



Guidelines for safe seal usage

-Flanges and Gaskets -

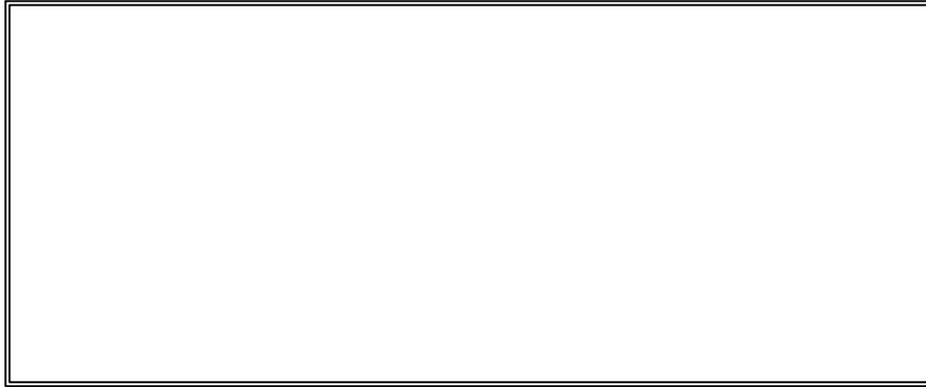
Part 1 - guidelines for maintenance operators / engineers / fitters

Guidelines for safe seal usage

-Flanges and Gaskets -

Part 1 - guidelines for maintenance operators / engineers / fitters

This document has been presented by:



This document is the copyright © 1998 of the European Sealing Association (ESA) and Fluid Sealing Association (FSA).

All rights reserved.

Members of the ESA and FSA may copy this document as required.

No part of this publication may be reproduced in any form by non-members
without prior written permission of the ESA or FSA.

Fluid Sealing Association
994 Old Eagle School Road
Suite 1019
Wayne, PA 19087 – 1802
United States of America
☎ : 610 971 4850
Fax : 610 971 4859

European Sealing Association
Bowerham House
The Grove
Lancaster LA1 3AL
United Kingdom
☎ : +44 1524 844 222
Fax : +44 1524 844 222

This document is published jointly by the **European Sealing Association (ESA)** and **Fluid Sealing Association (FSA)**. Publication is sponsored by the ESA Flange Gasket Division, the FSA Non-metallic Gasketing Division and the FSA Metallic Gasketing Division, on behalf of the Members of both Associations.

The **European Sealing Association (ESA)** is a pan-European organisation, established in 1992 and representing over 85% of the fluid sealing market in Europe. Member Companies are involved in the manufacture, supply and use of sealing materials, crucial components in the safe containment of fluids during processing and use.

The **Fluid Sealing Association (FSA)** is an international trade association, founded in 1933. Members are involved in the production and marketing of virtually every kind of fluid sealing device available today. FSA membership includes a number of companies in Europe and Central and South America, but is most heavily concentrated in North America. FSA Members account for almost 90% of the manufacturing capacity for fluid sealing devices in the NASFTA market.

Acknowledgements

The ESA and FSA are pleased to recognise the co-operation of Member Companies and others 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:

Wolfgang Abt	Frenzelit Werke GmbH & Co. KG
Ivan Borovnicar	Donit Tesnit d.d.
Frans Borsboom	Lapinus Fibres B.V.
Fred M Burgess	Armstrong Industrial Specialties Inc.
Rod Corbett	Rotabolt Ltd
Jim Drago	Garlock Sealing Technologies
David Edwin-Scott	James Walker & Co. Ltd
Brian S Ellis	European Sealing Association
Andreas Graudus	Du Pont de Nemours International S.A.
Doug Guimond	Hollingsworth & Vose Company
Jan Kasprzyk	Spetech Sp. z o.o.
Gary L Milne	Hedley Purvis Ltd
Joost F A Nas	Du Pont Dow Elastomers
Roy Nelson	W L Gore & Associates Ltd
John R Hoyes	Flexitallic Ltd
Jörg Latte	Klinger Administration AG
Francisco J Montero	Fibras y Elastomeros S.A.
Pete Petrunich	Fluid Sealing Association
Jim A Reynolds	Latty International Ltd
Gavin Smith	Klinger Ltd
Michael Werner	Teadit International Produktions GmbH

This publication is intended to provide information for guidance only. The European Sealing Association and Fluid Sealing Association have made diligent efforts to ensure that recommendations are technically sound, but do not warrant, either expressly or by implication, the accuracy or completeness of the information, nor do the Associations assume any liability resulting from the reliance upon any detail contained herein. Readers must ensure products and procedures are suitable for their specific application by reference to the manufacturer. Also, the document does not attempt to address compliance requirements of regulations specific to a particular industrial facility. Readers should consult appropriate local, regional, state, national or federal authorities for precise compliance issues.

Contents

	<i>Page</i>
1. Document scheme	7
2. Introduction	8
<i>Background to environmental legislation</i>	
<i>The modern sealing challenge</i>	
3. Flange / bolt / gasket system overview	10
4. Flange / gasket arrangements	12
<i>Common systems</i>	
<i>Flange surface finish</i>	
<i>Fasteners</i>	
<i>Nuts</i>	
<i>Washers</i>	
<i>Live-loading</i>	
<i>Flange protection systems</i>	
5. Gasket selection	20
<i>Material selection</i>	
<i>Gasket types</i>	
<i>Thickness selection</i>	
<i>Cutting soft gaskets</i>	
<i>Gasket and gasket material storage</i>	
<i>Handling of gaskets and gasket materials</i>	
<i>Reuse of gaskets / fasteners</i>	
6. Assembly procedures	27
<i>Tools required</i>	
<i>Cleaning</i>	
<i>Visual inspection</i>	
<i>Lubrication</i>	
<i>Gasket installation and centralisation</i>	
<i>Calculation of torque</i>	
<i>Bolt / stud tightening pattern</i>	
<i>Tagging</i>	
<i>Re-tightening</i>	
7. Disassembly procedures	33
<i>Release compounds</i>	
8. Key recommendations	34
9. Guidelines to minimise joint failure	36
<i>Failure due to the fastener</i>	
<i>Failure due to the gasket</i>	
<i>Failure due to the flange</i>	
<i>Minimising the chances of joint failure</i>	
10. Health and safety aspects of gasket materials	38
11. Summary schematic	39
12. Overview	40
13. References	40

Member Companies of the ESA Flange Gasket Division

Akzo Nobel Faser AG	Wuppertal, Deutschland
Armstrong Industrial Specialties Ltd	Uxbridge, United Kingdom
Donit Tesnit d.d.	Medvode, Slovenia
Du Pont de Nemours International S.A.	Le Grand Saconnex, Schweiz
Econosto Ltd	Cleckheaton, United Kingdom
Federal Mogul Sealing Systems Europe	Slough, United Kingdom
Feodor Burgmann Dichtungswerke GmbH & Co.	Wolfratshausen, Deutschland
Ferd. Jagenberg & Söhne GmbH & Co. KG	Altenkirchen, Deutschland
Fibras y Elastomeros S.A.	Bilbao, España
Flexitallic Ltd	Rochdale, United Kingdom
Frenzelit Werke GmbH & Co. KG	Bad Berneck, Deutschland
Garlock GmbH, Sealing Technologies	Neuss, Deutschland
Hollingsworth & Vose Co. s.r.l.	Garessio, Italia
James Walker & Co. Ltd	Woking, United Kingdom
Klinger Administration AG	Egliswil, Schweiz
Lapinus Fibres B.V.	Roermond, Nederland
Latty International s.a.	Orsay, France
RM Engineered Products, Inc.	N. Charleston, USA
Reinz Dichtungs GmbH	Neu-Ulm, Deutschland
SGL Technik GmbH	Meitingen, Deutschland
Siem Supranite	Paris, France
Spetech Sp. z o.o.	Bielsko-Biala, Polska
Teadit International Produktions GmbH	Kirchdorf, Österreich
Tecnotrex S.p.A.	Sarnico, Italia
W L Gore & Associates GmbH	Putzbrunn, Deutschland

Member Companies of the FSA Non-metallic Gasketing Division

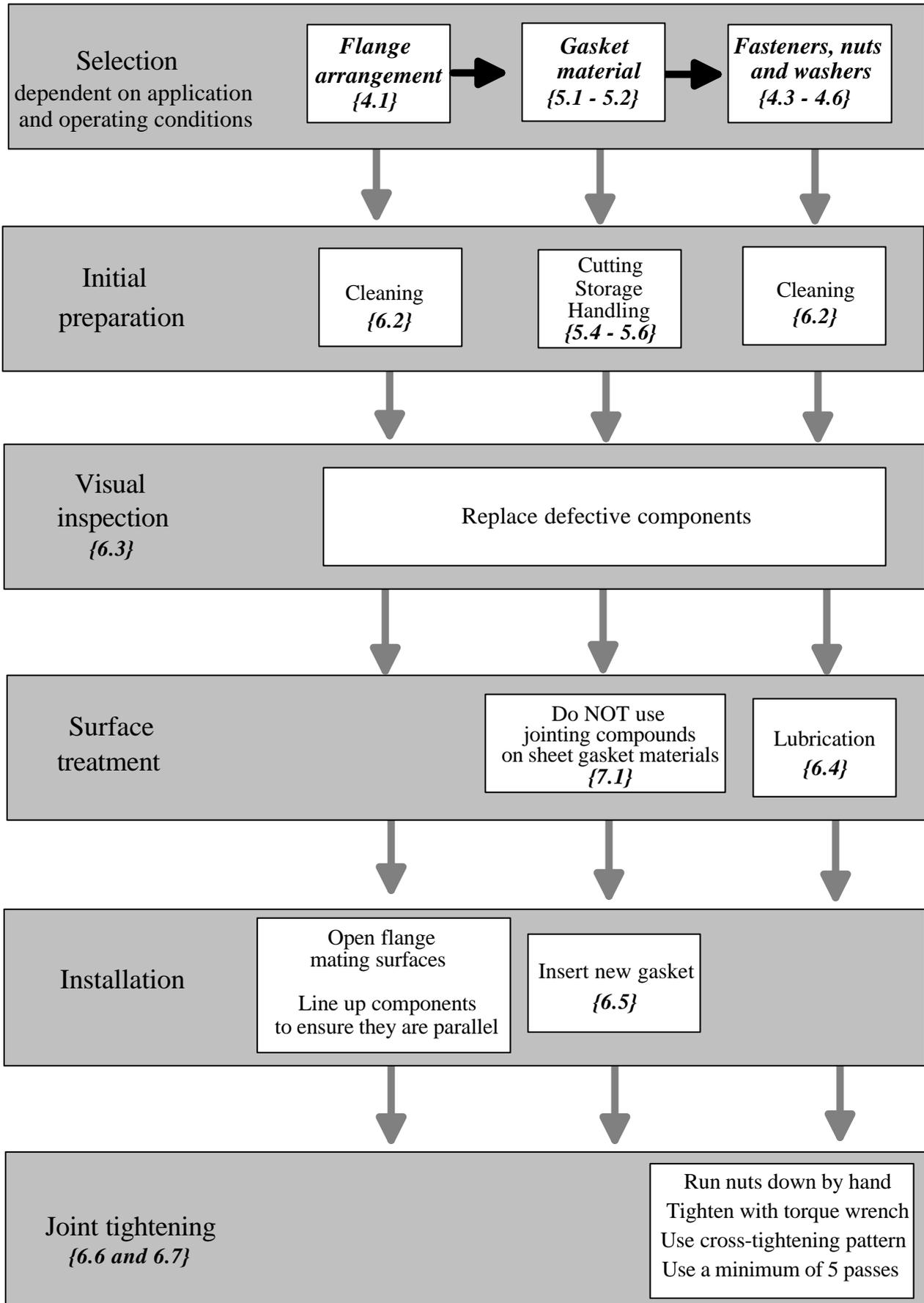
Du Pont – AFS	Richmond, VA
Du Pont Dow Elastomers	Elkton, MD
Durabla Canada Ltd	Belleville, ON, Canada
Econosto Ltd	Cleckheaton, United Kingdom
Flexitallic Group	Houston, TX
Garlock Sealing Technologies	Palmyra, NY
JM Clipper Corporation	Denver, CO
John Crane Mechanical Seals	Morton Grove, IL
Lapinus Fibres B.V.	Roermond, Nederland
Latty International s.a.	Orsay, France
Marine and Petroleum Mfg. Co.	Orange, TX
RM Engineered Products, Inc.	N. Charleston, SC
Pyramid Technologies	Pheonix, AZ
Robco, Inc.	Ville LaSalle, PQ, Canada
SGL Technic, Inc. Polycarbon Division	Valencia, CA
Sterling Fibres	Ramsey, NJ
Teadit Industria E. Comercio Ltda	Rio de Janeiro, Brazil
Teadit N.A. Inc.	Houston, TX
Thermodyne Corp.	Sylvania, OH
Thermoseal, Inc.	Sidney, OH
UCAR Carbon Co., Inc.	Humble, TX
WL Gore & Associates, Inc.	Elkton, MD
YMT / Inertech, Inc.	Monterey Park, CA

Member Companies of the FSA Metallic Gasketing Division

A R Thomson Ltd	Surrey, BC, Canada
Chicago-Wilcox Mfg. Co.	S. Holland, IL
Econosto Ltd.	Cleckheaton, United Kingdom
Empak, Mex. S.A.	Zinacantepec, Mexico
Flexitallic Group	Houston, TX
Garlock Sealing Technologies	Palmyra, NY
Gasket Engineering	Richmond, CA
JM Clipper Corporation	Denver, CO
Lamons Gasket Co.	Houston, TX
Latty International s.a.	Orsay, France
Leader Gasket, Inc., Division of JM Clipper Corp.	Baton Rouge, LA
Marine & Petroleum Mfg. Co.	Orange, TX
Metallo Gasket Co.	New Brunswick, NJ
Pyramid Technologies	Pheonix, AZ
Rowe Metals, L.P.	Dallas, TX
SGL Technic, Inc. Polycarbon Division	Valencia, CA
Teadit Industria E. Comercio Ltda.	Rio de Janeiro, Brazil
Thermodyn Corp.	Sylvania, OH
YMT / Inertech, Inc.	Monterey Park, CA

1. Document scheme

In the diagram below, the Section of this document which describes each item is indicated as {1.}:



2. Introduction

This document has been prepared for use by original equipment manufacturers, engineering contractors and end users. It is focused on solutions to the typical challenges faced by maintenance engineers and fitters responsible for pipe and equipment connections involving flanges and gaskets. The document aims to provide the reader with a series of guidelines for the safe usage of sealing components, in order to ensure maximum performance of the seal under service conditions. Throughout this document, key recommendations are represented:

key recommendation

The primary purpose of a seal is to contain a fluid and so protect the immediate environment from contamination (and *vice versa*), which may vary in significance from innocuous fluid loss (such as steam, water, etc) up to nauseous, toxic or hazardous fluid loss. In the former case, the loss of such innocuous fluid will lead primarily to lack of plant efficiency for the operator, although such leakages may still present hazards (such as leakages of high pressure water or steam). Clearly, in the latter case it is not only financially inefficient but also environmentally dangerous; for employees, members of the public and for nature at large! Consequently, the correct selection and use of the appropriate sealing technology for the application is just part of the environmental responsibility of the plant operator.

