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GASKET MATERIALS (NONMETALLIC)

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Gasket Materials (Nonmetallic) 26 September 1958

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1. This handbook on Gasket Materials (Nonmetallic) has been developed by the Ordnance Corps, under the direction of the Standardization Division, OASD (S&L).

2. The Department of Defense has approved this publication for printing and inclusion in the Military Handbook series of reference handbooks for use by the Departments of the Army and the Navy.

3. In accordance with established procedure, the Standardization division has designated the Ordnance Corps, the Bureau of Ordnance, and the Air Force (Wright Air Development Center), respectively, as the Army-Navy-Air Force custodians of this handbook.

4. Every effort has been made to reflect the latest information on nonmetallic gasket materials It is the intent to review this handbook periodically to ensure its completeness and accuracy Those making use of this document are encouraged to report any errors discovered and any recommendations for changes or inclusions to the Staff Director for standardization, Office of the Assistant Secretary of Defense (Supply and Logistics), Washington 25, D. C.

PREFACE

The primary objective of this handbook is to provide in condensed form information of direct usefulness to interested military personnel. Although the handbook is general only, and is not applicable to aircraft practice, the data have been selected from a large number of industrial and government publications and have been checked for suitability for use in design.

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Gasket Materials (Nonmetallic)

GASKETS IN ENGINEERING DESIGN

1. Definition of Gasket. Engineering designs often specify the use of some device between separable members of a mechanical assembly to prevent the escape of liquids, gases, or solids. Such a device may be termed a seal, a packing, or a gasket, but by common consent among engineers, designers, and manufacturers, these three terms designate particular forms of the device. A seal is the general name for any means of preventing the migration of matter across a joint or opening in a vessel or assembly. A dynamic seal, used where some form of relative motion occurs between rigid members of an assembly, is known as a packing, while a seal used where there is no relative motion between the joined parts is a gasket.

2. Classification of Gaskets. Gaskets are classified according to their function and the type of material used in their manufacture. They may be metallic or nonmetallic and used for specific or general applications. The nonmetallic gaskets are used in a wide variety of applications Metallic gaskets are usually required in specific high-pressure, high-temperature applications that demand complex technical considerations. As a result, metallic gaskets are beyond the scope of this general analysis of gaskets.

The nonmetallic, general-purpose gaskets are composed of asbestos, cork, leather, paper, rubber, and several composites and combinations. Many other materials may act as gaskets in particular applications, but such materials are excluded from this pamphlet except for a general treatment of the gasketing functions of molded rubber and plastic parts of O-rings Molded rubber and plastic parts may function as gaskets while actually satisfying other design requirements. O-rings are a form of packing that may also function as ordinary flat gaskets in many applications, and thus merit comparable treatment.

3. Characteristics. A gasket creates and maintains a tight seal between separable members of a mechanical assembly in which there is no relative motion between the joined parts When properly designed and installed, a gasket seal is economical and efficient It is superior to other forms of sealing, such as machining and grinding the faying surfaces for a perfect mating, because the gasket itself is usually inexpensive, easily replaced, and capable of withstanding complex and variable pressures. The gasket with these characteristics is an ideal seal that also prolongs the life of the parent assembly. Such an ideal seal can be obtained only by selecting the proper material and forms to satisfy basic design requirements.

4 Design Requirements. A gasket seal must withstand forces and pressures as illustrated in figure 1. In order to withstand these forces, a gasket must satisfy four basic design requirements First, a gasket must be impermeable Secondly, it must make complete contact with the joint contact faces. Thirdly, it must maintain this complete contact despite various pressures, and finally, it must be compatible with factors in its immediate environment Each of these requirements is summarized below A more detailed discussion will be found in the sections on each material, in the discussion of methods for improving the service of gasket materials (pars. 35 to 40), and in the analysis of joint and gasket designs (pars. 41 to 51).

In general, these four requirements constitute the basis for evaluating the gasket materials analyzed in this pamphlet. The selection of a material for any gasket application depends upon how well and by what means it can be made to fulfill these basic requirements.

A gasket must be impermeable in order to offer a barrier to the passage of gases or liquids that are contained in the assembly. Impermeability must be maintained under intense compression and for the service life of the gasket A material that meets other design requirements but is not impermeable may be made impermeable by certain processes

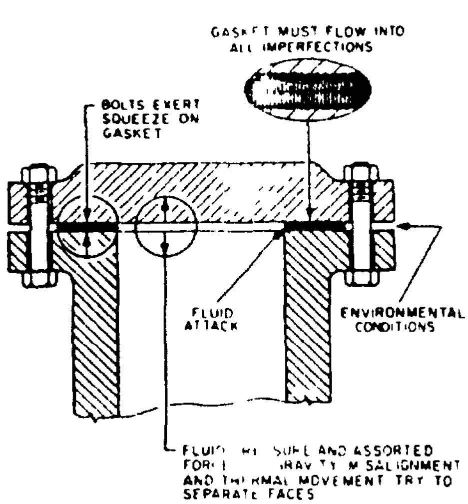


Figure 1. Forces Acting Upon a Gasket

A gasket must make complete contact with the flanges and flow into all imperfections of the joint contact faces. The extent to which a gasket will flow, and thus present an impervious seal, depends upon several factors. These include the finish of the flange face, the alignment of the contact flange faces, the relative rigidity of the joint, the degree to which the gasket is kept positioned, and the surface treatment applied to the gasket

A gasket must maintain complete contact with the flanges despite movement, temperature changes, vibration, mechanical strains, and similar pressures. The ability of the gasket to respond to these conditions and maintain complete contact depends upon factors such as the relative elasticity of the gasket material, the degree to which the gasket material swells in contact with the sealed liquids or gases, the elasticity of bolts and flanges, and the adhesion of the gasket to the flanges.

The gasket must be compatible with the characteristics of its environment The gasket material must withstand temperature changes, corrosive attack by the sealed substances, and the effects of miscellaneous hazards such as ultraviolet light, vermin, ozone, salt spray, fungi vibration, shock, and general aging. Special design requirements may be required in applications that involve wide and rapid temperature fluctuations, contaminant reaction between the gasket and the sealed material, or other unusual environmental features.

5. **Gasket Materials.** No one group of gasket materials will satisfy all the basic design requirements for a specific application. In fact, the specific applications often inspire the introduction of new material combinations or modifications of old material groups. However, nearly all gasket materials can be

grouped for analysis into one of the following categories: asbestos products, cork composition, cork-and-rubber combinations, rubber, plastic, treated and untreated papers, leather, and combination and miscellaneous gaskets. The general properties and uses of these gasket materials are summarized in table 1. A discussion of their characteristics, properties, limitations, and applications can be found in the section dealing with the particular material. For the most part, these discussions only summarize and highlight the important considerations. The appropriate specifications should be consulted for more precise data on particular forms.

ASBESTOS GASKETS

6. **Characteristics.** Asbestos fibers have certain characteristics that make them valuable as gasketing materials. They are resistant to the effects of high temperatures, possess dimensional stability, effectively withstand shear and compression, and easily combine with other materials. A general discussion of these characteristics is presented below. Subsequent paragraphs similarly treat the composition, properties and limitations for gasketing, and major gasket applications of asbestos.

Asbestos fibers retain most of their inherent strength at temperatures up to about 750 deg. F. Above that temperature they tend to lose their water of crystallization; this loss is instantaneous at 1300 deg. F. When the water of crystallization is driven from asbestos, slight rubbing will reduce the material to a powder. In actual application, however, asbestos is rarely used alone or in its pure form. Therefore, the heat resistance of asbestos materials also depends upon the heat resistance of the constituents in the composition.

Asbestos and asbestos-composition gaskets have excellent resistance to the pressure of heavy loads and the cutting action of narrow, sharp-edged flanges.

Asbestos materials are, for the most part, unaffected by changes in humidity. As a result, they maintain their original size and shape regardless of variations in the amount of moisture present in the atmosphere.

Pure asbestos products are porous and weak, and therefore, are almost always combined with other substances Asbestos fibers may be combined with cellulose or metallic fibers for added strength; they may be joined with binders and saturants for greater imperviousness; or they may be added as a filler to rubber and plastic compounds.

7. **Principal Compositions.** The two types of asbestos fibers from which asbestos gasket materials are made are chrysotile and crocidolite Crocidolite is more commonly known as blue asbestos and is a sodium-iron-silicate complex It is used chiefly for the manufacture of acid resistant gaskets Chrysotile is common white asbestos, a mineral consisting primarily of magnesium silicate combined with approximately 14 percent water of crystallization. It is resistant to weak acids and most alkali solutions, but is susceptible to the action of strong acids

Resistance to corrosive agents may be increased by combining these two fiber types with binders such as rubber. The characteristics of the particular binder and of the asbestos will determine the properties of the resulting composition The most common type of asbestos combination is the asbestos-rubber composition. It is considered the principal asbestos material, although woven or braided asbestos and mill board or paper are also used. Each of these three groups of asbestos materials is analyzed in the following paragraphs.

The rubber-asbestos compositions include "compressed asbestos" and several other forms of asbestos sheeting or composition with similar characteristics and applicability. Of the three groups of asbestos materials, this group is produced in greatest quantity and has the widest range of use. Rubber-asbestos sheets vary according to the formula and process of manufacture; and some forms are pigmented while others are given some external after-treatment. The type known as "compressed asbestos" is made by calendering a dough of asbestos

TABLE 1. GENERAL PROPERTIES AND USES OF GASKET MATERIALS

Classification	Special Characteristics	General Uses
Asbestos, Compressed	Tough and durable Dimensionally stable Relatively incompressible Good steam and hot water resistance Oil and solvent resistance determined by characteristics of rubber binder	For heavy duty bolted and threaded joints, as in water and steam pipe fittings, manifold connections Temperatures to 500°F
Cork-and-Rubber	Provides fluid barrier and resilience of rubber with compressibility of cork Properties of flow versus compression subject to controlled variation according to proportions of cork and rubber Some sacrifice of rubber's tensile and elongation properties Chemical properties about same as base polymers Higher in cost than cork composition or fiber types, but lower than straight rubbers Does not extrude from joint Die cuts easily High coefficient of friction	For general-purpose gasketing, except steam lines, combustion chambers, etc Enables design of metal-to-metal joints with gasket positioned in channel or counter-bore and with no allowance for flow High friction keeps gasket positioned even where closing pressure is not perpendicular to flange faces
Cork Composition	Versatile, dependable general-purpose material Variable as to binder, texture and hardness (density) Truly compressible High friction whether dry, wet or oily Low cost Excellent oil and solvent resistance Poor resistance to alkalies and corrosive acids	For mating rough or irregular parts, as glass, light stampings, unfinished castings Oil sealing at lowest cost in normal range of temperatures and pressures
Rubber and Plastic	Highly variable according to compounding, hardness, modulus, fabric reinforcement, etc Generally impervious, but entirely incompressible	For installations involving stretching over projections, or where flow of gasket into threads or recesses is desired For lowest compression-set and maximum resistance to fluids such as alkalies, hot water and certain acids. Ability to be molded permits use for special design and assembly conditions
Paper, Untreated	Low in cost, may induce corrosion	Spacers, dust barriers, splash seals, where breathing and wicking not objectionable
Paper, Treated	General-purpose material having better tensile strength than cork composition, but less compressibility Good oil, gasoline and water resistance, but alternate wet and dry cycles may cause shrinkage and hardening of some types	For machined or reasonably uniform flanges where adequate bolt pressures can be applied Relative firmness and high tensile strength permit use of thin gaskets to give good alignments of covers and connected parts
Leather	Tough, porous, abrasion resistant, flexible at extreme low temperatures Tanning and impregnation are important variables Can be molded to simple shapes — cups, V's, U's	Widely used in dynamic packing applications and as back-up for rubber O-Rings in high pressure joints Avoid steam, acids, alkalies
Combination Constructions	Innumerable modifications available, depending on materials used and methods of combining	Usually employed for extreme conditions and special purposes.

Data, courtesy *Product Engineering*

fibers and rubber cement. It has a pronounced grain and usually contains clumps of undispersed asbestos fibers. It is hard, tough, unyielding, and dimensionally stable.

Composition of rubber and asbestos may be made by several other methods, including latex treatment of asbestos paper or impregnation of asbestos felt with a rubber solution. These forms are not as hard as the compressed asbestos, but they are more resilient. The rubber latex, beater solution treatment is a recently developed process that produces a more homogeneous, nondirectional material with greater flexibility and resilience. Natural rubber and synthetic rubbers are also used to make certain compositions. Asbestos materials made with natural or SBR rubber are not oil-resistant, but neoprene and nitrile compositions are, especially the nitrile compositions which are extremely resistant to oil and aromatic fuel. The rubber binder constitutes 10 to 25 percent of the total weight in typical compositions.

Woven and braided asbestos are softer than compressed sheets and are often saturated by special treatments. They may be processed into cloth, spun into yarn, or braided into various rope-like forms. The asbestos yarn may be reinforced with metallic wire or strands for added strength without the sacrifice of high temperature resistance. Heat resistance is lowered, however, in forms reinforced with cotton. Braided forms are frequently impregnated with a lubricant and graphite treatment, while woven asbestos fabrics may be frictioned with rubber or saturated with latex or resin. Both the blue and white asbestos fibers are used for these forms, although the blue asbestos is generally used for applications that require acid resistance.

The millboard and paper materials are relatively pure forms of asbestos fiber, bonded perhaps with starch or sulphites. They do not have a wide range of applicability and are not as important as the other forms of asbestos materials

8. Properties and Limitations. In comparison with other gasketing materials, asbestos products have properties and limitations that classify them as midway between the soft gasketing materials and the metallic or hard nonmetallic types. The asbestos products used for gaskets are primarily compressed asbestos and the rubber-asbestos materials grouped with it. For purposes of a general analysis, the properties and limitations of these asbestos materials can be evaluated by indicating how well these products fulfill the basic requirements of gasket design. Thus, the following discussion will briefly analyze the impermeability of asbestos, its ability to make complete contact with the flanges, and to maintain this contact despite various pressures, forces, and environmental factors.

The impermeability of asbestos is limited. The characteristic clumps of undispersed fibers in compressed asbestos may offer some conduction to the sealed liquids unless bolting pressures are high and there is sufficient compacting force to compress the material into impermeability.

To achieve complete contact with the flange faces the asbestos gasket must be subjected to a heavy load. There is a threshold pressure that is necessary to achieve complete seating and ensure contact even under very light or atmospheric pressures. This threshold pressure averages about 1500 psi, with variations according to the type of rubber-asbestos used, and the flange finish, rigidity and bolt spacing.

