Gasket roundup: sheet requirements, fabricator enhancements, and methods of measuring stress in a gasketed joint

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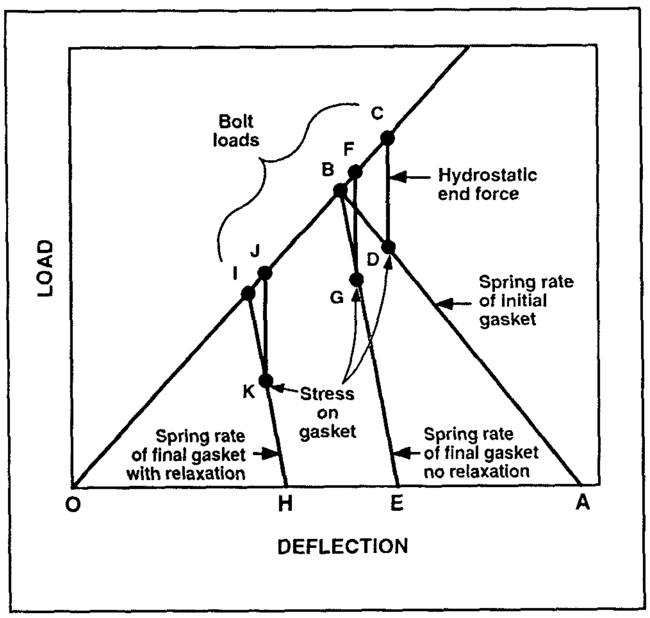
Gasket sheet stock must perform on three levels. It has to provide a durable seal in its intended application, withstand the rigors of post-production added-value operations, and be easy to install.

The sheets used by gasket fabricators to produce nonmetallic seals have strict requirements. Sheet properties must be tailored to meet the end-use application while satisfying processing requirements and installation needs. This article reviews the material properties relevant to the gasket fabricator and shows how these properties affect a gasket's ability to form a dependable, durable seal.

The article also describes some of the techniques fabricators use to enhance the base gasket material for demanding applications where the sheet alone provides an inadequate seal. Finally, the various methods of testing the stress distribution in a gasketed joint are described and evaluated.



1. Load-deflection curves for initial gasket, gasket under initial load (no relaxation), and gasket under load after relaxation

Important material properties

Application requirements

The following material properties are important because they affect the gasket's ability to create an effective seal.

- Compatibility—to be resistant to the media being sealed
- Heat resistance—to withstand the temperature of the environment
- Compressibility—to conform to the distortions and undulations of the mating flanges
- Microconformability—to "flow into" irregularities in the surface finishes of the mating flanges
- Recovery—to follow the flanges as they shift in response to thermal or mechanical forces
- Creep relaxation—to retain sufficient stress for continued sealing over an extended period of time
- Compressive strength—to resist crush and/or extrusion at high stress
- Erosion resistance—to accommodate fluid impingement in gaskets that function as a metering device
- Tensile strength—to resist blow-out from internal pressure
- Shear strength—to handle the thermally induced shear motion of the mating flanges
- *z*-direction strength—to prevent the gasket from fracturing upon removal
- Anti-stick—to prevent the gasket from sticking upon removal
- Heat conductivity—to facilitate heat transfer
- Acoustic isolation—to muffle noise generated by the application.

General sheet requirements

The most important material characteristic is that it be nontoxic. Next on the list is sealability. The ability to form

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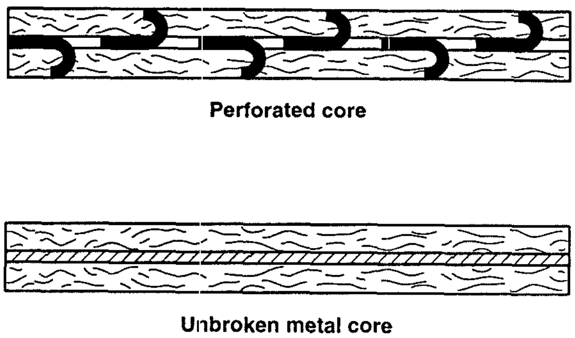
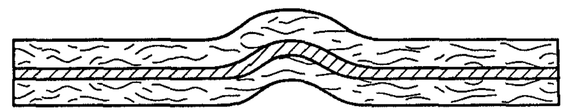


2. Reinforced gaskets



3. Metal core of reinforced gasket is unbroken after embossing.

an effective seal is a function of sheet properties as well as environmental conditions such as clamp load, bolt span, and flange rigidity.