2.1. Background to environmental legislation

It is recognised that industry must reduce its impact on the environment if we are to continue global development for future generations (the so-called “sustainable development” option). A major contributory factor will be through the lowering of industrial emissions, which has been catalysed by a combination of public pressure, environmental legislation and the internal requirement to minimise the loss of valuable feedstocks. Large proportions of the emissions to atmosphere are represented by the by-products of combustion (notably the oxides of carbon, nitrogen and sulphur), along with known losses of volatile hydrocarbons and steam. In general, these are all emissions anticipated from the industrial process, under the control of the plant operator, and will not be considered further here.

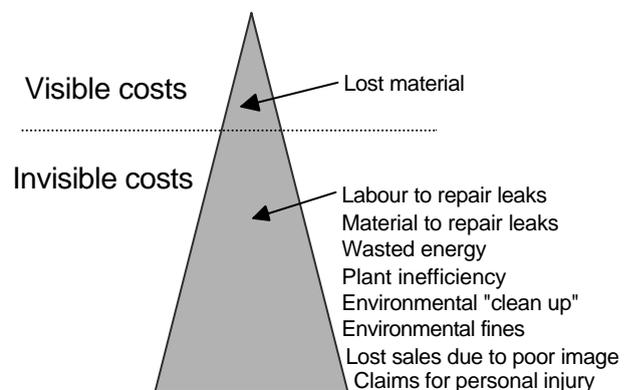
However, a proportion of industrial emissions occurs through unanticipated or spurious leaks in process systems. These equipment leaks are usually referred to as “*fugitive emissions*”, and in this area the sealing industry is playing a vital role, through the development and application of innovative sealing technology appropriate to low or zero emission requirements. Correct selection, installation and use of sealing materials are equally important to ensure reliable performance over the lifetime of the seal, and this is the prime focus in this publication.

To put the scale of the challenge in perspective, fugitive emissions from leaking valves, pumps and flanges in the USA have been estimated to be in excess of 300,000 metric tonnes per year, accounting for about **one third of the total organic emissions from chemical plants**, and inevitably mirrored in Europe. Irrespective of any environmental impact which it may cause, this is a tremendous financial burden on industry because it represents a huge loss of potentially valuable materials, and cause of plant inefficiency. Yet in most instances, the true costs to industry are not appreciated, since many of the costs associated with fugitive emissions are invisible.

Leakage from valves is often the biggest culprit, reportedly accounting for over 50% of the fugitive emissions within the chemical and petrochemical industries, while leakage from pumps and flanges represent smaller, but still important, proportions.

The development of legislation to control fugitive emissions has been well reported for both the USA ¹ and European markets ². Although the early developments started in the USA, the European Union is catching up quickly, and the

focus of attention is moving closer together. Recent legislation in both the USA and Europe is aimed at the reduction of **specific pollutants from specific operations**. However, despite a broad series of approaches, there is no Europe-wide, harmonised legislation aimed at controlling fugitive emissions. Instead, Member States are implementing control measures within their own national legislative systems. Inevitably, these limits will tighten, and good seal performance will play an increasingly important role in ensuring efficient plant operation and emission control.



2.2. The modern sealing challenge

Historically, compressed asbestos fibre sheet material has been the material of choice for “soft” gasket materials. It was regarded as easy to use and very tolerant of abuse, for which it was recognised as very “forgiving”. Consequently, the material was used to seal almost all common applications, and usually gave reasonable performance. A broad experience of the material was established over many years amongst manufacturers and users alike.

Similarly, testing specifications for traditional soft gasket materials were intended for application to asbestos-based materials where there was a large body of user experience which indicated that such materials would perform satisfactorily in service, provided that they were manufactured under an appropriate level of quality control. Few of the properties measured by such quality control tests were of direct functional importance. Rather, they provided assurance that the current batch was similar to its predecessors in composition and therefore, by implication, in performance.

More recently, with the tendency away from the use of asbestos fibres, a new generation of asbestos-free substitutes has been developed by the sealing industry. This has created an enormous challenge, because relatively limited experience is available for the new materials in service. Many of the new materials provide improved levels of sealing performance, although they are usually more application specific than their asbestos equivalents. Equally, handling of these new materials requires more care in general. Overall, these new materials can outperform their asbestos equivalent, but are usually less forgiving; users must exercise more care in selecting the right material for the job and assembling the seal.

There is an urgent need for guidance notes for users about these new materials, and this has been the catalyst for the production of this publication. It is hoped that this document will also be taken up by interested organisations to form the basis of maintenance operative training schemes.

Over time, new sealing methods have been developed, especially for more severe services, and these include the “hard” gasket materials, primarily of metallic or semi-metallic construction. These offer users even more choice in selecting the right sealing technology for the job and reinforce the need for guidance notes.

The same challenge has been observed in standards and testing methods. Attention has been given increasingly to tests of more functional relevance, with resultant significant changes in the types of testing undertaken. National and international testing specifications will increasingly include functionally important tests which simulate service conditions and are of long duration as opposed to short term tests for product consistency.

Further complicating this situation are the different procedures which have been developed for national specifications across Europe and the USA. Although there are many parallel test methods, differences in the manipulation of protocol and results reflect the historical variety of approaches. Fortunately, recent advances in test specifications have tended to show increasing similarity, and this must be encouraged in order to harmonise standardisation procedures wherever possible.

Information is available on testing methods and standards in a recent publication³ by the ESA, the *Glossary of Sealing Terms (Flanges and Gaskets)*. This particular document also provides information on:

- *relevant units and conversion factors*
- *relevant standards*
- *standards issuing organisations and other relevant bodies*
- *common abbreviations*

So, with increasing requirements to reduce industrial emissions, with new sealing technologies, and with new sealing materials requiring more careful selection, handling and installation, this document aims to provide some useful guidance notes for maintenance operators and users.

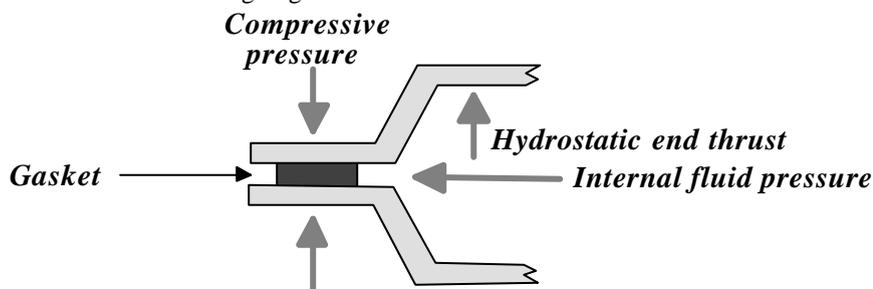
3. Flange / bolt / gasket system overview

A gasket is used to create and retain a static seal between two stationary flanges, which connect series of mechanical assemblies in an operating plant, containing a wide variety of fluids. These static seals aim to provide a complete physical barrier against the fluid contained within, and so block any potential leakage path. To achieve this, the gasket must be able to flow into (and fill) any irregularities in the mating surfaces being sealed, while at the same time be sufficiently resilient to resist extrusion and creep under operating conditions. The seal is effected by the action of force upon the gasket surface, which compresses the gasket, causing it to flow into any flange imperfections. The combination of contact pressure between the gasket and flanges, and densification of the gasket material, prevents the escape of the contained fluid from the assembly. As such, gaskets are vital to the satisfactory operation of a broad range of industrial equipment.

On seating, a gasket must be capable of overcoming minor alignment and flange imperfections, such as:

- *non-parallel flanges*
- *distortion troughs / grooves*
- *surface waviness*
- *surface scorings*
- *other surface imperfections*

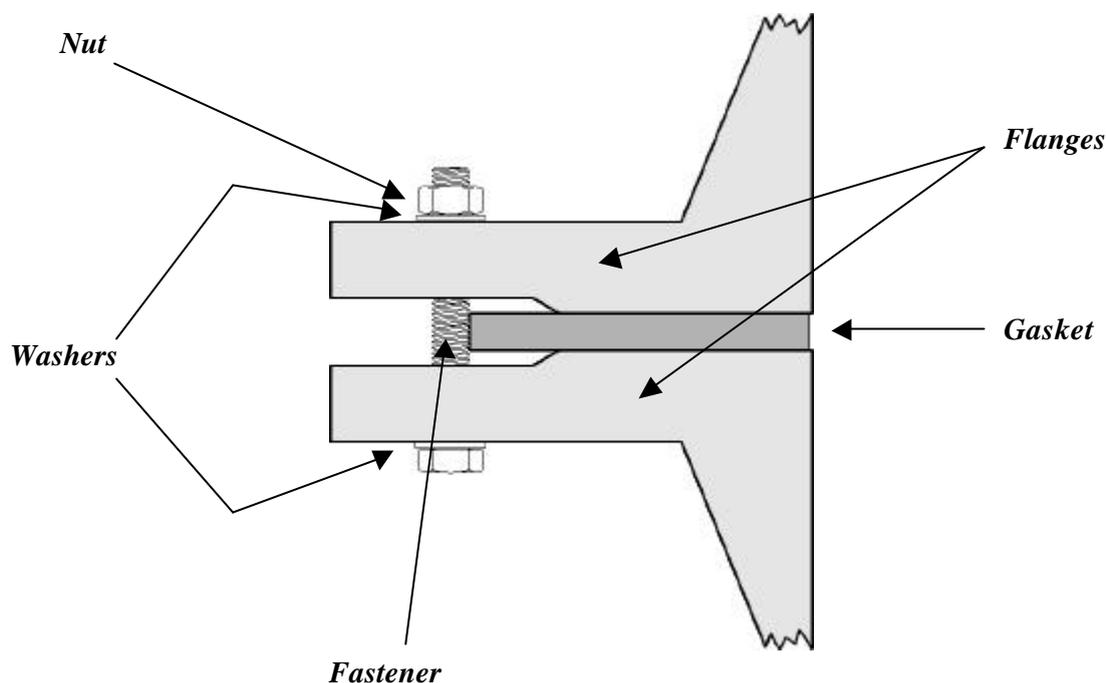
When assembled, a flange gasket seal or ‘joint’ is subject to compressive pressure between the faces of the flanges, usually achieved by bolts under load. In order to ensure the maintenance of the seal throughout the lifetime of the assembly, sufficiently high pressure must remain on the gasket surface to prevent leakage. Under operating conditions, this pressure will be relieved by *hydrostatic end thrust*, the force produced by internal pressure which acts to separate the flanges. The gasket itself is also subject to a side load due to the internal fluid pressure tending to extrude it through the flange clearance space. To maintain seal integrity, the effective compressive pressure on the gasket (that is, the assembly load minus the hydrostatic end thrust) must be greater than the internal pressure by some multiple, dependent upon the gasket type, manufacturing process involved and level of tightness required. For soft gaskets, there must also be adequate friction between the gasket and flange faces to help prevent extrusion (blowout) of the gasket from the joint. To allow for any relaxation of gasket compressive pressure which is normally inevitable, a factor of at least two is usually recommended between the compressive pressure on the assembly and that required to maintain a seal. A number of publications^{3, 4, 5, 6} provide more detail of the flange / gasket interaction.



So, the primary function of a gasket is to create and maintain a seal between flanges, under conditions which may vary markedly from one joint to another, dependent upon the nature and type of application. To meet these varying conditions, a number of flange / fastener / gasket systems have been developed, and many factors must be considered when selecting the most appropriate assembly, including:

<u>Application</u>	<u>Flange arrangement</u>	<u>Gasket</u>
Pressure of media	Configuration / type	Blow out resistance
Temperature of media	Surface finish	Creep resistance
Chemical reactivity of media	Material	Stress relaxation
Corrosive nature	Available bolt load	Ability to recover / elasticity
Searching ability of media	Likelihood of corrosion / erosion	Expected service life
Viscosity	Flange strength / stiffness	Comparative cost
pH of media (acidity)	Alignment tolerance	Chemical compatibility
Concentration		Ease of handling / installation / removal
		Fire resistance
		Sealability
		Combined pressure temperature resistance

Importantly, for all of these systems, the performance of the seal depends upon the interaction of the **various elements of the system**:



Only when all the components of the system are working together in harmony can the seal be expected to provide a good performance over a reasonable lifetime. The integrity of a safe seal depends upon:

- ☑ *selection of correct components appropriate for the application*
- ☑ *careful preparation, cleaning, installation and assembly*
- ☑ *correct bolt tightening and loading*

The behaviour of a flanged joint in service depends on whether or not the tension created in the fasteners will clamp the joint components together with a force great enough to resist failure of the seal, but small enough to avoid damage to the fasteners, joint components, gasket etc. The clamping load on the joint is created on assembly, as the nuts on the fasteners are tightened. This creates tension in the fastener (often referred to as *preload*⁵). Although there may be some plastic deformation in the threads when a fastener is tightened normally, especially on the first tightening, most of the joint components respond elastically as the nuts are tightened. Effectively, the entire system operates as a spring, with the fasteners being stretched and the other joint components being compressed.

Joints fail, not just gaskets! Low bolting torques, over-tight bolt loads, weak bolt materials, inadequate bolt / washer / nut lubrication, poor flange design or materials, poor gasket cutting or storage, improper installation practices, may each and all contribute to seal failure, even though the gasket material itself may be correctly specified! This publication will attempt to provide solutions to all of the above challenges.