Complete contact between gasket and flange can be maintained by proper application rather than as a result of the characteristics of the material. Compressed asbestos has little elasticity and does not follow flange movement The material is relatively incompressible and forms a solid inert filler between the flanges. Moreover, the gasket becomes almost as unyielding as the metal assembly components after the flange bolts have been tightened to the point where the gasket is well seated and conforms to the irregularities of finish and alignment in the joint. Continuing tightening of the bolts causes them to stretch; it is the elasticity of these stressed bolts that provides the force that maintains the tight contact. However, over a period of time, and especially in applications where high temperatures are encountered, creep will occur within the structure of the gasket and the bolts. This creep will produce a reaction known as stress relaxation, cold flow, or stress decay; the bolts become loose and must be tightened to maintain the seal If the joint is not separated during operation, it is best to permit the gasket to adhere to the flanges and thus prevent leakage in the seal. For applications where adherence is undesirable, compressed asbestos can be treated with graphite as a preventive measure (See paragraph 40.)

Compatability between the gasket and its environment depends upon the type of asbestos composition and the particular application. For example, chemical properties are determined by the rubber used in the composition while heat resistance is governed by the temperature range in the application. When certain rubbers are combined into rubber-asbestos, the resulting composition is resistant to the effects of petroleum products In general, rubber-asbestos is unaffected by most common industrial chemicals such as alcohol, glycerine, alkalines, caustic solutions, and weak acids It may also be used satisfactorily in high or low-pressure water joints. But, in chemical processing and similar uses, the application must be carefully studied to ensure that the asbestos does not come into contact with any substance capable of attacking it, such as nitric acid A careful examination of the application is also necessary for requirements that involve high temperatures. While asbestos may be used at temperatures of 500 deg. F., the design engineer is cautioned to consider the effects of continued exposure on the expected performance and service life of the gasket. Asbestos is not recommended for applications where temperatures continually exceed 500 degs. F.

9. Application. From the discussion of properties and limitations it is evident that compressed rubber-asbestos gaskets are best used in heavy, rugged construction employing flat, rigid flanges, adequate bolting pressures, a minimum of machining irregularities, and where temperatures do not exceed 500 deg. F. General pipe-flange applications such as found in oil refineries and chemical processing plants meet these requirements and, therefore, utilize rubber-asbestos gaskets. Other applications that specify resistance to particular chemicals require the appropriate rubber-asbestos composition. For certain applications woven and braided asbestos or millboard and paper may be preferred Their uses are discussed below. The appropriate specification should be consulted for more precise data.

Woven and braided materials are used for packing in stuffing boxes on reciprocating and rotating assemblies to prevent leakage of oil, water, steam, etc. For these purposes they may be in the form of coils or split-wall rings. Woven fabrics may be die cut to various sizes and shapes, or rubber-treated, then folded and pressed to make rings, ovals, squares, and other shapes required for applications such as tube plates in boilers. In tape form it may be used for gasketing in steam cylinder heads, heater doors, and other power-plant applications. As continuous-length tubing, asbestos fabric gaskets are used for steam service, hand holes, man holes, heater doors, and similar applications. Many of the forms of woven and braided asbestos that are described above are custom made by manufacturers for their equipment, and are therefore not available except as replacement parts. However, because the feasibility of these forms has been demonstrated, they should be considered if they satisfy design requirements more fully than the common factory assembled, mass-produced products.

In gasket manufacturing, millboard and paper are used principally as soft fillers for metal jacketed or other reinforced constructions. Automobile cylinder head gaskets are one of the most important and best known uses for these materials.

10. Determinants for Gasket Selection. There are several factors that must be considered in evaluating asbestos gaskets for specific requirements. Those factors that govern the choice of gasket material include particular requirements, comparative costs, and the availability of the desired form. The foregoing paragraphs on properties and limitations and applications indicate the design requirements that can be satisfied through the use of asbestos materials. When other gasket materials also satisfy the design requirements, the choice may be governed by advantages of one material over the other, as well as availability and cost. The following discussion analyzes these factors.

In certain applications asbestos products may be more advantageous than other materials that appear to do the job better. For instance, in some cases, plant fibers or other softer materials may seal more effectively and at lower flange pressures than asbestos materials But, if there are conditions that would cause shrinkage or drying out of the other materials, the rubber-asbestos is actually the more efficient and economical choice. Similarly, where there are acidic or alkaline conditions the asbestos fibers are more resistant than materials such as cellulose fibers On the other hand, some of the newer types of plant fiber gaskets with non-extractable saturants may replace asbestos in many low-pressure, low-temperature applications that require mainly dimensional stability and long service life.

Rubber-asbestos materials are available in sheets, rolls, or die-cut parts. The sheets range in size from 40 by 40 inches to 150 by 150 inches. Continuous roll products are available in standard packages that are at least 24 inches wide and up to 50 yards square. Thicknesses range from a minimum of 1/64 inch to the practical limitations set by design requirements and manufacturing methods. Gaskets are seldom thicker than 1/4 inch.

Rubber-asbestos composition sheets are available in various grades with an equally wide range in cost. They may be obtained by the pound or by the square yard It is, therefore, essential to have a basis for converting weight to area in order to compare various products.

In comparison with other gasket materials, the average grade of rubber-asbestos is more expensive than cork composition or vegetable fiber, but generally less expensive than synthetic rubbers, resins, or plastics. Fabrication costs and over-all size are important cost considerations.

CORK GASKETS

11. Characteristics. Cork structure is fibrous and noncapillary; the cells contain air and are surrounded by a membrane of cellulose cemented together by a natural resin Cork is a lightweight material that does not deteriorate with age. It is chemically inert and has a high coefficient of friction The application of pressure merely compresses the air within the corks cells and any resulting deformation is almost entirely in the direction of the applied pressure. Natural, unprocessed cork, however, is highly variable in texture, quality and size. In order to take advantage of its properties, it is best used in combination with other materials, as in cork-and-rubber compounds (pars. 15 to 18) or in the form of compositions which are briefly described, analyzed, and evaluated in the following paragraphs.

12. Cork Composition Characteristics. Cork compositions are made by combining granulated cork with a suitable binder under considerable heat and pressure. The resulting compositions combine softness, resistance to liquid penetration, and compressibility. Cork compositions vary in color from light tan to buff and in degree of homogeneity. Many compositions are essentially little more than a mass of granules cemented together by a binder, but there are grades made with finely granulated cork that appear quite homogeneous. The principal factors which determine the types and grades of cork composition are granule size, binder, and density. Each of these, and their effects, is discussed below. These cork compositions should not be confused with corkboard, a darker, lightweight boardy material used for low-temperature insulation and generally unsuited for gasket application Natural resins are the only binding agents used in corkboard while cork compositions are compounded with added binders and varying granule sizes.

Granule size has little effect on composition properties, but uniformity of size is important for obtaining consistent compositions Manufacturers, therefore, vary screen limits to obtain maximum yields of particular particle sizes from the grinding operation.

The proportion of cork to binder in typical cork gasket compositions is approximately 70/30 by weight. Binders are generally plasticized protein (glue-glycerine) or resin. Rubber cements and latices are sometimes applied, but the protein and resin types are the most widely used, because of their particular characteristics. The protein binder materials retain their flexibility, compression tendencies, and dimensions over a long period of time; the resin binders add the advantages of resistance to fungus, acids, and weather exposure.

The desired density is acquired after the material is set to the size to which it has been compressed. Other characteristics are determined as a result of the density Weight per cubic foot is determined by the amount of loose mixture of cork and binder that is compressed within a given mold size. Tensile strength varies directly with density while compressibility varies inversely The densities of cork gasket compositions usually range from 14 to 30 pounds per cubic foot, although densities as low as 10 pounds per cubic foot or as high as 40 pounds per cubic foot have been developed.

13. **Properties and Limitations.** The properties and limitations of cork compositions vary according to the type and grade of composition. There are so many types and grades that a discussion of their properties and limitations can be only a general guide. To make this guide a useful evaluation, the properties and limitations will be discussed by indicating how well cork compositions fulfill the basic requirements of gasket design The brief exposition below indicates the impermeability of cork compositions, their ability to make contact with the flanges, and to maintain this contact despite various pressures and environmental features.

The impermeability of cork composition depends upon the application In sealing assemblies against liquids it can withstand moderate pressure. But, when the cork composition is dry it may be slightly permeable to air or gases, due to minute interstices between granules which have not been entirely closed by the forming or flange pressures.

Complete contact with flange surfaces can be effectively achieved with cork composition. Cork is soft and conforming; and yet there is little if any side flow when compressed.

Contact with the flanges can be maintained because cork is a very resilient material that keeps pushing back against the applied pressure. This pushing action is strengthened by the swelling of the sealing edge of the cork gasket, caused by contact with contained liquids. This tendency to swell when wet is actually a release of the forces of compression created at the time the granules were originally compacted to form the composition. Cork composition should not be continually used at temperatures of 160 deg. F. or higher, because a condition of permanent set may result. As a rule, though, the material remains resilient and capable of functioning as a gasket.

Cork composition should not be used for certain applications It should not be used where temperatures exceed 160 deg. F. nor at sub-zero temperatures where the material becomes hard and unyielding. (The effects of exposure, however, do not permanently impair the material.) Cork should not be used in applications where there is sustained contact with water because the plasticizers may become extracted as a result In addition, alternate cycles of wetting and drying produce shrinkage and hardening. Cork compositions may induce corrosion when used with aluminum and magnesium alloys because of inherent acidity and contained moisture. It may also, to some extent produce the same effect in contact with some stainless steels.

Cork composition is unaffected by oils and aromatic solvents. Fungus resistance is good if the composition is made with a phenolic resin binder, but poor if the composition is made with a protein binder. Fungus protection can be provided by external treatment of the finished parts. (See paragraph 40.)

14. Application. The properties of cork composition make it a valuable gasketing material for mass production use in applications that involve the mating of irregular surfaces with moderate temperatures and low internal pressures. Cork gaskets are useful in any application involving widely spaced bolts and light construction where bowing is inevitable. Cork is also used in assemblies where glass or ceramic parts are joined to metal. The tolerances are wide in such assemblies and the cork serves as a shock-absorbent cushion for the glass and ceramic components.

Cork composition is available in many forms at a relatively low cost It is available in sheets ranging in size from 6 to 12 square feet for forming and fabricating. Cork composition can be economically molded into only the simplest of forms. The most common method for producing cork composition gaskets is by die cutting, usually using simple wood-backed steel rule dies. Shapes that can not be formed or die cut have been produced by combinations of machine finishing operations that include sawing, slicing, sanding, grinding, boring, and drilling.

Cork composition is the most inexpensive of the efficient, soft gasketing materials Plain paper and rag felt may cost less, but they do not have the range of applicability For some applications, however, density and fabrication cost are key factors that determine the choice of material. For example, rubber or cork-and-rubber tubing sliced into rings may be more economical than rings fabricated from cork sheets. It is rarely practical to use cork composition for applications where thickness requirements are less than 1/16 inch In such applications it may be economical to use the more expensive fiber gaskets with a thickness of 1/32 inch For the available forms, consult the appropriate specifications.

CORK-AND-RUBBER GASKETS

15. Characteristics of Cork and Rubber Combinations. Cork-and-rubber gasket materials are composed of cork and vulcanized compounds of natural or synthetic rubbers and conventional rubber compounding ingredients. Cork and rubber are materials of very different attributes. Cork is compressible; the application of a load causes a reduction in volume with negligible flow. Its response to pressure is pneumatic, and its service life under such applications is excellent Rubber, on the other hand, is incompressible, and hydraulic in its response to applied pressure By combining the two materials, it is possible to obtain a product which has many of the best features of both. For example, compressibility and flow characteristics can be controlled, and combinations can be produced which are nearly as compressible as cork or as incompressible as rubber. See figure 2. The variation in these and other characteristics is largely determined by the proportion of granulated cork to rubber, the size of the cork granules, and the type of rubber used. The effect of these factors on the cork-and-rubber compositions are discussed below. Subsequent paragraphs further analyze cork-and-rubber by indicating the gasketing properties and limitations of these materials and the general considerations in their application.

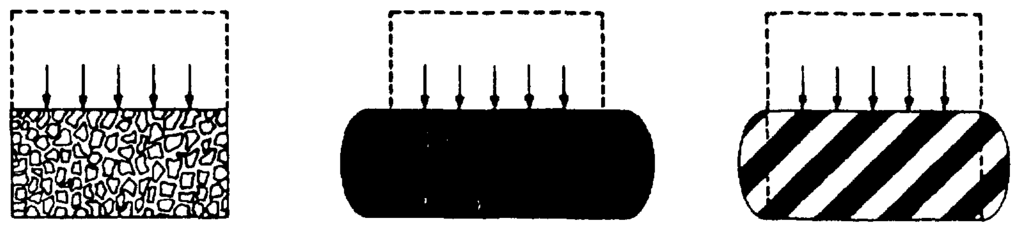


Figure 2 Comparative Compressibility of Cork, Rubber, and Cork-and-Rubber

Cork-and-rubber materials are usually mottled, with the mottling being fine or coarse, and subdued or pronounced, depending upon the proportion, type and granule size of the cork used. The high friction properties of cork and its inertness and resistance to swell can be controlled in cork-and-rubber materials by proper combinations. The appropriate composition may also derive from cork a resistance to the effects of petroleum products and a long service life In most cork-and-rubber combinations, the rubber is the continuous phase of the composition while the cork acts as a filler. In some compositions, however, the proportion of cork is at least equal to that of rubber (by weight). Compositions range in color from neutral to pigmented, with many variations caused by the use of carbon black and other fillers and ingredients that may affect appearance.

The synthetic rubbers most commonly used in cork-and-rubber materials are SBR, neoprene, and nitrile. The choice of rubber usually determines the chemical properties of the compound, but in all such compositions, the physical property of compressibility or controlled flow is retained. Because cork is impaired by high temperatures, it is usually combined with those rubbers that can be cured at moderate vulcanizing temperatures

.16. **Properties and Limitations.** The numerous cork-rubber compounds that can be produced make it difficult to specify properties and limitations, since these characteristics will vary with each composition. For purposes of a general analysis, however, the properties and limitations of cork-and-rubber compositions can be evaluated by indicating how well these materials fulfill the basic requirements of gasket design. The following paragraphs examine the impermeability of cork-and-rubber gaskets, their ability to make complete contact with the flange surfaces, and to maintain this contact despite various pressures, forces, and environmental conditions.

Cork-and-rubber materials are impervious to gases and liquids inasmuch as the rubber binder functions as the continuous phase in most of the compositions. Some porosity may be unavoidable in applications that require a thin, delicate cross-section, but otherwise cork-and-rubber is inherently impervious and does not require added treatment to induce this property.

Complete contact between gasket and flange can be easily achieved with cork-and-rubber materials; virtually no pressure is necessary to promote the contact. This material compresses easily and, under light pressure, flows effectively into irregularities.

