemical concentration, pressure and temperature. When checking chemical compatibility you can check the manufacturer's chemical compatibility chart or contact them directly.
Can you supply technical datasheets, material safety data sheets, etc. (specific to each company)	Contact the specific company regarding the Safety Data Sheet (SDS) or technical data for the specific product.
We seem to be getting an increasing number of questions and queries relating to NACE compliance (MR 0175, ISO 15156, and MR 0103, Sulfide corrosion cracking)	This is specific to the oil and gas industry. Contact your gasket manufacturer.

Are gaskets subject to the PED?	Sealing products are not pressure containing part in their own right and their purpose is only to ensure sealing so they don't have to comply with PED. But, the material should follow the requirements of paragraph 4 annex 1 of the PED attached – pages 31 et 32 of the PED you can be find at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:1997L0023:20031120:EN:PDF . Any gasket parameters should be tested according to applicable standards such as EN 13555
Can you supply a fire test certification to verify the fire safety of your gaskets?	Contact the gasket manufacturer for certification, or an accredited test facility for compliance with various standards such as API 6FB
What is the value of the coefficient of thermal expansion of your gasket style XYZ?	Contact the gasket manufacturer
What are the differences between the various grades of sheet PTFE sealing materials?	See FSA/ESA Gasket Handbook, Chapter 2 Section A1. Contact the gasket manufacturer for specific information.
What is the media resistance of sealing products?	See FSA/ESA Gasket Handbook, Chapter 3 Section A3. Contact the gasket manufacturer for specific information.
What is the temperature resistance of sealing products?	See FSA/ESA Gasket Handbook, Chapter 3 Section A1. Contact the gasket manufacturer for specific information.
How can I find Approval certificates (i.e. TA Luft, and API)?	Contact the gasket manufacturer for certification for compliance with various standards. Or check a website such as www.gasketdata.org .
What is the expected life time performance of my gasket?	It will depend on service conditions and gasket types. Contact your gasket manufacturer.
How should I select the most convenient type of gasket?	See FSA/ESA Gasket Handbook, Chapter 3
How much should I tighten the fasteners in our flanged unions?	Perform calculation according EN 1591-1 or ASME PCC-1
What gasket thickness should I use?	See FSA/ESA Gasket Handbook, Chapter 3 A 4

What are the temperature limits of compressed elastomer-based fiber gaskets?	See FSA/ESA Gasket Handbook, Chapter 3 A 1
What are the dielectric properties of my gasket?	Contact your gasket manufacturer
My flange is leaking. What can I do?	No general answer possible. Contact the gasket manufacturer for installation information. It may be helpful to fill out FSA Gasketed Joint Application Form prior to contacting the manufacturing so that you have all of the pertinent information required to troubleshoot your problem
What torque do I have to use to bolt my connection?	Calculation needed, typically according to EN 1591-1. Gasket manufacturers also supply torque tables for standard flanges under specified conditions.
Where do I get gasket factors for calculation? (m/Y, k0xkD/k1, Qsmin/Qsmax, ...)	Gasket factors are generally found on product technical specification pages or websites such as www.gasketdata.org . If you cannot find them, contact the manufacturer of the material being used in the calculation.
My temperature is XXX. Can I still use gasket XXX or what gasket do you recommend?	Temperature and pressure conditions affect performance. Check with the manufacturer for recommendation.
Do I need to re-torque the connection after XXX months of operation?	Compressed elastomer or rubber based material gaskets should not be re-torqued once the material has experienced operated temperatures as they can become brittle and crack upon retightening. Re-torquing with 4-24 hrs post installation prior to start-up is ideal. In the case of "Hot-Torquing" gaskets, contact the manufacturer for each case
Which gasket suits to my application XXX?	There are many variables before a recommendation can be made. Filling out the FSA Gasketed Joint Application Form will help you identify all of the requirements when contacting the manufacturer in regards to choosing the correct gasket material.
Can the gaskets be re-used?	No, in general all gaskets should not be re-used.
Can it be possible to ease the installation of gaskets with grease, glue or tape?	Grease, glue or tape can lead to uneven compression of the gasket which can create a leak path. The purpose of serrations in a