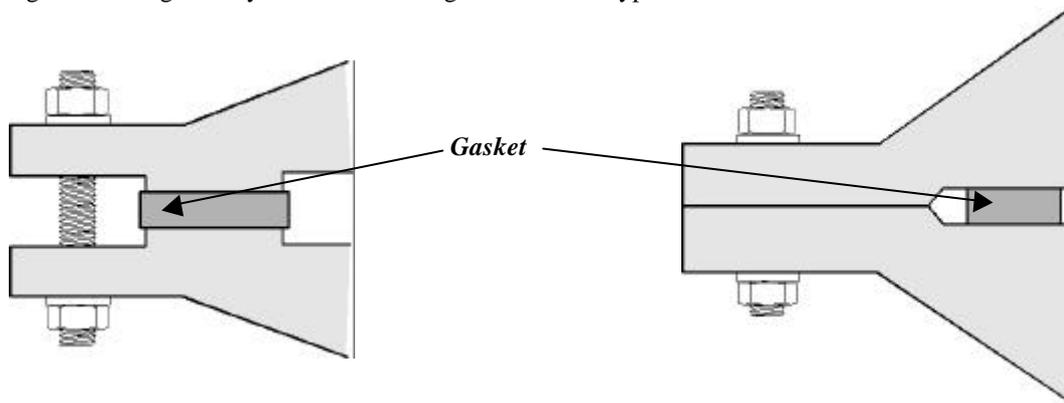
It must be emphasised that this document is aimed at maintenance engineers, fitters and mechanics; hence only limited information is included about flange design procedures. Readers should be aware that further guidance may be found in other documents, such as BS5500 and ASME Section 8.

4. Flange / gasket arrangements

There are many arrangements of flanges and gaskets in common use^{4,5}. While detailed discussion of flange design is beyond the scope of this document, it is valuable to at least outline some of the major 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 inertness. Generally, these flanges are less robust and dictate a softer gasket material, able to be seated under lower gasket pressure. Operating temperatures and pressures are usually less severe.

Flange arrangements are generally of either “floating” or “contact” type:

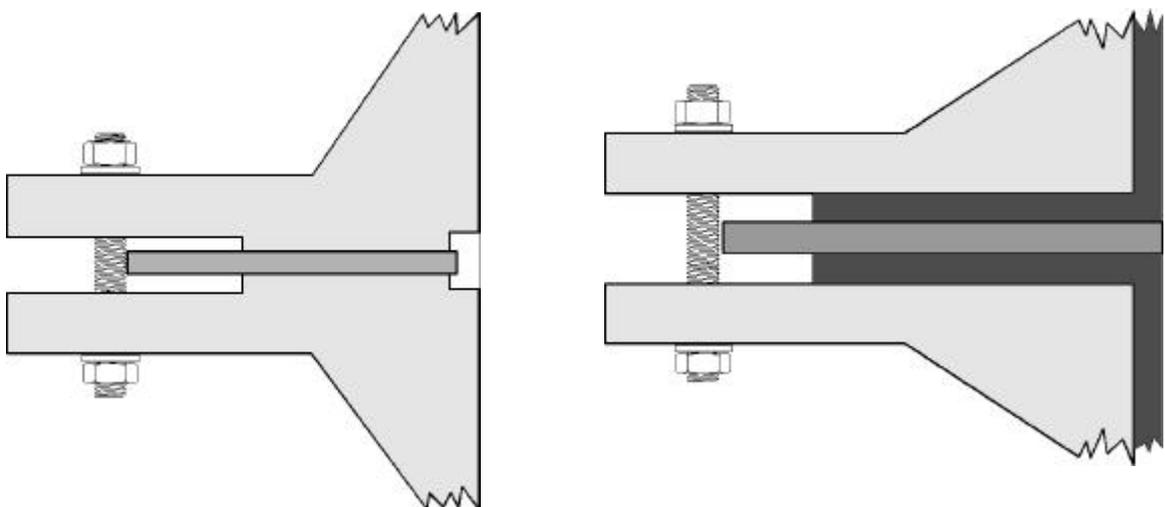


Floating arrangement

Contact arrangement

4.1. Common systems

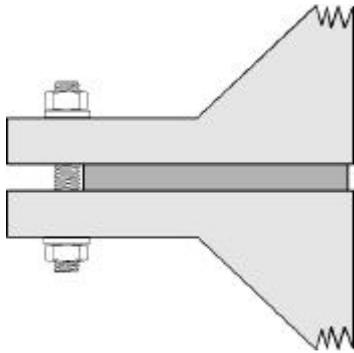
Raised face flanges are in common usage in pipework systems. The flange contact surfaces are raised, although the gasket is non-confined. Generally, the outside diameter of the gasket is equal to the bolt circle diameter, less the diameter of the bolts. This represents the inside bolt circle (IBC) gasket (also referred to as a “ring” gasket in the USA). In this case, the bolts act to centralise the gasket, allowing easy installation and removal of the gasket, without having to separate the complete flange system. Similar to the raised face flange is the **lapped joint** arrangement. This connection is used when the process requires a more inert piping system (possibly alloys, plastic or glass), but where the flange itself may be made from a less exotic material:



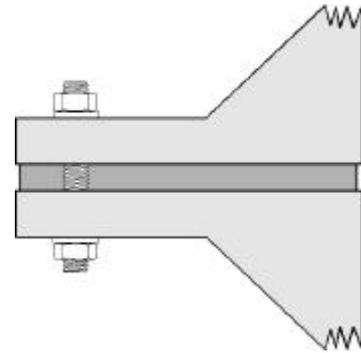
Raised face flange

Lapped joint

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

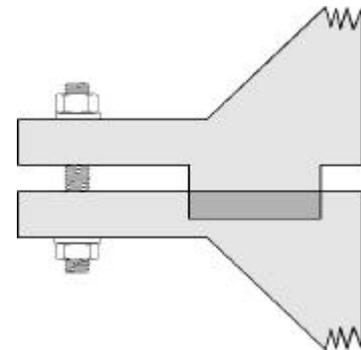


Flat face flange with IBC gasket

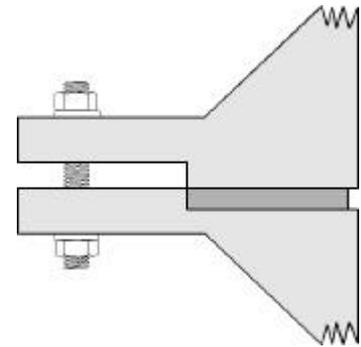


Flat face flange with full face gasket

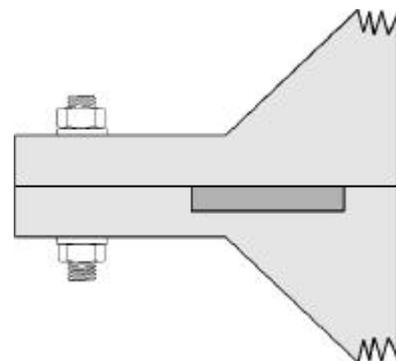
Tongue and groove flange, with a totally confined gasket. The groove depth is equal to or greater than the tongue height. Normally, the gasket has the same width as the tongue. In this arrangement it is necessary to separate the flanges completely in order to change the gasket. This flange system exerts high seating pressure on the gasket and is not usually recommended for soft gasket types:



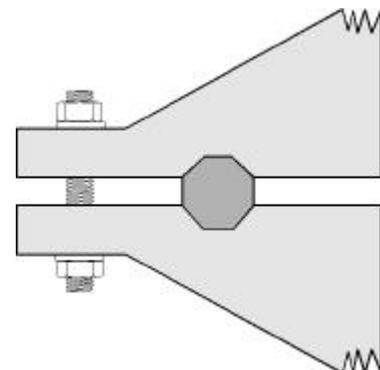
Male and female flanges (also known as *spigot flanges*) contain a semi-confined gasket, and may be in a variety of forms. The depth of the female flange is equal to or less than the height of the male, in order to avoid the possibility of direct contact between the flange faces when the gasket is compressed. The flange system must be separated in order to change the gasket:



Flat face and groove flange arrangement, with totally confined gasket. 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. When the gasket is seated, the flanges are usually in contact with each other. Only resilient gaskets should be used in this system:



Ring joint flange arrangement (also known as *API Ring*), in which both flanges have channels to accept the ring joint gasket, which is usually made of solid metal. The gaskets involved are often referred to as *RTJ* or *ring type joint* gaskets:



4.2. Flange surface finish

The ideal finish for any particular type of gasket is a hotly disputed subject! There have been some studies on the effect of flange surface finish, and, in general, most manufacturers provide recommendations about appropriate flange surface finishes for particular gasket materials.

Metallic flange surfaces may range from a rough casting to that produced by machine lapping, and each type of surface influences the sealing efficiency. Surfaces of pipe flanges for non-metallic gaskets are often of serrated-concentric or serrated-spiral (phonographic) configuration. By their very nature, metallic flanges are able to withstand higher gasket pressures and hence are absolutely required where operating parameters are more extreme.

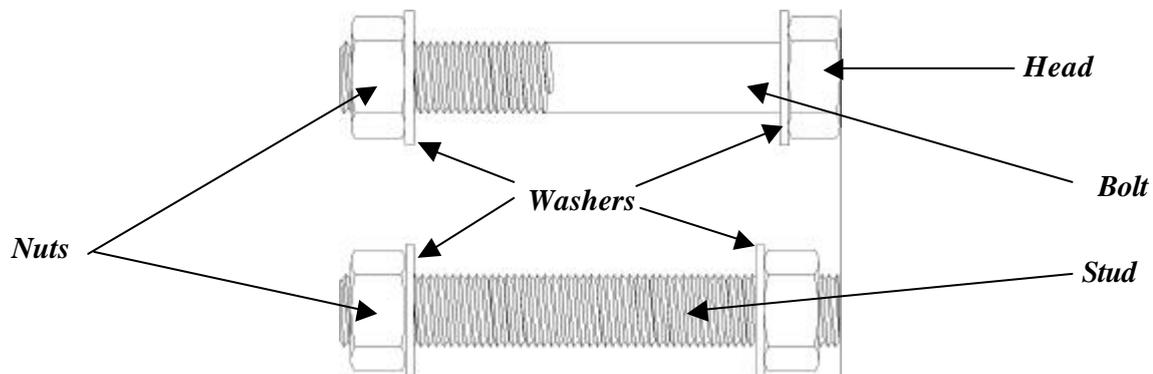
Some general rules applicable to the surface finish of the flange:

- *The flange surface has a definite effect on sealability and seal security.*
 - *A minimum seating pressure must be achieved in order to make the gasket material flow into the flange surface irregularities. The total force required to make this occur is proportional to the contact area of the gasket and the flange. Bolting force may be lowered by reducing the gasket area or the flange contact area.*
 - *The closer together are the ridge surfaces of a concentric serrated finish and the shallower are the grooves, the more the flange area begins to resemble a smooth face flange, and hence there is more contact area. Higher bolt loading is therefore required in order to seat the gasket. The opposite effect occurs as the ridge spans become wider.*
 - *In the limit, with a very smooth flange there will be reduced friction restraining the gasket from extruding outwards under the influence of the internal pressure of the retained medium.*
 - *A phonographic finish is more difficult to seal than a concentric serrated finish. Complete flow of gasket material must reach to the bottom of the “valley” surface in a phonographic finish to avoid a spiral leak path from one end of the spiral to the outside.*
 - *Serrated and phonographic finishes are often associated with pipe flange assemblies, whereas commercial ground finishes are likely to be found in flanged joints other than pipe flange assemblies. Take care with milled finishes, which may create additional leak paths if the milling action is not sufficiently smooth*
- ☑ ***Since gasket materials vary in hardness or resistance to flow, selection of the proper gasket material is important with regard to the flange finish and application***

For example; - for high temperature and /or pressure applications, use a rough (but controlled) surface finish and gaskets with high resistance to flow
- for low temperature and / or pressure applications, a smooth finish can be tolerated, especially with soft gaskets
- for weak or fragile flanges, use soft gaskets

4.3. Fasteners

For the majority of flange and gasket joints, the fasteners which provide the compressive pressure on the flanges (and through this onto the gasket) are normally bolts or studs in tension⁵. Effectively, a bolt is a threaded fastener to be used with a nut. A stud is a threaded fastener to be used with two nuts (in some cases with a fully threaded shank)



The function of the fastener is to clamp the joint sufficiently to prevent slip or leakage, and hence it must be strong enough to support the tension induced on initial tightening, together with the additional loads it will endure in service (as a result of

pressure, temperature and cycling). Importantly, a number of variables⁵ must be considered when determining fastener capability, including tensile strength, thread stripping, fatigue and stress corrosion cracking (SCC).

Fasteners exhibit stress relaxation behaviour dependent upon their material of construction. This will have a marked effect on the load they are able to generate on the flange / gasket assembly under operating conditions. Consequently, when selecting the fasteners to use for a particular application, always consider the temperature variations which the fasteners will experience in service.

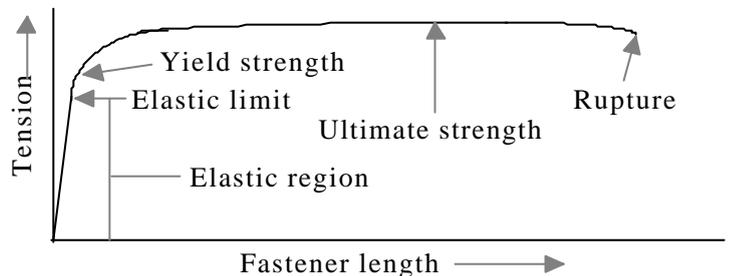
Recommended fastener working temperatures		
<u>Material</u>	<u>Temperature °C (°F)</u>	
	Minimum	Maximum
Carbon steel	-20 (-4)	300 (572)
B7, L7	-100 (-148)	400 (752)
B6	0 (32)	500 (932)
B8	-250 (-418)	575 (1067)
B16	0 (32)	520 (968)
B17B	-250 (-418)	650 (1202)
B80A	-250 (-418)	750 (1382)

In most flange assemblies, the distribution of pressure on the gasket is usually not the same at all points. For example, two large diameter bolts might provide the same overall load as 12 smaller diameter ones, but the distribution of the load would be very different. The gasket area surrounding the bolts or studs undergoes greater compression than midway between the bolts, due to flange bowing. Therefore, in order to distribute the gasket pressure as equally as possible, a higher number of properly spaced bolts or studs should be used. Importantly:

- ☑ ***never use fewer fasteners than the number designed for the flange***

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 fastener 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*). **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. The tensile force which produces a specified permanent deformation is known as the *proof stress* (often called *yield strength*), and 0.2% deformation is most commonly used for metals. The tensile force which produces this amount of deformation is often termed *0.2% offset proof stress* or *0.2% offset yield strength*.

At the maximum limit, the ultimate strength of the fastener is also known as the tensile strength.