Sheets produced by the beater-addition process are made by adding a rubber binder to a water slurry of fibers and materials. When the water is withdrawn on the paper machine, voids in the material are created. These voids must be closed for the gasket to seal. The gasket fabricator has several techniques for sealing voids in the sheet, and some of these techniques are described later in this article.

Sheet uniformity is another important characteristic. The formulation must be consistent throughout the sheet to ensure uniform compatibility with the materials that come into contact with the gasket. Sheet thickness, density, and surface finish also are important for general sealing performance.

Many gaskets have precise compressed-thickness requirements, since they must perform a dual function as shims and as gaskets. Thickness tolerance and density uniformity from lot to lot are important for control of compressed thickness. Uniform density is also of critical importance in the fabricator's added-value operations such as saturating, laminating, and surface coating. The surface finish has an impact on the material's sealing behavior and should be consistent within a lot and from lot to lot.

For long-term sealing performance, the gasket fabricator needs a material that shows little change in "spring rate" (deflection under load or stress) from initial clamp up to extended operation. The reason for this can be seen in the stress-strain curves[1] in **Fig. 1**, where

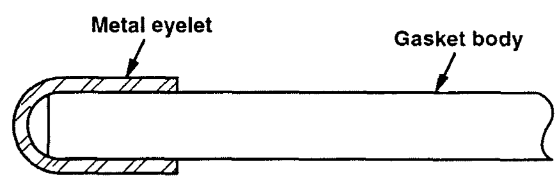
OB = Bolt load vs. gasket deflection

AB = Initial gasket compression under bolt load

CD = Hydrostatic end force

C = Increase in bolt load because of hydrostatic end force (CD)

D = Reduced stress on gasket because of hydrostatic end force (CD)



4. Gasket with metal eyelet

EB = Final gasket compression under bolt load and hydrostatic end force

FG = CD = hydrostatic end force

F = Increase in bolt load because of hydrostatic end force (FG)

G = Reduced stress on gasket because of hydrostatic end force (FG)

Note that the sealing stress on the gasket has been reduced from the initial level at point D to point G as a result of the change in the gasket spring rate during operation. The effect of relaxation of the gasket material can also be noted in this figure.

HI = Same spring rate as EB

BI = Relaxation of the gasket

JK = FG = CD = hydrostatic end force

J = Increase in bolt load because of hydrostatic end force (JK)

K = Reduced stress on gasket because of hydrostatic end force (JK)

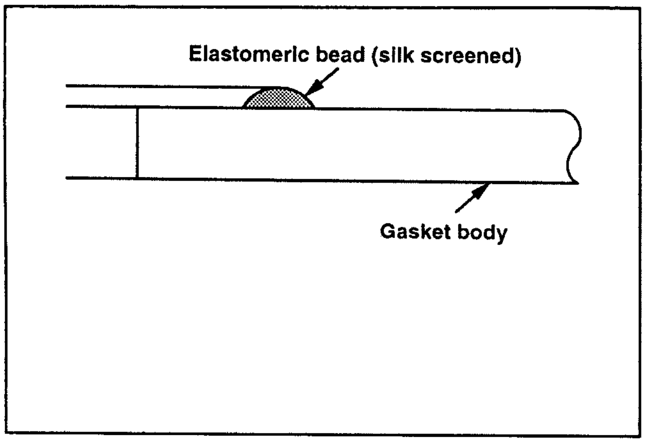
The reduction of the sealing stress on the gasket from G to K is due to the relaxation of the gasket.

Sheet requirements for processing and assembly

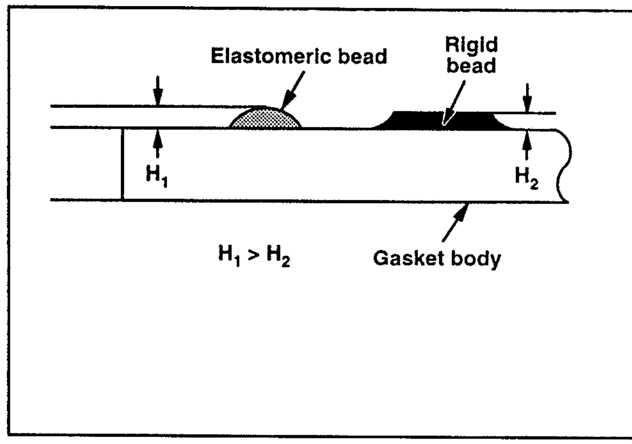
There are several important material qualities that affect the fabricator, who processes the sheets into gaskets, as

[1] Crouch, L. E., Czernik, D. E., Labrecque, V. J., and Lillis, S. M., in 1963 National Power Plant Proceedings, Society of Automotive Engineers, Warrendale, PA.