	flange is to “bite” into the gasket and hold it in place resisting pressure that is trying to force the gasket out. Adding lubrication will reduce the effects of the serrations. In addition, such components can also promote oxidation and corrosion within the flange, and piping system, or degrade the gasket.
Can a bolt torque be calculated using Taylor-Forge (ASME, CODAP...) calculation?	Taylor Forge calculations aim at verifying the mechanical integrity of the bolted assembly. Assumptions are done in the calculations that can lead to insufficient gaskets stress.
Which roughness would you recommend for the gaskets?	See FSA and ESA technical article. Standard roughness for: soft cut gaskets: Ra 3.2-12.5 µm / SWG, Kammprofiles: 3.2-6.3µm / metallic gaskets: <1.6µm / metal jacketed: <2.5µm. A serrated or phonographic finish is preferred.
Can the bolt be re-torqued (at ambient and at service temperature)?	Re-torquing can be critical, dependent on gasket type and service conditions. Please ask for detailed advice.
What are the advantages of gaskets with metal eyelets?	The metal of the eyelet protects the inner diameter of the gasket from mechanical and chemical attack of the flowing medium. This makes the gasket seal better and longer. In addition, the metal beading prevents the medium from penetrating and diffusing into and/or through the gasket.
Are PTFE based products also suitable for temperatures above 260°C?	No, only in specialist applications. Please consult the manufacturer. "Melting point" of PTFE is between 320 and 345 °C! Even higher temperature leads to toxic HF gases.
Can ePTFE sheets be used in oxygen applications?	Consult the manufacturer for suitable PTFE or ePTFE material for use with oxygen. Please note: the gasket may not be contaminated with oil or grease during handling or installation.
Can a flexible graphite gasket, cut from a sheet, be used with a temperature of 550°C?	Yes, but not in general and depending on the application. The temperature limit for high end graphite is approx. 450°C. Above it, it's recommended to avoid any possible oxygen attack from the outside or inside. In inert or reduced atmosphere graphite can withstand temperatures up to 3000°C.

Appendices

A. Gasket Testing Standards

ASTM F36 Test Method For Compressibility And Recovery Of Gasket Materials

ASTM F37 Test Methods For Sealability Of Gasket Materials

ASTM F38 Test Methods For Creep Relaxation Of A Gasket Material

ASTM F104 Classification System For Nonmetallic Gasket Materials

ASTM F112 Test Method For Sealability Of Enveloped Gaskets

ASTM F118 Definitions Of Terms Relating To Gaskets

ASTM F145 Practice For Evaluating Flat-Faced Gasketed Joint Assemblies

ASTM F146 Test Methods For Fluid Resistance Of Gasket Materials

ASTM F147 Test Method For Flexibility Of Non-Metallic Gasket Materials

ASTM F148 Test Method For Binder Durability Of Cork Composition Gasket Materials

ASTM F52 Test Methods For Tension Testing Of Nonmetallic Gasket Materials

ASTM F36 Practice For Design And Construction Of Nonmetallic Enveloped Gaskets For Corrosive Service

ASTM F363 Test Method For Corrosion Testing Of Gaskets

ASTM F433 Practice For Evaluating Thermal Conductivity Of Gasket Materials

ASTM F434 Test Method For Blow-Out Testing Of Preformed Gaskets

ASTM F495 Test Method For Weight Loss Of Gasket Materials Upon Exposure To Elevated Temperatures

ASTM F607 Test Method For Adhesion Of Gasket Materials To Metal Surfaces

ASTM F806 Test Method For Compressibility And Recovery Of Laminated Composite Gasket Materials

ASTM F868 Classification For Laminated Composite Gasket Materials

ASTM F1087 Test Method For Linear Dimensional Stability Of A Gasket Material To Moisture

ASTM F1276 Test Method For Creep Relaxation Of Laminated Composite Gasket Materials

ASTM F1277 Test Method For Determination Of Leachable Chloride In Packing And Gasketing Materials By Ion-Selective Electrode Technique

ASTM F1315 Test Method For Density Of A Sheet Gasket Material

ASTM F1574 Test Method For Compressive Strength Of Gaskets At Elevated Temperatures

ASTM F1909 Specification For Preformed Open-Cell Sponge Rubber Pail And Drum Gaskets

ASTM F2168 Specification For Packing Material, Graphitic, Corrugated Ribbon Or Textured Tape, And Die-Formed Ring

