



GRAFOIL®

Flexible Graphite

Engineering Design Manual

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2nd Edition

Sheet and Laminate Products

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GRAFT[®]TECH

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A BRIEF HISTORY OF GRAFTECH INC.

As a member of the GrafTech International Ltd. family of companies, Graftech Inc. is building its future on over 100 years of experience and expertise in carbon and graphite manufacturing. Since its inception in 1963, Graftech has identified and developed flexible graphite for high-tech applications, offering its customers advantages in performance and cost. In the 1970's, Graftech's core product, GRAFOIL flexible graphite, became a highly successful replacement for asbestos in high temperature sealing applications, a superior gasketing material for automotive engine applications in the 80's, and, in the 90's the basis for highly engineered products and solutions for applications in fuel cells, electronics, and in construction and building materials.

Flexible graphite's flexibility, resilience, and conformability enables Graftech to commercially manufacture a variety of materials and products, providing its customers with individually designed products and solutions for diverse applications in a wide range of industries. Graftech's rich history of innovation, technical expertise, and a dedication to quality and customer service will serve its customers well into the 21st century. Graftech's Product and Process Development Center in Parma, Ohio, is widely recognized as one of the world's finest facilities devoted to the study and development of carbon and graphite. Scientists, engineers, and technicians at Parma work to develop new products, and support our sales force by providing custom design assistance, consulting services, technical information, and educational programs to help customers obtain optimum performance and maximum value from our products.

As a global supplier, Graftech's success hinges on its reputation for quality... quality in its products and services, its people, and its relationships with customers, vendors and suppliers. Beginning in the early 1980's, Graftech embarked on an ambitious program of continuous quality improvement in every facet of its operations. It was among the first in its industry to adopt Statistical Process Control (SPC) manufacturing methods. Graftech employs the latest (SPC) methods to reduce product variation. At every stage of its manufacturing process -from raw materials to final finishing - rigid programs and procedures produce the highest quality flexible graphite products in the world. Graftech was also among the first to embrace a philosophy of Total Quality that extends throughout its organization, achieving ISO-9002 certification in 1996 and QS-9000 in 2000. Graftech's philosophy of Total Quality permeates the total organization from its stringent product and process standards to its innovative management methods and training programs. It is this constant quest for Total Quality, to meet the needs of its customers, that assures Graftech's continuing success as a world leader in its industry. Graftech has a proud heritage of more than a century of industry leadership and product innovation. Today, no other company in the world is better positioned to serve the needs of the growing global marketplace for high quality natural graphite-based products and solutions. With this knowledge and technology base, Graftech will continue to identify new growth opportunities.

Preface

In 1965 Graftech Inc. (formerly Union Carbide Corporation) introduced GRAFOIL flexible graphite. It was the first fluid sealing product made exclusively from pure, natural graphite. GRAFOIL flexible graphite was created by a unique Graftech process. GRAFOIL flexible graphite was invented in the United States and the patents on GRAFOIL products are held by Graftech Inc.

This special material exhibits outstanding fluid sealing characteristics that continue to solve the most challenging gasketing and packing problems in industry. Like its forerunner, pyrolytic graphite, GRAFOIL flexible graphite is resistant to heat, has no water of crystallization, is naturally lubricious, is chemically inert, and is an excellent conductor of heat and electricity.

Unlike manufactured pyrolytic graphite, GRAFOIL material is flexible, compactible, conformable and resilient. GRAFOIL flexible graphite can be made into an infinite variety of shapes to fit virtually any fluid sealing application.

The intent of this engineering design manual is to assist the engineer in using GRAFOIL flexible graphite by providing technical data regarding GRAFOIL sheet and gasketing materials. For specific guidelines on gasket requirements and design, the reader is encouraged to follow the recommendations put forth by the American Society of Mechanical Engineers. Some of these recommendations are included in Appendix 5. In addition, the pamphlet "Optimum Gasketing with GRAFOIL Flexible Graphite" by Henry S. Raub, is available on request from Graftech Inc.

Since pioneering the development of GRAFOIL flexible graphite, Graftech Inc. has been committed to finding new ways to make this unique product work for fluid processing industries. As time and technology create new problems, Graftech Inc. will continue to provide users of GRAFOIL flexible graphite with the ultimate design control in fluid sealing products.

Graftech Inc. makes no warranty, expressed or implied, concerning the information or statements set forth in this manual and expressly disclaims any liability for incidental and consequential damages arising out of damage to equipment, injury to persons or products, or any other harmful consequences resulting from the use of the information or reliance on any statement set forth in this manual.

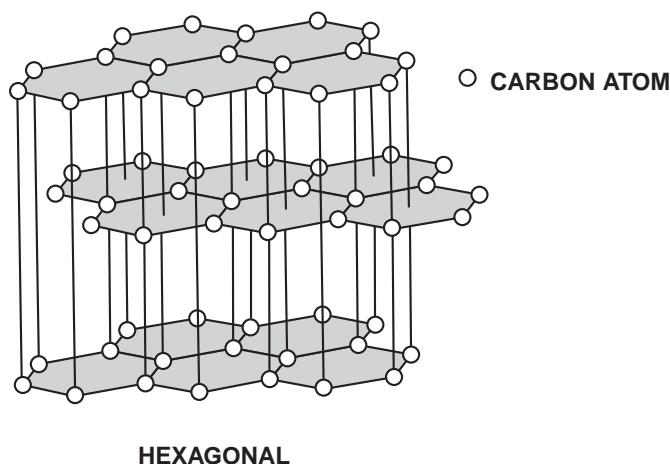
GRAFOIL FLEXIBLE GRAPHITE MATERIALS

General Graphite Properties

GRAFOIL flexible graphite, manufactured by Graftech Inc., has unique physical and chemical properties that make it ideal for sealing and for high-temperature applications, such as thermal radiation shielding.

GRAFOIL flexible graphite is manufactured using crystalline, naturally-occurring graphite flake. The crystal structure of natural graphite consists of layered planes of hexagonally arranged carbon atoms (see Figure 1) with co-valent bonding of each carbon atom with three other carbon atoms within the layer planes and weak bonding (Van der Waals forces) between the planes. This structure leads to the directional differences (or anisotropy) in electrical, thermal, and mechanical properties of graphite and explains its natural lubricity.

Figure 1 Crystal Structure of Graphite



GRAFOIL flexible graphite is a distinctive material with the essential characteristics of graphite plus some unique properties which make it a valuable material for packings and gaskets. Standard properties of manufactured graphite include thermal stability, thermal conductivity, natural lubricity and chemical resistance to fluids. GRAFOIL flexible graphite combines these properties with the added characteristics of flexibility, compactibility, conformability and resilience. These characteristics differentiate GRAFOIL flexible graphite from other forms of graphite, making it a superior, high-performance sealing material. The essential characteristics of graphite and GRAFOIL flexible graphite are described in Table I.

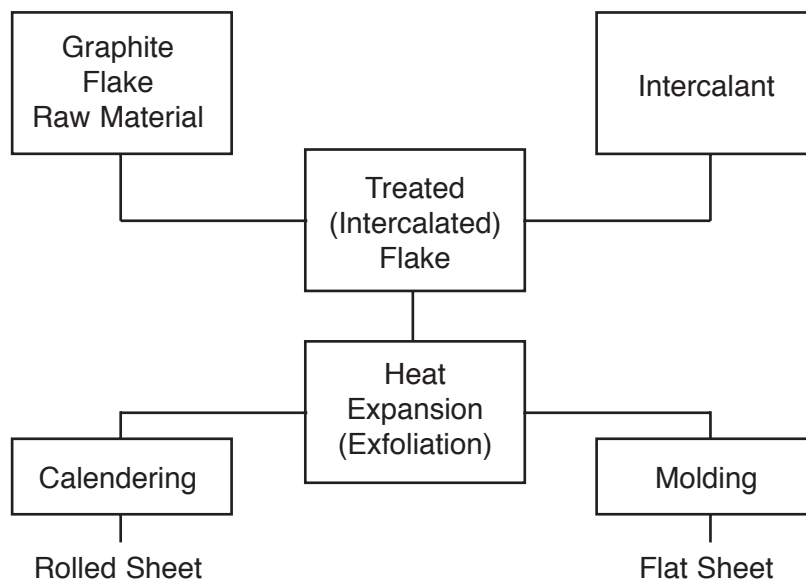
Table I Essential Characteristics of Graphite and Flexible Graphite

	Manufactured Graphite	Flexible Graphite
Thermally Stable	X	X
Thermally Conductive	X	X
Naturally Lubricious	X	X
Chemically Resistant to Fluids	X	X
Flexible		X
Compactible		X
Conformable		X
Resilient		X

GRAFOIL Sheet Manufacturing Process

GRAFOIL flexible graphite is prepared by chemically treating natural graphite flake to form a compound with and between the layers of the graphite structure. This intercalation or “between the layer” compound is then rapidly heated to decomposition. The result is an over eighty-fold expansion in size compared with the flake raw material. This expansion (exfoliation) produces worm-like or vermiform structures with highly active, dendritic, rough surfaces which are generally calendered into sheet form. Figure 2 shows the manufacturing process for GRAFOIL flexible graphite.

Figure 2 Manufacturing Process for GRAFOIL Flexible Graphite Sheet Products



The calendering involves only mechanical interlocking of the expanded flakes, and no added binders are required. The resulting sheet product is essentially pure graphite: at least 98% elemental carbon by weight, and having a highly aligned structure. All of the chemicals added to the flake to promote expansion are removed during the high temperature expansion process. Only naturally occurring minerals (from the raw materials) remain as part of the product in the form of oxides of metals, typically referred to as ash. Premium sheet products (such as those required for nuclear service) are specially processed with extremely low levels of potential impurities (typically 99.9% carbon). Added corrosion and oxidation resistance can be introduced as an integral part of the sheet material.

Rolls of GRAFOIL flexible graphite are available in sheet thicknesses of 0.003" to 0.065" (0.08 to 1.65 mm) and widths of 24", 39.4" or 60" (61, 100, 152.4 cm). The standard roll length is 100' (30.48 m), although other lengths up to 4000' (1200 m) are available upon request.

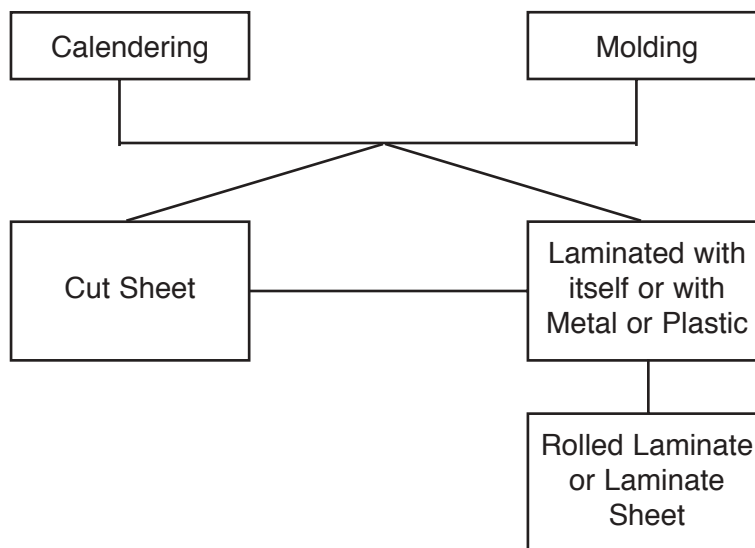
Methods for Producing GRAFOIL Laminates for Industrial Use

GRAFOIL sheet can be laminated together with an adhesive or thermal bond to form gaskets for many uses. The primary use of GRAFOIL-to-GRAFOIL laminates is to increase the thickness of a gasket or packing ring. The GRAFOIL laminate can be thermally treated to decrease outgassing when it is to be used in a high-temperature application, such as a furnace lining, or when small quantities of volatiles from outgassing of the adhesive could promote contamination.

GRAFOIL sheet can also be laminated with metallic and nonmetallic materials to improve its handling, blowout resistance and mechanical strength. The use of these laminating materials may alter the physical, thermal, chemical and electrical properties of the laminate. Even though the inherent sealing ability of GRAFOIL flexible graphite can be reduced when the non-graphite laminating materials are on the external surfaces of the gasket, such GRAFOIL laminates have some important gasketing applications.