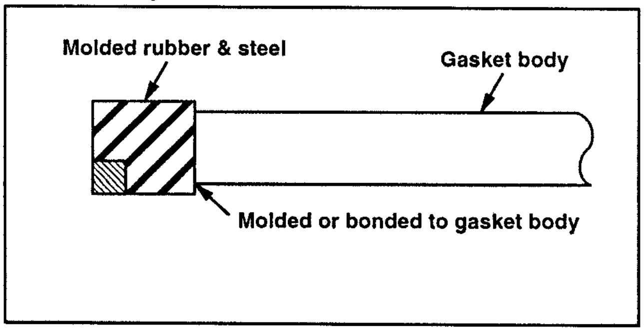
5. Gasket with elastomeric bead on surface



6. Typical profiles of rigid and elastomeric beads



7. Gasket with grommet



well as the end user, who assembles the gasketed joint.

Absence of dust and slivers. Sheets that create dust during blanking operations are undesirable. Dust gets into bearings and other machine components, resulting in premature repair and excessive downtime. Further, dust on the gasket surface compromises adhesion in subsequent coating and printing operations. Dust is also a major complaint of workers. Problems with dust have been troublesome since the conversion from asbestos to inorganic materials such as clay and aramid fibers.

The occurrence of slivers during blanking operations is another undesirable characteristic of nonasbestos materials. Slivers can cause dents in the gasket, resulting in potential leak paths. Sliver-free materials are highly prized by gasket fabricators because manual sliver removal is costly.

Low rate of tool wear. Tool wear has increased significantly since the conversion from asbestos-based sheets to nonasbestos. Reports of decreased tool life abound, with fabricators citing reductions in tool life by factors of 1/3 to 1/20. The exact reasons for the increased wear are not known, but the aramid fibers and inorganics are thought to be possible contributors. Many gasket manufacturers are investigating the causes of tool wear, and the Gasket Fabricators Association is in the process of studying this phenomenon.

Scuff resistance. The sheet's ability to resist scuffing is important to the fabricator. The rough handling and transporting of materials during fabrication can scuff the gasket surface, compromising its sealing performance.

Breaking strength. The material must have sufficient breaking strength to resist fracture during processing. Some operations exert considerable tensile pull on the material.

Suitable handling characteristics. The handling characteristics of the gasket material are important during processing as well as during gasket assembly. Rigidity of the gasket, for example, may be important for ease of assembly and insurance of proper installation. In some cases, such as when gaskets are installed by robots, special handling requirements must be taken into account.

Sealing enhancements

Some gaskets have sealing requirements that exceed the characteristics of the base gasket sheet. In such cases, the gasket fabricator relies on a number of sealing aids to improve the gasket and meet these requirements.

Saturation

Voids in the gasket material can be filled with any of several chemical resins. Saturants also can be used to enhance the gasket's heat and chemical resistance or to alter the physical properties of the material.

Coating

Coatings are applied to gaskets to

- Improve surface seal
- Improve gasket resistance to shearing motion from flange
- Reduce or eliminate sticking upon removal
- Provide tack for ease of assembly
- Provide a barrier coat for subsequent printing
- Reduce gasket-to-gasket sticking during processing and shipping
- Add color for identification.

Combining and laminating

The gasket material can be mechanically combined with a perforated core or chemically laminated to an unbroken rigid material such as metal, as seen in **Fig. 2**. Such reinforcements improve the mechanical properties of the material.

Embossing

A gasket material that has been reinforced by combining or laminating can be embossed, as seen in **Fig. 3**. The high stresses created at the embossments enhance sealing in localized areas.

Eyelets

Metal eyelets are used at port openings to protect the gasket material from the sealed media and to provide high sealing stress on the eyelet. Eyelets can also be used at bolt holes to reduce distortion of the gasketed joint. **Figure 4** is a cut-away side view of an eyelet applied to a gasket body.

Printing

Gaskets are commonly printed with elastomeric beads to enhance their sealing characteristics.[2] The elastomer is applied to strategic locations on the gasket surface via a silk-screening-type process, and a typical bead is illustrated in **Fig. 5**. The seal at these locations is improved because of the higher stress of the rubberlike interface with the mating flange. The beads also provide longer-term sealing because of their higher recovery properties. Various elastomers are used, with silicone being the most popular. These materials enhance sealing by reducing the sizes of voids in the gasket material and providing a rubber-to-metal seal.