ASTM F2325 Classification For Multi-Layer Steel (MLs) And Other Metal Layer Gaskets For Transportation Applications

ASTM F2378 Test Method For Sealability Of Sheet, Composite, And Solid Form-In-Place Gasket Materials

ASTM F2466 Practice For Determining Silicone Volatiles In Silicone Rubber For Transportation Applications

ASTM F2467 Practice For Measuring Static Sealing Pressure Using Pressure-Indicating Film (Pif) In Transportation Applications

ASTM F2468 Classification For Specifying Silicone Adhesives And Sealants For Transportation Applications

ASTM F2523 Practice For Blowout Resistance Of Room-Temperature Vulcanized Elastomers

ASTM F2524 Practice For Determination Of Volatile Content For Formed-In-Place Gaskets (Fipg) Silicone Adhesives And Sealants For Transportation Applications

ASTM F2716 Practice For Comparison Of Nonmetallic Flat Gaskets In High Pressure Saturated Steam

ASTM F2837 Test Method For Hot Compression Properties Of Gasket Materials

CEN EN 1514 Flanges and Their Joints – Dimensions of Gaskets for PN-Designated Flanges

- **Part 1**: Non-Metallic Flat Gaskets With or Without Inserts
- **Part 2**: Spiral Wound Gaskets for Use with Steel Flanges
- **Part 3**: Non-Metallic PTFE Envelope Gaskets
- **Part 4**: Corrugated, Flat or Grooved Metallic and Filled Metallic Gaskets for use with Steel Flanges
- **Part 6**: Covered Serrated Metal Gaskets for Use with Steel Flanges
- **Part 7**: Covered Metal Jacketed Gaskets for Use with Steel Flanges
- **Part 8**: Polymeric O-Ring Gaskets for Grooved Flanges

CEN EN 12560 Flanges and Their Joints – Gaskets for Class-Designated Flanges

- **Part 1**: Non-Metallic Flat Gaskets With or Without Inserts
- **Part 2**: Spiral Wound Gaskets for Use with Steel Flanges
- **Part 3**: Non-Metallic PTFE Envelope Gaskets
- **Part 4**: Corrugated, Flat or Grooved Metallic and Filled Metallic Gaskets for use with Steel Flanges

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- **Part 5**: Metallic Ring Joint Gaskets for Use with Steel Flanges
 - **Part 6**: Covered Serrated Metal Gaskets for Use with Steel Flanges
 - **Part 7**: Covered Metal Jacketed Gaskets for Use with Steel Flanges

CEN EN 1591 Flanges And Their Joints - Design Rules For Gasketed Circular Flange Connections

- **Part 1**: Calculation
- **Part 2**: Gasket Parameters
- **Part 3**: Calculation Method For Metal To Metal Contact Type Flanged Joint
- **Part 4**: Qualification of Personnel Competency in the Assembly of the Bolted Connections of Critical Service Pressurized Systems
- **Part 5**: Calculation Method For Full Face Gasketed Joints

CEN EN 13555 Flanges And Their Joints – Gasket Parameters And Test Procedures Relevant To The Design Rules For Gasketed Circular Flange Connections

CEN EN 14772 Flanges And Their Joints – Quality Assurance Inspection And Testing Of Gaskets In Accordance With The Series Of Standards CEN EN 1514 And CEN EN 12560

CEN EN 12308 Installations And Equipment For Liquefied Natural Gas - Suitability Testing Of Gaskets Designed For Flanged Joints Used On Lng Piping

CEN EN 12308 Installations And Equipment For Lng - Suitability Testing Of Gaskets Designed For Flanged Joints Used On Lng Piping

DIN 2696 Flange Connections With Lens Shaped Gasket

**DIN 3436 Gas Valves For Gas Installations - Nozzles With Conical Sealing
And Gasket**

DIN 3528 Valves For Gas Installations; Nozzles With Gasket

**DIN 3535-6 Gaskets For Gas Supply - Part 6: Gasket Materials Based On
Fibres, Graphite Or Polytetrafluoroethylene (Ptfе) For Gas Valves, Gas
Appliances And Gas Mains**

**DIN 28090-2 Static Gaskets For Flange Connections - Part 2: Gaskets Made
From Sheets - Special Test Procedures For Quality Assurance**