Complete contact with the flanges can usually be maintained with little difficulty because of the elastic and frictional properties of cork-and-rubber compositions. The material does not flow or extrude appreciably and the cork granules exposed at the surface resist sliding on the flange. Therefore, a cork-and-rubber gasket maintains its position in a joint even when oil or other lubricant is present. The material has great elasticity at normal temperatures, but some compression set will occur at elevated temperatures and under prolonged pressures. Over a period of time cork-and-rubber gaskets usually adhere to metal flanges and thus increase the life of the seal.

Compatibility between the gasket and its environment depends upon the particular composition and the application. For example, chemical properties and temperature resistance are two properties determined by interrelated factors of composition and usage. Generally, chemical properties vary with the type of rubber used in the compound, but the presence of cork produces certain chemical reactions that determine the suitability of particular applications. Cork in the composition prevents the use of the material in strongly alkaline or acidic solutions but permits the use of the material where resistance is required against the effects of petroleum products and other solvents. Cork-and-rubber materials will swell somewhat in contact with liquids, but this reaction is usually not an indication of deterioration. Rather, it is the mechanical release of forces of compression in the cork originally created during manufacture. (See paragraph 13.)

Cork-and-rubber, like most organic gasket materials, is best used at temperatures below 160 deg. F. Some compositions may function satisfactorily at temperatures of 250 deg. F.; and other materials compounded with the new synthetic rubbers of the polyacrylic esters type may be used at temperatures as high as 300 deg. F.

17. Application. In general, cork-and-rubber can fulfill most of the requirements usually associated with rubber, provided the high distensibility of straight rubber is not necessary and alkaline conditions are not present. As a substitute for rubber, it is a more economical choice. Cork-and-rubber can outperform cork composition, but in this case it is a more expensive substitute. The role of comparative cost in the selection of cork-and-rubber for certain applications is important, and is discussed in paragraph 18. Several representative forms indicate its range of usefulness. These forms involve cork-and-rubber in metal-to-metal joints, for joining light or fragile members, for joining heavy, irregular members, and in joints that require fuel and solvent resistance. The appropriate specifications cover the particular compounds available for Ordnance applications.

It is often necessary to design metal-to-metal joints in order to preserve close tolerances and alignment of internal parts, and also to avoid heavy pressure on the gasket. This type of design usually specifies that a groove be made in one flange surface to contain the gasket. Cork-and-rubber is excellent for this type of flange design and does not require allowance for side flow. Figure 3 illustrates several variations of this basic design.

In joining light or fragile members it is often necessary to compensate for comparatively wide tolerances and irregularities, and to provide more of a cushioning effect than a seal. An automotive tail light is an example of this type of design requirement: it involves the gasketing of a joint between a glass or plastic lens and a metal stamping that forms the reflector or housing for the entire unit. The cork-and-rubber material used in this application is chemically blown for extra softness. Soft cellular rubber alone can be used for this type of gasket, but the cork-and-rubber gasket is usually more rigid and easier to handle for rapid assembly.

Electrical transformer cover and bushing gaskets are an example of a heavy-duty application requiring long service life The construction is rugged and massive and tolerances are wide Cork and neoprene composition gaskets are used for this type of application because they resist the effects of both external atmospheric conditions and internal insulating oils. These gaskets are often cemented in place to take advantage of the enduring tight seal resulting when the gasket adheres to the flanges

Flanges on joints connecting to fuel cells require gaskets with a resistance to the effects of fuel and solvent A cork and nitrile composition is the standard material for this service.

18. Availability and Cost. Cork-and-rubber is available in many forms and can be formed and fabricated with little difficulty. It is generally furnished as sheets split from blocks that are usually 36 inches square. It is available in thicknesses from 1/32 inch to 1/2 inch or more Various styles of ribbon and tape are available, including a variety that is chemically blown and has a pressure sensitive adhesive applied to its fabric reinforcing back Cork-and-rubber materials can be extruded to a limited extent, usually in the form of tubing. Many sizes and shapes can be molded, but the characteristic properties of the compositions are best preserved by die-cutting or machine-shaping the material; these two methods are the most commonly used fabricating processes.

The fabrication cost and the particular composition are the major factors in cost variations. The cost range is as wide as the range of possible cork-rubber proportions and the types of cork and rubber used. For example, a composition of reclaimed rubber and cork will cost less than a specification material made with one of the expensive rubbers Cork-and-rubber is generally more expensive than cork composition and vegetable-fiber sheet packings but less costly than the higher-grade rubber-asbestos compositions. Cork-and-rubber is generally not as expensive as high quality rubber sheets made of the same polymer.

Fabrication factors may affect cost comparisons with other materials Where the parts involved are simple rings, they may be produced at a lower cost from sliced cork-and-rubber tubes than from die cut cork or vegetable fiber sheets Cork-and-rubber gaskets may be less expensive than rubber gaskets if they are specified in quantity; cork-and-rubber can be die cut and machine finished in large quantity with greater economy than the same number of gaskets molded from rubber. The problem for the design engineer is to select the material that will best perform the job at low cost

RUBBER GASKETS

19. Characteristics. The term "rubber" covers many natural and synthetic rubbers, each of which can be compounded into numerous varieties. The characteristics of these varieties have an equally wide range. However, for analytical purposes, the general properties and special characteristics of natural rubber and the major synthetics can be summarized. Table 2 presents such a summary, evaluating natural and synthetic rubbers for gasketing. It is evident from the table that with the exception of a few basic similarities, these polymers have diverse properties and limitations, and, therefore, requirements for specific applications should be carefully studied. In order to obtain the correct elastomer, the design engineer is urged to consult the appropriate specifications. For a comparison with other gasketing materials, the essential characteristics of rubber can be described briefly and generally by two broad statements: rubber is incompressible; and it is extensible. These statements are elaborated upon in the following discussion.

Rubber is incompressible: it can be deformed with relative ease (depending upon hardness and cross section) but it can not to be reduced in volume. Therefore, space must be provided for the flow or deformation. The rubber must be so confined as to control the amount of deformation or flow that results from the application of pressure

TABLE 2. GENERAL PROPERTIES OF NATURAL AND SYNTHETIC RUBBERS

	Natural Rubber[a]	SBR	Nitrile[b]		Neoprene[c]	Butyl[e]	Thiokol[f]	Silicone[g]	Poly-acrylates
			Low Swell	Hi Swell					
Specific Gravity Pure Gum	0 92	0 94	0 98	0 98	1 23	0.92	1 34	0 98	1 1
Tensile Strength, psi Pure Gum	3000	400	600	600	3500	3000	300	200-450	—
Black Reinforced	4500	3000	3500	3500	3500	3000	1500	—	2500
Elongation, percent	700	500	600	600	600	700	400	300	500
Tear Resistance	G	P-F	F	F	G	G	P-F	P	F
Aging Resistance to Ozone	F	P	P	P	E	E	E	E	VG
Oxidation	P-G	P-G	P-G	P-G	G-E	G-E	G-E	E	VG
Heat	F-G	F-G	G	G	VG	G	P	E	E
Shelf Life	G	G	G	G	VG	E	G	E	VG
Compression Set Resistance	G	G	VG	VG	d	P-G	P	E	P-G
Oil Resistance Low Aniline Oils	P	P	E	G	F	P	E	P	E
High Aniline Oils	P	P	G	E	G	P	E	G	E
Gasoline Resistance Aromatic	P	P	P	G	P	P	E	P	E
Nonaromatic	P	P	F	E	G	P	E	P	E
Acid Resistance Dilute (Under 10%)	G	G	G	G	G	E	F	F	F
Concentrated (Except Nitric and Sulfuric Acids	F-G	F-G	G	G	F	E	F	P	F
Alkali Resistance Dilute (Under 10%)	G	G	G	G	G	G	P	F	P
Concentrated	F	F	F	F	G	G	P	P	P
High Temperature Resistance (200°F or more)	F	G	G	G	G	G	F-G	E	E
Low Temperature Resistance (−67°F)	G	G	F	F	F	G	F	E	P
Impermeability to Gases	F	F	F	F	G	E	G	G	G
Water Resistance	G	VG	VG	VG	F	G	F	F	P

Note E = Excellent, VG = Very Good, G = Good, F = Fair, P = Poor

[a] Swells in contact with turpentine, carbon bisulfide, chloroform, carbon tetrachloride, and vegetable oils White glycerine, ethylene glycol, and water produce negligible swell. Functions best at temperatures under 160 deg F, but can tolerate intermittent exposures to 250 deg. F.

[b] Resists swelling action of petroleum oils, fuels, and solvents Usually will not adhere to metal flanges

[c] Includes types GN and W.

[d] Resistance of type GN is fair, of type W, good

[e] Excellent resistance to vegetable oils, dilute organic acids, and alkalis Poor solvent resistance Poor compression set properties

[f] Includes types PR-1 and ST Excellent solvent resistance.

[g] Excellent dielectric properties, high and low temperature resistance, and resistance to tendencies to adhere at high temperatures Good resistance to oxidation, weathering, high aniline point oils. Poor resistance to low aniline point oils, aromatic and nonaromatic gasolines. Low abrasion resistance Deteriorates in contact with steam under pressure

Rubber is extensible: except for certain plastics, rubber can be used for more applications that require extensibility than any other material Just as the property of incompressibility provides problems, extensibility also requires design and assembly controls For example, rubber may be used for a gasket that is designed to extend over a shoulder or projection and snap tight within a groove, but the rubber may overstretch and fail to return to its original or planned size.

20. Properties and Limitations. The preceding paragraphs and table 2 briefly point out the great range of properties found in the materials classed under the term rubber. Even the natural and synthetic rubbers evaluated for gasket applications have varying properties and limitations However, for purposes of a comparative survey study, there are certain properties and limitations that should be examined These properties and limitations can be best examined by indicating how well rubber satisfies the basic gasket design requirements Accordingly, the following paragraphs discuss the impermeability of rubber, and its ability to make complete contact with the flanges and to maintain this contact despite pressures, forces, and environmental conditions

Rubber is impermeable· all types of rubber will form a barrier against the passage of gases or liquids Neoprene and butyl rubber are outstanding in this respect, but the other types of natural and synthetic rubbers are adequately impermeable for gasketing applications and require no supplementary measures to improve impermeability

Complete contact between flange and gasket can be easily achieved with rubber gaskets The material conforms, flows, and equalizes easily as it adjusts to the irregularities of the flange surface; very little flange pressure is required to seat a rubber gasket. The hardness of the particular type of rubber determines the amount of pressure required and the conformability of the gasket. The rubbers that have a hardness of no more than 80 Shore A are easiest to use for gasket requirements. Those rubbers with a hardness over 80 Shore A require a contact pressure comparable to the pressures necessary for gaskets of asbestos composition sheets. (See paragraphs 7 to 9) On the other hand, a soft rubber compound that conforms more easily than a medium or hard type may present other problems, such as excessive extrusion

Rubber has the elasticity required to follow the normal movements of flange surfaces and maintain complete contact. The gasket must be confined; for if it is not, it may tend to be extruded from the joint with successive tightenings of the bolts, or it may rupture if overstressed. The best compounds for gasket use are those which have been formulated for low compression set

The compatibility between rubber gasket and environment depends upon the particular type of rubber (There is great variation in resistance to the effects of petroleum derivatives, acids, alkalis, solvents, ozone, etc. Table 2 indicates many of these variations) The heat resistance of rubber is about the same as that of other organic materials. Silicones and polyacrylates will function at temperatures as high as 500 deg F., but natural rubber and the other synthetic rubbers are best used at temperatures below 160 deg. F. and 360 deg F., respectively Heat resistance is modified by compounding and can be indicated only in a general way. (See table 2.) Low temperature flexibility is highly variable according to the elastomer being used, but compounding, and especially the choice of plasticizer, will affect the basic characteristics. Since rubber does not absorb and hold moisture, it is not likely to cause corrosion of the flange surfaces. However, when used with certain metals, some staining or similar surface reaction will occur due to contamination by the compounding ingredients For example, silver tarnishes in contact with rubber that has been compounded with sulphur.

21. Application, Forms, and Uses. Rubber is best used in applications where controlled deformation is a feature of the design. The ordinary type of flanged joint (where the gasket is subjected to straight compressive stresses) does not fully utilize the unique properties of rubber. In fact, this type of joint often accentuates its less desirable gasketing characteristics. In order to effectively apply rubber to gasketing designs, the various forms of rubber and their proper uses must be considered. Solid sheet rubber, cellular sheet rubber, molded rubber, and tubing all have their own particular characteristics and areas of application. The following discussion analyzes each of these forms of rubber and presents applications for which they are best suited.

Solid sheet rubber is a common rubber gasket material. As a compound of SBR or natural rubber it is known as "red rubber sheet packing", and it is often used for pipe-flange gaskets in systems that handle liquid solutions at moderate temperatures and where no petroleum derivatives are encountered. Red rubber sheet packing contains filler to reduce the tendency of rubber gaskets to be extruded from the joint under compression. Gaskets with less inert filler might be extruded under excessive stress if the flanges became oily or the gaskets were too thick. Designing and fabricating the proper gasket thickness is an intricate problem because the load-deflection characteristics of sheet rubber gaskets fluctuate erratically with variations in thickness and face width. Moreover, die-cutting is likely to result in concavity and tapering of the edges unless the cutting is done from very thin sheets Even when the die-cutting is done from very thin sheets problems persist: the material may be too easily deformed for accurate cutting. In some instances, the use of fabric compounds alleviates these difficulties, but the general problem remains as a design consideration.

Cellular sheet rubber is produced in two forms, closed cell and interconnected cell. Both types are results of attempts to create a truly compressible material that will respond pneumatically to applied pressure. Although closed-cell cellular rubber is preferred for gasketing because it is more impervious to moisture, both types are used in many applications, especially where the requirements are similar to applications where cork composition is used. Cellular rubber is especially useful for gasketing between members which are fragile and irregular. Only relatively light pressures are required and the principal function of a typical cellular rubber gasket is to prevent the entrance of moisture and dust into the interior of the assembly Applications such as automotive tail lamps are the primary adaptations

Rubber is most useful as a gasketing material in applications employing special cross-sections that are obtained by molding and extruding Molding from rubber is one of the most facile means for producing O-rings (par. 22) and other unusual self-energizing types of gaskets devised by design engineers. Manufacturers of hydraulic and pneumatic devices are particularly dependent upon molded rubber for many sealing applications, including both packings and gaskets. The primary limitation on the use of molded rubber is cost, rubber molds are more expensive than the relatively simple tooling devices required for producing die-cut or lathe-cut parts. The molding of rubber is most feasible when quantity justifies mold costs and when molding minimizes waste and scrap.