The manufacturing processes for producing GRAFOIL laminates are shown in Figure 3. Specific composites can be tailored to meet many difficult sealing requirements.

Figure 3 Manufacturing Processes for GRAFOIL Sheet and Laminates



The industrial gasket grades are made from laminates processed from various thickness of GRAFOIL sheet. The use of a metal interlayer also improves the compressive load carrying ability of GRAFOIL laminates. For example, Grade GHE has a perforated and tanged stainless steel interlayer mechanically clinched to GRAFOIL sheet. Pressure sensitive adhesives may also be applied to the surface of the GRAFOIL sheet to aid in fabrication of form-in-place gasket tape or thread sealant tapes. When interlayers and adhesives are used, the thermal, mechanical, and chemical behavior of the gasket is modified.

Fabrication of Other GRAFOIL Products

An assortment of engineered sealings products can be fabricated from GRAFOIL flexible graphite sheet and roll stock. For example, Ribbon Pack® corrugated tape can be slit from rolled sheet, then corrugated (crinkled) for use in valve stem or pump packings. It is also the raw material used for making Die Molded Rings for valve and pump packings (GTR and GTZ). Adhesive-backed grades (GTH and GTF) can also be made from GRAFOIL sheet to fabricate form-in-place gasket tapes or flat thread sealant tape.

The different grades of GRAFOIL sheet and GRAFOIL laminate products are shown in Appendix 1.

GRAFOIL GASKETING FOR INDUSTRIAL APPLICATIONS

Introduction

GRAFOIL flexible graphite gasketing materials can be engineered for specific industrial static sealing applications. This manual is an engineering aid for a wide variety of industrial fluid sealing applications. Appendix 5 contains helpful information for GRAFOIL gasket design and applications.

The ASTM Standard F-104 “Standard Classification System for Nonmetallic Gasket Materials” classifies flexible graphite as a Type 5 nonmetallic gasket material. The type is further divided into Class 1 for homogeneous sheet and Class 2 for laminated sheet.

GRAFOIL flexible graphite is an ideal replacement for asbestos-based gaskets. GRAFOIL flexible graphite can also be used in high-temperature applications where asbestos is not suitable. The common asbestos fiber, chrysotile, begins to decompose at 900°F (480°C), and organic elastomeric binders in typical gasket materials begin to decompose at even lower temperatures. GRAFOIL products can be used at temperatures as high as 5400°F (3000°C) in reducing environments. Oxidation of graphite occurs above 850°F (455°C) in the presence of oxygen or air. However, the temperature and rate of oxidation and consequent useful life is a complex phenomenon depending on many variables, such as extent of exposure to temperature, gas velocity, and oxygen concentration. GRAFOIL gasketing products are seldom exposed in bulk form. The “thin edge” exposure of GRAFOIL packing and gasketing has successfully withstood extended periods of exposure to air at process fluid temperatures up to 1500°F (815°C). GRAFOIL material is available in special grades with oxidation inhibitors which significantly reduce bulk graphite oxidation rates at temperatures up to 1560°F (850°C). The chemical resistance and thermal stability of GRAFOIL flexible graphite makes it an effective sealing material where fire-safe sealants are required.

GRAFOIL flexible graphite is compatible with most organic and inorganic chemicals that are non-oxidizing. Flexible graphite should not be used in highly oxidizing chemicals such as mixtures of sulfuric acid and nitric acid or in very strong mineral acids. In each application, the Material Safety Data Sheets (MSDS) of the chemical should be reviewed. If there are compatibility questions, contact Graftech Inc.

The gasketing performance of GRAFOIL flexible graphite is superior to conventional elastomeric bonded gasketing. GRAFOIL flexible graphite is more thermally stable and chemically inert with considerably less creep relaxation than elastomeric bonded gasketing materials. GRAFOIL flexible graphite gaskets are also superior to other nonasbestos type

sheet gaskets. When nonasbestos fillers such as aramids, fiberglass, and mica have been used to replace asbestos, the elastomeric component of the gasket has been increased to maintain saturation and bonding. The elastomer typically reduces gasket thermal stability and increases creep, often resulting in poor performance under load.

A growing number of research papers show that GRAFOIL flexible graphite not only provides better sealing performance in those applications where asbestos has traditionally been used, but that it offers excellent sealing capability over a wider range of chemical and temperature conditions. As in all gasket applications, however, the equipment and flange design must be adequate in order to achieve a seal. GRAFOIL flexible graphite is not a “cure all” gasket material, and should not be depended on to compensate for poorly designed or poorly maintained sealing systems.

GRAFOIL Sheet Designations

There are presently five grades of GRAFOIL homogeneous sheets produced for fluid sealing applications: Grades GTA, GTB, GTJ, GTK, and GTY. The primary differences between these grades are their purity levels (percent graphite), resistance to oxidation/corrosion, and thickness.

Grade GTA is a high-purity grade (minimum 99.5% graphite) containing less than 50 ppm leachable chlorides, and less than 630 ppm total sulfur.

Grade GTJ is a high-purity grade based on Grade GTA. This grade contains phosphorous oxides as an inorganic, nonmetallic, passivating corrosion inhibitor that also increases resistance to oxidation by about 125°F (70°C). Grade GTJ has a minimum 99% graphite content. Grade GTJ is recommended for nuclear and other special applications where corrosion of stainless steel components is of critical concern. Both grades GTA and GTJ meet the General Electric Non Metallic Nuclear Materials Specification D50YP12 Revision 2. The passivating inhibitor in Grade GTJ is uniformly distributed throughout the product during its manufacture and significantly reduces possible galvanic corrosion of stainless steel surfaces. This process eliminates localized “hot spots” of corrosion which can occur with impregnated or coated passivating and sacrificial inhibitors. Corrosion protection of stainless steel components such as valve stems, pump shafts, and flanges is comparable with that of the sacrificial metal inhibitors, such as zinc and aluminum.

Grade GTB is the standard industrial grade with oxidation/corrosion inhibitors (minimum 95% graphite) containing less than 50 ppm leachable chlorides and less than 1000 ppm total sulfur content. Note that Grade GTB has a leachable chloride level well below most conventional asbestos based gaskets. Grade GTB meets the material requirements of the Naval Sea Systems (NAVSEA) specification MIL-P-24503.

Grade GTK has the same purity level as Grade GTB and the improved resistance to oxidation and/or corrosion similar to Grade GTJ.

Properties of GRAFOIL Sheet and Laminates

Physical and Chemical Properties

The physical property data for various grades of GRAFOIL sheets are presented in Table II. The data presented in this table are typical values. As indicated in Appendix 1, most gasketing grades are produced with metallic interlayers, although some are made with plastic and glass interlayers. Sometimes special oxidation/corrosion resistant sheet grades are used to prepare these laminates. Call Graftech Inc. for the purchase specifications for each of the grades.

Bulk Density

The density of a GRAFOIL sheet is obtained from the physical measurements of length, width, thickness, and weight. The standard density is 70 lbs/ft³ (1.12 g/cc), although densities from 45 lbs/ft³ (0.72 g/cc) through 85 lbs/ft³ (1.36 g/cc) are also available. Density is controlled in the manufacturing process by the degree of compaction during the calendering operation. The theoretical density of graphite is 140 lbs/ft³ (2.26 g/cc). Therefore, the standard GRAFOIL sheet at 70 lbs/ft³ (1.12 g/cc) density is only one-half the theoretical density. This allows the sheet the compressibility required to produce an effective seal in gasket applications.

The density of the GRAFOIL sheet also affects other properties. Increasing the density will affect the trend of other properties as shown in Table II.

Table II The Effect on Other Properties of Increasing GRAFOIL Sheet Density

Compressibility	Decrease
Recovery	Increase
Sealability	Increase
Tensile Strength	Increase
Thermal Conductivity	Increase
Oxidation Rate	Decrease
Flexibility	Decrease
Young's Modulus	Increase
Hardness	Increase
Abrasion Resistance	Increase
Electrical Resistance	Decrease

As a comprehensive load is applied, the percent strain of the homogeneous sheet is increased. This relationship is logarithmic, as shown in Figure 4.

Table III Typical Room Temperature Properties of GRAFOIL Flexible Graphite Sheets

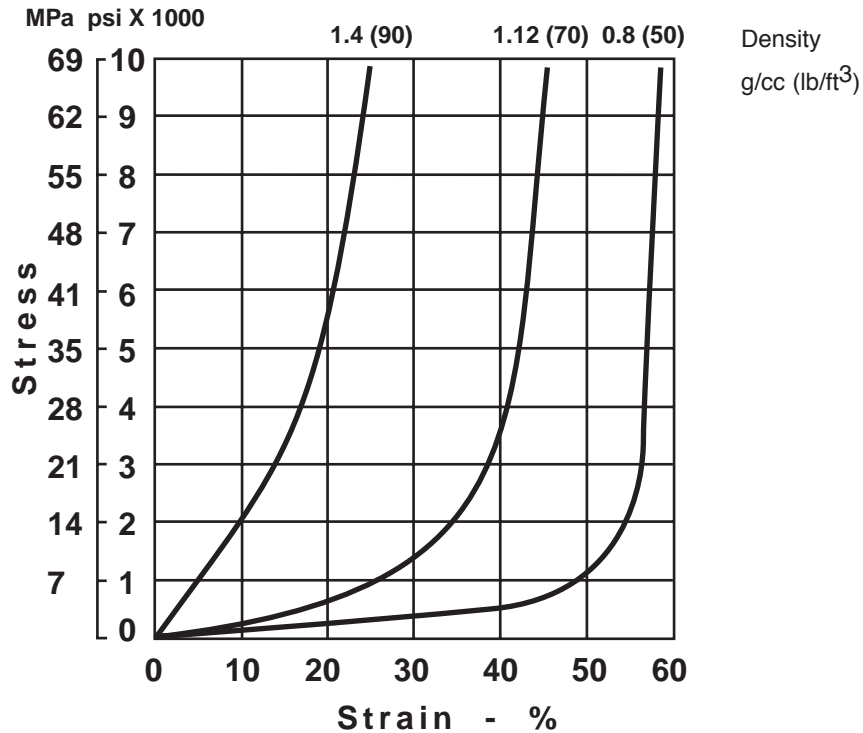
Property	Units		Method	GRAFOIL Sheet Grades			
	English	ASTM Metric		GTA	GTB	GTJ	GTK
Bulk Density of GRAFOIL Sheet	lbs/ft ³	g/cc	F-1315	70/1.12	70/1.12	70/1.12	70/1.12
Tensile Strength along Length and Width (1)	lbs/in ²	MPa	F-152	750/5.2	650/4.5	750/5.2	650/4.5
Young's Compress. Modulus Through Thickness	10 ³ lbs/in ²	GPa	—	27/0.19	27/0.19	27/0.19	27/0.19
Compression Strength Maximum Usable Unconfined	lbs/in ²	MPa	C-695	24,000/165	24,000/165	24,000/165	24,000/165
Gas Permeability Through Thickness	Darcy's X 10 ⁻⁶	Darcy's X 10 ⁻⁶	C-577	<10/<10	<10/<10	<10/<10	<10/<10
Friction Static	Coefficient	Coefficient	—	All from 0.05 to 0.20			
Minimum Working Temperature	°F	°C	—	-400/-240	-400/-240	-400/-240	-400/-240
Maximum Working Temp. (2)	°F	°C	—	5400/3000	5400/3000	5400/3000	5400/3000
Thermal Conductivity Along Length and Width Through Thickness	BTU•in/hr•ft ² •°F	W/m•K	Fitch Method	All at 70°F(21°C) = 960/140 All at 70°F(21°C) = 36/5			
Coef. of Ther. Exp. (Linear) Along Length and Width Through Thickness	10 ⁻⁶ in/in•°F	10 ⁻⁶ m/m•°C	—	All at 70 to 2000°F (21°C to 1094°C) = -0.2/-0.4 All a 70 to 4000°F (21°C to 2206°C) = +15.0/+27.0			
Specific Heat (3)	Btu/lb•°F	J/kg•K	—	All at 75°F(24°C) = 0.17/711			
Electrical Resistivity Along Length and Width Through Thickness at 100 psi (.69MPa)	ohm•in	ohm•m	C-611	3.1 x 10 ⁻⁴ /8 x 10 ⁻⁶ .59/15000 x 10 ⁻⁶	3.1 x 10 ⁻⁴ /8 x 10 ⁻⁶ .59/15000 x 10 ⁻⁶	3.1 x 10 ⁻⁴ /8 x 10 ⁻⁶ .59/15000 x 10 ⁻⁶	3.1 x 10 ⁻⁴ /8 x 10 ⁻⁶ .59/15000 x 10 ⁻⁶
Carbon Content (Minimum)	w/o	w/o	C-571	99.5/99.5	98.0/98.0	99.0/99.0	98.0/98.0
Ash Content (Maximum)	w/o	w/o	C-561	0.5/0.5	2.0/2.0	1.0/1.0	2.0/2.0
Sulfur Content (Maximum)	ppm	ppm	Leco Method	630/630	1000/1000	630/630	1000/1000
Oxidation Rate at 500°C (932°F) 700°C (1292°F)	Loss oz/ft ² •hr	Loss g/m ² •hr	—	0.28/0.75 49.4/130	0.17/0.45 34.2/90	0.01/0.03 4.5/12	0.026/0.07 11.4/30
Leachable Chlorides (Maximum)	ppm	ppm	F-1277	50/50	50/50	50/50	50/50

(1) Tensile strength measured with cross-head rate of 0.5 in/min.