Where a specification includes a *proof load* test on a full size fastener (often reported as *stress under proofing load*), this assured value may be used for maximum load capacity. However, some specifications provide a 0.2% *proof stress* value as an indication of the elastic limit. Note that this is only an arbitrary value, based upon a stress strain test on a machined test piece from the alloy bar stock (not a full size fastener). In reality, the true elastic limit of many alloy fasteners may be significantly lower than the 0.2% *proof stress* value. This discrepancy is not a problem where design loads do not fully utilise the fasteners supposed strength; however, there is an increased risk of fastener yield or rupture if a high percentage of assumed yield is utilised, which is dependent primarily on the material and method of fastener construction. For example, the following table (adapted from EN 20898-1 of 1991) indicates the mechanical properties of certain fasteners at ambient (room) temperature, and shows the different values for proof load and 0.2% proof stress:

	Property class					
	4.6	6.8	8.8		10.9	12.9
			$d < 16$ mm	$d > 16$ mm		
Tensile strength, MPa [ksi]	400 [58]	600 [87]	800 [116]	830 [120]	1040 [151]	1220 [177]
Stress under proofing load (“proof load”), MPa [ksi]	225 [33]	440 [64]	580 [84]	600 [87]	830 [120]	970 [141]
0.2% proof stress, MPa [ksi]	-	-	640 [93]	680 [99]	940 [136]	1100 [160]

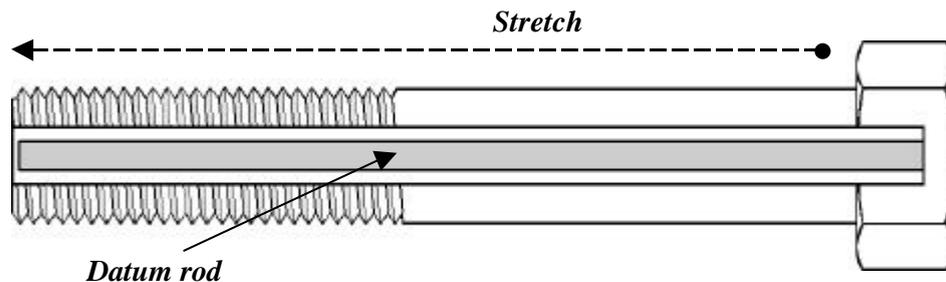
For fasteners of property class 8.8 with diameters $d < 16$ mm, there is an increased risk of nut stripping in the case of inadvertent over-tightening inducing a load in excess of proof load (reference to ISO 898-2 is recommended).

Readers should be aware that fasteners may have corrosion resistance coatings, or may be galvanised. Note that the tables in this section are applicable only to untreated fasteners.

Similar mechanical requirements are indicated in the following table (adapted from ASTM A 193 / A 193M), at ambient (room) temperature:

	B6	B7 (Cr-Mo)		B16 (Cr-Mo-V)			Class 1 B8 etc	Class 2 B8 etc			
Diameter, in	up to 4 incl.	up to 2½ incl.	>2¼ incl.	>4-7 incl.	up to 2½ incl.	>2¼ incl.	>4-7 incl.	All	up to ¾ incl.	>¾ incl.	>1-1¼ incl.
Diameter, mm	up to 100 incl.	up to 65 incl.	>65- 100 incl.	>100- 180 incl.	up to 65 incl.	>65- 100 incl.	>100- 180 incl.	All	up to 20 incl.	>20- 25 incl.	>25- 32 incl.
Tensile strength, ksi [MPa]	110 [760]	125 [860]	115 [795]	100 [690]	125 [860]	110 [760]	100 [690]	75 [515]	125 [860]	115 [795]	105 [725]
0.2% yield strength ksi [MPa]	85 [585]	105 [720]	95 [655]	75 [515]	105 [725]	95 [655]	85 [586]	30 [205]	100 [690]	80 [550]	65 [450]

Consequently, the modulus of elasticity of the fastener is an important criterion. Devices are available to measure the stretch of the fastener, such as a datum rod, which is placed in a hole drilled along the axis of the bolt. The datum rod is connected to the head of the bolt, but otherwise is free along the bolt axis. This means that as the bolt is put under load, the change in length of the bolt (stretch) can be measured with a depth micrometer.



Measurement of bolt stretch using a micrometer is time consuming and may not provide control of preload with sufficient accuracy. The use of ultrasonics overcomes many of the disadvantages, offering a more accurate method for the determination of bolt stretch⁵, although not always very convenient and requires a high degree of operator skill. Fastener stretch can also be monitored by using tension control fasteners, which are pre-set to the required load.

Obviously, when a fastener gets hot, it will expand in length, effectively reducing the load on the gasket. Even before this, as the system heats up towards operating temperature, the flange itself will also expand. Hence, the coefficient of expansion of the components of the flange system must be taken into account in the design of the joint.

The performance of the seal is dependent largely upon the correct level of tension in the fastener. Within reason, it is usually recommended that the stress on the fastener should approach the “maximum fastener stress”, which of course should also be within the elastic region for the fastener. If the fastener is to perform effectively and safely within its elastic region for the service life of the joint, a margin of safety is required. This will be dependent upon the fastener material, method of construction and size, plus the method of tightening. The following table may act as a prudent guide for maximum fastener loads at ambient temperature:

Fastener specification	Proof load as a % of 0.2% proof stress	Maximum fastener load as a % of proof load	
		by torque methods	by tensioner methods
ISO 898, BS 1768, SAE J429	see specifications	85%	90%
B7, L7, B16	Up to M36 (1½in.)	88%	90%
	> M36 (1½in.)	80%	90%
Non-ferrous alloys, cupro metals, duplex stainless steels, nimonic	70%	85%	90%
Austenitic stainless steels, B8	60%	85%	90%

As an example, if you plan to use austenitic stainless steel fasteners and tighten by torquing methods, use a maximum of 85% of 60% of the 0.2% proof stress reported for the material. This will ensure an adequate margin of safety. **For specific guidance on maximum loads for fastener materials, always refer to the fastener manufacturer.**

It is vitally important that engineers select a fastener size and grade with sufficient elastic strength to accommodate the design tension within its elastic limit. When selecting fasteners (bolts or studs):

- select fasteners with sufficient yield strength to ensure they are within their elastic limit at the required load*
- select fasteners with the same modulus of elasticity*
- ensure there is no corrosion of the fasteners - this may significantly affect the performance!*
- to ensure fasteners follow the above guidelines, do not reuse*

4.4. Nuts

The tension in the fastener (and hence the compressive pressure on the gasket) is generated by tightening nuts along the threads of the fastener. 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 fastener and nut are made*

The threads on a larger fastener are “longer” per turn and have thicker roots than the threads of a smaller fastener. This means that the per-thread area which must be sheared to strip the threads is greater on a larger fastener, 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 fastener and nut material 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 fastener. In this way, the fastener 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 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. The following may help:

- *use coarse threads, rather than fine*
- *use the correct lubricant*
- *select materials for fasteners 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.*

When selecting nuts:

- select nuts with a specified proof load 20% greater than the ultimate tensile strength of the fasteners*

4.5. Washers

Note that in the diagrams in the previous section, the fasteners (bolts or studs) are equipped with washers. These are important, not only to distribute the load more evenly, but more importantly to assist in the tightening process, by allowing more consistent torquing of the nut along the thread. Flat, hardened washers should always be used with fasteners, because they offer a number of important advantages. Namely, washers can:

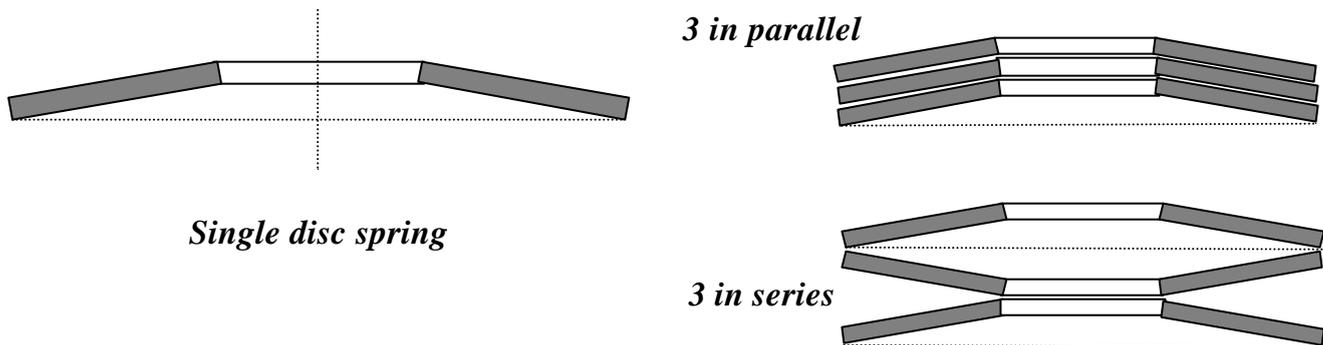
- *reduce significantly the friction between a turning nut and the joint components. This improves the consistency of the torquing operation, so improving accuracy and repeatability, while reducing the torque required*
- *reduce problems of fatigue by spreading the load placed by the fastener on the 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*

always use washers!

use the same material for the washers and the nuts

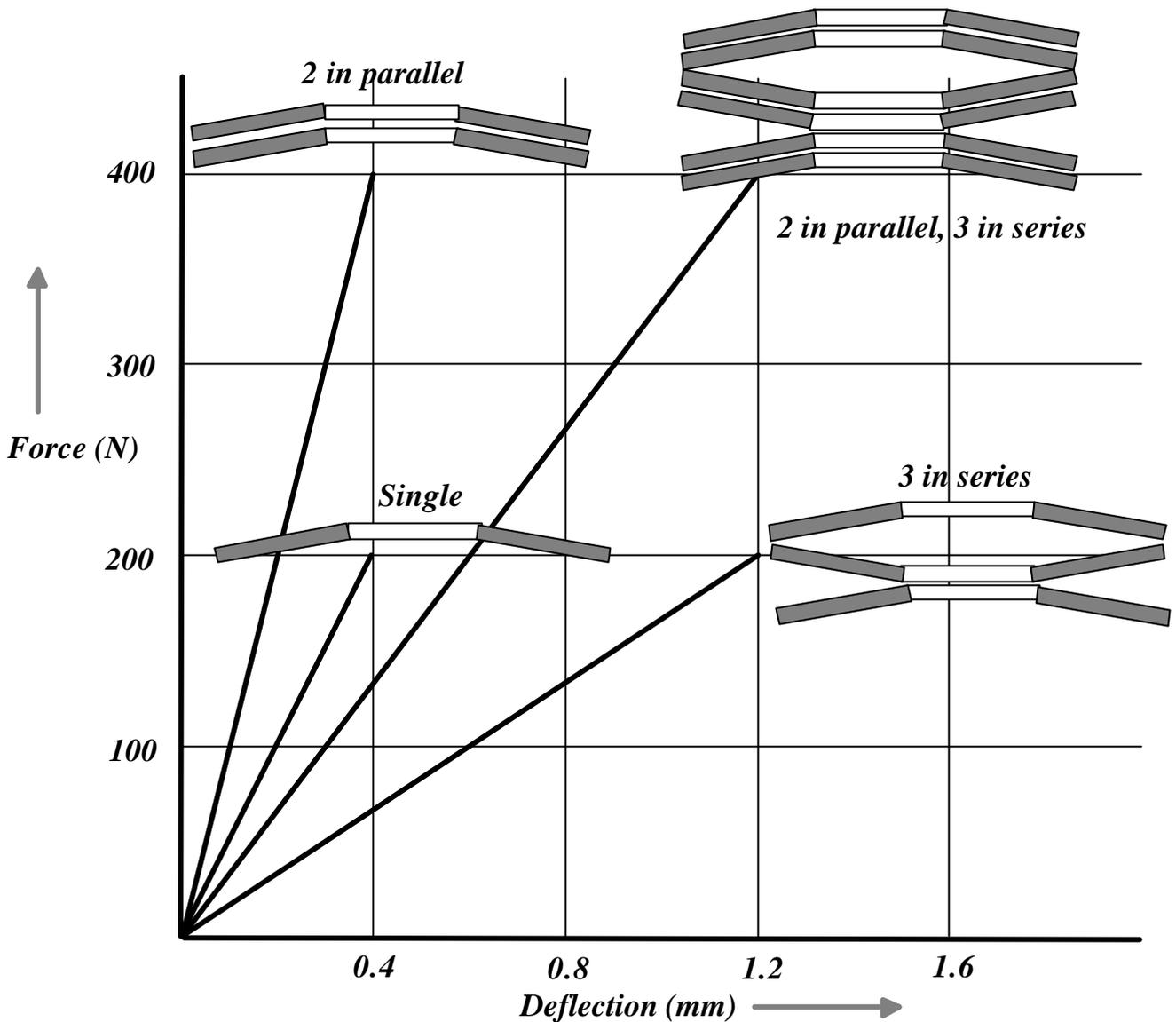
4.6. Live-loading

Throughout the service life of a flange gasket seal, the compression load on the gasket will vary with time, due to relaxation of the gasket and bolt materials, temperature and pressure cycling, vibration etc. To offset these changes, systems are sometimes used in order to provide a more constant load over time by altering the elasticity of the assembly. This can be achieved by using longer fasteners (with spacers), or live-loading. The latter is usually provided by metal disc springs (often called “Belleville washers”), which are carefully engineered, selected and arranged to provide a known load, so limiting the clamping force in the system.



Effectively, the disc springs are compressed to a specific deflection of load at flat. This offers a form of stored energy as a live-load, and is converted to a compressive load on the flange, and hence, onto the gasket. Very careful consideration must be given to the amount of live-loading applied, since it may lead to excessive pressure on the flange and gasket. When working as a stack, the design usually allows for a maximum disc spring deflection of around 75% compression of its uncompressed shape (such that the spring retains 25% of its uncompressed shape).

Applications may have disc springs stacked in series, parallel and combinations of both. Each combination provides a different level of stored energy under deflection, typically:



Regardless of configuration, the stack of disc springs requires a guide, on the inside or outside diameter, to prevent lateral movement under load. When an outside encasement is used, this can also protect the system from environmental corrosion, adding the advantage of maintaining constant lubrication provided by a high-pressure grease. Alignment of the disc springs and lubrication minimises friction between the contact surfaces. While providing a means of containment, the external encasement may also offer a security lock, to prevent misuse or alteration of the original design, adding to plant operational security. Note that the grade of steel employed may limit the maximum operating temperature of the live loading system.

4.7. Flange protection systems

It is common practice for new flanges to be supplied with a plastic 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 *soft* gaskets are being used this can cause a joint failure due to excessive creep induced by the low level of friction (see also the section on **Release Compounds**).

5. Gasket selection

This publication is focused on maintenance engineers and fitters, and it is assumed that, in general, the selection of materials 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 available. Primarily, selection must be based upon:

- *compatibility with the operating medium*
- *operating temperature and pressure*
- *variations of operating conditions (for example, during cycling)*
- *the type of joint involved*

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.