In certain situations it is possible to have the advantages of molded rubber at a lower cost. This can be done by obtaining the rubber in simple stock shapes and fabricating as desired prior to assembly An example would be the use of rubber gaskets in electrical equipment such as transformers and lightning arrestors. For these applications it is feasible and practical to obtain square or rectangular cross-section rings produced by slicing from tubes, and in assembly, distort these rings into various other shapes such as triangles and rhomboids. This technique is more flexible and economical than specifying simple parts molded to the final shape

Economical and practical lathe-cut rings and washers of rectangular cross-section are sliced from tubes made either by extrusion or by a laminating process. The latter process involves wrapping a mandrel with a number of plies of uncured stock sufficient to build up the required diameter or wall thickness. Pressure is applied during the vulcanizing cycle by some means such as wrapping with cloth tape, after which, the tube is ground (if necessary for finish and accuracy) and then sliced This form of fabrication frequently enables rubber to compete with forms and materials ordinarily considered to be of lower cost, as the preceding paragraph indicates

Rubber can sometimes be machine finished by processes such as slicing, grinding, punching, or sanding, but these methods of production are not practical except for the production of small quantities or where inexpensive, standard, mass-produced parts can be easily modified into the desired shape.

22. **O-rings.** The O-ring is essentially a molded rubber packing, but it is designed, fabricated, and applied with such careful attention that it cannot be adequately described as just another form of rubber molding A considerable variety of compounds is available, varying in hardness, fluid resistance, and high and low temperature response The popularity of the O-ring is based upon its simplicity, versatility, effectiveness, ease of installation, and standardization. The limitations that prevent wider application of the O-ring include its vulnerability to certain environments, its tendency to extrude, and the special type of joint required for economic utilization These advantages and disadvantages are treated more extensively in the following discussion

O-rings can be used for dynamic or static seals For most uses, O-rings are simple in shape and require only the simplest groove or channel designs This simplification contributes to low fabrication costs, compact mechanisms, and effective performance Physical property specification, ring sizes, and the sizes of the grooves or counterbores in which the rings fit, have all been standardized (See figures 11 to 13, paragraph 47.) O-rings are easily installed · in general, all that is required is to snap the ring into place and complete the assembly In most applications the O-ring can withstand comparatively high pressures In typical assemblies it can hold pressures up to 1500 psi, and, when supported by a leather or plastic back-up member, O-rings can withstand pressures of 3000 psi. The back-up ring controls extrusion of the O-ring into the clearance space between assembly members.

The tendency to extrude into clearance spaces under high pressure or vacuum is a basic disadvantage of the O-ring. Extrusion may result in damage to adjacent assembly members and failure of the seal. In actual use, O-rings are vulnerable to certain environmental elements because of their exposed surface. Instead of offering a thin edge to the sealed liquids, an O-ring is almost completely exposed. It is only effective as long as it is resilient; any environmental feature which reduces the resiliency of the O-ring eventually destroys the joint seal. There is no follow-up device and no opportunity to renew the seal by tightening bolts. Even when used as a static seal, pressure pulsations cause the O-ring to rub against the confining metal parts, producing abrasion, wear, and perhaps failure of the joint. To reduce these effects, the adjoining surfaces usually must be super-finished or chromium plated This requirement may be impractical to comply with for reasons of design and cost.

PLASTIC GASKETS

23. **Characteristics.** There are many types of plastics produced, but the most useful types for gasketing purposes are fluoroethylene polymers The trade names of the basic versions are Teflon (polytetrafluoroethylene), Kel-F (polytrifluorochloroethylene),

and Fluorothene (polytrifluorochloroethylene). These rubber-like plastics are relatively extensible and incompressible Moreover, they are distinguished by a number of characteristics that include chemical inertness, applicability over a wide temperature range, low friction properties, resistance to adhesion, extremely low dielectric loss over a wide range of frequencies, and a resistance to the attack of most chemicals. Teflon is the outstanding type. It has superior physical properties and can be used over a wider temperature range than Kel-F, although the latter is likely to be more versatile in fabrication and more economical. Teflon has a high coefficient of thermal expansion, almost four times that of steel and cast iron. This property must be considered in many design applications. The following paragraphs highlight the general gasketing properties, basic forms, and areas of application of the fluoroethylene polymers, emphasizing Teflon as the leading type.

24. General Gasketing Properties. In general, the fluoroethylene polymers, particularly Teflon, are advantageous gasketing materials that satisfy the basic requirements of gasket design. As gaskets they are relatively impermeable; they make complete contact with the flange face, and successfully maintain this contact despite pressure, temperature changes, and other environmental effects. The following discussion indicates several design considerations that determine how well a Teflon gasket will maintain complete contact under various conditions.

Solid Teflon gaskets are useful for many standard flanges, but particular properties of the material necessitate proper design of the flange and study of the environmental conditions. Applications which involve varying pressures and temperatures require special precautions. At low pressures (150 to 300 psi) raised flange faces are normally used, but for higher pressures, some confining arrangement is necessary such as tongue and groove or male and female. Solid gaskets of Teflon with tongue and groove flanges have withstood pressures as high as 30,000 psi However, when the gasket is confined, Teflon's high coefficient of thermal expansion is an important design factor. In certain situations, Teflon is subject to cold flow; but, research generally indicates that this tendency is not excessive and is encountered only during the first few hours after the load has been applied Under any given temperature and pressure, equilibrium will be rapidly reached with a minimum of flow, and no further change will occur unless the temperature or load is changed.

Teflon, like rubber, is incompressible and flows under pressure, but the most successful Teflon gasket designs are those that generally follow the principles of compressed rubber-asbestos gasket designs. (See paragraphs 7 to 9.) There is a similar lack of resiliency in both materials. This characteristic presents a problem in operations or situations where variation in temperature will change the pressure on the gasket through expansion and contraction of the flanges and bolts. In some cases, spring-loaded bolts solve the problem.

Spiral-wound metal gaskets with a filler of Teflon (fig. 3) have an inherent mechanical "kick-back" action due to the shaping of the metal used. They require comparatively heavy bolting pressure to accomplish initial seating, but they are probably the best plastic gasket for high pressure and high temperature chemical applications. Design calculations covering required bolt loadings generally follow the ASME Unfired Pressure Vessel Code, using *m* and *y* values specified for spiral-wound metal and asbestos gaskets

All the fluoroethylene polymers are resistant to high temperature, remain tough at high and low temperatures, and resist all solvents including high boiling ketones, boiling sodium hydroxide, aqua regia, hydrofluoric acids, and fuming nitric acid. Teflon can be used at temperatures ranging from minus 90 deg F. to approximately 480 deg. F Kel-F may soften at temperatures over 300 deg. F and is adversely affected by ultraviolet light and X-ray exposure.

25. **Forms Available.** The fluoroethylene polymers are available in a variety of gasket sizes, styles, and shapes. Forms include sheets, rods, tubes, and tapes; molding powder that is shredded or granulated, and suspensoids, which are stable aqueous dispersions containing 50 percent solids. Complex items are formed by machining the standard shapes. Research has yet to develop a means for molding Teflon into the standard variety of forms; it does not melt or flow. Although conventional molding techniques can not be used, Teflon can be formed into simple shapes by an adaptation of the compression molding process. As a suspensoid, it can be applied in successive thin coats (about 0.001 inch), each followed by fusion at 750 deg F. Obviously, this process can be used only with materials that have high temperature resistance. Teflon gaskets are supplied in solid, jacketed, and spiral-wound styles, and as an impregnating material The characteristics of each form are outlined below.

Solid Teflon gaskets are produced by die cutting from a molded sheet, by slicing from the end of a molded cylinder, or by molding directly from powder The pressure and temperature characteristics of solid Teflon gaskets are discussed above in paragraph 24

Jacketed, envelope gaskets have been developed for glass, porcelain, and glass-lined equipment where misalignment of flanges and low bolting pressures prevent the use of solid Teflon. Envelope gaskets are also used for diameters over 24 inches or for areas larger than the size of available solid gaskets The usual construction of the envelope gasket is the "French" type, consisting of a soft filler covered by a jacket or envelope of Teflon Depending on the application, the filler may be fabric-reinforced rubber, asbestos-rubber, asbestos paper, and similar materials, including even certain metallic types

Spiral-wound gaskets with a filler of Teflon are especially suited for high pressure chemical service since they combine the chemical resistance of Teflon with the strength of metal Such gaskets are made in a variety of shapes and dimensions, using stainless steel, Monel, and other metals according to the particular chemical conditions to be encountered.

Many of the valuable attributes of Teflon can be obtained at a comparatively low cost by impregnating suitable fiber sheet products with Teflon suspensoid The fiber generally used in this process is asbestos, either as a woven fabric or paper. Research and testing continually seeks to discover particular fibers that can be successfully combined in this process. According to some test results, the coating of Teflon protects the fiber, such as asbestos, from chemical attack. Accordingly, combinations such as blue asbestos and Teflon will result in gaskets that are acid resistant and inexpensive.

TREATED AND UNTREATED PAPERS

26. **Classification.** The types of papers that are used for gaskets are generally made from organic fibers, especially vegetable fibers. Almost any form of untreated paper can be used for gasket application, including such diverse types as plain brown wrapping paper, fish paper, drawing paper, chipboard, tagboard, felt, and many others. Treated papers also have wide applicability. The treated paper gasket materials are made by a solution saturation process or by beater saturation. Such papers are classified according to the saturation process employed as well as the saturant used. The saturants used are primarily glue-glycerine, resins, dry oils, or synthetic rubber latices. Another form of paper material that is used occasionally for gaskets is vulcanized fiber. The characteristics of vulcanized fiber and of the two forms of saturization treatment mentioned are discussed below Other paragraphs indicate the gasketing properties and limitations of paper and point out general areas of application.

Vulcanized fiber, analyzed here as a treated paper, is used as gasket material in applications that require hardness and incompressibility or in which the gasket serves as a shim Fiber vulcanized by a zinc chloride process can also function as an electrical insulator. Vulcanized fiber gaskets are frequently coated with a thin film of synthetic rubber to ensure complete contact between gasket and flanges.

Solid saturation of paper materials is accomplished by passing the paper stock through a tank or trough containing a liquid solution or dispersion of suitable solids such as gelatins, resin, or latex The base paper is made from rope or kraft pulp and is made porous so that it will saturate easily. Various other materials can be added to produce combinations with desired features, as for example, using granulated cork to obtain greater porosity and compressibility. Leather fibers and cotton linters have been utilized also in this manner for other properties

Beater-addition or beater-saturation processes are designed to combine the fibres and the particles of saturant uniformly, and in a controlled manner, prior to the formation of the fibers as a sheet

27. Properties and Limitations. General-purpose paper gaskets are rarely used where critical physical and mechanical property requirements are involved. Furthermore, the properties and limitations of paper gasket materials vary, depending upon the type of paper and whether it is treated or untreated. To present a useful evaluation, the properties and limitations will be discussed by indicating how well paper materials fulfill the basic requirements of gasket design. Treated and untreated papers will be generally evaluated according to the basic requirements that gaskets be impermeable, make complete contact with the flanges, maintain this contact despite various pressures, and function harmoniously with environmental factors.

Impermeability is not a property of untreated papers; these papers are inherently permeable and generally remain so under compression and after saturation with the contained liquids. Treated papers, on the other hand, are moderately impermeable, and become increasingly impermeable under compression. Solution-saturated materials are more impermeable in the unconfined state than are beater-saturated materials the latter require compression to close the pores natural to any fibrous structure.

Completeness of contact is generally not a problem with untreated papers, since they are not used where requirements are severe. Treated papers require a pressure on the area of the gasket to obtain an initial and enduring seating of flange to gasket. This pressure will vary according to the type of paper and flange; it may range from 500 to 1000 psi.

Complete contact can be maintained by treated papers under a variety of pressures and forces, depending upon the type of paper and treatment. The serviceability of treated paper gaskets under increasing pressures can be improved by using thin gaskets and long bolts capable of ensuring follow-up pressure after the gasket has taken its permanent set.

Compatibility with environmental factors is seldom a problem with untreated papers; they are rarely considered where requirements are critical Treated-paper gaskets, however, have been applied successfully to seal oil, gasoline, and in some cases, cold water. But certain of the saturants used in treating gasket papers have characteristics which restrict the utility of these gaskets. Synthetic rubber saturants, for example, are generally flexible and nonextractable while the glycerine saturants are extractable. Therefore, glycerine-saturated materials should not be used on contact with water because such contact results in extraction, followed by shrinkage and hardening of the gasket. For applications that involve contact with water, the rubber latex beater saturated types are recommended. Glycerine saturants may also cause corrosion of flange surfaces, whereas latex saturated materials generally do not. Paper gasket research has attempted to develop nonextractable plasticizers to replace the extractable saturants now in wide usage. As a result, beater-saturated materials employing latex saturants have been used instead of the glue-glycerines.

Fungus resistance is poor in plain or protein-saturated materials, but latex or resin treated papers exhibit fair to good resistance. Fungicides may be added to saturants by the manufacturer, or applied as external treatments by the fabricator or user. (See paragraph 40)

28. **Application.** Untreated paper gaskets are generally quite inexpensive; probably the most inexpensive gaskets available. Treated gaskets are intermediate in cost, generally more expensive than cork, but not as costly as compressed asbestos. All types of treated and untreated papers are available in thin sheets, rolls, and in multiple plies or laminations for greater thicknesses Die cutting is the usual method of fabricating gaskets For specific applications the design engineer must remember the limitations of paper gaskets. Furthermore, untreated and treated papers have far different uses. The following discussion outlines varying applications for untreated, glue-glycerine saturated, and latex saturated papers

Untreated papers are generally used where the service requirements are no more severe than the creation of a barrier against the passage of dust particles or splash of internal or external liquids Hard or soft papers are used according to the nature of the joined surfaces Untreated papers may be used where the requirement is simply for a spacer, as in the mounting of a radio speaker. They may also be utilized for applications where requirements are not critical, and where some relatively simple modification is necessary The user of the gasket may want to apply some particular substance to the gaskets prior to installation. For example, a pump manufacturer desiring oil saturated gaskets purchases cut manila paper or drawing paper gaskets, cements them in place, and then applies an oil soak.

Glue-glycerine saturated paper gaskets are still the most widely used general-purpose gasket, despite the increasing application of latex solution saturated and beater saturated materials. The glue-glycerine saturated materials can be used in many applications normally performed by cork, if compressibility is not necessary. In requirements where extreme stability, heat resistance, and toughness are not necessary, these treated papers will perform many of the functions usually associated with compressed asbestos They are best used with oils and gasoline to hold moderate pressures and at moderate temperatures not exceeding 160 deg. F. Such treated papers should not be used in applications that involve contact with alkalis, strong acids, steam and alternate wetting and drying Glue-glycerine papers are available in widths of 36 inches or more and in long rolls; they are easy to stock and dispense. The design engineer is cautioned to specify the particular grade required, because there are many grades manufactured which vary in quality.

Many beater saturated, latex treated materials will perform as well as the glue-glycerine types in general oil and gasoline applications. Furthermore, they have distinct advantages over the glue-glycerine types: they have nonextractable binders and can be used in water and alternate-wet-and-dry applications, they reduce the possibilities of flange corrosion, and they are more resistant to fungi attack.