(2) Nonoxidizing — In an oxidizing atmosphere, 850°F (445 °C) is the maximum for Grade GTA and 975°F (525°C) is the maximum for Grades GTB, GTJ and GTK.

(3) Specific Heat from UCAR Carbon & Graphite Handbook.

Figure 4 Stress vs. Strain of GRAFOIL Sheet at Different Initial Densities



Tensile Strength

Generally, Grades GTA and GTJ have typical tensile strengths of 700 to 1000 psi (4,800 to 6,900 kPa) along the length and width when measured on 1” by 4” (2.54 cm by 10.16 cm) samples at a cross-head rate of 0.5 inches per minute (12.7 mm per minute). Grades GTB and GTK have typical tensile strengths of 550 to 750 psi (3,800 to 5,170 kPa).

GRAFOIL laminate grade GHP can be used for high volume, OEM applications, and where a certain degree of toughness is required for handling, and in applications where stainless steel is not recommended. This grade contains a 0.0015” (0.038 mm) interlayer of plastic and a 0.015” to 0.060” (0.38 to 1.52 mm) layer of GRAFOIL sheet material on each side. The remaining laminate grades have metal or woven glass interlayers to increase tensile strength and blowout resistance. The metal interlayers consist of flat foil or tanged (perforated) metal. The flat foil interlayers are *chemically* or adhesively bonded to the GRAFOIL sheet while the tanged metal interlayers are *mechanically* bonded. The use of interlayers substantially increases the strength of the GRAFOIL laminates. The type of interlayer and the adhesive used determine the service conditions where the laminates can be used.

Compressive Strength

The compressive strength of homogeneous, unconfined GRAFOIL flexible graphite sheets depends considerably on the test method, sample thickness and web width. Values of 10,000 psi to 40,000 psi (69 to 276 MPa) have been recorded. A one-inch diameter disk of GRAFOIL flexible graphite can be compressed between smooth, flat steel plates to 40,000 psi (276 MPa) without tearing. At this pressure the diameter of the unconfined sample will increase considerably. The fact that this material can compact and “flow” under high loads without actually breaking is one of its unique properties. The cross-sectional area of the sample and whether confined or not, also effects the compressive strength.

The compressive strength of unconfined GRAFOIL homogenous sheet is often given as 24,000 psi (165 MPa). If the sample is confined, this value can increase to as much as 150,000 psi (1034 MPa).

The compressive strength of GRAFOIL laminates is dependent on the interlayer material. More creep relaxation can take place when a polymer insert or adhesive is used. A tanged metal interlayer laminate (no adhesive present) can significantly reduce the lateral “flow” under high pressure.

Young's Compressive Modulus

The compressive modulus was measured by stacking GRAFOIL disks with an area of one square inch to a height of one inch. The stack was prepressed to a 90 lbs/ft³ (1.4 g/cc) density. Then the deflection at that load was measured and the modulus calculated. The compressive modulus of homogeneous GRAFOIL sheet is 24,000 psi to 29,000 psi (166 MPa to 200 MPa), over the 2000 psi to 7500 psi (14 MPa to 52 MPa) load range. The compressive modulus of laminates is influenced by the interlayer material and use of an adhesive.

Gas Permeability

The room-temperature gas permeability through the thickness of homogeneous GRAFOIL sheet is extremely low. The helium permeability was measured through 0.010” (0.254 mm), 66 to 76 lbs/ft³ (1.06 to 1.22 g/cc) density Grade GTA stock by the pressure decay method. The permeability was measured between 0.4 and 9.0 x 10⁻⁶ Darcy's. This low flow level causes the spread in the results because of the accuracy in the measurements at these levels. The permeability through the edge of GRAFOIL sheet is much greater than through the thickness. A fluid can flow down the edges of the graphite crystals more easily than through them. This is shown in the sealability section of this manual.

The interlayer material can have an effect on gas permeability through the thickness. When a polymer or metal sheet is the interlayer material, the permeability can be reduced. When metal screen or tang metal is used, the permeability is not reduced because of the porosity of the metal.

Working Temperature of GRAFOIL Flexible Graphite

Homogeneous GRAFOIL sheet can be used over a wider temperature range than of any other sealing material. Under special circumstances, this material can be used in temperatures as low as -400°F (-240°C) and as high as 5400°F (3000°C). In oxidizing atmospheres, oxidation of GRAFOIL flexible graphite can begin at 850°F (455°C) for Grades GTA, and at 975°F (525°C) for Grades GTB, GTJ and GTK. Threshold oxidation is defined as that temperature at which one square meter of 70 lbs/ft³ (1.12 g/cc) density, 0.015" (0.38 mm) thick GRAFOIL sheet will lose 1% of its weight over 24 hours in hot flowing air. This is under worst case conditions. The surface area exposed, gas velocity, and oxygen concentration greatly affect the use temperature. In gasketing conditions, the 975°F (525°C) temperature should not be considered a maximum use temperature in air but merely a "caution flag" that requires further examination of the operation. The thin-edge exposure of GRAFOIL packings and gaskets has successfully withstood extended periods of exposure to air at process fluid temperatures up to 1500°F (815°C).

In a neutral, reducing, or vacuum environment, GRAFOIL flexible graphite stiffens slightly between the temperatures of 2000°F (1095°C) and 3600°F (1980°C), but remains very usable. At 4980°F (2750°C), the vapor pressure is about 5×10^{-2} mm of Hg; at 5430°F (3000°C), the vapor pressure is approximately 0.4mm of Hg, as the flexible graphite begins to sublime.

The useful temperature of reinforced laminates is influenced by the adhesives and inserted materials. For example, AISI 316 stainless steel limits the use temperature of Grades GHE and GHR to 1600°F (870°C), even in reducing or neutral atmospheres, because of the characteristic limitation of the stainless steel inserts.

Friction Coefficient

The friction coefficient of homogeneous GRAFOIL flexible graphite was measured during a shear test. On a metal surface with a 63 RMS or smoother finish, and a pre-load of 5000 psi (34.5 MPa) for 30 minutes, the friction coefficient was 0.2. This test was performed two additional times, using the same test fixtures with residual graphite embedded in the surface from the previous testing. In these two tests, the pre-load of 5000 psi (34.5 MPa) was held for five days. The friction coefficient was reduced to 0.09. In an unrelated test with GRAFOIL sheet against stainless steel with an 8 psi (55 kPa) load, the friction coefficient was measured at 0.05. Since the friction coefficient is a surface effect, the same values would apply to all GRAFOIL laminates where the surfaces are the base grades of GRAFOIL sheet. Table IV shows the friction coefficient of laminates made from GRAFOIL flexible graphite on stainless steel at various loads.

Table IV Coefficient of Friction of GRAFOIL Laminate on Stainless Steel

<u>Face Pressure</u>		<u>Coefficient of Friction</u>	
<u>psi</u>	<u>kPa</u>	<u>Surface Plane</u>	<u>Edge Plane</u>
4	28	0.02	0.06
8	55	0.05	0.06
12	83	0.16	0.20

Impact Resistance

Impact resistance cannot be satisfactorily measured on standard GRAFOIL sheet. It is a ceramic material composed of graphite crystals physically bonded together by a relatively low strength mechanical bond. This compressible structure does not readily lend itself to standard impact tests designed to measure the impact resistance of brittle materials.

Adhesion of GRAFOIL Flexible Graphite to the Sealing Surface

GRAFOIL flexible graphite releases very easily from clean, impervious metal surfaces such as flanges. Flanges with GRAFOIL gaskets that have been stressed at high loads can easily be taken apart by hand. When compressive loads as high as 40,000 psi (276 MPa) have been used, the GRAFOIL gasket material may be pressed into the machine marks and pores of the metal surfaces. In such cases, some gentle scraping may be required to remove some of the transferred particles of graphite. This particle transfer is the mechanism responsible for inherent “micro-sealing” capability of GRAFOIL flexible graphite. For those critical applications where the gasket must release cleanly from the flange surface, Graftech has developed a release coating that is compatible with GRAFOIL gaskets.

Heat Transfer

The thermal conductivity of GRAFOIL flexible graphite is very directional or “anisotropic.” Along its length and width (Figure 5) heat transfer may range from that of molybdenum to silver. Through its thickness, (Figure 6) GRAFOIL flexible graphite will transfer heat in a manner that varies based on gasket density, flange finish, temperature, and clamping load of the system. At very low density and load, the foil will conduct at a rate similar to stainless steel. At the load and density obtained during its use in flange gaskets, heat transfer approaches that of aluminum (See Table V). This unique property allows GRAFOIL flexible graphite to rapidly dissipate heat along the plane of the gasket and away from the surface of the flange. At the same time, GRAFOIL flexible graphite can be used as a radiative heat barrier in high-temperature furnaces (see the section on emissivity).

Table V Heat Transfer Through GRAFOIL Flexible Graphite Joints

<u>Temperature</u>		<u>Along Length and Width</u>		<u>Through Thickness</u>	
°F	°C	BTU•in/hr•ft ² •°F	W/m•°C	BTU•in/hr•ft ² •°F	W/m•°C
70	21	960-2700	140-400	36-1000	5-150
2000	1095	300	44	20	3

The thermal conductivity when measured through the thickness (Figure 6) decreases as temperature increases to 1500°F (815°C), then remains relatively unchanged as the temperature is increased to 3500°F(1925°C). See Appendix 4, Thermal and Electrical Conductivity, for additional in depth information.