- importantly, 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.***

5.1. Material selection

There are a wide variety of materials which can be used in the manufacture of gaskets. This section is aimed at providing a brief overview, primarily of the common materials which can be used. For simplicity, it is divided into 5 parts;

- *elastomeric materials*
- *fibrous materials*
- *other materials*
- *European equivalents for stainless steel materials*
- *metallic materials*

Elastomeric materials

Often the “entry level” to sheet sealing products. More commonly, they act as the binder when compounded with various fibres and fillers. Composition (and hence performance) may vary, so always consult the manufacturer.

Butyl rubber (IIR, also known as isobutylene, isoprene)	An elastomer offering good resistance to ozone and gas permeation. Suitable for mild acids, alkalis and esters, but little resistance to oils and fuels.
Chlorosulphonated polyethylene	An elastomer with excellent chemical resistance against acids and alkalis. Good oil resistance. Outstanding fire protection properties.
Ethylene propylenediene (EPDM)	Elastomer which offers good resistance to ozone, steam, strong acids and alkalis, but is not suitable for solvents and aromatic hydrocarbons.
Fluoroelastomer	A fluorinated hydrocarbon which offers excellent resistance to acids, aliphatic hydrocarbons, oils and many corrosive applications. Not suitable for amines, esters, ketones or steam.
Natural rubber (NR)	Excellent for recovery properties. Good resistance to most inorganic salts, mild acids and alkalis. Not recommended for oils and solvents, or where exposure to ozone, oxygen or sunlight is prominent.
Neoprene (chloroprene, CR)	Excellent resistance to oils, ozone and weathering. Suitable for moderate acids, alkalis, salt solutions, petroleum, solvents, oils and fuels. It is not recommended for strong acids or hydrocarbons.
Nitrile (NBR)	Improved chemical resistance and temperature capabilities over neoprene. Good resistance to hydrocarbons and oils. Not suitable for chlorinated hydrocarbons, esters, ketones and strong oxidising agents.
Silicone	Excellent temperature properties, and unaffected by ozone and sunlight. Not suitable for many hydrocarbons and steam.
Styrene butadiene (SBR)	Suitable for use with weak organic acids and moderate chemicals. Not suitable for strong acids, most hydrocarbons or ozone.

Fibrous materials

Aramid	Aromatic amide fibre, offering high strength and stability, with medium temperature suitability. Raw fibres can fibrillate.
Asbestos	Since the 1890's, the most common material used for sealing flanges, because of its ability to seal effectively over a broad range of service conditions. Now increasingly replaced by asbestos-free substitutes (mandatory in many locations).
Carbon fibre	High thermal conductivity ensures rapid heat dissipation and allows high temperature capability (except in oxidising atmospheres). Wide chemical resistance, and may be used in the pH range 0 - 14, although must not be used in oxidising environments
Cellulose	Natural fibre, suitable for low temperature and medium pressure applications. Raw fibres can fibrillate.
Glass	Inorganic complex of metal silicates, which offers good strength and moderate chemical resistance. Suitable for medium to high temperature applications. The fibres do not fibrillate.
Man made mineral fibre (MMMMF)	Also referred to as "mineral wool". Inorganic fibres consisting of metal silicates, with a wide range of diameters. Suitable for medium to high temperature applications. Fibres do not fibrillate.

Other materials

Flexible graphite	Following processing into its exfoliated form, the material is essentially pure graphite, typically over 95% elemental carbon. Consequently, the material has a wide chemical resistance, although must not be used in oxidising environments. Commonly supplied at a bulk density of 1.1 Mg.m ⁻³ (70 lb.ft ⁻³), which is ~50% theoretical maximum and ideal for the majority of industrial applications. Material can be supplied at a higher density (for applications operating at high fluid pressure), or at lower density (where sealing loads are relatively low or where good conformability is required).
Mica (vermiculite)	Naturally occurring, complex aluminium silicates, characterised by laminar morphology and near-perfect basal cleavage. The structure possesses a high degree of flexibility, elasticity and toughness. Excellent thermal stability and chemical resistance.
PTFE	Extremely wide chemical resistance (PTFE is attacked only by molten alkali metals and fluorine gas), with excellent anti-stick and dielectric properties. Material has high compressibility, which allows it to conform well to flange surface irregularities. Easy to handle. Susceptible to degradation by radiation.

European equivalents for stainless steel materials

USA	Deutschland	España	France	Italia	Sverige	UK
AISI	DIN / W.-Nr.	UNE	AFNOR	UNI	SS	BS
304	X5CrNi 18 9 / 1.4301	X5CrNi 18 10	Z6CN 18.09	X5CrNi 18 10	2332	304 S 15
304L	X2CrNi 18 9 / 1.4306	X2CrNi 19 10	Z2CN 18.10	X2CrNi 18 11	2352	304 S 12
316	X5CrNiMo 18 10 / 1.4401	X5CrNiMo 17 12	Z6CND 17.11	X5CrNiMo 17 12	2347	316 S 16
316L	X2CrNiMo 18 10 / 1.4404	X2CrNiMo 17 12	Z2CND 18.13	X2CrNiMo 17 12	2348	316 S 11 316 S 12
321	X100CrNiTi 18 19 / 1.4541	X7CrNiTi 18 11	Z6CNT 18.10	X6CrTi 18 11	2337	321 S 12
347	X100CrNiNb 18 9 / 1.4550	X7CrNiNb 18 11	Z6CNNb 18.10	X6CrNiNb 18 11	2338	304 S 17
410	X100Cr 13 / 1.4006	X12 Cr 13	Z12 C 13	X12 Cr13	2302	410 S 21

Metallic materials

	Trade name	Description	Comments
Carbon steel		Sheet forged or rolled steel, (<i>soft iron</i>)	For general applications only
316		18-12 Cr / Ni austenitic stainless steel, with Mo	Excellent corrosion resistance, but subject to stress corrosion cracking (SCC) and intergranular corrosion with certain media
316L		Variation of 316, with reduced carbon content	Reduced SCC and intergranular corrosion
304		18-8 Cr / Ni austenitic stainless steel	Excellent corrosion resistance, but subject to SCC at high temperatures
304L		Variation of 304, with reduced carbon content	Reduced SCC and intergranular corrosion
321		18-10 Cr / Ni stainless steel, with Ti	Subject to SCC, but reduced intergranular corrosion
347		18-10 Cr / Ni stainless steel variant	Subject to SCC, but reduced intergranular corrosion. High temperature suitability
410		12-9 Cr / Ni ferritic stainless steel	Excellent high temperature suitability, good corrosion resistance
Titanium			Excellent high temperature corrosion resistance, outstanding in oxidising media
Alloy 600	Inconel 600®	70% Ni, 15% Cr, 8% Fe alloy	Excellent high temperature corrosion resistance
Alloy 625	Inconel 625®	Ni / Cr alloy, with Mo and Nb	Outstanding corrosion resistance in a wide range of acid and alkali media
Alloy 800	Incoloy 800®	32% Ni, 20% Cr, 46% Fe alloy steel	Excellent high temperature corrosion resistance
Alloy 825	Incoloy 825®	Ni, Cr, Fe, Mo, Cu alloy steel	High resistance to hot acids and outstanding resistance to SCC
Alloy 200	Nickel 200®	99.6% wrought Ni	High resistance to reducing media and alkalis
Alloy 400	Monel® 400	67% Ni, 30% Cu alloy steel	High resistance to hydrofluoric acid
Alloy B2	Hastelloy B2®	Ni / Mo alloy steel	Excellent resistance to acetic, hydrochloric, phosphoric and sulphuric acids
Alloy C276	Hastelloy C276®	Ni / Cr / Mo alloy steel	Excellent corrosion resistance to both oxidising and reducing media
Alloy 20	Carpenter 20	Fe / Ni / Cr alloy steel	Developed for applications which require resistance to sulphuric acid
Alloy x - 750	Inconel® x-750	Ni / Cr / Fe alloy steel	Precipitation hardened, high resistance steel
Aluminium			Excellent ductility and malleability
Copper			General corrosion resistance

5.2 Gasket types

Gaskets can be defined into 3 main categories:

- *soft (non-metallic)*
- *semi-metallic*
- *metallic*

The mechanical characteristics and performance 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 usually influenced primarily by:

- *temperature and pressure of the medium to be contained*
- *chemical nature of the medium*
- *mechanical loading affecting the gasket*

- ☞ **Soft gaskets (non-metallic)** Often composite sheet materials, suitable for a wide range of general and corrosive chemical applications. Generally limited to low to medium pressure applications.
Types include : Compressed asbestos fibre (“CAF”) and asbestos-free (non-asbestos) fibre materials, graphite, PTFE
- ☞ **Semi-metallic gaskets** Composite gaskets consisting of both metallic and non-metallic materials, the metal generally providing the strength and resilience of the gasket. Suitable for both low and high temperature and pressure applications.
Types include : Kammprofile, metal eyelet, metal jacketed, metal reinforced soft gaskets (including tanged graphite and wire reinforced “it” materials), corrugated metallic and spiral wound gaskets
- ☞ **Metallic gaskets** Can be fabricated from a single metal or a combination of metallic materials, in a variety of shapes and sizes. Suitable for high temperature and pressure applications. Higher loads are required to seat the gaskets.
Types include : Lens rings, ring type joints, and welded gaskets

The gasket must be resistant to deterioration from the fluids being sealed, and it must be compatible chemically. For metallic gaskets, consideration must be given to electrochemical (or “galvanic”) corrosion, which can be minimised by selecting gasket and flange metals which are close together on the electrochemical series (or alternatively the gasket should be sacrificial, to minimise damage to the flange). This type of corrosion is an electrochemical process occurring in the presence of an ion-conducting medium, which may be an aqueous solution made conductive by dissolved ions. The base element is dissolved in a redox process, in which electrons emitted by the base element (anode) are taken into solution and deposited on the noble element (cathode).

Electrochemical series of some commercial metals / alloys

(in sea water)

Anode (base)	Magnesium
	Zinc
	Cast iron
	Carbon steel
	Stainless steel 304 (active)
	Stainless steel 410 (active)
	Copper
	Stainless steel 316 (active)
	Inconel
	Stainless steel 410 (passive)
	Titanium
	Stainless steel 304 (passive)
	Monel
	Stainless steel 316 (passive)
	Gold
Cathode (noble)	Platinum

A brief guide follows on the major gasket materials and types which may be used to ensure safe and reliable sealing solutions. If a release coating is required for easier removal of the gasket from the flange after service, use materials with an anti-stick coating which has been applied by the manufacturer (see **Release Compounds**).

Please note that in the listings which follow, operating limits are **indicative only**. Many of the gasket types are composites, containing a variety of binders, fillers, etc., the inclusion of which will modify the performance envelope of the gasket material. Operating limits and suitability may vary significantly, dependent upon material constituents and specific operating conditions; under these circumstances the advice of the manufacturer is vital! **Always consult the 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!

<u>Gasket material or type</u>	<u>Comments</u>
Beater addition	A wide variety of fibres, fillers and binders can be combined using beater addition chemistry. The products are then produced in a paper manufacturing process, which generally involves calendering, to provide materials with a wide range of performance capabilities.
Compressed asbestos fibre (“CAF”)	Manufactured by the “ <i>it</i> ” calendering process (see base of page), in which the mixture is compressed between two rollers under load. Asbestos sheet material often contains a high fibre content, and can be formulated with a wide variety of fillers and binders. Regarded as a very forgiving material, with extremely wide applicability.
Compressed asbestos-free (compressed non-asbestos)	A wide variety of fibres, fillers and binders can be formulated, using the “ <i>it</i> ” process. Consequently, compressed fibre gasket materials can be designed to function over an extensive range of fluids, pressures and temperatures. In general, these materials can equal or outperform the asbestos fibre original, although they require different selection, handling and installation care.
Constant volume	Gasket with the sealing element enclosed on both the inside and outside diameters by metal rings, such that at full compression, there is metal to metal contact between the flange faces and the metal rings. Consequently, the volume of the sealing element, and the stress on it, is constant, irrespective of excess load imposed. Sealing element may be any suitable material (for example, graphite), as appropriate for the application.
Cork composition	Economical and generally suitable for light bolting, and relatively mild service conditions. Ideal for easily damaged flanges (for example, glass or ceramic). Usually limited to light duty service.
Cork and rubber composite	Desirable characteristics of cork, combined with the advantages of synthetic rubber, giving improved handling and shelf life over cork composition, while it may also have better chemical resistance (dependent on the rubber binder). May also be reinforced with fibres for improved load retention. Ideal for light duty applications.
Corrugated metallic	Gasket of metal construction, usually incorporating a filler material on the corrugations. The seal is formed between the peaks of the corrugations and the flange mating surfaces.
Envelope	Primarily used in conjunction with corrosive resistant equipment constructed of glass, glass-lined metal etc. The envelope, usually of PTFE, serves as a chemically resistant layer with insert materials providing compression and resilience.
Eyelet	A soft gasket which is reinforced with a metal ring on the inner circumference, which provides additional blowout resistance and reduces chemical degradation. Usually improves sealability.
Flexible graphite	Normally supplied with a metal reinforcement layer to fortify the structure, thereby assisting handling and installation. Usually a mechanical (tanged) core is used, although chemical adhesive bonding to flat metal is easier for cutting operations.
Jacketed	Traditional heat exchanger gasket, consisting of metal cladding over a resilient core material. May have a seal-enhancing, soft surface layer of graphite.
Kammprofile	Metal gasket with grooved faces, with or without resilient sealing layer on surfaces.
PTFE (simple)	Manufactured from pure PTFE, with a minimum of processing, these gaskets offer extremely wide chemical resistance, but they suffer from cold flow and creep under compression. Often skived or moulded.

Note: “*it*” comes from the last letters of the two words *gummi asbest* (from the German), meaning “CAF” or compressed asbestos fibre sheet.