LEATHER GASKETS

29. **Characteristics** The fiber structure of leather is that of interwoven fibre bundles combining a roughly directional weave and a complex nondirectional interlocking. Leather is a closely knit material that is generally tough, pliable, and relatively resistant to abrasion, wear, stress, and the effects of temperature changes. Because it is porous it is able to absorb lubricating fluids. This porosity, however, makes it necessary to impregnate leather for most uses In general, leather must be tanned and treated in order to make it useful as a gasket material. The tanning processes are those normally used in the leather industry and include vegetable or oak tanning, mineral tanning

with compounds such as chromium salts, and combination tannages that blend both methods. Waxes, resins, and synthetic polymers are also used to improve natural leather characteristics. A brief summary of the properties, limitations, and typical applications of leather gaskets follows.

30. **Properties.** The tensile strength of leathers varies according to the type of leather and processing, but is usually at least 3000 psi. Leather is generally resistant to abrasion regardless of whether the grain side or the flesh side is exposed to abrasive action. Leather remains flexible at low temperatures and can be forced with comparative ease into contact with metal flanges. When properly impregnated, it is impermeable to most liquids and some gases, and capable of withstanding the effects of temperatures ranging from minus 70 deg. F. to 220 deg. F. It can be made relatively impervious to the effects of oil, gasoline, gases or fumes. The use of new and improved impregnating materials enhances the basic properties.

31. **Limitations.** Leather has four basic limitations. First, the size of the typical hide limits the size of the parts than can be made from leather. And since all parts of the hide are not of equal quality, a second limitation is imposed. Another limitation is that under heavy mechanical pressures leather tends to extrude. Finally, many of the properties (such as impermeability, tensile strength, high and low-temperature resistance, pliability, and compatibility with environment) depend upon the type of leather and impregnation. Leathers not tanned and impregnated for specific conditions and properties will become brittle, dry, and completely degreased by exposure to particular chemicals. Leather is never used with steam pressure of any type, nor with acid or alkali solutions.

32. **Application.** Leather can be formed, cut and molded within limits. It can be split into thin sheets, die cut, and machine finished to a degree Leather can also be skived and joined to form long strips or belts These available forms can be applied to such uses as packing and as back-up washers in specific applications, as discussed below. The lubricating wick effect of leather is useful in applications that involve relative motion between machine parts and seals. However, the limitations of leather make it necessary for the design engineer to carefully study the application. For example, because leather extrudes under heavy mechanical pressure, leather gaskets and washers are best used in a recess. In other applications of leather gaskets, the initial tension of the bolts must hold the joint tight, for if the bolt should loosen under shock or vibration, the joint will leak. In applications where leather gaskets are used between metal flanges, the flanges must be flat, rigid, and smoothly finished to ensure complete contact.

Leather back-up washers, used in conjunction with synthetic O-ring packings and gaskets, improve the seal of high pressure joints. The leather back-up washer acts as a barrier to prevent the extrusion of the rubber O-rings into the clearance spaces between metallic members The leather back-up washer also enables the seal to function under such high pressures. In applications where the pressure is at least 1500 psi, a back-up washer is necessary; and it may further increase the useful range of the O-ring to pressures exceeding 3000 psi

Leather may be used as packing. When molded into V's and U's, and cups, and other shapes, it can be applied as dynamic packing, while in flat form it can be used as straight compression packing.

COMBINATION AND MISCELLANEOUS GASKETS

33. **Material Combinations.** In spite of the many natural and synthetic materials used for gaskets, there are applications which require even more specialized or unusual forms. For such applications, designers and manufacturers have developed combinations and design modifications that utilize desirable properties and minimize undesirable

effects. A basic technique in developing a combination is to laminate a strong, relatively incompressible material with a highly compressible, weak material. Similarly, a weak material may be protected by an outer covering or envelope. Jacketed gaskets, corrugated metal with soft fillers, or spiral-wound gaskets are versions of this design. Each of these combinations and constructions is summarized below.

Laminated materials that have been successfully used include vegetable fiber and cork compositions, asbestos and cork sandwich constructions, and asbestos coverings over various metals. Vegetable fiber and cork have approximately the same chemical properties and the same response to atmospheric conditions. Hence, they are easily combined by lamination, and, depending upon the ultimate use, either material may serve as the center filler. Gasket combinations composed of a thin filler of cork between two layers of asbestos are also highly compressible. Inexpensive automobile cylinder head gaskets have been made by attaching a sheet of asbestos millboard to each side of a steel sheet, and punching the steel so that small prongs or stakes hold the asbestos in place mechanically

Jacketed gaskets are illustrated in figure 3. They usually consist of a center filler and a metallic or nonmetallic outer covering or envelope. The purpose of the jacket is to protect the filler material against some injurious environmental condition. For example, Teflon-jacketed gaskets with fillers of asbestos, rubber, or other similar materials, serve as gasketing for glass-lined vessels and piping used in chemical processing Metal-clad or metal jacketed gaskets are used for heat or erosion resistance in a wide variety of designs. Boiler gaskets and automotive cylinder head gaskets are applications of this design.

Gaskets of corrugated metal with soft fillers are primarily for pipe connections, especially where there are warped flanges. Such gaskets are circular in shape, and subject to moderately heavy bolting pressures. A closely related design is the serrated metal ring with serrations that have been packed with asbestos filler, as illustrated in figure 3.

Spiral wound gaskets consist of plies of preformed metal and asbestos or other filler strip. See figure 3. A center corrugation in the metal strip ensures constant tension and resilience when the gasket is under compression. It is a self-adjusting, noncorrosive gasket that produces a tight seal. This gasket may be advantageously utilized where initial cost is a factor of minor importance.

34. **Miscellaneous Gaskets.** Some representative types of gaskets developed to meet new or unusual applications include flowed-in gaskets, coated gaskets, gasket pastes, felt, and automotive glass channel filler. Each is discussed in the following paragraphs.

Flowed-in gaskets are actually synthetic rubber and resin compounds that are applied as a liquid, usually sprayed through a nozzle, into a suitable groove or recess and then baked in place. They have limited usage in such items as instrument panel bezels and covers for food containers.

Gaskets may be coated to produce level surfaces or as protection against burning or chemical attack. It is customary to specify the nature of gasket coatings on the blueprints. See paragraph 40 for additional information on coatings and treatments.

Gasket pastes include those spreadable compounds which are intended to set by air drying or which may be designed to remain flexible indefinitely. There are problems with such materials: they are difficult to control during installation and very often do not adhere, allowing the surfaces to slip.

Felt readily picks up and conducts fluids; therefore, felt is widely used for wipers, wicks, ball-bearing retainers and similar applications. Few attempts have been made to make felt impermeable by impregnation because of the high cost and the availability of other more suitable materials. The application of impregnated felt is rare.

Automotive glass channel filler is usually a compound of reclaimed rubber and fiber,

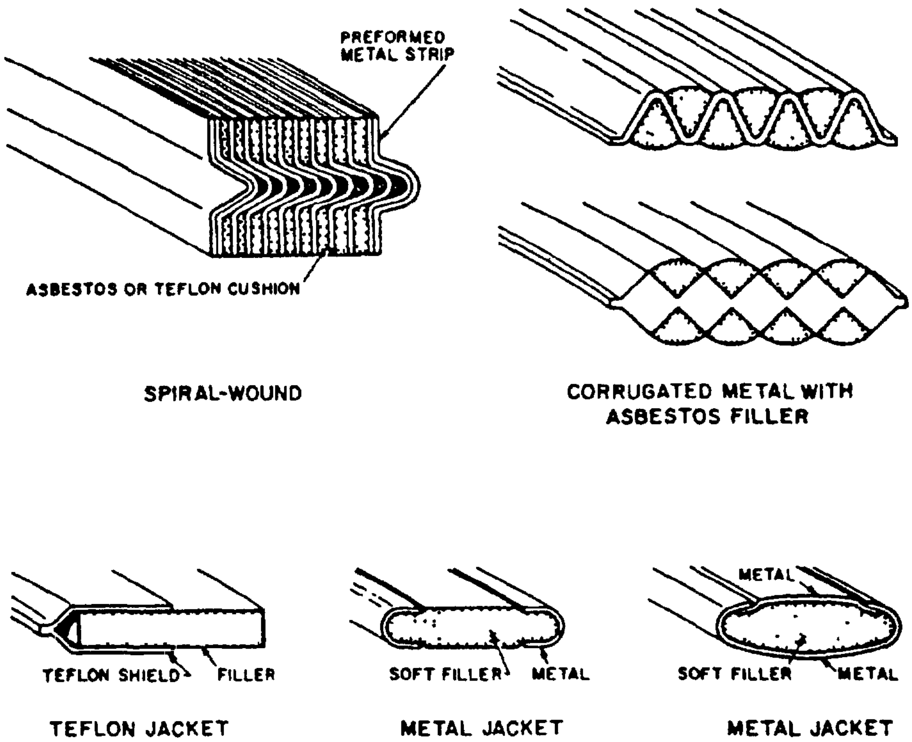


Figure 3. Basic Forms of Combination Gaskets

uncured and in ribbon form, used for holding safety glass in windows and for installing ventilating fixtures. Cork and reclaimed rubber mix on bias-woven fabric is another version of this product.

IMPROVING GASKET SERVICE AND DESIGN

35. **Improving Basic Properties of Gasket Materials.** In paragraph 4 and in sections throughout this pamphlet, the basic design requirements of an effective gasket have been discussed. Satisfactory fulfillment of these requirements may be facilitated by several means: the natural characteristics of the material may be improved, a more satisfactory material may be selected, gasket design may be modified, and various joint or flange conditions may be adjusted However, before design suggestions are considered, beneficial results may be obtained by outlining the methods for producing gaskets that will satisfy more fully the basic requirements of design. Accordingly, the following paragraphs present general techniques, processes, and design factors which may increase the impermeability of a gasket and improve its ability to make complete contact with the flanges, and maintain this contact despite environmental forces. Specific methods are often suggested in the discussions of the gasket materials and in paragraphs 41 to 51.

36. **Improving Impermeability.** Gasket materials that are not naturally impermeable may be compressed, saturated with the sealed liquid, or coated to induce this property.

Compression is effective with fiber sheet materials having a saturant or binder, usually of pasticized protein or synthetic rubber. Saturation with the sealed liquid is sometimes effective with plain paper or fiber, especially if the liquid is viscous and internal pressures are low. Coating that consists of dipping the gasket in synthetic rubber latex or in cement glue, or resin, may be effective with cork composition and fiber sheet materials It is applied when these materials can not be compressed sufficiently to develop adequate impermeability.

37 Ensuring Complete Contact. Complete contact between gasket and flange is improved with changes in flange face finish, alignment, flange rigidity, and bolt spacing. Keeping the gasket positioned and applying surface treatments may also contribute to a more perfect contact A rough flange face finish is preferred to a smooth surface. (See paragraph 51) The latter may require less flow of the gasket materials, but may result in slipping of the gasket. The rougher surfaces require thicker, softer gasketing materials or heavier bolting For a given depth of tool cut, concentric serrations will seal better than the continuous spiral "phonograph" finish A surface that has been planed and has tool marks in one direction is probably the most difficult to seal.

Parallel alignment of the flange faces is necessary to prevent the gasket from being greatly compressed at some points and lightly compressed at others. Unequal compression may result in failure of the seal unless easily compressed materials are used, such as cork composition or cork-and-rubber. There must be a sufficient number of bolts of proper size so that the necessary load can be applied to the gasket to make it flow into flange irregularities Depending on the flange material and the gasket thickness, a beam effect may be created between bolts, followed by bowing The design engineer must consider these problems and select bolt spacing designs that employ either numerous, closely spaced light bolts or fewer, but larger bolts. (See paragraph 48)

Gasket extrusion at the joint also prevents firm contact and retention of the flanges. A gasket can be kept positioned by proper design or by special surface treatment. A high coefficient of friction or rough flange finish may solve the problem, but there are some applications that require confining and positioning by means of walls and grooves In some cases, a thin coating of synthetic rubber applied to both sides of a hard fiber gasket provides a surface that enables the gasket to flow more easily into flange irregularities and remain positioned However, such a thin coating, usually about 0.001 inch, does not serve to improve impermeability

38. Maintaining Contact. Complete contact between flange and gasket can be maintained if certain factors are properly evaluated and accommodated The elastic response of the gasket, the edge effect of the sealed liquid, the extent of adhesion, and the elasticity of bolts and flanges are the prominent factors. When materials with a low modulus of elasticity are used in low pressure, moderate temperature joints, the elastic response of the gasket is usually the most important factor effecting the life of the seal A gasket material that swells moderately in contact with sealed liquids promotes an effective seal, while a material that is not affected or which shrinks at the exposed edge during contact will hasten the failure of the seal. However, precautions must be taken to avoid using a gasket material that will dissolve, deteriorate, or cause contamination upon contact with the sealed liquids It is also desirable to utilize a gasket material that will adhere to the flanges, providing the flange faces are not to be separated during operation of the assembly. Gaskets of rubber, cork, and certain other materials, tend in time to adhere to the flanges. When this occurs, the problem of maintaining gasket pressures is solved; a firmly adhered gasket will hold liquid pressures with very low residual flange pressure even during joint movements of considerable magnitude Rubber cements may be used to ensure adhesion

In cases where adhesion is undesirable, gaskets can be treated with graphite or mica as a preventive measure. (See paragraph 40.)

The elasticity of the bolts and flanges is the factor that determines the continued tightness of high pressure, heavy-duty joints held by gaskets with low compressibility and high modulus of elasticity In such joints the bolts function as the resilient forces in relation to the joined members. The problems involved require careful study and design. The ASME Unfired Pressure Vessel Code covering design calculations is a valuable aid. (See also paragraph 49.) Proper assembly is also a vital factor; for example, the use of torque wrenches helps ensure adequate tightening (See also paragraph 44.)

39. Ensuring Environmental Compatability. A gasket will function harmoniously with its environment if the factors of temperature response, chemical inertness, and resistance to miscellaneous hazards are considered in gasket design and selection of the material. Temperature response of materials is a complex problem, and high-temperature behavior is better understood than low temperature behavior. Research has been able to define more accurately the high temperature limits of various materials, and to predict at what point creep or stress relaxation will occur and how rapidly the material will age at different temperature levels. It is known that extreme low temperature exposures cause sluggishness and brittleness in most gasket materials unless they have been compounded primarily for such conditions Gasket materials in general have a higher coefficient of thermal expansion than most of the metals from which flanges and bolts are made. In applications that involve wide and rapid temperature fluctuations, this factor of relative expansion and contractions due to temperature may require special consideration. Chemical reaction between the gasket and the sealed substances may be beneficial if it results in moderate swell, but the possibilities of deterioration, contamination, staining, and corrosion require careful evaluation. The possible effects of other environmental factors such as ultra-violet light, vermin, ozone, salt spray, fungi, vibration, shock, and general aging all demand consideration as determinants in the selection of the gasket material and the design of the joint.