Rigid beads, created by deposition of rigid epoxies, are sometimes incorporated in gaskets for compression-limiting purposes or to reduce joint distortion. Rigid beads are typically shallower than elastomeric beads, as illustrated in **Fig. 6**.

The printing technique has changed the look of the engine-gasket industry. While the printing patents were in existence, there were more than 30 worldwide licensees of the technology. An extension of this technique is to deposit the bead or beads using a tracer or robot. This permits utilization of more material and extends the range of bead thickness. Another variation is to combine printing with embossing, wherein a robot deposits an elastomeric bead into the emboss. The end result can be likened to a trapped O ring that possesses extensive recovery characteristics.

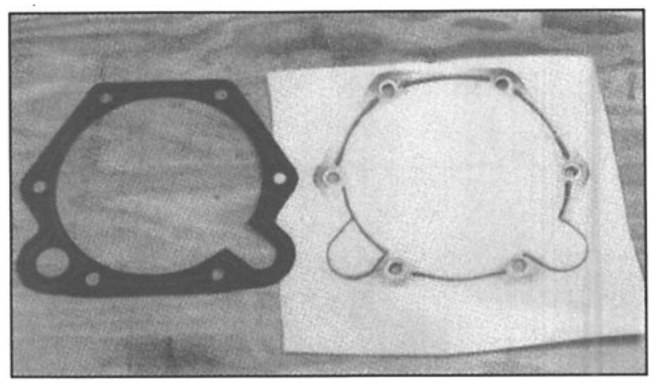
Another adaptation of the printing technique is called mold in place (MIP), wherein an elastomeric bead is molded to the gasket material or gasket. This technique provides precise control of bead thickness to produce exacting three-dimensional gaskets. The MIP technique can be done using injection-molded liquid silicone.

Grommets

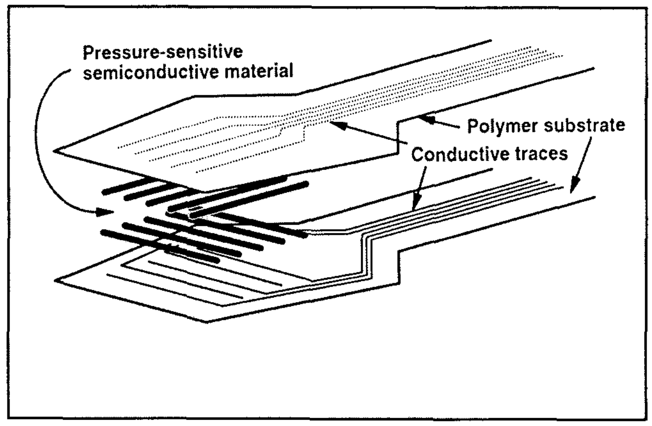
In the gasket industry, grommets are molded rubber parts, sometimes reinforced with metal or plastic. Grommets are molded or bonded to the gasket to improve sealing at troublesome locations, as seen in **Fig. 7**. Grommet cross-sections are virtually unlimited, permitting a large range of design possibilities. Many materials are used for grommets, including nitrile, neoprene, polyacrylic, silicone, and fluorocarbon.

[2]Czernik, D. E., Recent developments and new approaches in mechanical and chemical gasketing, SAE paper 810367, Society of Automotive Engineers, Warrendale, PA., Feb. 1981.

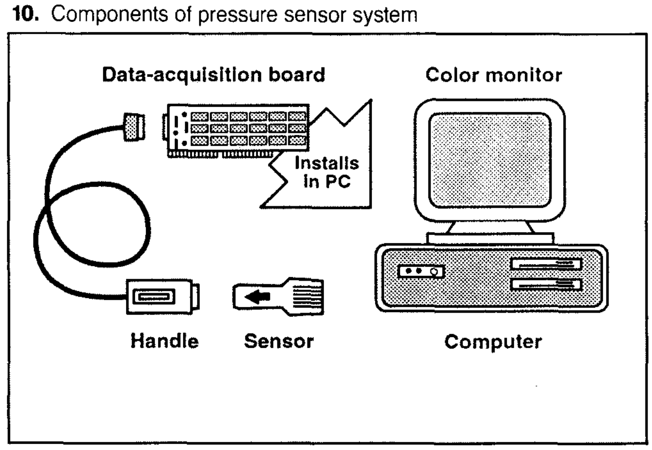
8. Stress distribution in a gasketed joint as measured by the impression method



9. Pressure sensor



10. Components of pressure sensor system



Measuring stress distribution in a gasketed joint

Proper stress distribution is essential if the gasket is to provide an effective seal. Stress distribution in a specific gasketed joint can be measured by one of several impression methods or by a recently developed pressure sensor.