<u><i>Gasket material or type</i></u>	<u><i>Comments</i></u>
Phyllosilicate	High temperature gasket material based on members of the mica family, available in sheet form, with or without metal reinforcement.
Processed PTFE	Extremely wide chemical resistance can be combined with high compressibility and significant improvement in cold flow and creep. Variety of processing options, fillers and designs provide a wide range of performance capabilities from a number of types (such as expanded PTFE, filled PTFE and biaxially-orientated PTFE).
Ring-joint	Metallic gaskets, manufactured from a variety of metals and alloys, usually oval or octagonal in cross-section. Used in conjunction with ring-joint flanges. Extremely high pressures may be contained (generally up to 100 MPa or 14,500 lbf.in ⁻²), while maximum temperature is normally limited by the metal concerned.
Rubber	A wide variety of rubber types are available, able to satisfy an extensive range of (elastomeric) service conditions. Properties may be designed into a single product to meet specific performance needs. Selection of the grade appropriate to the performance required is essential.
Spiral-wound	Versatile, semi-metallic gaskets which consist of alternate layers of (usually) V-section metal strip and a filler, wound in spiral form. Metal component may be stainless steel, Monel, inconel etc, while the filler may be asbestos or other fibres, PTFE, graphite, ceramic etc, as appropriate for the application. Can be used over a wide range of temperatures and pressures.
Tape / cord expanded PTFE (also known as <i>joint sealant</i>)	Usually on a spool or roll, this high compression material is very flexible and is available with adhesive on one side to aid installation. Material has some improvement in cold flow and creep as other processed forms. The material can be rolled out onto the flange mating surface, cut off, overlapped and compressed between the flanges. Hence, often referred to as “form in place”, an ideal do-it-yourself gasket material for easy field installation. Generally used for less severe pressures and temperatures, especially where flanges are lightly loaded or of relatively flimsy construction

5.3. Thickness selection

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

- ensure the gasket is as thin as possible***

5.4. Cutting soft gaskets

The performance of soft gaskets can be significantly affected by the way in which it is cut to shape.

- use a good cutter to cut the shape of the gasket required***
- never try to cut out a gasket by hammering material against the flange! This may damage the flange, and will certainly reduce the performance of the gasket***
- ensure the gasket is the correct size, to avoid corrosion of exposed flange faces and minimise hydrostatic end thrust***
- cut the bolt holes slightly larger than the bolts, to ensure proper seating***
- ensure that the inside diameter of the gasket is not less than the inside diameter of the process line, to minimise obstruction of the process line***

5.5. Gasket and gasket material storage

Although many gasket materials can be used safely after storage for many years, ageing will have a distinct effect on the performance of certain types of gasket materials, resulting from chemical degradation which occurs over time. Primarily, this is a concern with materials which are bonded with elastomers, which, in general, 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 catalysed by intense sunlight. Although this is of little concern with metallic gaskets, it may have an effect on semi-metallic gaskets (specifically, those which are combined with elastomer-bound materials). Since graphite and PTFE materials contain no binders, sheets and gaskets of these materials have a virtually indefinite shelf life. In general:

- ☑ ***during storage, gaskets should not be subjected to extreme heat or humidity - store in a cool, dry place, away from direct sunlight, water, oil and chemicals***
- ☑ ***store sheet materials flat***
- ☑ ***avoid hanging gaskets - they may distort. Store soft gaskets flat. Large diameter spiral wound gaskets should be retained on their mounting board***
- ☑ ***gaskets should be kept clean and free from mechanical damage (for maximum protection, store in sealed poly bags)***

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

5.6. Handling of gaskets and gasket materials

The condition of the gasket plays an important part in its performance. Some gasket materials are relatively robust (such as metallic gaskets), others are reasonably forgiving (such as CAF and PTFE), but others may be very brittle or prone to cracking. Consequently, all gaskets and gasket materials are best handled with the same care and attention. Bent, nicked, gouged, scratched or hammered gaskets will rarely seal effectively! When working in the field, carry cut gaskets carefully, ideally within some form of protective cover. Although carrying small gaskets in a pocket is a common practice, it is best avoided! If you bend the gasket it will be damaged. If it picks up debris from the inside of your pocket or elsewhere, it may scratch the surface.

- ☑ ***carry gaskets carefully, ideally within some form of protective cover***
- ☑ ***do not bend or buckle***
- ☑ ***do not damage the surface***
- ☑ ***for large diameter metallic and semi-metallic gaskets, always transport the gasket on its mounting to the installation site***

5.7. Reuse of gaskets / fasteners

Never reuse a gasket, since it may have been modified dramatically under operating conditions. Even if the gasket appears to be okay, it is not worthwhile! The cost of a new gasket is minuscule compared to the cost of down time caused by a leak or blowout and the considerations of safety and environmental protection.

Similarly, bolts or studs may have been damaged due to corrosion, or may have lost ductility by being tightened past yield; if you cannot be sure - do not take the chance!

- ☑ ***do not reuse gaskets or fasteners***

6. Assembly procedures

For the seal to perform as designed, proper assembly of the joint is crucial. This process is subject to a large number of variables, including the condition of all the components, the smoothness, the hardness, the lubricity of surfaces, the calibration of the tools, the accessibility of the fasteners, the environment in which the engineers must operate

Most importantly, it is a good idea to be consistent. If your present practices have proved robust, then don't change them! You should aim to keep the number of variables to a minimum. If possible, use the same tools in the same manner.

6.1. Tools required

You will require tools to both clean the flange and tension the fasteners. The tensioners will require regular calibration and may include torque wrench, hydraulic or other tensioners. Instruments to measure tension may include a micrometer, or ultrasonics.

Generally, this can be a pretty messy job! Therefore you will need appropriate clothing (protective clothing where necessary), safety helmet, safety goggles, gloves, and a security pass to the area, as appropriate.

6.2. Cleaning

To ensure good seal performance, all load-bearing surfaces must be clean:

- ☞ **Fasteners / nuts / washers** - clean with a wire (ideally brass) brush to remove dirt on the threads
- ☞ **Flange assembly** - clean gasket seating surfaces with suitable implements (see below)

On opening the flange and removing the previous gasket, the flange faces will often be contaminated with fragments of the old gasket material, which must be removed before a new gasket can be safely installed. Suitable implements for cleaning the faces of a flange may include a wire brush (use stainless steel bristles on alloy components). However, always brush in the direction of the grooves (rather than perpendicular to them), in order to minimise undue wear. Inevitably, use of a wire brush will result in wear across the faces over time. Consequently, other tools have been developed, such as the *brass drift*. This concept is based upon the use of a softer material (brass) than the flange surface (usually steel) to avoid damage. A suitable drift can be made from a sheet of brass, ~5 mm (0.2 in) thick x 50 mm (2 in) wide, which is filed and shaped to a 45° chisel across the width. Using a hammer, lightly tap the drift into the flange grooves to remove debris.

6.3. Visual inspection

All load-bearing surfaces must be free from any serious defects. Even a perfect gasket will be unable to seal a badly damaged or warped flange:

- ☞ **Fasteners / nuts / washers** - examine after cleaning to assure freedom from defects, such as burrs or cracks
- ☞ **Flange assembly** - inspect the flange surfaces for defects, such as radial scores and warping
- ensure the flange surfaces are sufficiently flat and parallel
- ☞ **Gasket** - check that the correct gasket is available (suitable for the service, size, thickness)
- examine the gasket prior to installation to ensure it is free from defects

If any defects are observed, don't take chances!

- ☑ ***replace defective components with a good alternative. If in doubt, seek advice***

Note that for spiral wound gaskets in particular, the flatness and parallelism of the flanges are important factors for good sealing performance:

- **flange surface flatness** should vary by less than 0.2mm over the gasket seating width
- **flange surface parallelism** should be less than 0.4mm total out of parallel across the whole flange

6.4. Lubrication

It is estimated that, in the absence of a suitable lubricant, up to 50% of the torque effort may be used to merely overcome friction. Effectively, this would mean that the same torque applied to non-lubricated fasteners on a joint might provide markedly different loads on each one! Therefore, lubrication is essential when torque is used as the control for setting tension in the joint.

When selecting a lubricant, the following factors should be considered:

- ☞ **lubricity** - the better the lubricant, the lower will be the effect of friction
- ☞ **compatibility** - the lubricant must be compatible with the fastener materials (including nuts and washers), and ideally also with the process fluid. For example, copper-based lubricants may contaminate the process fluid, while chlorides, fluorides and sulphides may contribute to corrosion of the fastener materials (including nuts and washers)
- ☞ **temperature** - ensure the recommended service temperatures of the lubricant are within the process service temperature limits

The following procedures are recommended:

- ☑ *lubricate fastener threads and all bearing surfaces (underside of bolt heads, nuts, washers)*
- ☑ *use only specified or approved lubricants*
- ☑ *apply the lubricant in a consistent manner as a thin, uniform coating (avoid “lumps” of lubricant as this may reduce the efficiency)*
- ☑ *ensure lubricant does not contaminate either flange or gasket faces*
- ☑ *avoid contamination of the lubricant by storing it in a closed container (equally, avoid contaminating the gasket with the lubricant!). After use, store in a “clean” area*

6.5. Gasket installation and centralisation

Prior to installation, ensure that the flange components are correctly assembled and the flange mating surfaces are parallel.

- ☑ *carefully insert the new gasket between the flanges to prevent damage to the gasket surfaces*
- ☑ *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*
- ☑ *ensure the gasket is central in the flange*
- ☑ *do not use tape to secure the gasket to the flange. If it is necessary to secure the gasket to the flange, use a light dusting of spray adhesive (e.g. 3M type 77)*
- ☑ *do not use jointing compounds or release agents*
- ☑ *line up the joint components (including the flanges and the gasket) and examine them to ensure that an acceptable fit has been obtained*
- ☑ *take care when bringing the flanges together, to ensure that the gasket is not pinched or otherwise damaged*

6.6. Calculation of torque

Despite the number of developments to improve the reproducibility of fastening flanged joints (such as tension control fasteners, hydraulic tensioning devices, ultrasonic fastener analysis and simultaneous torque / turn methods), torque remains the most popular method to control joint tightening. When using torque tightening methods, there are 3 main factors to take into account in order to ensure that the required forces are produced:

Factor 1 (torque applied to load the fastener)	+	Factor 2 (torque applied to overcome thread friction)	+	Factor 3 (torque applied to overcome friction at the nut)
--	---	---	---	---

These factors include the pre-load on the fastener spot face. Factors 1 and 2 include the dimension of the thread and Factor 3 includes the dimension of the nut. Factors 2 and 3 also include the coefficient of friction between these surfaces, which is dependent upon the type of lubricant used.

It must be emphasised that friction makes a significant contribution to the torque which must be applied (see Section 6.4), and hence the use of specified lubricants is crucial for good torque control. Values for the coefficient of friction provided by the lubricant must be known, in order to establish the fastener load accurately. Torque may be represented (in either metric or imperial units):

$$T = W \left[\frac{P}{2p} + \frac{R_e m}{\cos q} + R_s m \right]$$

↙

Incline plane
(constant)

↓

Thread friction
at effective radius
(variable)

↘

Nut friction
at spot face
mean radius
(variable)

where : $T = \text{Torque}$
 $W = \text{Force}$
 $P = \text{Thread pitch}$
 $q = \frac{1}{2} \text{Thread included angle}$
 $R_e = \text{Effective thread radius}$
 $R_s = \text{Nut spot face mean radius}$
 $m = \text{Coefficient of friction}$

In simplified form, for lubricated fasteners, washers, nuts etc (see also Section 6.4), the relationship between torque and fastener load may be represented as:

$$T = L \times 0.2 \times db$$

where : $T = \text{torque per fastener in N.m (in-lbf)}$
 $L = \text{load per fastener in kN (lbf)}$
 $db = \text{nominal diameter of fastener in mm}$
 $0.2 = \text{factor of loss due to friction}$

Note also that the factor of 0.2 may vary considerably. It may be increased to 0.3 for non-lubricated systems, or reduced to 0.15 for lubricants with a low coefficient of friction.

The performance of the seal is largely dependent upon the correct level of tension in the fastener. Remember that for maximum effectiveness, the load on the fastener should be kept within its elastic region (for guidance, please refer to **Section 4.3, Fasteners**).

Other points to consider:

- *the crushing strength of the gasket material*
- *hydrostatic end thrust will increase the fastener tension under the operating internal pressure*
- *using a fastener stress which represents less than 50% of yield may cause problems*
- *most flanges are tightened by ordinary wrenching methods, and it is advantageous to have design stresses which can be achieved with this! (often impossible for larger diameter fasteners)*

6.7. Bolt / stud tightening pattern

One of the most difficult jobs facing the specifying engineer is to produce the correct assembly pressure on the gasket, low enough to avoid damaging the gasket, but high enough to prevent a leak in the seal. The gasket supplier will always be happy to assist in this task. Asbestos sheet materials are sufficiently robust usually to resist damage from overloading, but the same is not always true for asbestos-free alternatives! Consequently, when tightening up fasteners on a flange with any gasket type not incorporating a metal stop (such as a sheet gasket), never use an impact tool or scaffolding pole (often referred to as a “cheater bar” in the USA)! It is vitally important to control accurately the amount of force applied to any particular flange arrangement, and hence:

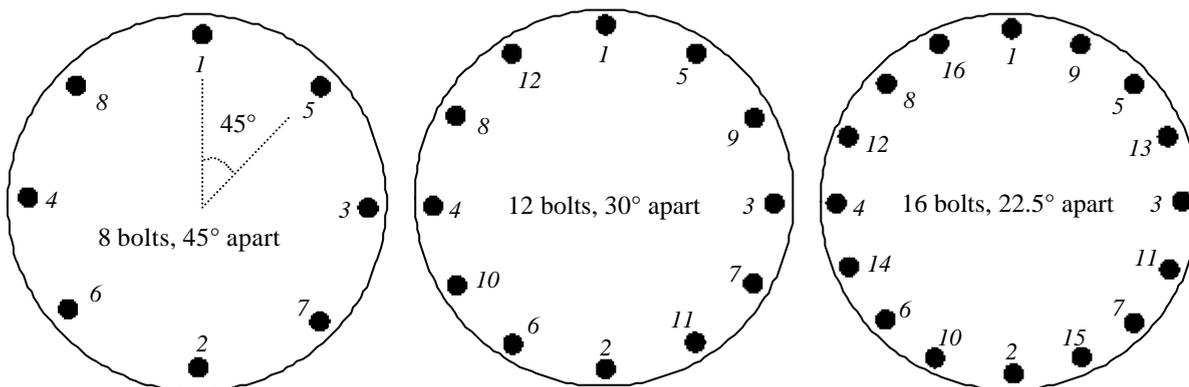
- ☑ *always use a torque wrench or other controlled-tensioning device (recently calibrated)*

The sequence in which bolts or studs are tightened has a substantial bearing upon the distribution of the assembly pressure on the gasket. Improper bolting may move the flange out of parallel. A gasket will usually be able to compensate for a small amount of distortion of this type, but serious difficulties may be encountered if the flanges are substantially out of parallel. Consequently:

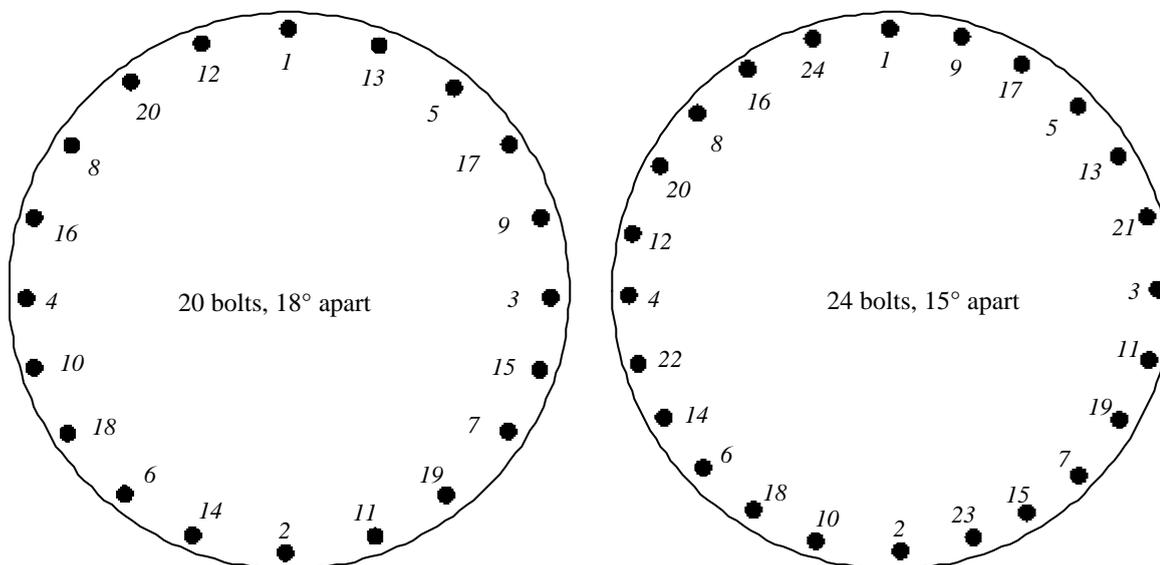
- ☑ *always torque nuts in a cross bolt tightening pattern*

Always run the nuts or bolts down by hand. This gives an indication that the threads are satisfactory (if the nuts will not run down by hand, then there is probably some thread defect - check again and, if necessary, replace defective parts).