Figure 5 Relative Thermal Conductivity vs. Temperature of GRAFOIL Flexible Graphite (Thermal Conductivity Along the Length and Width)

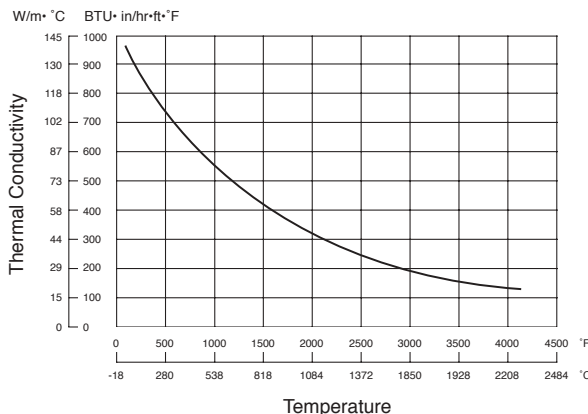
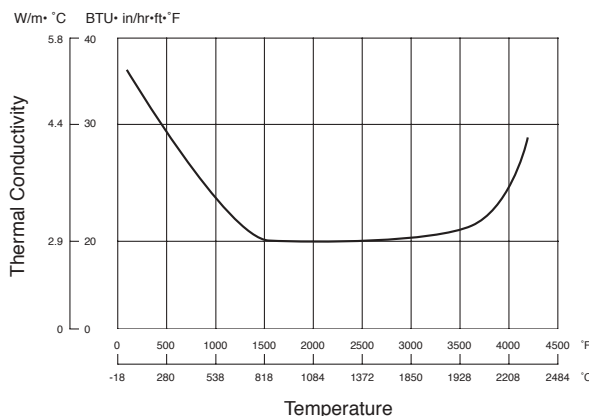


Figure 6 Thermal Conductivity vs. Temperature of GRAFOIL Flexible Graphite (Thermal Conductivity Through the Thickness)



Coefficient of Thermal Expansion

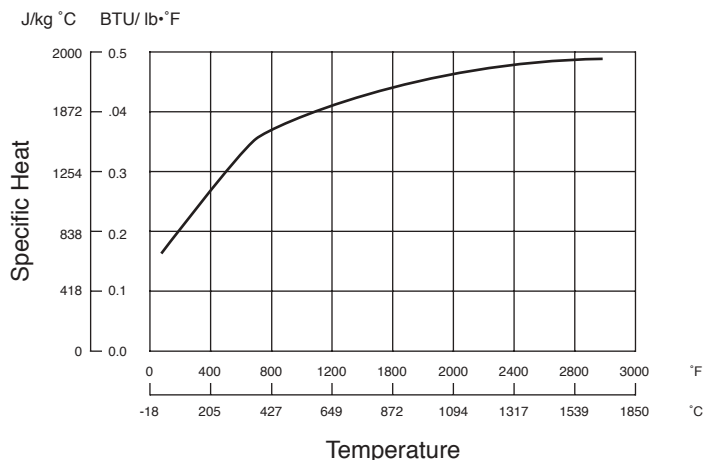
When measured along its length or width, the coefficient of linear thermal expansion for GRAFOIL flexible graphite is very low compared to metals. From ambient temperature to 2000°F (1095°C), GRAFOIL flexible graphite shrinks in both dimensions when heated as a result of relieving internal stress. The average coefficient for this temperature range is -0.2×10^{-6} in/in·°F (-0.4×10^{-6} m/m·°C). From 2000°F to 4000°F (1095°C to 2200°C), GRAFOIL flexible graphite expands slightly with temperature, the average coefficient being $+0.5 \times 10^{-6}$ in/in·°F ($+0.9 \times 10^{-6}$ m/m·°C). Because of the anisotropic structure of GRAFOIL flexible graphite, the linear thermal expansion coefficient through the thickness is significantly different from that measured along its length or width. The average coefficient from ambient temperature to 4000°F (2200°C) is $+15.0 \times 10^{-6}$ in/in·°F ($+27.0 \times 10^{-6}$ m/m·°C).

This value of linear thermal expansion through the thickness of GRAFOIL flexible graphite is similar to metals. Therefore, in gasket applications, the sealing ability is little changed by temperature. The linear thermal expansion coefficients of GRAFOIL laminates containing metallic interlayers will be influenced by the metal in the length and width dimension to the extent that the metal will control the expansion. In the thickness dimension of the laminate, the thermal expansion will be directly proportional to the thickness of the metal and its coefficient and to the thickness of GRAFOIL flexible graphite and its coefficient.

Specific Heat

The specific heat of GRAFOIL flexible graphite is dependent on temperature. The specific heat from ambient to 3000°F (1650°C) is shown in Figure 7. At ambient temperature, the specific heat of GRAFOIL flexible graphite is 0.17 BTU/lb•°F (711 J/kg•°C), approximately that of steel.

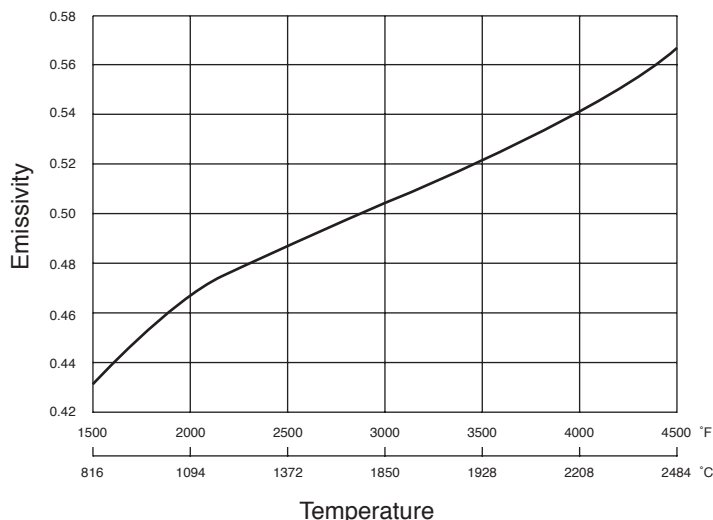
Figure 7 Specific Heat of GRAFOIL Flexible Graphite



Emissivity

The total spectral emissivity of the surface of GRAFOIL flexible graphite for temperatures between 1500°F and 4500°F (815°C and 2480°C) is shown in Figure 8. The average emissivity over this temperature range is 0.5. This indicates that the surface of GRAFOIL flexible graphite in this temperature range radiates half as much thermal energy as a perfect black body. For this reason, GRAFOIL flexible graphite is an excellent reflector of thermal radiation. Therefore, GRAFOIL flexible graphite is an excellent insulator when radiation is the principal mode of heat transfer, i.e., above 1500°F (815°C). In addition, the surface of GRAFOIL flexible graphite does not change with time in contrast to metals (such as molybdenum) that are also used to reflect thermal radiation. The emissivity and radiative reflectivity of GRAFOIL flexible graphite remain stable over long service periods.

Figure 8 Total Emissivity vs. Temperature of GRAFOIL Flexible Graphite

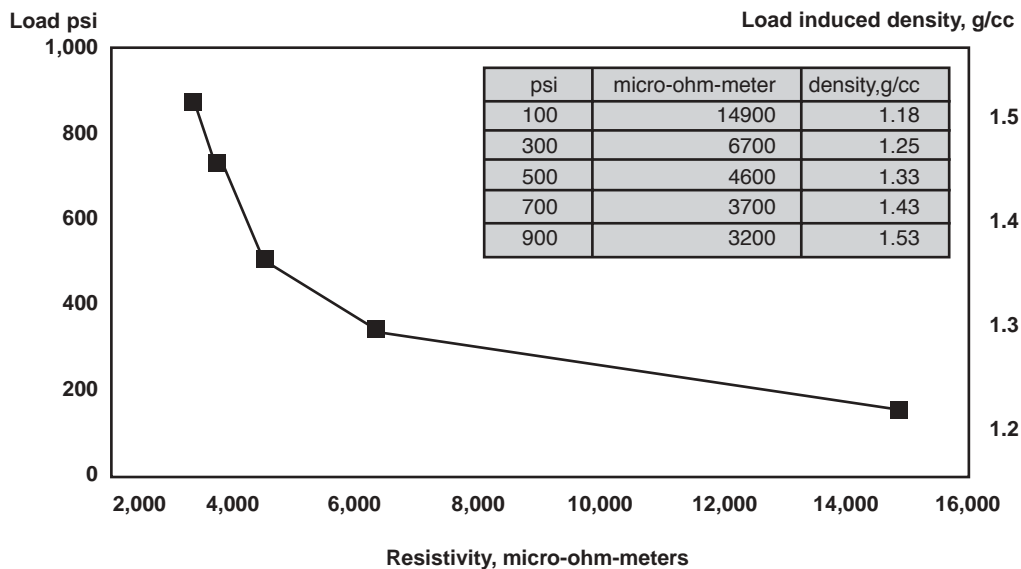


Electrical Resistivity

The electrical properties of GRAFOIL flexible graphite are very directional and the resistivity along the length and width is much less than that through the sheet. GRAFOIL flexible graphite is anisotropic and has higher electrical resistance through the thickness of the sheet than in the plane of the sheet, normally about 500 times higher.

Our lab did significant work to measure the resistance of 70 lbs/ft³ (1.12 g/cc) GRAFOIL sheet in both the plane of the sheet and through its thickness, 6.8 micro-ohm-meters and from 15,000 to 3,200 micro-ohm-meters respectively. The wide range of through thickness electrical resistivity (15,000 to 3,200 micro-ohm-meters) of GRAFOIL flexible graphite is dependent on the amount of clamping load applied to the sheet and the resulting density of the sheet as a result of being compressed. As the density increases, the electrical resistivity decreases. As the load on the sheet was increased from 100 to 900 psi (0.69 to 6.2 MPa), the sheet “effective” density increased from 75 to 95.5 lbs/ft³ (1.2 to 1.5 g/cc), and the resistance was reduced by about 80% as shown in Figure 9.

Figure 9 GRAFOIL Flexible Graphite Electrical Resistivity Through Thickness, Load and Density vs Resistivity



GRAFOIL flexible graphite laminates containing polyester interlayers would have approximately the same electrical resistivity as the homogeneous sheet in the length and width dimensions. However, in the thickness dimension, the electrical resistivity will be controlled primarily by the plastic interlayer and is very high. The electrical resistivity of GRAFOIL laminates with metal interlayers is reduced in all directions, but the amount of this reduction is influenced by the adhesive layer of the laminate.

Carbon and Ash Content

The carbon content of GRAFOIL flexible graphite is a measure of material purity. The flake graphite used to produce GRAFOIL flexible graphite is a natural material mined in several areas of the world. Since it is mined, the impurities in the graphite are those normally found in the accompanying ores. These impurities are collectively known as the ash content and include such substances as silicon oxide, iron oxide, and aluminum oxide. The purity of the graphite is dependent on its source and on any processing steps taken to remove the non-carbon material. For Grades GTB or GTK, analyzes indicate that typically the ash content consists of less than 2.0% of these chemically stable oxides, silicates or sulfates. The relative amounts of the major oxide components are given in Table VI.

Table VI Oxide Impurities in GRAFOIL Flexible Graphite

OXIDES	% OF MINERAL CONTENT
MgO	10
Al ₂ O ₃	17
SiO ₂	40
CaO	9
Fe ₂ O ₃	15
Balance	9

The constituents typically represent about 2% of the weight, or about 1% of the volume of grades GTB and GTK. This small amount of ash will not create leak paths in a seal or gasket. Grades GTA and GTJ typically contain only 0.1% ash in a similar oxide ratio.

The ash content of GRAFOIL flexible graphite is determined by completely oxidizing a sample of the material as instructed in the ASTM Method C-561. Since the ash in the GRAFOIL sheet is mostly in stable oxides, it has little effect on the properties and end use. However some of the trace element impurities in flexible graphite can behave as oxidation and corrosion catalysts. We carefully control our raw material sources and processing to minimize these harmful elements. GRAFOIL flexible graphite contains fewer of these harmful elements than most other brands of flexible graphite produced world wide.

Table VII shows the typical elemental analysis results for grades GTA and GTB obtained using inductively coupled plasma atomic emission spectroscopy.

Table VII Typical Quantitative Analysis of Grades GTA and GTB Obtained by Inductively Coupled Plasma Atomic Emission Spectroscopy

<u>ELEMENT</u>	<u>GTA (ppm)</u>	<u>GTB (ppm)</u>
Na	15	142
Mg	78	1301
Al	68	962
Si	379	3972
K	32	356
Ca	93	1229
Ti	5.8	43
V	2.5	2.2
Cr	2.4	1.7
Mn	5.4	11
Fe	53	1336
Ni	1.2	2.0
Cu	1.5	2.3
Zn	18	2.4
Sr	1.2	3.9
Zr	11	10
Mo	1.7	11
Ba	1.9	3.4

Sulfur Content

The sulfur content of flexible graphite is influenced by the source and composition of the raw material and subsequent processing steps. Thus there are small amounts of sulfur containing compounds in the ash component of all flexible graphite. Sulfur can increase the corrosion rate of metals. The oxidation state (or valence state) of the sulfur compound also reportedly influences the extent of corrosion. A valence value of +6 is considered particularly aggressive (see General Electric Nuclear Specification D50YP12 Revision 2). While all GRAFOIL flexible graphite has a relatively low total sulfur content, the levels in premium grades GTA and GTJ are especially low. Grades GTA and GTJ have maximum sulfur levels of 630 ppm and typical levels of around 400 ppm. These levels will meet the most critical specifications within the nuclear power generation industry. Standard industrial grades GTB and GTK have maximum sulfur levels of 1000 ppm and a typical level of 500-700 ppm.