DIN 28091-1 Technical Delivery Conditions For Gasket Sheets

- **Part 1: Gasket Materials - General Requirements**
- **Part 2: Fibre-Based Gasket Materials (Fa) - Requirements And Testing**
- **Part 3: Ptfе-Based Gasket Materials (Tf) - Requirements And Testing**
- **Part 4: Expanded Graphite-Based Gasket Materials (Gr) - Requirements And Testing**

DIN 86076 Gasket Sheets For Ship Building - Requirements And Tests

BS 3063(1965) Specification For Dimensions Of Gaskets For Pipe Flanges

**BS 3381(1989) Specification For Spiral Wound Gaskets For Steel Flanges To
Bs 1560**

**BS 7076-3(1989) Dimensions Of Gaskets For Flanges To Bs 1560 -
Specification For Non-Metallic Envelope Gaskets**

**BS 10(2009) Specification For Flanges And Bolting For Pipes, Valves And
Fittings**

**BS 1560-3.2(1989) Circular Flanges For Pipes, Valves And Fittings (Class
Designated) - Steel, Cast Iron And Copper Alloy Flanges - Specification For
Cast Iron Flanges**

BS 4882(1990) Specification For Bolting For Flanges And Pressure Containing Purposes

JIS B1217 Bolting For Use With Pipe Flanges

JIS B2205 Basis For Calculation Of Pipe Flanges

JIS B2206 Basis For Calculation Of Aluminium Alloy Pipe Flanges

JIS B2207 Basis For Calculation Of Aluminium Alloy Pipe Flanges With Full Face Gasket

JIS B2220 Steel Pipe Flanges

JIS B2239 Cast Iron Pipe Flanges

JIS B2240 Copper Alloy Pipe Flanges

JIS B2241 Aluminium Alloy Pipe Flanges

JIS B2251 Bolt Tightening Procedure For Pressure Boundary Flanged Joint Assembly

JIS B2290 Vacuum Technology - Flange Dimensions

JIS B2404 Dimensions Of Gaskets For Use With Pipe Flanges

JIS B2490 Test Method For Sealing Behavior Of Gaskets For Pipe Flanges

JIS K7036 Plastics Piping Systems - Glass-Reinforced Thermosetting Plastics (Grp) Pipes And Fittings - Test Method To Prove The Design Of Bolted Flange Joints

ISO 4708 Composition Cork - Gasket Material - Test Methods

ISO 4709 Composition Cork- Gasket Material- Classification System, Requirements, Sampling, Packaging And Marking

ISO 7005-1 Pipe Flanges

- **Part 1:** Steel Flanges For Industrial And General Service Piping Systems
- **Part 2:** Cast Iron Flanges
- **Part 3:** Copper Alloy And Composite Flanges

ISO 7483 Dimensions Of Gaskets For Use With Flanges To ISO 7005

Note, many of the tests referred to above are utilized for non-metallic gasket materials, but do not cover all types. Many are not applicable to rubber or essentially elastomer based gasket products.

Both mica and vermiculite have the same temperature and chemical resistance properties – the difference being that vermiculite can be exfoliated due to “water” being between the layers and no “water” between the mica layers.

B. Gasket Manufacturing

Beater Addition Gasketing

The Beater Addition process of manufacturing gasket materials is a wet process utilizing a cylinder or fourdrinier paper machine. The components are dispersed in water at low concentrations.

A wide range of natural or synthetic fibers can be employed. The fibers are beaten or refined, which fibrillates the main fiber into numerous fibrils. This significantly increases the fiber's surface area and the additional fibrils impart high strength to the product. The main synthetic fiber used in this process is aramid, an example of a natural fiber is cellulose fiber. Aramid is the most commonly used fiber.

Binders are added to the fiber and/or filler slurry and deposited (precipitated) evenly throughout the mix, onto the fibers and fillers. Typical binders used in the BA method are SBR, Nitrile, Chloroprene, and Poly-Acrylates. Other resins may be added which chemically combine with the rubbers to increase strength or improve heat and/or chemical resistance.

The material is formed on a cylinder(s) or a moving wire screen. In this above process, the product is dried on dryer cans or in conveyor ovens to remove the water. The dried product can be passed through calenders to obtain the desired thickness and density. Post operations such as coating, curing, laminating and cutting to size are performed depending on the end user requirements.