Now torque the joint using a minimum of 5 torquing passes, using a cross-bolting sequence for each pass, as shown. The following procedure is recommended:



Cross bolt tightening pattern



- ☑ *Pass 1 - Tighten nuts loosely by hand in the first instance, according to the cross bolt tightening pattern, then hand-tighten evenly*
- ☑ *Pass 2 - Using a torque wrench, torque to a maximum of 30% of the full torque first time around, according to the cross bolt tightening pattern. Check that the flange is bearing uniformly on the gasket*
- ☑ *Pass 3 - Torque to a maximum of 60% of the full torque, according to the cross bolt tightening pattern*
- ☑ *Pass 4: Torque to the full torque, according to the cross bolt tightening pattern*
- ☑ *Pass 5 : Final pass at full torque, in a clockwise direction on adjacent fasteners*

After the five basic torquing passes are completed, it may be beneficial to repeat pass 5 until no further rotation of the nut is observed. The final tightening must be uniform, with each bolt pulling the same load.

Hydraulic tensioners are often used to preload fasteners. Although a number of engineers believe that these tensioners provide very good control (because the hydraulic ram exerts an accurate force on the fastener during the assembly operation), some load on the fastener is lost when the tensioner is removed as a result of elastic recovery. When the tensioner load is applied, the nut is run down against the joint (finger tight). The hydraulic pressure is then released and the tensioner removed. The nut and fastener now carry the full load, although there may be some embedment of material at the thread surfaces and at the nut bearing surfaces, which will reduce the load. Although hydraulic tensioners provide a consistent result, they require particular care, because the fasteners must be given a higher load to compensate for relaxation when the tensioner is removed. This may create hydraulic overload, which can cause fastener yielding (despite the apparent safety margin below 0.2% proof stress), especially a risk with certain fastener alloys (such as duplex stainless steels and other cupro nickel alloys), where the true elastic limit can be over 30% below the 0.2% proof stress value.

Alternatively, there are tension control fasteners available, which are pre-set to the required load.

Another way to tighten large bolts is to insert a heating rod in a hole drilled down through the centre of the bolt. As it heats up, the bolt expands length wise, and the nut can be run down against the joint (finger tight). The heater is now removed, and as the bolt cools, it shrinks, so developing tension. The method is relatively slow, but inexpensive (heaters are cheaper than high torque tools, for example). However, by itself, heating is not an accurate way to control a specified tension, and it should be combined with a measure of the residual stretch of the fasteners (such as with ultrasonics), which will then provide much more accuracy. There is some danger that heaters may alter the surface characteristics of the fastener, leaving them more susceptible to fatigue and stress corrosion cracking. If you plan to use heaters, use several at once at cross points around the joint, go for the final stretch in a single pass, measure the residual stretch after the bolts have cooled, re-heat and re-tighten those which are not correct.

6.8. Tagging

During a major overhaul, many thousands of flanges are required to be disassembled and then reassembled, usually involving teams of fitters who work their way through the plant. After the event, if a poorly assembled joint is discovered, it can be difficult (if not impossible!) to identify the root cause of failure. Consequently, tagging has been employed successfully on a number of industrial installations to encourage fitters to assemble the flange joints with care. It relies upon the following principles:

- *each fitter is given a unique identification (letters and / or numbers)*
- *each fitter is provided with metal or plastic tags (“dog tags”) stamped with his/her unique identification number*
- *one tag is connected (by wire or cord) to each flange joint as the fitter completes the assembly*
- *tag may vary from one metal to another, one colour to another, one shape to another, at every overhaul*

Hence, as the installation comes back on stream, the plant operator will be able to identify which fitter has assembled which joint. Obviously, a fitter who is working sloppily will know that he/she can be readily identified after the event. However, on a positive note, the procedure will encourage some competition between fitters to be the best! It will identify those fitters who may need more training in one (or more) aspect of the job, and it will identify those fitters who are particularly good at their job - can they help to train others?

Equally, it may also highlight inferior quality gaskets.

With tags which vary from one overhaul to another, the operator can easily identify the date of assembly.

6.9. Re-tightening

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 usually the creep relaxation of the gasket. These 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, some engineers recommend that fasteners should be re-tightened (to the rated torque) 24 hours after the initial assembly, and again after 48 and 72 hours (care: always re-tighten at ambient temperature); however, this is an area of conflicting views!

Certainly, care must be exercised with repeated re-torquing in order to avoid damage to the gasket. This is especially important in the case of gaskets with relatively narrow sealing areas, as the stress on the gasket is liable to be high and therefore closer to the limit which the gasket can withstand.

Elastomer-based “*it*” gasket materials continue to cure in service, especially on start up as the operating temperature is reached. Once fully cured, gasket materials may become embrittled and liable to cracking under excessive load, and this is especially the case with elastomer-based asbestos-free materials. It is impossible to predict the time for embrittlement to start, as it will depend on the application temperature and the gasket composition. **Always consult the manufacturer for advice about re-tightening**, but as a general rule:

- Do not re-torque an elastomer-based asbestos-free gasket after it has been exposed to elevated temperatures***

7. Disassembly procedures

Many industrial installations have extensive procedures for the installation and assembly of flanged joints, but very few focus on the trials and tribulations of disassembly! This section describes some items to consider.

Before starting to disassemble the fasteners, **check that the line has been de-pressurised**. Take care, in case seepage has allowed pressure to build up again.

There is an enormous amount of elastic energy stored in a fastened flange. In effect, the joint is a spring which has been held and compressed by the fasteners. As the fasteners are removed one by one, the stored energy of the joint may begin to load the fasteners remaining. This can have the effect of distorting the flange and may damage the flange surfaces. In some cases, the few fasteners remaining in a flange have actually been irreparably damaged or fractured as they attempted to hold the expanding joint together!

If you have experienced problems caused by taking the joints apart too casually, then the best advice is to use the reverse of the procedure which you used to tighten them:

- *use a cross bolt untightening procedure*
- *use several passes - partially loosen each fastener before further loosening any of them*
- *gradually slacken the nuts (by running them back along the fasteners) but do not remove them*
- *only when the fasteners are sufficiently loose to verify that the seal has been broken should the nuts be removed*
- *handle the flange and fastener components carefully to avoid damage*
- *you may need to scrape out remnants of the gasket which have stuck to the flange surfaces - in which case use an implement (such as a brass brush or brass drift) which is softer than the flange material*

These steps can save you additional challenges when you come to reassemble the joint!

Remember to consider the safety aspects. Are you or others in danger? Always double check and ask yourself:

- *what if the flange is still under pressure?*
- *what if there is still gas or fluid in the line?*
- *what if the piping springs up on release?*
- *what if the load swings in my direction?*

If you have difficulty releasing the joint, caused by galling of nuts and fasteners, there are a number of approaches which have been used (although not all of them may be successful!):

- *use a nut-splitter, or, less desirably*
- *use iodine solution as a penetrating solution (although be sure to clean it off afterwards)*
- *use other mild acids as a penetrating solution (again, be sure to clean them off afterwards)*
- *heating or cooling the fastener may free it*
- *weld a nut to the end of the stud and use this as a “head” to get a good grip on the fastener*
- *if all else fails, saw off the fasteners or drill them out (although take care to minimise damage to the flange)*

7.1. Release compounds

After time under load at elevated temperatures and pressures, there is a tendency for gasket materials to become embedded in the flange, as a result of surface interactions between the gasket and the flange materials. It is often difficult to remove the gasket from the flange on opening, or sometimes the gasket disintegrates and pieces stick to both flange mating surfaces. In an effort to overcome this, various ‘jointing’ compounds have been offered for use on the gasket faces.

However, these jointing compounds have some serious disadvantages:

- *a jointing compound placed between the surfaces of the flange and gasket will effectively “lubricate” the joint, and so allow easy extrusion of a soft gasket under operating conditions*
- *a jointing compound may not be compatible with the gasket material - it may reduce substantially the performance and lifetime of the seal or cause corrosion of the flanges or fasteners*

For these reasons, jointing compounds must not be used! A much better option for ease of removal is to use a *soft* gasket material which has been given an anti-stick coating by the sheet manufacturer. These ensure full compatibility with the gasket material and minimal lubricity of the joint. Alternatively, use a gasket which is inherently free from adhesion, such as a PTFE gasket

- do not use jointing compounds***
- use soft gasket materials which have an anti-stick coating applied by the manufacturer***

8. Key recommendations

A summary of the key recommendations made throughout this publication, listed according to each section. Further information may be found within each section, marked as [3]:

[3] Overview of flange / bolt / gasket system. The integrity of the seal depends upon:

- ☑ *selection of correct components appropriate for the application*
- ☑ *careful preparation, cleaning, installation and assembly*
- ☑ *correct bolt tightening and loading*

[4] Flange / gasket arrangements:

- ☑ *selection of the proper gasket material is important with regard to the flange finish*
- ☑ *never use fewer bolts than the number designed for the flange*

[4.3] When selecting fasteners (bolts or studs):

- ☑ *select fasteners with sufficient yield strength to ensure they are within their elastic limit at the required load*
- ☑ *select bolts / studs with the same modulus of elasticity*
- ☑ *ensure there is no corrosion of the fasteners*
- ☑ *do not reuse fasteners*

[4.4] When selecting nuts:

- ☑ *select nuts with a proof load 20% greater than the ultimate tensile strength of the fasteners*

[4.5] Washers:

- ☑ *always use washers*
- ☑ *use the same material for the washers and the nuts*

[5] Gasket selection:

- ☑ *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*

[5.3] Thickness selection:

- ☑ *ensure the gasket is as thin as possible*

[5.4] Cutting of gaskets:

- ☑ *use a good cutter*
- ☑ *never try to cut out a gasket by hammering material against the flange*
- ☑ *ensure the gasket is the correct size*
- ☑ *cut the bolt holes slightly larger than the bolt shaft diameter*
- ☑ *ensure that the inside diameter of the gasket is not less than the inside diameter of the process line*

[5.5] Storage of gaskets and gasket materials:

- ☑ *store in a cool, dry place, away from direct sunlight, water, oil and chemicals*
- ☑ *store sheet materials flat*
- ☑ *avoid hanging gaskets. Store gaskets flat. Large diameter spiral wound gaskets should be stored in a horizontal position*
- ☑ *gaskets should be kept clean and free from mechanical damage (ideally, store in sealed poly bags)*

[5.6] Handling of gaskets and gasket materials:

- ☑ *carry gaskets carefully, ideally with some form of protective cover*
- ☑ *do not bend or buckle*
- ☑ *do not damage the surface*
- ☑ *for large diameter metallic and semi-metallic gaskets, always transport the gasket on its mounting to the installation site*

[5.7] Reuse of gaskets / fasteners:

- do not reuse gaskets or fasteners*

[6.3] Assembly procedures, visual inspection:

- replace defective components with a good alternative. If in doubt, seek advice*

[6.4] Lubrication:

- lubricate fastener threads and all bearing surfaces (underside of bolt heads, nuts, washers)*
- use only specified or approved lubricants*
- apply the lubricant in a consistent manner as a thin, uniform coating*
- ensure lubricant does not contaminate either flange or gasket faces*
- avoid contamination of the lubricant by storing in a closed container. After use, store in a "clean" area*

[6.5] Gasket installation and centralisation:

- carefully insert the new gasket between the flanges to prevent damage to the gasket surfaces*
- for larger diameter spiral wound gaskets, seat the gasket in its mounting on the flange, remove the securing straps, then slide the gasket from its mounting onto the flange using an appropriate number of persons to avoid damage to the gasket*
- ensure the gasket is central in the flange*
- do not use tape to secure the gasket to the flange. If necessary, use a light dusting of spray adhesive*
- do not use jointing compounds or releasing agents*
- line up the joint components and examine them to ensure that an acceptable fit has been obtained*
- take care when bringing the flanges together, to ensure that the gasket is not pinched or otherwise damaged*

[6.7] Bolt tightening pattern:

- always use a torque wrench or other controlled-tensioning device (recently calibrated)*
- always torque bolts or nuts in a cross bolt tightening pattern*

[6.7] Tighten up using a minimum of 5 passes:

- Pass 1 - tighten bolts loosely by hand in the first instance, according to the cross bolting pattern, then hand-tighten evenly*
- Pass 2 - using a torque wrench, torque to a maximum of 30% of the full torque first time around, according to the cross-bolting pattern. Check that the flange is bearing uniformly on the gasket*
- Pass 3 - torque to a maximum of 60% of the full torque, according to the cross bolting pattern*
- Pass 4 - torque to the full torque, according to the cross bolting pattern*
- Pass 5 - final pass at full torque, in a clockwise direction on adjacent fasteners*

[6.9] Re-tightening:

- do not re-torque an elastomer-based asbestos-free gasket after it has been exposed to elevated temperatures*

[7.1] Disassembly procedures, release compounds:

- do not use jointing compounds*
- use soft gasket materials which have an anti-stick coating applied by the manufacturer*

9. Guidelines to minimise joint failure

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

Although this list is by no means exhaustive (further details are available in a number of publications⁵), some common failure modes follow.