Oxidation Rate

GRAFOIL flexible graphite has a carbon content which is typically 97–99.8%.

The remainder is composed mainly of inorganic oxides with very small amounts of other elements, such as sulfur. The carbon begins to oxidize at temperatures over 450°F (230°C), in the presence of oxidizing gases, such as air. However, the initiation of GRAFOIL flexible graphite oxidation occurs at a higher temperature than that of other carbon based materials; approximately 850°F (455°C) for uninhibited grades. The initiation temperature for oxidation or the “oxidation threshold”, as it is often called, must be defined. Graftech defines oxidation threshold as the temperature at which a sample of 70 lbs/ft³ (1.12 g/cc) density, 0.015” (0.38 mm) thick by meter by meter GRAFOIL sheet will lose 1% of its weight in 24 hours. The atmosphere used in the test was hot air flowing totally around the sample. This data is used in determining the relative oxidation resistance between various grades of GRAFOIL flexible graphite and competitive products, and is not indicative of the performance in actual fluid sealing applications.

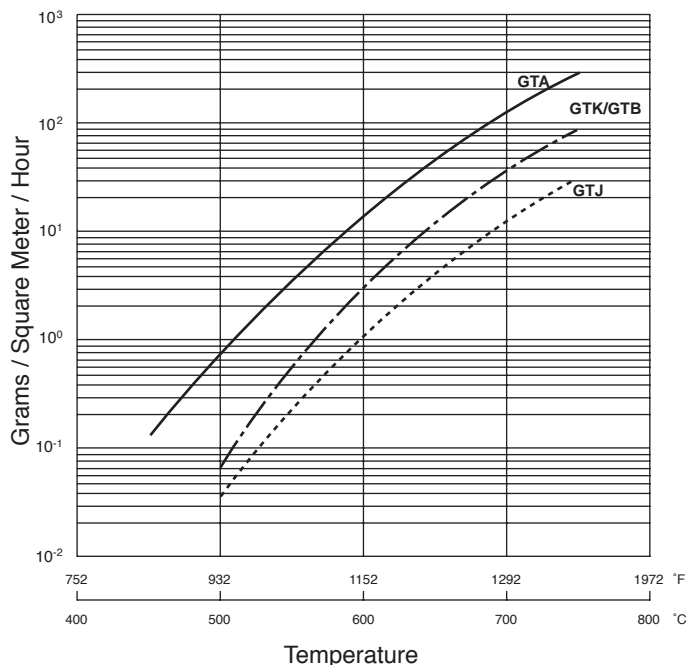
The degree of oxidation and subsequent useful life of GRAFOIL flexible graphite is a complex phenomenon depending on many variables. For example, the extent of exposure to the atmosphere must be considered. In a gasketing application between flanges of a pipe that is carrying an oxidizing atmosphere (or is exposed to air) the contact area of the atmosphere with the gasket is very small. Also, the high thermal conductivity of the GRAFOIL flexible graphite can reduce the temperature of the gasket in this application and, therefore, reduce the oxidation rate. The velocity of the oxidizing atmosphere across the GRAFOIL flexible graphite is also important. High fluid or gaseous velocities break up the oxide boundary layer and increase the oxidation rate.

The rate of oxidation is also related to the concentration, type, and amount of mineral impurities in the graphite. Some elements, such as sodium and manganese, can act as oxidation catalysts. Therefore, the 850°F (455°C) temperature should not be considered a maximum upper limit use temperature in air. This temperature could be higher or lower depending on the application. The edge-plain of GRAFOIL gaskets has successfully withstood extended exposure to air at process fluid temperatures up to 1500°F (815°C). Grades GTJ, GTB and GTK contain oxidation inhibitors which significantly reduce graphite oxidation rates. The threshold temperature for these grades is about 975°F (525°C). These grades should be considered where oxidation could pose a problem.

The weight loss of GRAFOIL flexible graphite when oxidized in flowing air at elevated temperatures is shown in Figure 10. The graph shows the weight loss per unit area per hour over the temperature range of 840°F to 1380°F (450°C to 750°C) for the standard

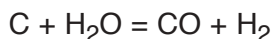
GRAFOIL Grades GTA, GTJ, GTB, and GTK. These curves show, for instance, that at 600°C the weight loss per unit area per hour of Grade GTA is 14 times that of Grade GTJ. The density of the GRAFOIL flexible graphite (between 50 and 90 lbs/ft³ (0.8 and 1.44 g/cc) has little effect on the weight loss per unit area caused by oxidation. But it must be remembered that at the lower densities there is less material to oxidize and the effect on the performance will be more dramatic. The thickness of the GRAFOIL sheet also has an effect on the weight loss per unit area; with the weight loss decreasing with increased thickness.

Figure 10 Oxidation in Air of Various Grades of GRAFOIL Flexible Graphite



Reaction of GRAFOIL Flexible Graphite with Steam

Carbon and graphite are known to react with steam beginning at about 1300°F (700°C). This is known as the water gas reaction. The overall reaction is:



Therefore care must be taken when GRAFOIL flexible graphite is used in steam above this temperature.

Reaction of GRAFOIL Flexible Graphite with Peroxide

GRAFOIL grades GTA, GTB, GTJ, GTK, and laminate grade GHW have been tested in 35% and 70% standard grade hydrogen peroxide for one month. None of these grades caused significant decomposition of hydrogen peroxide. By comparison, standard asbestos gasket material caused rapid decomposition in this test. Laminates containing stainless steel are not recommended because the metal can cause decomposition of the peroxide and GRAFOIL GHW laminates would be the preferred gasket material. The above GRAFOIL grades are also compatible with a mixture of 20% tertiary butyl peroxide and 80% hydrocarbon at 280°F (138°C) and 465 psi (3.2 MPa) pressure.

Wetting of GRAFOIL Flexible Graphite with Molten Metals

GRAFOIL flexible graphite is generally considered as not wettable by molten metals. This is true with some exceptions. To some degree, GRAFOIL flexible graphite is soluble in liquid aluminum, silicon, molybdenum, chromium, nickel, and iron. GRAFOIL flexible graphite has excellent thermal conductivity, and the metals are quickly cooled, stopping the reaction at the interface. If these liquid metals are held at high temperature against the GRAFOIL flexible graphite, wetting can take place. The excellent thermal shock resistance of the GRAFOIL flexible graphite also makes it an excellent material to have in contact with molten metals.

Table VIII The Wetting Angle of Some Molten Metals:

<u>Metal</u>	<u>Wetting Angle-Degrees*</u>
Copper	140-142
Silver	136
Indium	141
Gallium	137-141
Germanium	139
Tin	149-153
Lead	138
Antimony	140
Bismuth	136

*From "Calculations of Interfacial Energy of Some Liquid Metals in Contact with Diamond or Graphite" by M.P. Doahov, Russian Journal of Physical Chemistry, Vol. 55, pp. 623-1248, 1981.

Durometer Hardness

The Shore Durometer Hardness A-2 for GRAFOIL flexible graphite is shown in Table IX:

Table IX Shore Durometer Hardness for GRAFOIL Flexible Graphite

GRAFOIL Density <u>lbs/ft³</u>	Hardness <u>Shore A-2</u>
10	30-35
30	80-85
50	85-90
70	90-95
90	95-98

Poisson's Ratio

GRAFOIL flexible graphite does not have a Poisson's ratio. Under compression, it first compacts without sideways motion. As the force becomes very high, there is sideways motion, but this essentially does not recover when the force is reduced.

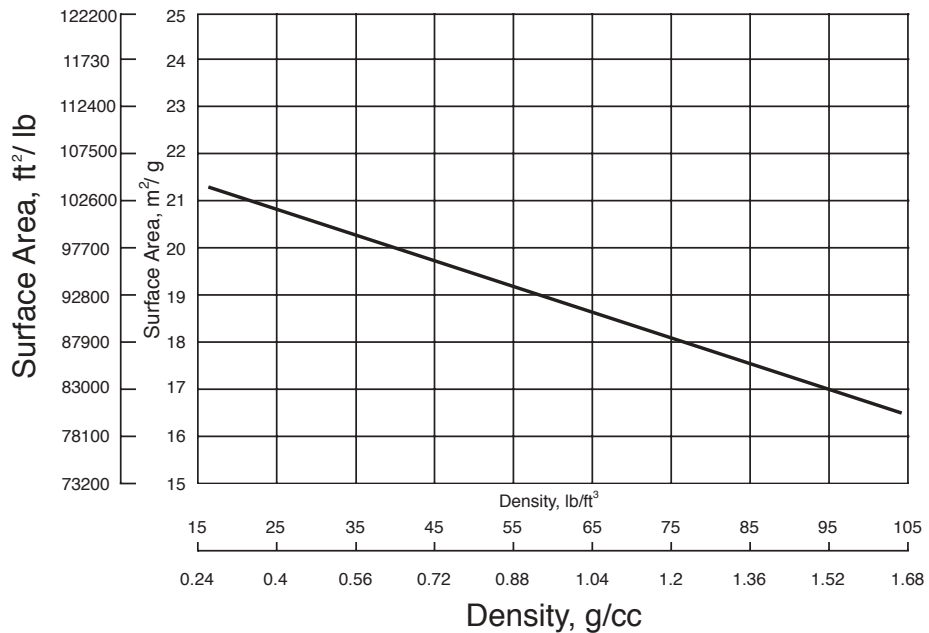
Sonic Velocity Through GRAFOIL Flexible Graphite

The sonic velocity through 70 lbs/ft³ (1.12 g/cc) density GRAFOIL flexible graphite was measured using a James V meter. Through the length or width of the GRAFOIL sheet the velocity is 1050 to 1250 m/sec. Through the thickness of this GRAFOIL sheet the velocity is about 600 m/sec. The sonic velocity through the thickness is slower because there are more air interfaces between the graphite crystals in this direction. The sonic velocity would be expected to increase with an increase in density and an increase in temperature.

GRAFOIL Flexible Graphite Surface Area vs. Density

The surface area of GRAFOIL flexible graphite was measured using the nitrogen desorption method. This method measured the internal surface area of the GRAFOIL flexible graphite as well as the external surface area. The surface area was measured on GRAFOIL sheet that had a density from 16 lbs/ft³ to 104 lbs/ft³. The results are shown in Figure 11. The surface area decreases slightly with an increase in density. The average surface area of 70 lbs/ft³ density sheet is about 18.5 m²/g (90,000 ft²/lb) with a normal range of 12 to 25 m²/g.

Figure 11 Surface Area for Various Densities of GRAFOIL Flexible Graphite



Leachable and Total Chlorides and Fluorides

GRAFOIL flexible graphite contains very small amounts of halides, i.e., chlorides and fluorides. Chlorides and fluorides catalyze corrosion, and in critical applications, such as nuclear power plants, the level must be kept very low.

Soluble or leachable halides are of greatest concern from a corrosion standpoint. Leachable halides in aqueous solutions accelerate pitting corrosion by permeating stainless steel's chromium oxide film, greatly increasing electrical conductivity of the film at its weakest points and eventually causing its complete physical breakdown. The chloride ions act as a catalysts since they speed the reaction without actually entering into it. During the corrosion reaction of stainless steel, no chlorides are formed, only iron oxides and hydroxides.

The typical total halide content of Grades GTA and GTJ is 70 ppm, with the typical total fluoride content less than the detectable limit of 10 ppm. These grades are certified to have a combined maximum of 50 ppm leachable chlorides and fluorides, with the typical value of each below the detectable limit of 10 ppm. The *leachable* halogen content is less than the *total*, since only a portion of the halides is removed by the leaching procedure. Both grades meet the General Electric Nuclear specification D50YP12 Revision 2.