The BA process can yield gasket materials ranging in thickness from .005" to .250" and densities ranging from 25 to more than 100 pounds/cubic foot. By controlling the composition, density and state of cure, properties such as compressibility, strength and fluid resistance can be varied to serve many industry requirements.

Dip Saturated Gasketing

The Dip Saturation method is most often applied to Beater Addition materials, and involves dipping a material into a latex, or resin saturant and impregnating the sheet by squeezing between rolls. Drying, calendaring and other post operations may also be performed.

Laminated Beater Addition Products

These products were commonly used in automotive gaskets in the past (less so today). Beater sheet materials can be laminated to support materials such as stainless steel sheet (using either adhesives or mechanical methods such as using tanged steel). In some cases the beater sheet is saturated, in some cases it is not, depending on the application or the formulation of the beater sheet. In some cases a metal eyelet can be added around critical openings, such as cylinder bores, to improve sealing, reduce erosion or improve chemical resistance. Compressed elastomer based fiber sheet gasketing products were first introduced in the 1890's. Since that time compressed gasketing has been the single most widely used non-metallic gasket in the world for sealing flanges because of its ability to seal effectively over an extremely wide range of service conditions.

In the manufacture of compressed gasketing, fibers (most commonly aramid fibers) are mixed with a variety of elastomers and fillers. A viscous dough is formed in mixers with the introduction of a suitable solvent. The dough is then formed into sheets using a specially designed two-roll calender called a "Sheeter".

A "Sheeter" has one large steam heated roll and one smaller water cooled roll. Each roll revolves toward the other forcing the dough located in the nip onto the heated roll, where it continuously builds up until the desired thickness is reached. A controlled pressure is constantly applied by the cold roll. As the thickness increases the rolls slowly back off from one another until the finished thickness is achieved.

The percentage and type of each constituent used, process times and temperatures, mixing and roll speeds, and carefully controlled, constantly applied loads on the dough during the combined compression/curing cycle on the "Sheeter" are the critical factors that impact the sealing characteristics of the products made by this unique process.

Sheets are stripped from the large roll, after which they may be given a surface treatment with a "release agent" (sometimes called "anti-stick"), and may be branded and cut into smaller size sheet sizes. The most common sheet sizes are 150" x 150", 120" x 120" and 180" x 60". Likewise, the most common cut-down sheet sizes are 50" x 50" and 60" x 60", although any number of combinations can be furnished. The most used thicknesses are 1/64", 1/32", 1/16" and 1/8"; however, thicknesses up through 1/4" are available. Wire

inserted sheet is available in sheet sizes as large as 180" x 60" and in thicknesses of 1/32" through 1/8".

Cork Gaskets

Cork gaskets are produced from sheet composed of bark from the cork oak (*Quercus Suber*) tree. Sheets are made by grinding the cork bark into granules, and bonding with protein or synthetic resin binders, forming into blocks or mats, and slicing into sheets. The result is a material with high compressibility, unusual crush resistance, negligible extrusion, good recovery, and a high degree of impermeability under relatively low bolt loads.

Rubber

While various synthetic rubber compounds are employed as binders in the processing of gasket material, homogeneous rubber sheet also is used in many industrial applications. Rubber processed from a naturally occurring latex was the basis for development of synthetic rubbers but availability and property limitations restricted its broad application. The majority of synthetic rubbers used as gasket material are made by the polymerization of petroleum-based precursor monomers. Monomers also are mixed in various portions and copolymerized to produce material with a wide range of physical and chemical properties. One of the most prevalent is styrene-butadiene (SBR) rubber derived from the copolymerization of styrene and 1, 4 butadiene. SBR rubber was developed as an improved alternative to natural rubber and gaskets made of this material are commonly called Red Rubber gaskets. Some of the other more commonly used synthetic rubbers include butyl (HR), chloroprene (CR), ethylene propylenediene monomer (EPDM), and nitrile (NBR). Silicone and fluoroelastomer (FKM) elastomers are applied primarily in high temperature aggressive environments. All of these materials are compounded and processed into sheet from which gaskets can be cut. Formulations with various degrees of resistance to the effects of temperature, fluids, aging and abrasion can be compounded while retaining the resilience and other physical properties needed for gaskets.