9.1. Failure due to the fastener

Fasteners which are insufficiently tight provide the most common cause of joint failure, which may result from:

- *incorrect assembly*
- *fastener failure*
- *self-loosening*
- *fatigue / relaxation over time*

On the other hand, when a **fastener is too tight** (usually as a result of an over-enthusiastic fitter or mechanic during assembly!), the joint may fail because the excessive load has:

- *crushed the gasket*
- *encouraged stress corrosion cracking*
- *increased fatigue*

Fastener failure occurs when the applied load exceeds the ultimate strength of the fastener or threads, and for a variety of reasons, typically:

- *fasteners do not meet design specifications (ruptured during assembly or at elevated temperature)*
- *over-tightened during assembly*
- *corrosion*
- *stress corrosion cracking*
- *fatigue*

9.2. Failure due to the gasket

This may result from a number of causes, such as:

- *selection of incorrect gasket for the application conditions*
- *selection of incorrect gasket thickness, particularly for soft gaskets*
- *excursions outside normal operating envelope or bending moments on pipework*
- *gasket damaged in storage, handling or on installation*
- *gasket crushed by excessive load during assembly*
- *deterioration over time*
- *gasket reused*
- *re-tightening after exposure to service (elevated) temperature*

9.3 Failure due to the flange

Fairly unusual, but may result from:

- *flange surfaces damaged*
- *flanges warped*
- *flanges not parallel*
- *corrosion*
- *flanges not clean on assembly*

9.4. Minimising the chances of joint failure

From the above list of key causes of joint failure, it is obvious that the selection of the correct materials for the application is fundamental. Make sure that all components of the joint are compatible with each other and with the conditions which they will face during service. Allow an additional safety margin, just in case the application conditions move outside of the expected operating envelope (known as “excursions!”).

Follow the gasket storage and handling (and cutting recommendations, where appropriate) key recommendations throughout this publication.

Follow the cleaning and visual inspection key recommendations, to ensure that the joint components are free from defects and fit for subsequent use.

The above list also emphasises the requirement for good assembly practices. Unless the joint is put together with sufficient care, it cannot be expected to provide a safe seal. Ensure that the engineers involved are thoroughly trained in assembly procedures and briefed about the challenges they will face on site. Follow the key recommendations on installation, assembly and bolt tightening.

Corrosion is one of the most common challenges in the field! It can affect the integrity of the clamping force and will reduce the life of the joint components. It requires all four of the following conditions:

- *an anode*
- *a cathode*
- *an electrolyte*
- *an electrical connection between anode and cathode*

If any one of the conditions can be eliminated, corrosion will not occur. A solution is to keep the area dry by providing drainage holes (not always feasible) or, more commonly, by selecting fasteners manufactured from corrosion-resistant material. Most popular of all, by providing some form of protective coating on the fasteners and /or the flange.

Stress corrosion cracking (SCC) is the result of a combination of stress and electrochemical attack. Just humid air, or a dirty fingerprint, may be sufficient to initiate SCC! It is a specific form of corrosion and requires:

- *a susceptible material*
- *an electrolyte*
- *an initial flaw*
- *stress levels above a threshold*

All metallic fasteners are susceptible to SCC under certain conditions, but most of the problem can be minimised with suitable heat treatment. As with corrosion, provision of a suitable coating (aluminium, ceramics, or graphite) on the fasteners can minimise contact with the electrolyte. However, stress control is the most common way to reduce SCC, by keeping the stress level in the fasteners below a given limit (specific for the material).

Fatigue is time dependent and requires:

- *a susceptible material*
- *elevated stress levels above an endurance limit*
- *cyclic tensile stress*
- *an initial flaw*

In general, the higher the loads, the faster fatigue will set in. The item which usually has the greatest impact on reducing fatigue of the joint is the reduction of load excursions. Therefore, identify and achieve the correct preload in the fasteners. Note the differences in maximum preload between fasteners with rolled versus machined threads. Also, periodically replace the fasteners before they fail (it is advisable to keep records of how long they have lasted between failures, and then reduce the time frame somewhat to provide a reasonable safety margin). Ideally of course, always replace the fasteners when reassembling the joint!

Self-loosening is usually experienced in the presence of vibration, requiring:

- *relative motion between fastener, nut and joint components*
- *cyclic loads perpendicular to the fastener axis*

This is often countered by preventing slip between the fastener, nut and / or joint components by mechanical lock nuts or washers, or by the use of adhesives.

10. Health and safety aspects of gasket materials

A variety of fibres have been used in the production of gasket materials, asbestos being one of the earliest and most common. As experience has grown, a number of medical conditions have been ascribed to fibre exposure, including:

- *diffuse interstitial pulmonary fibrosis (such as asbestosis)*
- *malignant tumours (such as mesothelioma)*
- *benign pleural disorders (such as pleural plaques and diffuse pleural thickening)*

The adverse health effects of exposure to high airborne levels of asbestos have been well documented, which has led to the development of a wide range of restrictive legislation. Although it is apparent that health effects vary markedly amongst all the fibre types (even amongst different forms of asbestos), the health effects of many alternative natural and man-made fibres have also been studied increasingly during the last decade. In terms of European legislation on the use of asbestos, actions by certain EU Member States to limit the marketing and use of the material were followed by the adoption of several Directives, including 83/478 EEC, 85/610 EEC and 91/659 EEC. In addition, Directives 83/477 EEC and 91/382 EEC were adopted to control the use of asbestos in the workplace.

Despite these concerns above, as a result of the polymerisation and binding processes which take place during manufacture, fibre-reinforced or fibre-containing gasket materials are believed to present no health and safety hazard.

Under normal handling and use, it is unlikely that these products will give rise to significant levels of exposure to constituent materials. The fibres are encapsulated usually within an elastomeric binder (or are themselves polymerised), and as such, are unable to enter the human body as airborne dust. However, under harsh mechanical treatment (such as high speed stamping operations or abrasion), or if the product has become embrittled by high temperature service, the constituents may give rise to irritant dust, which may lead to more serious respiratory problems in extreme cases of exposure. Consequently, irrespective of the fibres involved, it is recommended that fibre-containing gasket materials should be treated with sufficient care, to avoid the production of unnecessary dust. Equally, when such a gasket is to be removed from a flange after service, always take precautions to minimise dust. In all cases, good standards of hygiene should be applied during gasket cutting operations, and off-cuts should be disposed of by transfer to a site which is licensed appropriately to accept industrial materials of this nature.

In most cases, although the reinforcing fibres and fillers are inherently flame resistant, at elevated temperatures or in a sustained fire, decomposition will occur and give rise to irritant and in some instances harmful or toxic fumes.

Materials containing asbestos

Gasket materials containing asbestos fibres may give rise to harmful dust under harsh mechanical treatment or if the product has been embrittled. Over exposure to this dust can lead to such diseases as asbestosis, lung cancer and mesothelioma. Asbestos is classified by the IARC as a Group 1 material “for which there is sufficient evidence of carcinogenicity in humans”. Occupational exposure to asbestos dust should be minimised and kept well below national exposure limits.

Materials reinforced with non-asbestos fibres

These may include aramid, carbon, cellulose, glass and man made mineral fibre (MMMF), while filler materials may include, barium sulphate, crystalline silica and kaolin. Most are flame resistant (although cellulose is flammable). Some of these fibres (usually of specific diameter) may cause irritation for those with a sensitive skin. Although the majority of these materials are considered non-hazardous, some are under suspicion or have been classified by the IARC (for example, MMMF has been classified as Class 2B material, “possibly carcinogenic to humans”). Occupational exposure to such dusts should be minimised and kept well below national exposure limits.

Materials containing graphite

Graphite is highly reactive under oxidising conditions and is combustible. At elevated temperatures, or in a sustained fire, toxic fumes may be produced. The material is conductive. Therefore, graphite dust or debris should not be allowed to penetrate electrical equipment.

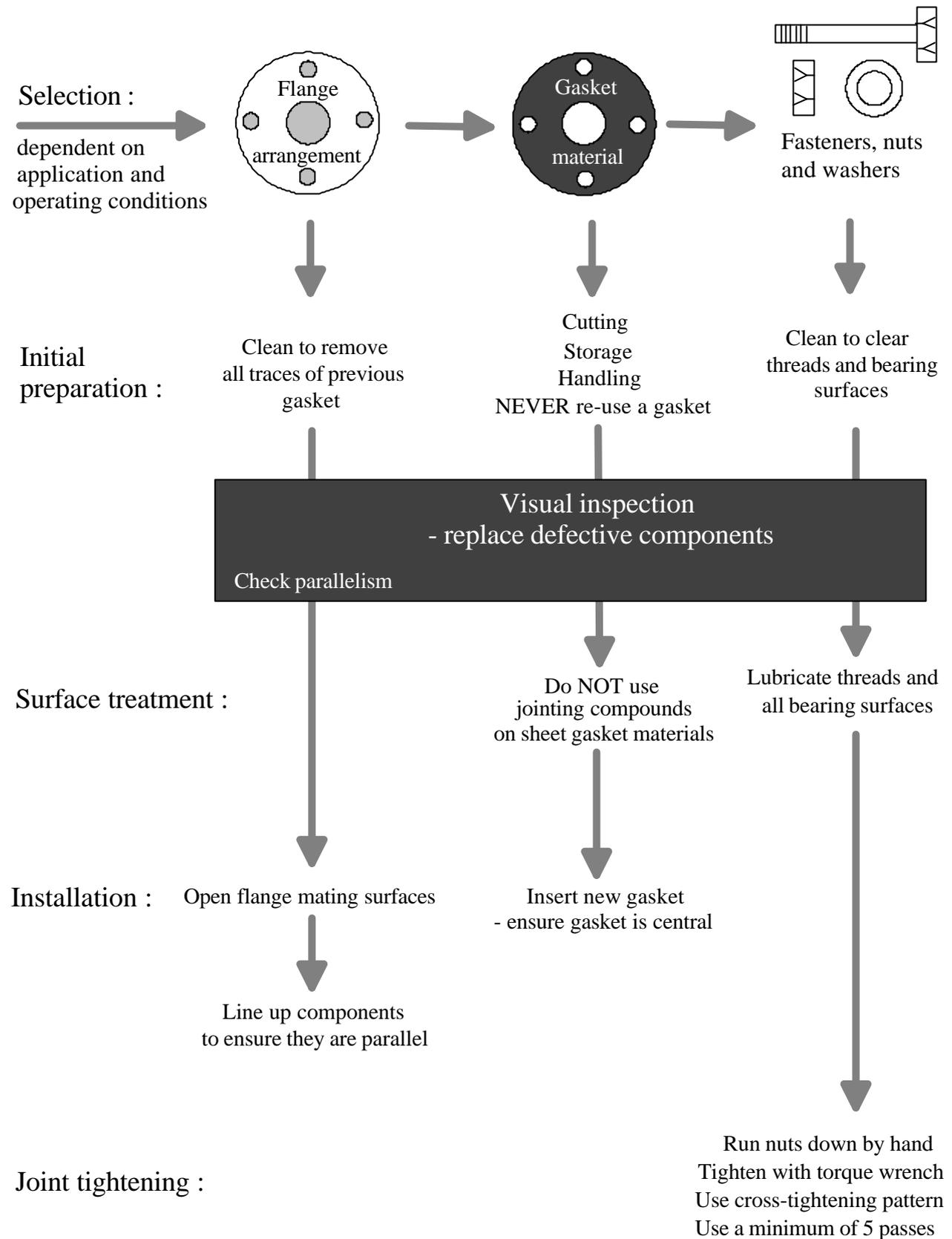
Materials containing PTFE

Although these materials are generally non-flammable, at elevated temperatures or in a sustained fire, decomposition will occur and give rise to irritant and in some instances harmful or toxic fumes.

Always check with the manufacturer for detailed advice on specific products!

11. Summary schematic

A summary of the considerations and key recommendations to produce good seal performance:



12. Overview

	<u>Flange</u>	<u>Gasket</u>	<u>Fastener</u>
Selection	Select flange arrangement suitable for the application	Select gasket appropriate for flange arrangement and application : - always use a good quality gasket from a reputable supplier - for sheet gaskets, do not use jointing compounds - for soft gaskets, select the appropriate thickness	Select fastener required to provide appropriate load on flange/gasket : - sufficient ductility - same modulus of elasticity - nuts with 20% greater proof load - always use washers
Initial preparation	Clean gasket seating surfaces to remove all traces of previous gasket : - wire brush - brass drift	Cut the gasket : - use a good cutter - ensure gasket is correct size - do not reuse gaskets	Clean the fasteners, nuts, washers : - use a wire brush to remove dirt on the threads and all bearing surfaces
Storage and handling		- store in a cool, dry place - store away from direct sunlight - store gasket flat and only remove from packing just before use - avoid hanging gaskets - do not bend or buckle - do not damage surface	
Visual inspection	Check gasket seating surfaces for defects, such as radial scores or warping	Check gasket is suitable for the application, correct size, correct thickness, and free from defects - replace defective components with a good alternative	Check the threads are free from defects, such as burrs or cracks
Lubrication		Do not use jointing compounds with sheet gaskets	Lubricate fastener threads and all bearing surfaces : - use approved lubricants - apply in a consistent, uniform manner
Installation	Open up the flange mating surfaces : - line up the components to ensure mating surfaces are parallel	Carefully insert the gasket between the flanges : - ensure gasket is central in the flange	
Joint tightening			- run down nuts by hand - use cross bolt tightening pattern - use a torque wrench - use a minimum of 5 passes

13. References

1. *USA Regulations on Fugitive Emissions* (ESA Report N° 003/94), published by the European Sealing Association, June 1994.
2. *European Emission Legislation* (ESA Report N° 004/95), published by the European Sealing Association, April 1995.
3. *Glossary of Sealing Terms, Part 1, Flanges and Gaskets* (ESA Publication N° 008/97), published by the European Sealing Association, November 1997.
4. *Seals and Sealing Handbook*, 4th Edition, edited by M. Brown, published by Elsevier Advanced Technology, 1995 (ISBN 1 85617 232 5).
5. *An Introduction to the Design and Behavior of Bolted Joints*, 3rd Edition, by John H. Bickford, published by Marcel Dekker Inc., 1995, (ISBN 0 8247 9297 1).
6. *The importance of high integrity bolted joints for engineering pipelines*, by Rod Corbett, IMechE 1993 C459/030.