40. Treatments and Coatings. Numerous special treatments have been devised for gaskets to improve resistance to mold, heat, friction, adhesion, and penetration, as well as to promote complete contact with flanges, increase adhesion, and inhibit shrinkage Many of these processes have been mentioned in connection with a particular material or as a means for improving the natural properties of gasket materials. For example, coatings to improve impermeability are noted (par 36); measures for preventing adhesion (pars. 8 and 38) or promoting adhesion (par. 38) have been mentioned, and coatings have been suggested as a means for reducing flow and extrusion (pars 34 and 37). The best methods for applying and utilizing these treatments are described in the following discussion, explaining the use of graphite, talc or mica dust, oil or hot paraffin, synthetic rubber, adhesives, reflective coatings, and fungicides.

Graphite applied as a dry flake or mixed with oil in a water emulsion serves either to reduce adhesion or to provide a more level surface.

Talc or mica dust is applied dry or in an adhesive vehicle and will similarly reduce friction. It is particularly useful in applications requiring rotation of parts to close the joint.

Oil or hot paraffin is applied by dipping to prevent drying out under adverse conditions of storing It is most commonly used with vegetable fiber and cork composition gaskets

Synthetic rubber is applied to soft gasketing materials Neoprene applied as a dip coat to cork composition oil pan strips for automobile engines increases resistance to oil penetration, inhibits loss of moisture, and helps prevent installation breakage.

Thiokol applied to fiber sheet materials by doctor blade or roller provides a more level surface that promotes seating contact of these materials to flange faces.

Adhesives, usually synthetic rubber or resin in combination, may be used wet or partly dry, or may be entirely dry. Entirely dry adhesives may be applied with the purpose of subsequent reactivation by solvent or heat Adhesives are used when an immediate permanent bond is desired to promote adhesion between gasket and flange for strengthening the seal during wide temperature fluctuations and joint movement.

Reflective coatings function as reflective insulation protecting gaskets located near a source of heat Aluminum paint or lacquer applied as a dip is a common form of protection.

Fungicides can be incorporated in gasket compositions or applied as a surface treatment. Materials such as beta-naphthol, pentachlorophenol, salicylanilide, copper-8-quinolineate, and various other copper and mercury compounds are used to resist mold growth. The type of treatment and the expected degree of protection must be specified during procurement agreements. Many forms of protection may not be applied by the manufacturer and may have to be obtained from other sources because they are hazardous and require application by specialists. If a fungicidal treatment is desired to protect gaskets during shipment and storage, formaldehyde powder dusted in cartons may be adequate if the carton is vapor tight Some gasket materials are inherently resistant to mold, and extra treatment should not be specified until the application is studied. Precautions must be taken to avoid use of fungicides which may damage the gasket material or result in staining, contamination, and corrosion.

41. **Determining Gasket Thickness.** Under many circumstances, gasket thickness is a critical consideration. It is important that the thickness be neither excessive nor unusually restricted. Thin walls and delicate cross section in relation to over-all size results in high scrap loss as well as stretching or distortion in shipment or use. Moreover, such designs limit the choice of materials to those of high tensile strength. Gasket thickness is often determined by a general rule that may be stated as follows: use the thinnest gasket that will pack the joint, provided the ultimate compressibility of the gasket exceeds the cumulative deviation of the two flange surfaces from perfect parallelism. For example, a commercial compressed asbestos gasket 1/8 inch thick can be compressed only about 0.020 inch; if the cumulative inaccuracies of the flanges approach 0.020 inch, then the joint can not be sealed with 1/8 inch compressed asbestos. The alternatives would be to consider the use of a thicker compressed asbestos gasket (which may be impractical) or the application of a softer, more yielding gasket. Since considerable leeway exists in the choice of gasket thickness, a standard or commercial thickness should be specified for reasons of economy and ready procurement.

42. **Practical Tolerances For Gaskets.** Generally, the tolerances specified for metal-working can not be applied to the manufacture of nonmetallic gaskets, for three reasons. First, the ability to be deformed under pressure (the property that really makes a material valuable for gasketing purposes) also prevents the material from being processed commercially with the same precision as a rigid material. It will yield under the pressure of cutting tools. Secondly, because of easy deformability, gaskets can not be measured with the same results by different people using different equipment. Tolerances reflect human and mechanical variations. Finally, nearly all gasket materials are affected to some degree by temperature and humidity variations, with the result that temporary or even permanent dimensional changes may occur. Thus, comparison of measurement is possible only under standardized conditions. As a rule, attempts to apply metalworking tolerances to nonmetallic gaskets result in a high percentage of unnecessary rejections and in increased costs,

and consume valuable time in negotiating agreements on acceptable limits The design engineer is urged to try standard or commercial tolerances before concluding that special accuracy is necessary. Commercial tolerances on most nonmetallic gaskets and gasketing materials will range approximately as follows:

Thickness

Materials made by rolling, calendering or by paper-making processes; plus or minus 10 percent

Soft materials sliced or split from thicker sheets or blocks: plus or minus 0.010 to 0.020 inch, according to thickness.

Length, width, and spacing

Plus or minus 0.010 to 0.031 inch

Diameters

Bolt holes, gasket and washer OD's and ID's: plus or minus 0.010 to 0.020 inch.

43. Obtaining Precise Tolerances. The above general information on practical tolerances may not apply to particular manufacturers, who may list their own range of tolerances. As a rule, variation within a single gasket will be 50 percent or less of the over-all variation specified for the lot That is, the producer offering gaskets with an over-all thickness tolerance of plus or minus 0.015 inch, may be willing to accept a specification calling for a maximum variation of 0.010 inch or 0 015 inch in any one gasket.

Inspection of mass produced gaskets is generally based on a sampling method that uses tables corresponding to 2 to 10 percent defective tolerance per lot, depending upon the material and ultimate use. The low cost of many mass produced gaskets for assembly-line use precludes any effective production inspection system. However, gasket producers will often agree to supply more precise tolerances and more thorough inspection at extra cost and by specific agreement. Before requesting special tolerances, the design engineer should study all calculations; for the necessity of using noncommercial tolerance standards may be an indication of defective design.

44. Handling and Installation. Certain features and properties of gaskets may tend to produce varying results according to whether the parts are for maintenance installation or are intended for assembly in production-line units. In either case there are certain considerations which the design engineer must be aware of, in addition to the more fundamental design requirements. This discussion includes considerations which apply to general handling and installation as well as to use on a rapidly moving assembly line.

Gaskets must be handled carefully so that they can be applied without cracks, creases, or other damage Some critical installations require the use of mechanical aids such as torque wrenches. In general, proper installation involves tightening of bolts or fasteners correctly and in the prescribed sequence. A pattern of installation should be developed that will distribute the increasing load on the gasket uniformly It may be necessary to hand-tighten all screws or nuts and then to proceed with wrenches or other drivers.

For rapid handling, stiff gaskets are preferred to very flexible types that may be easily deformed by any handling For use in service or maintenance application this feature is not vital, but where a great number of gaskets are to be assembled in units in a moving line, these characteristics merit consideration Gaskets which are almost symmetrical in shape should be provided with an index notch or other feature to indicate their proper position Very large gaskets may be easier to handle if they are brought to the assembly point with interlocking ends rather than in one solid piece. Also, if the bolt holes are made elongated instead of perfectly round, such gaskets can be put into position more rapidly.

Where a precise degree of fit is critical, it may be necessary for the design engineer to provide the manufacturer or user of the gasket with detailed information on the part or parts to which the gaskets are fitted. Because of differences in measuring equipment and techniques, a blueprint alone may not be sufficient to guarantee the desired pattern of fit To prevent slipping during installation, the gasket, if possible, should be made of a material that will not slip on oily surfaces and lubricants and wet adhesives should not be used on any flanges where slipping can occur.

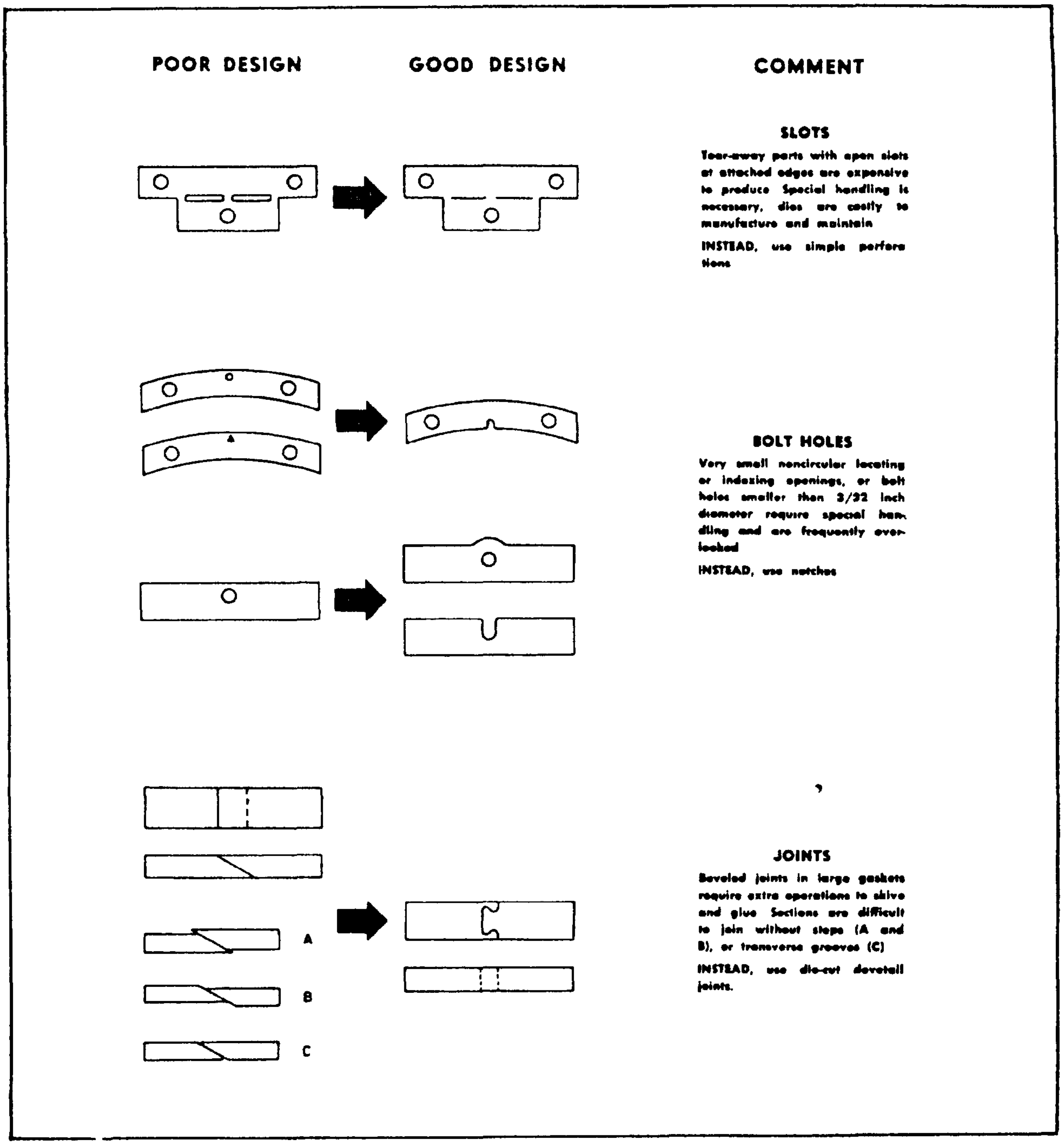


Figure 4. Improving Gasket Design

45. **Avoiding Common Design Defects.** In the preceding discussion (pars 35 to 44) many aspects and problems of proper gasket design have been outlined. From this discussion it is apparent that unless the engineer studies prospective designs carefully, the gasket product may be difficult to fabricate and install, or it may be unsatisfactory in service. Therefore the engineer should consider the gasket design during the early stages of the development of the complete assembly so that desirable features may be incorporated and undesirable characteristics avoided.

Further economies will be effected through careful consideration of the design requirements and the avoidance of specifying unnecessary preshaping as a result of transference of fillets, radii, etc., from mating parts to the gasket Unless the part is molded, such features mean needless extra operations and higher costs Actually most gasket stocks will conform to mating parts without preshaping Any radii, chamfers, etc., designed into the gasket should be functional, not merely copied from metal members.

Other design considerations are summarized by figure 4, which illustrates several common gasket design defects and remedies

JOINT DESIGN

46. **Relationship of Joint and Gasket Design.** Joint design and gasket design are related · a joint is only as effective as its gasket, and the gasket may succeed or fail according to how well the joint makes the best use of the gasket. The joint assembly components and the gasket must be considered as a unit or system for producing a seal In some assemblies, the flange design has been predetermined and a gasket material and design must be selected to function in the prescribed type of flange In other applications, environmental conditions dictate the type of gasket material, compelling the design engineer to develop flange designs that will work best with the particular material This section will demonstrate the relationship of joint and gasket design by illustrating representative designs, discussing the function and spacing of bolts, analyzing bolt stresses in pressure joints, indicating stresses for various low-pressure joints, and suggesting proper surface finishes.