Standard Industrial Grades GTB and GTK also contain less than the detectable limits of 10 ppm leachable chlorides and fluorides, significantly lower than that of asbestos based sealing materials.

Test method ASTM F-1277 was developed by Graftech Inc. to determine leachable chlorides by an ion selective electrode technique.

Nuclear Radiation Resistance

GRAFOIL flexible graphite is highly resistant to nuclear radiation and has been used as a component in test reactors for many years. In one set of tests, homogeneous GRAFOIL sheet specimens were exposed to 170 Mrad absorbed dose in a 960 gamma facility while immersed in air. This is equivalent to 100 years of exposure to the reactor environment, which will normally produce a substantial change in mechanical properties of a material. However, it is shown in Table X that there was only a minor change in the measured properties of the GRAFOIL sheet.

Table X Mechanical Properties of Radiated* GRAFOIL Flexible Graphite After 170 mega Rads Exposure

Test	Sample	ASTM Test	Result	Remarks
Ultimate Tensile Strength (psi/MPa)	Control	F-152	730/5.63	Statistically Insignificant
	Irradiated		830/5.720	
	% Change		+14	
Elongation at Fracture (%)	Control	F152	1.8	Statistically Insignificant
	Irradiated		1.3	
	% Change		-28	
Creep Relaxation ⁽¹⁾ (Room Temperature)	Control	F-38	4	Statistically Insignificant
	Irradiated		5	
	% Change		+25	
Compressibility (%)	Control	F-36	51.7	Statistically Insignificant
	Irradiated		51.3	
	% Change		-0.8	
Recovery (%)	Control	F-36	22.9	Statistically Insignificant
	Irradiated		23.1	
	% Change		+0.9	

(1)Specimens under load for one hour.

* Irradiation: Gamma from Cobalt source in air. All test specimen conditions at 100°C for 24 hours.

Fire Test Results

Factory Mutual Engineering has evaluated samples of GRAFOIL flexible graphite and concluded that “graphite gaskets may be used on any flammable liquid piping or equipment in accordance with recommendation of the gasket, pipe, or equipment manufacturer and when the graphite is void of organic fillers or resins.” Several valve manufacturers have fire-tested valves containing GRAFOIL flexible graphite gaskets as an integral part of the valve. These successful tests were performed to a number of fire test standards, such as: (1) API 607 (Second Edition, 1980 ; Third Edition, 1985; and Fourth Edition, 1995); (2) API Spec. 6FA (First Edition, 1985); (3) Exxon BP3-14-4 (1980); (4) British Standard 5146 (1974 Appendix A) and, (5) API Standard 607, 4th Edition and Exxon Specs, 1995 conducted by Southwest Research Institute, Dept. of Fluid Systems.

GRAFOIL FLEXIBLE GRAPHITE IS THE PREFERRED REPLACEMENT FOR ASBESTOS GASKETS WHERE FIRE SAFETY IS A CONCERN.

Health and Safety Information

The high stability and purity levels of homogeneous GRAFOIL sheet make it safe to handle. GRAFOIL flexible graphite is not a fire or explosion hazard. GRAFOIL flexible graphite is not reactive and requires no special protective equipment or precautions.

In chemical analysis for polynuclear aromatics (PNA), samples of GRAFOIL sheet were refluxed with benzene. No PNAs were detected by sensitive gas chromatographic analysis. Other samples were extracted with chloroform and methanol in sequence for infrared analysis. Again, no polynuclear aromatic compounds were detected.

Unlike most gasket material, GRAFOIL flexible graphite is electrically conductive. **IT CANNOT BE USED FOR ELECTRICAL ISOLATION.** This should be considered in applications where electrical isolation is required.

If flexible graphite is ground or chopped up into dust, the airborne respirable nuisance dust has an ACGIH (TLV) respirable exposure limit of 2.0 mg/m³. GRAFOIL flexible graphite also contains very low levels (<0.3%) of crystalline silica. Crystalline silica has an ACGIH (TLV) respirable limit of 0.05 mg/m³. Personnel samples taken during cut-part fabrication showed non-detectable levels of crystalline silica. There should be no silica hazards to product users or fabricators as long as graphite dust levels are below the 2.0 mg/m³ respirable limit.

Please contact Graftech, GRAFOIL Products for the latest revision of the material safety data sheet (MSDS).

Material Compatibility

GRAFOIL flexible graphite is chemically resistant to attack from nearly all organic and inorganic fluids with the exception of highly oxidizing chemicals and concentrated, highly oxidizing mineral acids. Homogeneous GRAFOIL sheet contains no resin binders or organic fillers. Only graphite, which is highly resistant to chemical attack, is present. Also, because GRAFOIL flexible graphite is all graphite, it can be used at high temperatures with most chemicals. When GRAFOIL laminates are used, the non-graphite component will influence or limit the laminate's chemical resistance. Appendix 2 shows a list of materials that have been evaluated for compatibility with graphite. Appendix 3 shows a list of materials that have been evaluated for compatibility with the interlayer materials.

CARE MUST BE TAKEN, HOWEVER, IN SELECTING COMBINATIONS OF GRAFOIL FLEXIBLE GRAPHITE, INTERLAYER MATERIAL, AND CHEMICALS. THE COMBINATIONS MAY NOT BE COMPATIBLE.

GRAFOIL flexible graphite is compatible with a number of unusual materials under unusual conditions. For example, GRAFOIL Grades GTB, GTA, GHE, GHR, and GHV have been approved by a major chemical company for use with ethylene oxide with no detrimental effect. These same grades have been approved by the U.S. Coast Guard for use with ethylene oxide, propylene oxide, and butylene oxide. In addition, GRAFOIL flexible graphite can be used as a gasket with molten aluminum at 1350°F (730°C) and 5000 psig (34.5 MPa) pressure and in piping conveying molten plastic at 600°F (315°C) and 600 psig (4.1 MPa) pressure.

GRAFOIL Grades GTB, GHR, and GHE have been approved by a major industrial gas supplier, for use with both liquid and gaseous oxygen service up to 2000 psig (13.7 MPa) pressure at a maximum temperature of 752°F (400°C). Produced as both adhesive-backed crinkle tape and thread sealant, Grades GTF and GTH are approved for oxygen service up to 200 psig (1.4 MPa) and up to 140°F (60°C).

Galvanic Corrosion

Galvanic corrosion is the result of an electrochemical reaction between two dissimilar metals, or between a metal and graphite, *in the presence of an electrically conductive fluid (such as water)*. The rate and degree to which the reaction (pitting) will occur is dependent upon how widely separated the two materials are on the galvanic scale shown in Table XI. Graphite or GRAFOIL flexible graphite is near the cathodic end of the galvanic scale, between silver and gold. The greater the separation between the two materials in the table, the more rapid the corrosive attack on the anodic material. Galvanic corrosion is not a problem unless an electronically conductive fluid is present.

Table XI Galvanic Series

Anodic

- Magnesium
- Zinc
- Aluminum
- Cadmium
- Steel or Iron
- Cast Iron
- 13% CR Iron (Active)
- Nickel Resist
- 410 Stainless Steel (Active)
- 416 Stainless Steel (Active)
- 18-8 Stainless Steel (304) (Active)
- 316 Stainless Steel (Active)
- Hastelloy C
- Lead
- Nickel (Active)
- Inconel (Active)
- Hastelloy U
- Brass
- Copper-Nickel Alloy
- Monel
- Nickel (Passive)
- Inconel (Passive)
- 410 Stainless Steel (Passive)
- 416 Stainless Steel (Passive)
- 13% CR Iron (Passive)
- 18-8 Stainless Steel (304) (Passive)
- 316 Stainless Steel (Passive)
- Aloyco 20 (Passive)
- Titanium
- Silver

Graphite or GRAFOIL Flexible Graphite

- Zirconium
- Gold
- Platinum

Cathodic

Stainless steel resists corrosion by the formation of a chromium oxide film. If this film breaks down, corrosion can progress. Leachable chlorides in aqueous solutions accelerate pitting corrosion. The chloride ions act as catalysts since they speed the reaction without actually entering into it. They permeate the chromium oxide film, greatly increasing electrical conductivity at its weakest point, eventually causing its complete physical breakdown. If a conductive fluid is present, it is recommended that 17-4-PH or a 300 series stainless steel be used with GRAFOIL Grade GTJ or GTK sheet. When using GRAFOIL Grade GTA, a sacrificial metal, such as zinc is recommended if it is compatible with the remainder of the system.

Figure 12 is a photograph of the surfaces of 420 stainless steel after a seven-month corrosion test in deionized water. Grade 420 stainless steel is vulnerable to corrosion. Uninhibited flexible graphite was placed against the stainless steel sample on the left and the inhibited GRAFOIL flexible graphite Grade GTJ was placed against the stainless steel sample on the right. There was minimal visible pitting when Grade GTJ was used; the maximum pit depth was 0.0007” (0.018 m). When the uninhibited flexible graphite was used, there was extensive pitting with a maximum pit depth of 0.0053” (0.13 mm).

Figure 12 Photograph Showing How Inhibited GRAFOIL Grade GTJ Reduces Pitting Corrosion



Some stainless steels are less vulnerable to pitting corrosion than others. The accepted ranking for some of the more common alloys is 17-4-PH, 316L, 316, 304, 347, and the most vulnerable 410. A stagnant, conductive fluid can have a marked effect on galvanic corrosion. If the alloy is vulnerable and conditions are conducive, then under the proper conditions pitting corrosion can take place in the presence of any material: asbestos, Teflon, even rubber. Cold, wet, stagnant films with good access to oxygen are most conducive to corrosion. A condition where the system components are stored “wet” will increase the potential for galvanic corrosion.

Usable pH Range

Homogeneous GRAFOIL sheet is unaffected by the pH range of 0-14. The nongraphitic component in a GRAFOIL laminate (such as a steel inner layer) will influence and can limit the acceptable pH range for the laminate.

Functional Properties of Laminates

Functional properties are those that relate to the performance of GRAFOIL flexible graphite as a gasket. In most cases, a GRAFOIL laminate would be used and not a homogeneous GRAFOIL Sheet. The functional properties are: sealability, creep relaxation, compressibility and recovery, “m” and “Y” factors, blowout tests, and tightness factors. (See Appendix 6 Glossary of Terms/Definitions Relative to Gasketing)

The functional properties, except for the “m” and “Y” factors and tightness factors are shown in Table XIV. All Standard Industrial Grades of GRAFOIL sheets and gaskets are shown. The nominal thickness is displayed in the first column. Sealability and the compressibility and recovery, creep relaxation were measured by the ASTM, BSI (British Standards Institute) or DIN (Deutsches Institut Für Normung) method indicated in the table. The test results are compared to high quality compressed asbestos sheet and compressed nonasbestos sheet.

Additional tests relating to the standard functional properties were also performed. These tests include: (1) creep at various stress levels and the corresponding modulus of decompression (which relate to creep relaxation), (2) springback, (3) compressive stress versus strain, and (4) temperature effect on load-bearing ability, which relates to the functional property of compressibility and recovery.

Sealability

The sealability of GRAFOIL gaskets and sheets was measured by several methods. In ASTM Method F-37B both nitrogen gas and Fuel “A” (iso octane) were used as the test fluid. For the non-interlayered GRAFOIL sheet (GTA, GTB, GHB and GHL), compressed asbestos, and compressed nonasbestos, 1000 psi (6.9 kPa) was applied to the gasket during the test. For the interlayered grades with a metal or polymer insert, the gasket was first flattened after die cutting using a load of 2000 psi (13.8 MPa). The pressure was then removed and 1000 psi (6.9 MPa) reapplied as required in the ASTM Test. Sealability results using the ASTM F-37B method are shown in table XII. Sealability of GRAFOIL sheets and gaskets as measured by the DIN 3535 method is also shown in Table XII. The DIN 3535 method uses a 90 mm OD x 50 mm ID test gasket. The clamping force on the gasket is 4640 psi (32 MPa) and the internal nitrogen gas pressure is 580 psi (40 bars). The test is run at room temperature. This test is a closer simulation of industrial gasket usage than is the ASTM test. In Table XII, sealability at 750°F (400°C) is shown. This test uses the same condition as the DIN 3535 test except for the high temperature of the test. Graftech believes that this test is more useful than the DIN 3535 test because many gasket applications are at elevated temperatures.