Skived PTFE

Skived PTFE sheets are made by peeling off a continuous layer of material from a solid PTFE rod or thick-walled PTFE tube (commonly called billets) by virtue of horizontally pressing the billet into a fixed knife/blade. The process itself originated from the wood veneer industry and many machines used today are modified machines from the 1950's and 1960's. Some modern machinery for this industry has been developed but tends to limit the billet length (thus sheet width) and maximum skived thickness. The skiving process can produce a continuous sheet in thicknesses ranging from 0.4mm to 8mm (1/64" to 5/16") with very good thickness consistency.

Filled PTFE

Filled PTFE sheets are made by two common processes: compression molding and skiving; and HS-10 calendering. The HS-10 method requires PTFE powder to be deagglomerated in a solvent with a large mixer. A filler is then blended with the PTFE resin and solvent. The resulting slurry is typically filtered to remove a portion of the solvent from the PTFE resin and fillers to form a cake. The cake is then squeezed through calender rolls to produce a sheet. The sheet is then dried to remove any remaining solvent followed by a sintering process to form a full-density PTFE sheet with homogeneously dispersed filler.

The compression molding process requires PTFE powder to be dry-mixed with filler at a very high intensity in a large volume mixer. This mixing process is referred to as compounding and is intended to homogeneously disperse the filler through the matrix. The compounded PTFE with filler is poured into a large mold and hydraulically compressed at high pressure to a size ratio of approximately 3:1. This compressed PTFE is called a billet and is then sintered to fully cure and densify. The cured billet is then skived (as described above) for sheet material or cut into gaskets or shapes on a turning lathe.

Microcellular

ePTFE (Charlie & Charlene)

Add brief discussion of basic process

Phyllosilicates

The phyllosilicates are a group of naturally occurring minerals that includes micas, biotite, muscovite, phlogopite, steatite, kaolin and vermiculite. All of the members of the group exhibit an extended sheet like structure and are found as flakes or plates that consist of a stack of numerous individual crystal sheets. All of the phyllosilicates are noted for their thermal and chemical resistance. Traditionally, mica has been used to produce a sheet gasketing material using a process like that used to produce beater addition gasketing and incorporating an elastomer binder. A process of chemically exfoliating vermiculite has been developed that produces a sheet gasketing material through a calendering process. Both common sealing types can be used as sheet gaskets, as the filler of spiral wound gaskets and the facing material for grooved metal gaskets.

Flexible Graphite

Manufacturing Method

Intercalation is a process that employs a high quality particulate graphite flake which is chemically treated, usually with mixtures of mineral acids to form an intercalation salt where acid is attracted into the space between the layers of the graphite material. This intercalation salt is then rapidly heated such that the acid turns rapidly to a gas, forcing the graphite crystal layers apart, resulting in an over eighty fold expansion in size

compared with the raw flake material. The expansion produces a worm-like or vermiform structure with highly active, dendritic-like rough surfaces which makes them readily formable into sheet via either a molding or calendering operation. Since the forming of flexible graphite involves only mechanical interlocking of worm-like flakes, the resulting sheet product is essentially pure graphite which is typically well over 95% elemental carbon by weight, with a highly aligned structure.

Density and related material properties

Increasing the density of flexible graphite decreases compressibility and permeability; however it does increase the recovery, tensile strength, and abrasion resistance properties. Typical density of flexible graphite used for gasketing is 1.0g/cm^3 (62.4 lb/ft^3) in Europe and 1.12 g/cc (70 lb/ft^3) in North America. Where a relatively large degree of conformability is needed and sealing loads are either relatively low, or the high compression caused by high load does not cause mechanical problems, then a lower density i.e. 0.8 g/cm^3 (50 lb/ft^3) can be used. Where high recovery, low compressibility and minimum permeability is needed, such as in a confined space with high internal gas pressure, a higher density i.e., 1.4 g/cm^3 (90 lb/ft^3) is preferred. The ultimate density of flexible graphite is 2.2 g/cm^3 (140 lb/ft^3), which would occur at 50% compression of the 1.1 g/cm^3 (70 lb/ft^3) material. The edge surfaces of the flexible graphite sheet are more permeable than the flat surfaces. Since this edge permeability is inversely related to sheet density, gasket designs sometimes employ densification of edges near bores to the ultimate density to minimize any fluid penetration.