47. **Representative Joint and Gasket Designs.** Typical applications of conventional gaskets and flange joints are illustrated in figures 5 to 13 inclusive

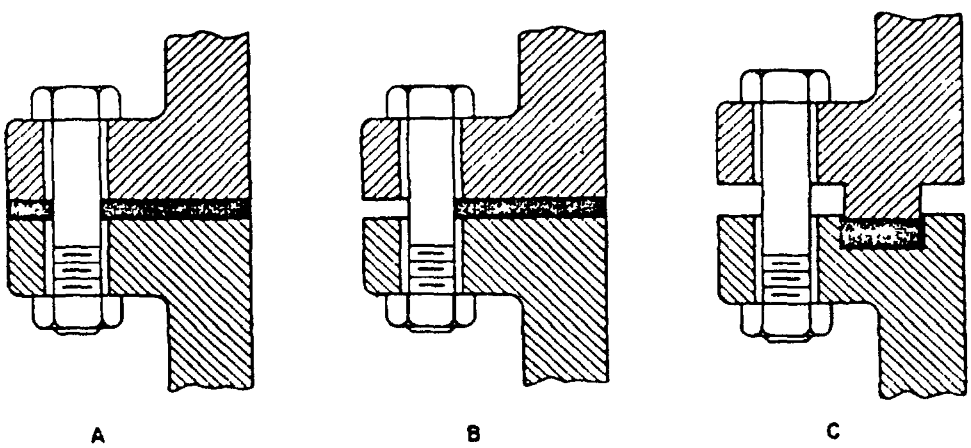


Figure 5 Use of Flat Gaskets in Basic Flange Joints

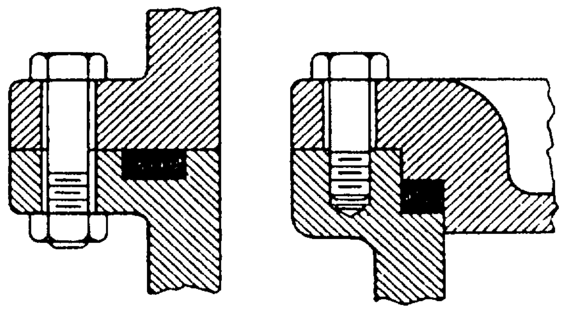


Figure 6 Use of Compressible Gaskets in Metal-to-Metal Joints

Figure 5 shows several basic flange joint designs suitable for all types of flat gaskets, both plain and jacketed Design *A* is capable of withstanding moderate pressures (less than 200 psi). Higher fluid pressures will require design variations such as those shown in *B* and *C* The comparative reduction in gasket wall section (design *B*) creates a joint capable of withstanding higher pressures (higher gasket stress) without change in bolt stress This design also reduces the cost of the gasket Completely confining the gasket (design *C*) permits the application of stresses capable of withstanding extremely high fluid pressures Design *C* is particularly suited for materials that are subject to flow, such as rubber

Figure 6 illustrates several joint designs that afford unobstructed interior surfaces and accurate alignment of internal parts. These designs also limit the application of compressive forces, which is an important factor when using highly compressible gasket materials such as cork composition, cork-and-rubber, and rubber O-rings. However, the shape and the volume of gaskets intended for use in these joint designs must be rigidly controlled. For example, if rectangular section rubber is used, the initial shape should allow at least a 25 percent deflection of the gasket when the joint is closed, and the initial volume must not exceed the volume of the cavity.

Figure 7 illustrates representative designs of self-energizing joints that normally require special molded shapes, although in some cases flat gaskets can also be used Design *A* pictures the use of a gasket formed of rubber or plastic so that it may be molded to a special shape. An example of a flat gasket used in a self-energizing joint is shown in *B*.

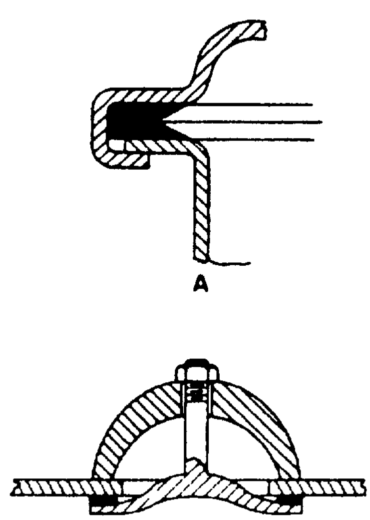


Figure 7. Use of Gaskets in Self-Tightening Joints

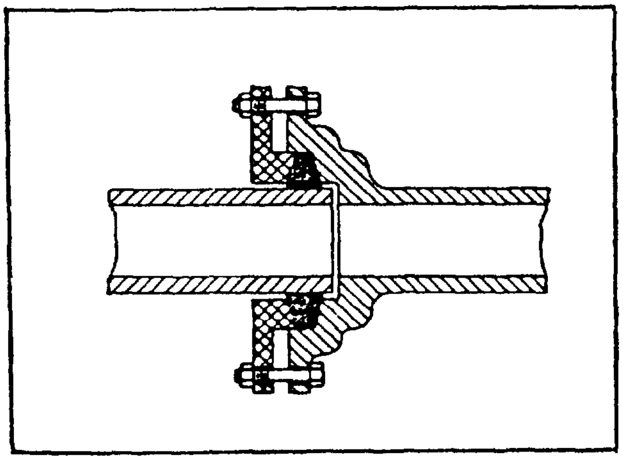


Figure 8. Use of Incompressible Gasket in Concentric Joint

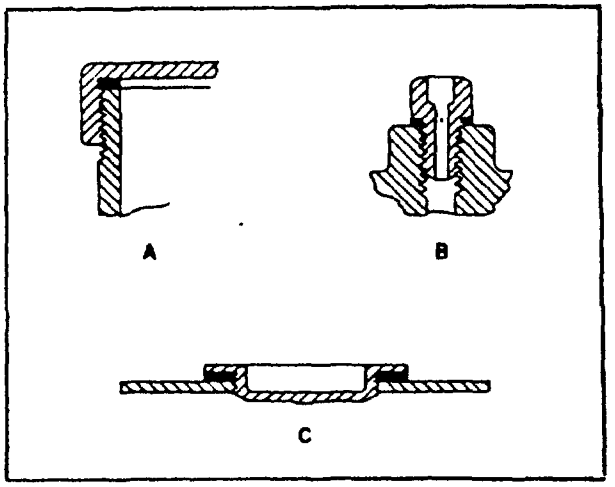


Figure 9. Use of Inextensible Gaskets in Threaded Joints

Figure 8 illustrates the use of a gasket in a concentric joint where the sealing force is in the direction normal to the applied bolt stress. This type of application requires a material which is not only deformable, but is also relatively firm and incompressible. Impregnated braided packings, cork-and-rubber, and rubber of 80 or 90 Shore A hardness are the most useful materials for this design. Soft rubber is unsatisfactory because it tends to extrude through clearances.

Figure 9 shows the use of gaskets in several threaded joints; that is, joints that close with torsion and necessitate the use of materials that are resistant to abrasion. For this application, hard compressed asbestos, leather, or metal-jacketed gaskets are most satisfactory. In the design, at least one of the mating surfaces should be smooth to permit the gasket to slide with minimum friction and abrasion.

Designers are urged to use simple round, square, or flat cross-section gaskets where possible, and to avoid the use of relatively expensive molded shapes. Figure 10 illustrates the adaptation of several simple gasket

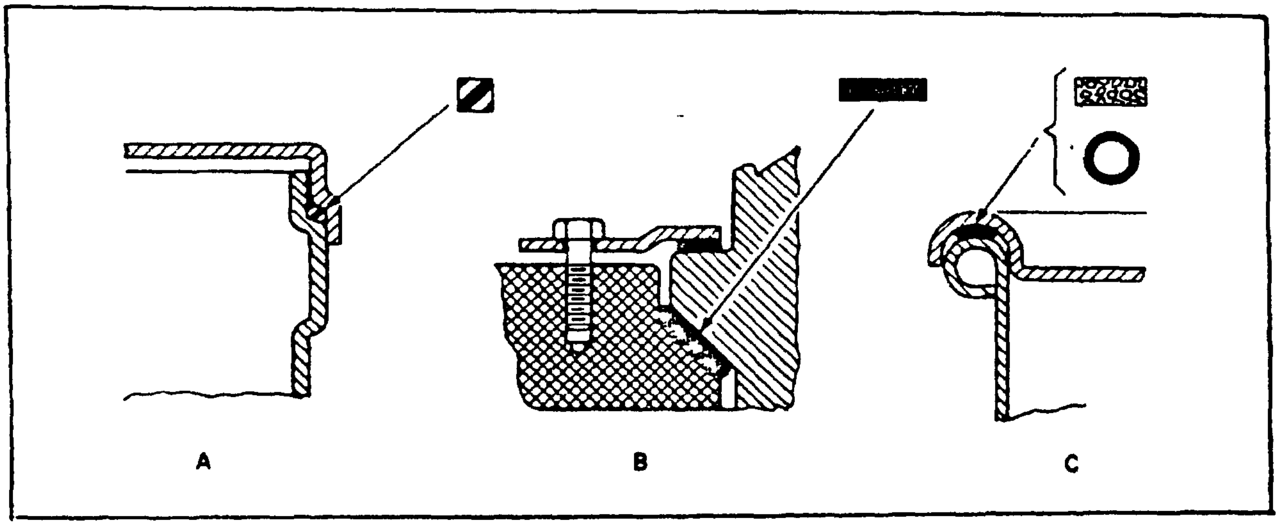


Figure 10. Adaptation of Simple Gasket Shapes for Complex Joints

shapes to more complex gasket cavity designs Design *A* shows a simple square-section rubber ring used in the assembly of a stamped container and cover. The rubber deforms to the necessary shape without requiring expensive molding. Similarly, in design *B*, a flat rubber gasket is used in a joint between a ceramic insulator and a transformer cover The flat rubber gasket is deformed to the required dish shape and held in place by steps or serrations in the sloping seat. In design *C*, a rectangular section cork composition gasket or hollow tubular rubber gasket is used in an open head steel drum

Figures 11, 12, and 13 point out joint designs and present data specifically for rubber O-rings Figure 11 illustrates several common design defects and methods of correcting them Figure 12 contains standards for rubber O-ring packings and gaskets installations Figure 13 contains design standards for O-ring static seals.

48. The Function and Spacing of Bolts. In general, the function of bolts, screws, or other fasteners is to bring about optimum or required deflection of the gasket In the case of low-pressure joints employing soft gaskets, bolt spacing need only maintain proper distribution of flange pressure over the face of the gasket In such cases, even where the bolts are far apart, uniformity of contact pressure can be obtained by various designs incorporating ribs and corrugations that provide extra rigidity for the metal members Bolts or other fasteners used in pressure vessel assemblies perform more particular functions and have special bolt spacing problems The more detailed functions and spacing of bolts in pressure joints are outlined below.

Pressure vessel assembly bolts prevent any separation of gasket and flange that might result from the pressures of the internal fluid load They also support additional stresses caused by gravity, misalignment, thermal expansion, and contraction. The bolts in these assemblies develop gasket stresses equal to the fluid pressure times a safety factor, to counteract natural relaxation. (This factor is the constant *m* in ASME formulas for bolted flanges.) These bolts also apply an initial yield or seating force to the gasket. This action is independent of the confined pressure, and is defined as the minimum stress that must be applied to the gasket to hold even a very low pressure (This figure is usually expressed as pounds per square inch and is the constant *y* in ASME formulas.) It may be treated as a property of the gasket (in ASME formulas), but to a great extent it is a measure of flange inaccuracies and will vary with each joint.

In pressure vessels, bolt spacing (pitch) may vary from 7 times the bolt diameter for installations with pressures not exceeding 50 psi, to 3.5 times the bolt diameter for installations with pressures of 200 psi. The limiting factor or required wrench openings may be a consideration in designs that call for closer spacing.

49. Measuring Bolt Stresses in Pressure Joints. The ASME rules for bolted flange connections are useful to a certain extent because they provide means for determining required bolt loads for particular operating and atmospheric conditions, and also for computing the required cross-sectional area of bolts. But, these rules do not provide a means for determining how tight the bolt must be torqued in order to provide given loads and stresses. Unfortunately, there is no standard method for determining these data accurately under typical field and shop conditions. It is possible to estimate such forces, though, by means of several methods of calculation The four methods are as follows:

A formula developed from experimentation based on the average load applied by experienced mechanics can be used in this manner: estimate from the formula $W = 16{,}000\ d$, where W is initial load in pounds due to screwing up, and d is nominal O D. of screw thread. (For additional details see *Elements of Machine Design,* Kimball and Barr, 3rd Edition.)

Obtaining the appropriate torque pressures as indicated in tables 3 and 4 provides another method The torque wrench settings can be specified with several qualifications. First, the bolts must be as described in the tables. Secondly, bolts must be well lubricated, preferably with oil and graphite; nonlubricated bolts may rate only 50 percent as efficient And lastly, extreme care is necessary to ensure that the gasket clears bolt threads and does not flow into them and thus create extra torsional resistance.

It is possible to measure bolt elongation and, from estimated modulus of elasticity, calculate bolt stress.

The bolt stress can also be computed from screw formulas. The design engineer is cautioned to bear in mind that refined calculations are considered useless and misleading by many authorities, especially for fastenings with less than 7/8 inch diameter.

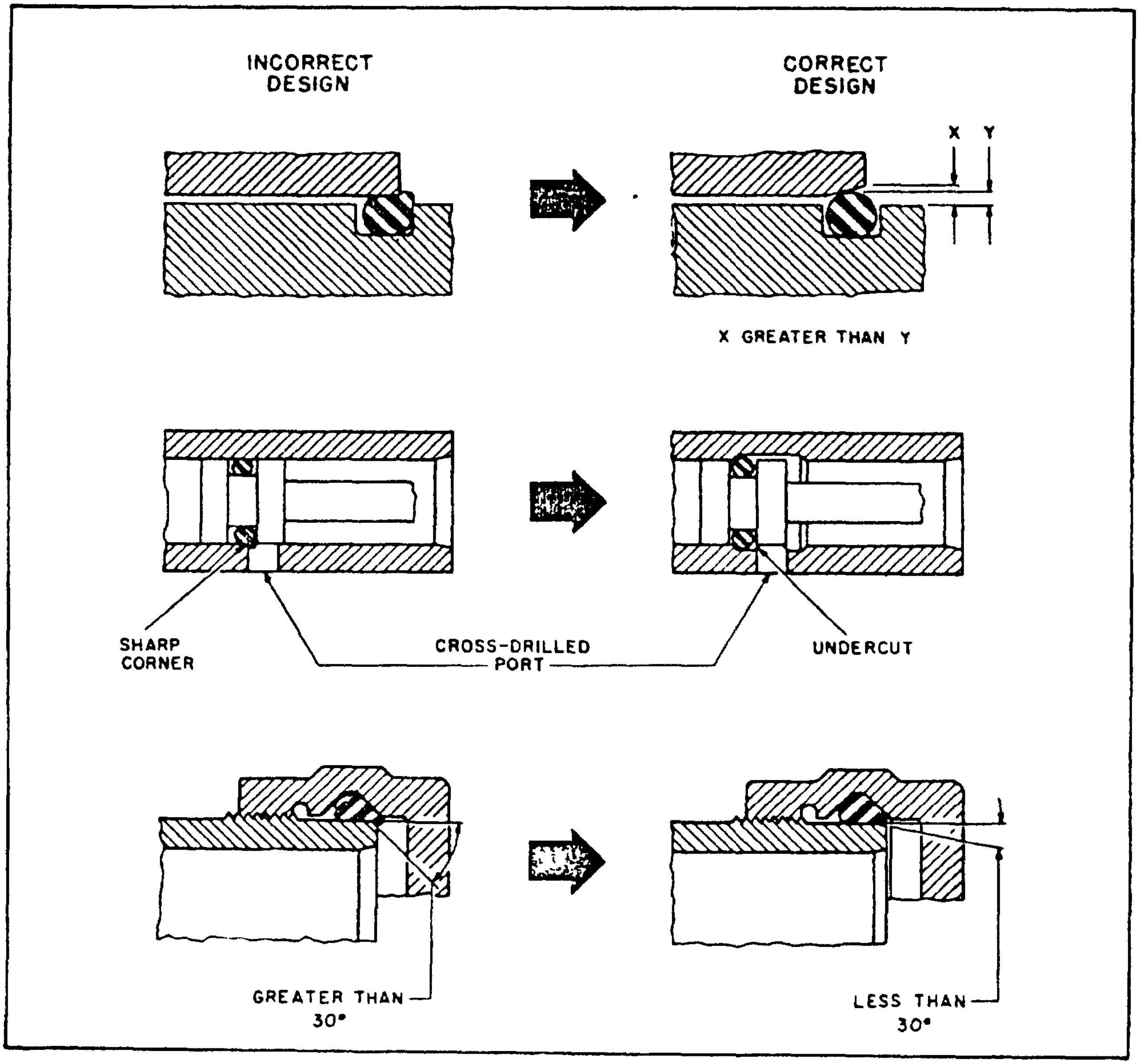
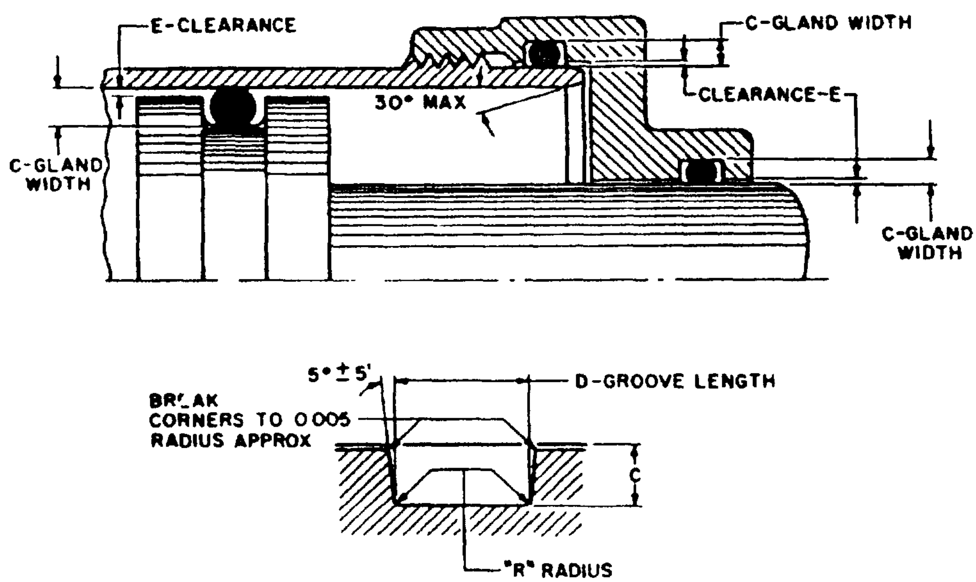