**Table XII Typical Functional Test Performed on GRAFOIL Sheets and Gaskets
Compressed Asbestos and Compressed Nonasbestos Sheets and Gaskets**

Grade	Nominal Thickness in. (mm)	Measured Thickness in. (mm)	F-37B ⁽¹⁾ Sealability		F-36/806 ⁽³⁾		F-38 ⁽⁴⁾ Creep Relaxation %	GRAFTECH Blowout Tests ⁽⁵⁾ MPa/psi	DIN 3535 Sealability ml/min	BSI-F125 Creep @400°C %	Hi-Temp ⁽⁶⁾ DIN 3535 Sealability ml/min
			N ₂ ml/hr	Fuel A ml/hr	Compressibility %	Recovery %					
GTA	0.005 (0.127)	0.0053 (0.1346)	2	<0.2	42	13	<5	—			
	0.015 (0.381)	0.0154 (0.3912)	6	<0.2	42	13	<5	—			
GTB	0.005 (0.127)	0.0058 (0.1473)	3	<0.2	42	13	<5	—	0.2	0	0.1
	0.015 (0.381)	0.0152 (0.3861)	15	0.2	42	13	<5	—	0.5	1	0.2
	0.025 (0.635)	0.0254 (0.6452)	20	0.2	42	13	<5	—			
GHB	0.030 (0.762)	0.0300 (0.7620)	30	0.4	42	13	<5	—	0.7	1	0.7
	1/32 (0.794)	0.0309 (0.7849)	25	<0.5	42	13	<5	34.5+/5000+			
	1/16 (1.588)	0.0641 (1.6281)	70	<0.5	42	13	<5	34.5+/5000+	1.6	1.5	0.6
GHL	1/8 (3.175)	0.1294 (3.2868)	80	<0.5	42	13	<5	34.5+/5000+			
	1/32 (0.794)	0.0317 (0.8052)	35	<0.5	42	13	<5	34.5+/5000+			
	1/16 (1.588)	0.0617 (1.5672)	40	<0.5	42	13	<5	34.5+/5000+	1.3	2	1.2
GHR ⁽²⁾	1/8 (3.175)	0.1210 (3.0734)	80	<0.5	42	13	<5	34.5+/5000+			
	1/32 (3.175)	0.0303 (0.7696)	15	<0.5	38	19	<5	34.5+/5000+			
	1/16 (1.588)	0.0635 (1.6129)	35	<0.5	40	16	<5	34.5+/5000+	1.5	2	0.4
GHE	1/32 (0.794)	0.0314 (0.7976)	40	<0.5	25	30	<5	34.5+/5000+			
	1/16 (1.588)	0.0538 (1.3665)	60	<0.5	38	16	<5	34.5+/5000+	3.1	1.5	1.0
GTH	0.005 (0.127)	0.0063 (0.1600)	3	<0.1	55	50	60	—			
	0.015 (0.381)	0.0161 (0.4089)	20	<0.1	45	50	50	—			
GTF	0.005 (0.127)	0.0610 (1.5494)	4	<0.1	55	50	60	—			
	0.015 (0.381)	0.0160 (0.4064)	22	<0.1	45	25	50	—			
GHP	1/32 (0.794)	0.0321 (0.8153)	35	<0.2	45	13	13	—			
	1/16 (1.588)	0.0621 (1.5773)	65	<0.2	40	15	13	—	1.4	3.5	0.2
High Quality Com. Asbestos	1/16 (1.588)	0.0638 (1.6205)	516	1.2	15	55	45	35.5+/5000+	30		115
High Quality Com. Nonasbestos	1/16 (1.588)	0.0601 (1.5265)	128	5.2	15	60	40	35.5+/5000+	0.1		

NOTE: All tests run per ASTM F-104 Type 5 Procedure for GRAFOIL flexible graphite unless noted

(1) For all laminates, 2000 psi (14 MPa) applied to flatten, then pressure reduced to 1000 psi (6.9 MPa) to test. Internal pressure used was 30 psi.

(2) GHR with 0.002" (0.0508 mm) stainless steel insert.

(3) Note change from ASTM F-36 to ASTM F-806 when laminates GHR and GHE are evaluated.

(4) Creep relaxation test performed at 212°F (100°C).

(5) Blowout test run at 11,000 psi (76 MPa) clamping force.

(6) Test run at 750°F (400°C).

Results in Table XII show that thick gaskets will leak more than thinner gaskets. This is generally true for any material because a thicker gasket will have more cross-sectional area for body leak paths. With nitrogen gas, GRAFOIL sheets and gaskets leak 20 to 800 times less than compressed asbestos gaskets of similar thickness. With Fuel "A", GRAFOIL sheets and gaskets leak 20 to 100 times less than compressed asbestos.

Creep Relaxation

Creep relaxation is the tendency of a material under load to move laterally in the flange, thereby reducing the applied load on the gasket. Creep relaxation is measured by three methods: ASTM F-38B, British Standards Institute (BSI) F-125, and Deutsches Institut Für Normung (DIN) 28090. When measured by the standard ASTM F-38B method, the creep relaxation of GRAFOIL flexible graphite sheets and gaskets is less than 5%. Grades GTH and GTF are adhesive-backed products which have a creep relaxation of only 7 to 8%. The polymer-inserted laminated product, Grade GHP, also demonstrates creep relaxation values in the 7-8% range. Laminates with low creep relaxation are important for applications that require multiple layers to achieve greater gasket thicknesses.

Because many materials are extremely sensitive to increases in temperature and load, creep relaxation must also be measured at the higher temperatures representative of real-use applications. The BSI-125 and DIN 28090 creep tests are normally conducted at 572°F (300°C). Graftech also conducts the BSI F-125 and DIN 28090 creep tests at 752°F (400°C) because of the importance of knowing gasket creep at even higher temperatures. In the 570°F to 750°F (300°C to 400°C) temperature range all GRAFOIL flexible graphite gasket grades that do not contain polymers have a creep relaxation between 2% and 2.5% when measured by either method. This is in stark contrast to many gasketing materials, where the degree of creep relaxation increases dramatically with temperature and load. The stability of GRAFOIL sheet and laminate assures consistent performance through a range of operating conditions, and makes it a better gasket material.

Room Temperature Creep Relaxation at Various Stress Levels

The percent creep relaxation at various stress levels for three grades of GRAFOIL gasket materials are shown in Table XIII. Measurements were made after one hour at constant stress levels between 1000 psi and 15000 psi (6.9 MPa and 103.4 MPa). The creep relaxation was from 0.14% to 0.35% for all the grades and stress levels. The very low creep level of GRAFOIL flexible graphite makes it an excellent gasket material since it is stable with time at high stress loads.

Table XIII Creep Relaxation for 1/16” (1.6 mm) Thick GRAFOIL Laminates

GRAFOIL GRADE	STRESS LEVEL		%CREEP ⁽¹⁾ AFTER ONE HOUR
	(MPa)	(psi)	
GHR	7.1	1,030	0.26
GHR	31.4	4,554	0.21
GHR	55.8	8,090	0.17
GHR	104.5	15,160	0.20
GHE	7.1	1,030	0.35
GHE	31.4	4,554	0.18
GHE	55.8	8,090	0.19
GHE	104.5	15,160	0.23
GHL	7.1	1,030	0.29
GHL	31.4	4,554	0.23
GHL	55.8	8,090	0.20
GHL	104.5	15,160	0.26

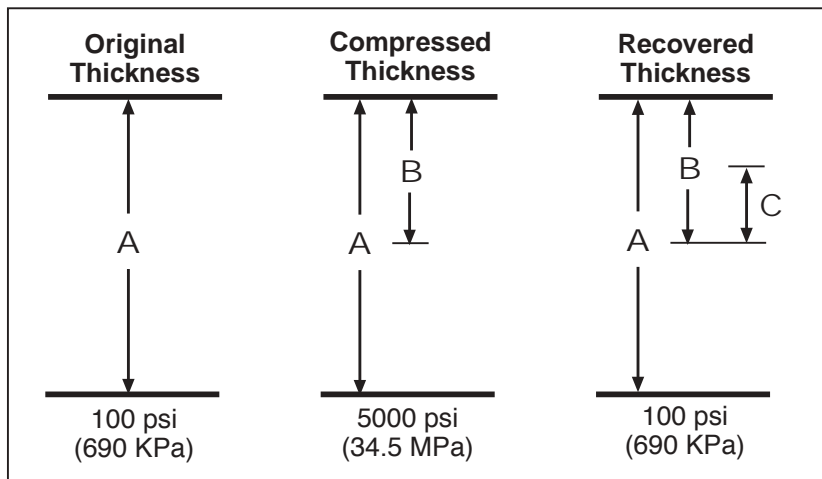
⁽¹⁾ Sample held at constant stress level for one hour at room temperature and deflection measured. Not ASTM F-38 method.

Compressibility and Recovery

Compressibility and recovery were measured on GRAFOIL sheets and laminates using ASTM Standard Method F-36. When a metal interlayer was present in the gasket, method F-806 was used.

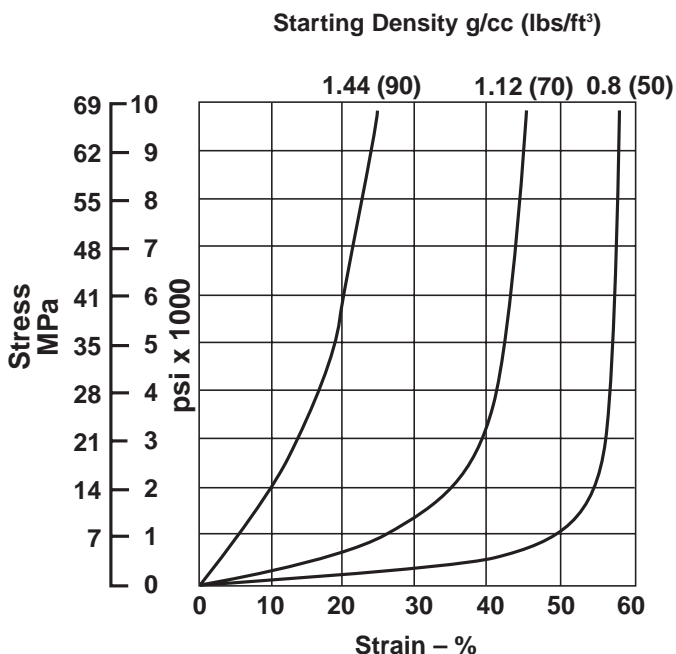
A graphical representation of the compressibility and recovery measurement is given in Figure 13. ASTM Method F-36 requires that both the initial and final thicknesses (A and C, respectively) be measured with a load of 100 psi (0.69MPa) on the gasket. For the compressibility measurement, the load is increased to 5000 psi (34.5 MPa) and the new gasket thickness (B) is measured. The compressibility is calculated by dividing the *decrease* in the gasket thickness (A-B) by the original thickness (A), and expressing the result as a percent. The recovery is calculated using the *increase* in the gasket thickness (C-B) when the 5000 psi (34.5 MPa) load is reduced. This value is divided by the *decrease* in the gasket thickness from the compressibility measurement (A-B), and is again expressed as a percent.

Figure 13 Representation of Compressibility and Recovery Measurement



The density of GRAFOIL flexible graphite affects the compressibility and recovery values, as shown in Figure 14. A reduced density material will have a higher compressibility and lower recovery, whereas a material with a higher density will have lower compressibility and higher recovery.