Impression methods

Carbon paper. Regular carbon paper, once extensively used to produce typewritten copies, is part of a two-piece system. One sheet is the carbon carrier, and the other is a clean sheet of paper to receive the transferred carbon. Stress impressions obtained with this technique provide a "yes-no" or "on-off" visual effect. That is, sufficient stress either was or was not available to transfer the carbon from the carbon paper to the clean sheet. This provides a very narrow range of stress information. It is possible to use multiple layers of carbon paper to obtain a better measure of the stresses. In such cases, however, the compressibility of the paper stack must be taken into account, particularly with gaskets that inherently possess little compressibility. Because of these limitations, the carbon paper method is rarely used.

Carbonless paper. Carbonless or no-carbon-required (NCR) paper is available as a single sheet containing pressure-sensitive chemicals within the paper. The applied stress crushes the encapsulated chemicals and imparts color to the paper. NCR paper is an improvement over regular carbon paper, since it is a single sheet and the impression density or color intensity is proportional to the stress applied. Load machines (e.g., Instron or MTS devices) can be used to establish the relationship between load level and the density of the color impression. Because the paper is available in only one pressure range, its use is limited.

Stress-sensitive film. Stress-sensitive film (Fuji Photo Film Co., Ltd.) functions in a manner similar to NCR paper and is available in one- or two-sheet systems in four pressure ranges. This film is an improvement over the carbonless paper in that it permits fine tuning of the stress distribution. Also, with the use of a commercially available densitometer, the color density of the impression can be directly converted to stress readings. Since the film is affected by time, temperature, and humidity, these conditions must be taken into account when analyzing the color intensities. As with the NCR system, color readings can be calibrated using a load machine to establish the relationship between load level and color intensity.

The first step in evaluating the stress distribution within a sealed joint is to cut the stress-sensitive film (or carbon or NCR paper) in the shape of the mating flanges. Holes for the fasteners are punched out. The film is then placed between the flanges, and the fasteners are tightened to the specified torque. When the paper is removed from the gasketed joint, it shows the stress distribution pattern on the gasket. **Figure 8** illustrates typical results for a gasket.

A deficiency of the impression techniques is that they all indicate a one-time maximum stress during the course of testing. The impressions are incapable of reflecting reductions in stress during the torquing sequence or from external forces.

Pressure sensors

The newest technology uses electrical sensors to measure stress distribution in real time. Stress can be measured during the loading and unloading modes, and in some cases, the unloading generated by hydrostatic end forces can be determined. This technology is patented in several countries, including the United States.

The sensor, approximately 0.1 mm thick, is made up of two flexible, thin, mylar-like sheets with conductive traces (electrodes) formed on them. As seen in **Fig. 9**, the inside surface of one sheet has a row pattern, while the inside surface of the other sheet has a column pattern. When the two sheets are brought into contact, the intersection of rows and columns forms a grid pattern with electrical point junctions.

Before assembly, a thin resistive/conductive ink coating is applied as an intermediate layer between the two electrical contacts (rows and columns). The ink provides an electrical resistance/conductance between the contacts, and this resistance changes with applied external force. When installed on a gasket and clamped within the sealing joint, the sensor provides an array of electrically conductive points. Associated with each of these points is a discrete electrical resistance/conductance that is related to force.

By measuring the minute changes in current flow at each junction, the pattern of force distribution can be measured and displayed on a computer screen as a two- or three-dimensional color image. The display includes a color bar chart that depicts the relative amount of force, and a windowing feature allows evaluation of stress in localized areas. The measuring system, illustrated in **Fig. 10**, uses a variety of universal and customized sensors.

Summary

The base sheets used in the manufacture of gaskets are subject to strict requirements. Not only must they fulfill the needs of the intended application, they also must meet the special needs of the gasket fabricator, who often adds enhancements such as eyelets, grommets, coatings, or elastomeric beads to improve the gasket's sealability in demanding applications. Finally, the end user who installs the gasket wants a product that is easy to put in and take out.

No gasket can form an effective seal in a joint where the bolted stress on the gasket is improperly distributed. There are several "impression" methods that measure the stress distribution using film or carbonless paper. However, a new computer-based method using electrical grids embedded in thin sheets of film provides precise, detailed measurements of the stress within a gasketed joint.□

Received for review Jan. 15, 1991.

Accepted Aug. 12, 1991.

Presented at the TAPPI 1991 Nonwovens Conference.

Keywords: Assembly, gaskets, mechanical properties, paper properties, sealability, sealing, sensors, sheets, specifications.