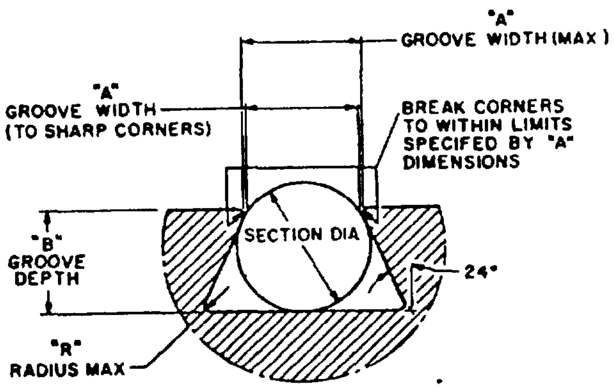
Figure 11. Design Considerations for O-ring Seals

50. Stresses in Low-Pressure Joints. The ASME formulas referred to above in paragraph 49 have been developed from research dealing specifically with pipe joints for which standard flange sizes and designs and standard bolting specifications are available. The formulas also are concerned with gaskets which lie completely within the bolt circle. Many of the principles indicated in the formulas are applicable to gasketing in general, but on the other hand, many joints and covers common to factory assembled mechanisms require a different approach. The various types of gasket materials require or tolerate quite different compressive stresses. For purposes of analytical discussion gasket

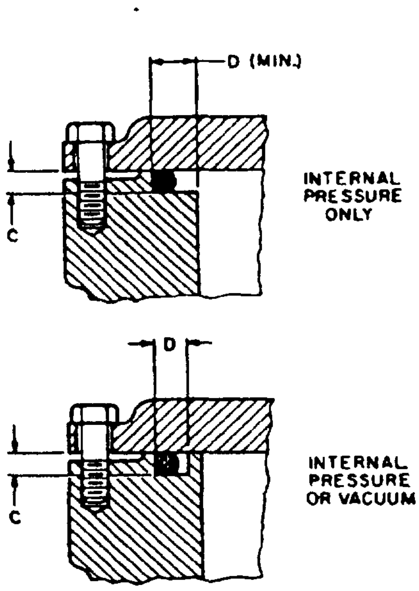


Specification Dash Number	Section Diameter, inch	Diametral Squeeze, min., inch		Gland Width (C), inch		Groove Length (D), inch					Radius (R), min., inch	Diametral Clearance (2 x E), max., inch
						Without Back-up Rings	With AN6246 Back-Up (Nonextrusion) Rings, +0.005, −0.000					
							Moving Seals		Static Seals			
		Moving Seals	Static Seals	Seals, Moving +0 000 −0.001	Static Seals, +0 000 −0 005		2 Rings	1 Ring	2 Rings	1 Ring		
AN6227 O-rings 1 to 7	0 070 ± 0 003	0 010	0 015	0 057	0 052	3/32	0 206	0.139	0.211	0 144	1/64	0 005
8 to 14	0 103 ± 0 003	0.010	0.017	0 090	0 083	9/64	0 238	0 171	0 245	0 178	1/64	0 005
15 to 27	0 139 ± 0 004	0 012	0 022	0 123	0 113	3/16	0 275	0 208	0.285	0 218	1/32	0 006
28 to 52	0 210 ± 0 005	0 017	0 032	0 188	0 173	9/32	0 410	0 311	0 425	0 326	3/64	0 007
53 to 88	0 275 ± 0 006	0 029	0 049	0 240	0 220	3/8	0 538	0 408	0 558	0 428	1/16	0 008
AN6230 Gaskets 1 to 52	0 139 ± 0 004	—	0 022	—	0 113	3/16	—	—	0 285	0 218	1/32	0 006

Figure 12. Standards for O-ring Packing and Gasket Installation



DOVETAIL GROOVE



STATIC FACE SEALS

Specification Dash No.	Section Diameter, inch	Groove Width (A), inch		Groove Depth (B), inch	Radius, min., inch	Depth (C), inch +0.000 −0.005	Width (D), inch
		To sharp Corners	Maximum				
AN6227							
1 to 7	0.070±0.003	0.057	0.062	0.056	0.005	0.052	3/32
8 to 14	0.103±0.003	0.085	0.090	0.083	0.010	0.083	9/64
15 to 27	0.139±0.004	0.114	0.119	0.113	0.010	0.113	3/16
28 to 52	0.210±0.005	0.168	0.173	0.173	0.015	0.173	9/32
53 to 88	0.275±0.006	0.226	0.231	0.220	0.015	0.220	3/8
AN6230							
1 to 52	0.139±0.004	0.114	0.119	0.113	0.010	0.113	3/16

Figure 13. Standards for O-ring Static Seals

materials can be classified into three groups, each with its own compression range These groups are: (1) the easily deformed, truly compressible types such as cork compositions and cork-and-rubber compounds, (2) incompressible compounds of rubber and rubber-like materials, and (3) fiber sheet packings

The general form of load compression curves for easily compressed materials is shown in figure 14, between points *A* and *B* The part of the curve below *A* indicates pressures which are too low to form and maintain a tight seal. Above point *B*, the pressures that are shown would compress the material almost to its ultimate density, while the forces indicated on the curve beyond *B* might produce compression set, creep, and rupture The suggested compression range for soft gasketing materials is between *A* and *B*. The pressures in that range will promote the necessary contact and maintain a ratio of stress to strain that is roughly proportional.

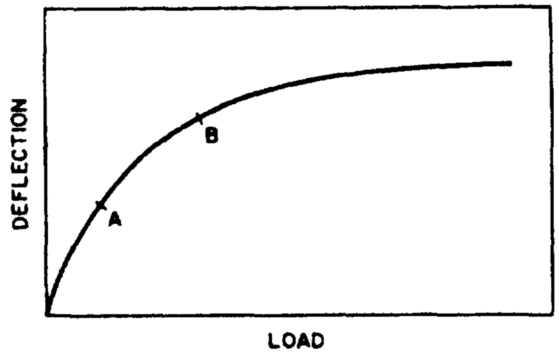


Figure 14. Typical Load-Deflection Curve for Easily Compressed Gasket Materials

For straight rubber compounds the problem is to apply pressure adequate to seal the joint, but not so compressive as to overstress the rubber or cause excessive extrusion. The load deflection characteristics of parts cut from sheet rubber will be highly variable according to such factors as: width and thickness of the gasket, type of flange finish, the presence of lubricants on the

TABLE 3. MACHINE BOLT AND COLD-ROLLED STEEL BOLT STUD LOADS[a]

Bolt Nominal Diameter, inches	Threads, per inch	Thread Root Diameter, inches	Thread Root Area, sq. inch	Bolt Stress					
				7,500 psi		15,000 psi		30,000 psi	
				Torque, lb.-ft	Compression, psi	Torque, lb.-ft	Compression, psi	Torque, lb.-ft	Compression, psi
1/4	20	0.185	0 027	1	203	2	405	4	810
5/16	18	0.240	0.045	2	388	4	675	8	1,350
3/8	16	0.294	0 068	3	510	6	1,020	12	2,040
7/16	14	0.345	0.093	5	698	10	1,395	20	2,790
1/2	13	0 400	0.126	8	945	15	1,890	30	3,780
9/16	12	0 454	0 162	12	1,215	23	2,430	45	4,860
5/8	11	0.507	0.202	15	1,515	30	3,030	60	6,060
3/4	10	0.620	0 302	25	2,265	50	4,530	100	9,060
7/8	9	0.731	0 419	40	3,143	80	6,285	160	12,570
1	8	0 838	0.551	62	4,133	123	8,265	245	16,530
1 1/8	7	0 939	0 693	98	5,190	195	10,380	390	20,760
1 1/4	7	1 064	0 890	137	6,675	273	13,350	545	26,700
1 3/8	6	1.158	1.054	183	7,905	365	15,810	730	31,620
1 1/2	6	1.283	1.294	219	9,705	437	19,410	875	38,820
1 5/8	5 1/2	1.389	1 515	300	11,363	600	22,725	1,200	45,450
1 3/4	5	1.490	1 744	390	13,080	775	26,160	1,550	52,320
1 7/8	5	1 615	2.049	525	15,368	1,050	30,735	2,100	61,470
2	4 1/2	1.711	2.300	563	17,250	1,125	34,500	2,250	69,000

[a] Data, courtesy Crane Co

contact surfaces, the durometer hardness and modulus of the particular stock involved, temperature, and rate and method of load application. A general recommendation is that for flat gaskets cut from a 60 durometer (Shore Type A) sheet rubber, the pressure is calculated as 500 to 1000 psi on the area of the gasket. For softer rubbers, the figure is decreased and for harder compounds it would be increased, but such computed figures should not exceed 25 percent deflection.

Fiber sheet packings generally require heavy pressures because of their relative firmness. The heavy pressures are necessary to produce adequate yielding for initial contact and, for many of these materials, to increase impermeability. Therefore, the problem is to apply adequate pressure rather than to be cautious for fear of overloading. In most cases, cellulose fibers require less flange pressure than asbestos-rubber types. The cellulose-fiber materials are preferred for light-pressure applications where constant operating temperatures do not exceed 160 deg. F., and where environmental conditions are not detrimental. The recommended minimum loadings for fiber gaskets in applications that do not involve holding liquid pressures are: for vegetables fiber, 500 psi, and for compressed asbestos and other hard sheets, 1000 psi

51. Surface Finishes. In joints designed for flat gaskets, some rough finish is desirable to prevent the gaskets from sliding or being extruded. The surface finish described as 250 microinch, or corresponding to General Electric standard F-6, provides a satisfactory finish for ordinary gasket applications In a heavy-duty joint, waviness and warping in flanges is undesirable, but in nonpressure applications it may be acceptable if soft, compressible gasket materials are used In O-ring joints, the gasket cavity must be very smoothly finished. The type of finish known as "super finish" is satisfactory, although in many applications the contact surfaces are chromium plated.

TABLE 4. ALLOY STEEL BOLT STUD LOADS[a]

Stud Nominal Diameter, Inches	Threads, per inch	Thread Root Diameter, Inches	Thread Root Area, sq inch	Bolt Stress					
				30,000 psi		45,000 psi		60,000 psi	
				Torque, lb-ft	Compression, psi	Torque, lb-ft	Compression, psi	Torque, lb-ft	Compression, psi
1/4	20	0.185	0.027	4	810	6	1,215	8	1,620
5/16	18	0.240	0.045	8	1,350	12	2,025	16	2,700
3/8	16	0.294	0.068	12	2,040	18	3,060	24	4,080
7/16	14	0.345	0.093	20	2,790	30	4,185	40	5,580
1/2	13	0.400	0.126	30	3,780	45	5,670	60	7,560
9/16	12	0.454	0.162	45	4,860	68	7,290	90	9,720
5/8	11	0.507	0.202	60	6,060	90	9,090	120	12,120
3/4	10	0.620	0.302	100	9,060	150	13,590	200	18,120
7/8	9	0.731	0.419	160	12,570	240	18,855	320	25,140
1	8	0.838	0.551	245	16,530	368	24,795	490	33,060
1 1/8	8	0.963	0.728	355	21,840	533	32,760	710	43,680
1 1/4	8	1.088	0.929	500	27,870	750	41,805	1,000	55,740
1 3/8	8	1.213	1.155	680	34,650	1,020	51,975	1,360	69,300
1 1/2	8	1.338	1.405	800	42,150	1,200	63,225	1,600	84,300
1 5/8	8	1.463	1.680	1,100	50,400	1,650	75,600	2,200	100,800
1 3/4	8	1.588	1.980	1,500	59,400	2,250	89,100	3,000	118,800
1 7/8	8	1.713	2.304	2,000	69,120	3,000	103,680	4,000	138,240
2	8	1.838	2.652	2,200	79,560	3,300	119,340	4,400	159,120
2 1/4	8	2.088	3.423	3,180	102,690	4,770	154,035	6,360	205,380
2 1/2	8	2.338	4.292	4,400	128,760	6,600	193,140	8,800	257,520
2 3/4	8	2.588	5.259	5,920	157,770	8,880	236,655	11,840	315,540
3	8	2.838	6.324	7,720	189,720	11,580	284,580	15,440	379,440

[a] Data, courtesy Crane Co.

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19 April 1988

GASKET MATERIALS (NONMETALLIC)

MIL-HDBK-212, Gasket Materials (Nonmetallic), adopted on 26 September 1958, has been reviewed and determined to be current.

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