Figure 14 Variation of Compressibility and Recovery with GRAFOIL Flexible Graphite Density



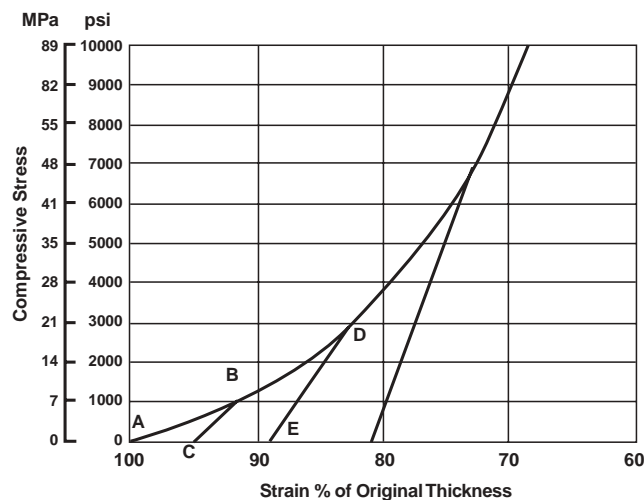
GRAFOIL flexible graphite grades without metal or polymer layers normally have 35-45% compressibility and 10-15% recovery. Grade GHE, interlayered with tang metal, has a slightly lower compressibility (and higher recovery) because the stainless steel tangs are

perpendicular to the surface of the GRAFOIL sheet and resist compression. The GRAFOIL sheet and laminates grades have higher values for compressibility than either compressed asbestos or compressed nonasbestos because GRAFOIL flexible graphite is designed to compact and seal. Because GRAFOIL flexible graphite has very low creep relaxation and is thermally stable, recovery is virtually unaffected by service conditions. The result is an effective, long-term seal.

Springback

The compressibility and recovery measurement described above represents a single cycle where a load is applied and removed. However, GRAFOIL flexible graphite can recover, or “springback” from the same compressive load millions of time. A graphic representation of the single cycle compressibility/recovery experiment and how it relates to springback is given in Figure 15. In the figure, points A,B, and C have the same meaning as those shown in the compressibility/recovery experiment. As the first compressive load is applied, the sample thickness decreases along the curve AB. Upon removing the load the thickness increases as shown by the line BC. Any subsequent loading of the sample, as long as it does not exceed point B, will still recover to thickness C. If the applied load is increased further to point D, the material thickness decreases along the curve CBD. Removing the load now results in an increase in thickness along the line DE. Repeated loading and unloading of the gasket will now cause the thickness to vary along the line labeled DE. This repeated springback of GRAFOIL flexible graphite results in excellent durability and performance for seals exposed to thermal or mechanical cycling.

Figure 15 Springback Resilience of 85 lbs/ft³ (1.36 g/cc) Density GRAFOIL Flexible Graphite Compressive Stress Versus Strain



Compressive Stress Versus Strain

The compressive stress versus strain curve for all GRAFOIL flexible graphite grades, except for those with a tanged metal insert, is shown in Figure 16. Figure 17 shows the stress versus strain curve for grades GHE and GHO which contain a tanged metal interlayer. The effect of the tang is evident by comparing the 0-2000 psi (0-13.8 MPa) compressive stress range in the figures. A high compressive force is required to bend the prongs of the tang.

Figure 16 Compressive Stress Versus Strain of GRAFOIL Flexible Graphite

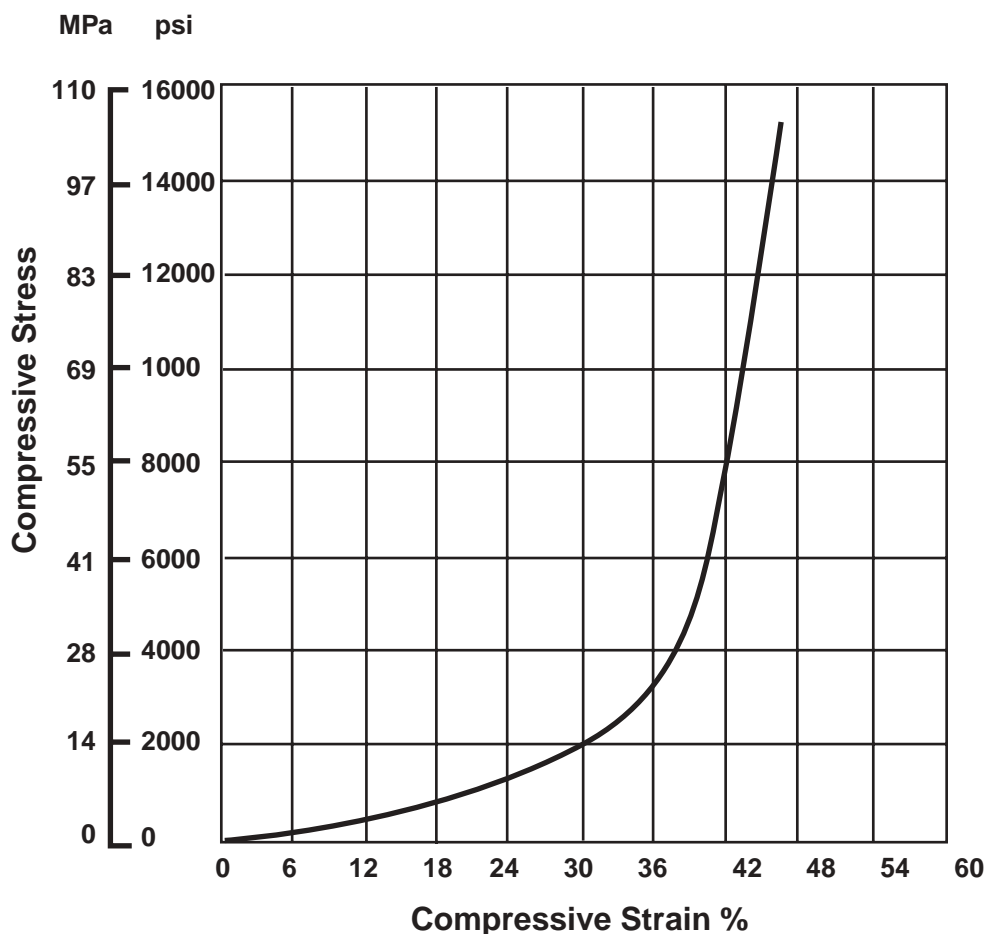
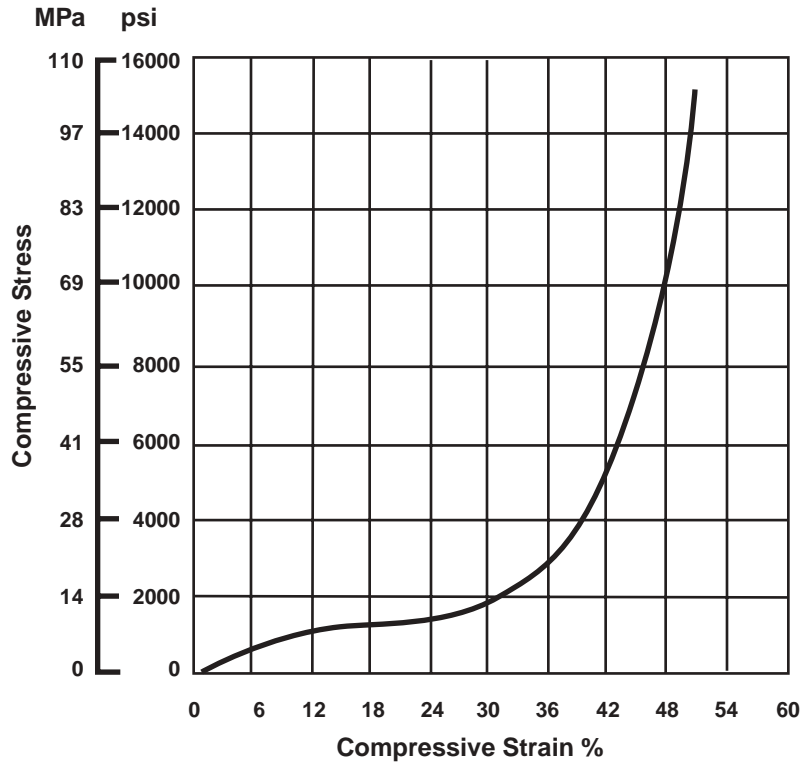


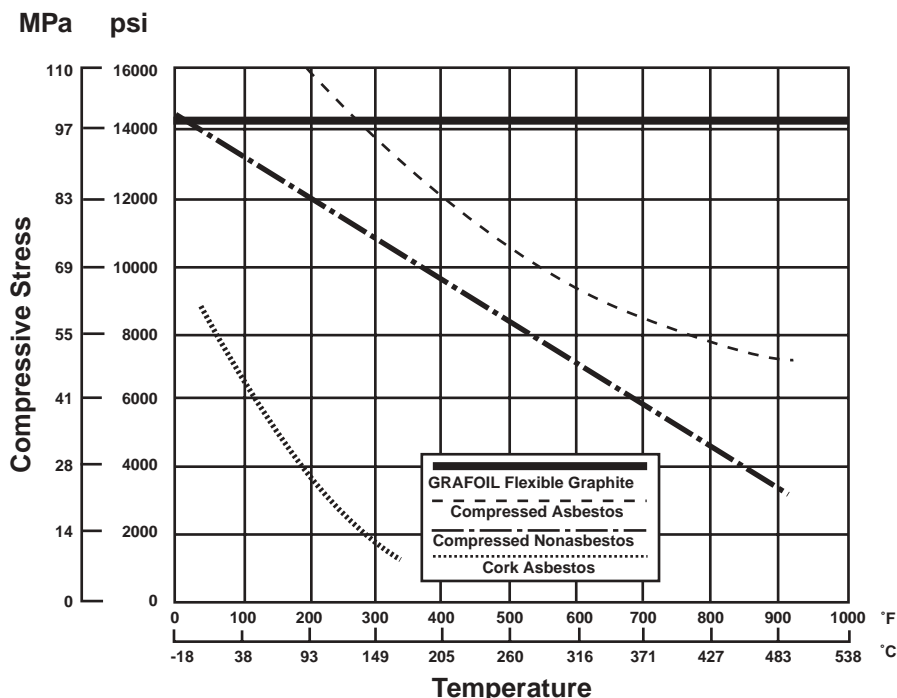
Figure 17 Compressive Stress Versus Strain for GRAFOIL Flexible Graphite Grades GHE and GHO



Effect of Temperature on Load-Bearing Ability

The effect of temperature on the load bearing ability of several gasket materials is shown in Figure 18. No effect on load bearing ability was seen for GRAFOIL flexible graphite sheet to the 850°F (455°C) test temperature. This result is compared to those obtained for compressed asbestos, compressed nonasbestos, and cork asbestos. These other gasket materials bear much less stress than GRAFOIL flexible graphite as temperature increases. Therefore, the non-graphite materials are limited with respect to the internal pressure that can be sealed as the temperature increases. The clamping force must also be increased as the internal pressure is increased; this will be limited by the load-bearing ability at the temperature required.

Figure 18 Gasket Load Bearing Ability: Compressive Stress versus Temperature



“m” and “Y” Stress

The yield factor, or “Y”, is used to designate the minimum load on a gasket required to provide a sealed joint where there is no internal pressure. The yield factor for GRAFOIL flexible graphite and GRAFOIL flexible graphite incorporated in flat laminates is 900 psi (6.2 MPa). For laminates with a tanged insert (such as GHO and GTE), the yield factor is 2500 psi (17.2 MPa).

If a joint is pressurized, an additional load will be required to maintain the integrity of the seal. The additional load requirement is usually defined in terms of the internal pressure, multiplied by a maintenance factor, or “m.” All GRAFOIL grades of sheet and laminates have a maintenance factor of 2. By comparison, 1/16” compressed asbestos sheet has a maintenance factor of 2.75 and a yield factor of 3700 psi, (25.5 MPa), and therefore requires higher loads to seal.

“m” and “Y” values can be used to calculate the minimum net unit load needed to maintain a good seal. In general, the minimum load required is equal to the yield factor “Y” plus “m” times the internal pressure (leak pressure). This relationship is shown in Table XIV for the various grades of GRAFOIL flexible graphite. The typical recommended net unit load should be twice these minimum values. The total flange clamping load must also overcome the hydrostatic end loads developed by the internal pressure. Call your Graftech Applied Technology representative if you have any questions on determining recommended bolt torques for a specific application.

Table XIV “m” and “Y” Values for GRAFOIL Products

Grade	Thickness		“m”	“Y”	
	mm	in.		MPa	psi
GHL	1.6	0.063	2	6.2	900
GHR	1.6	0.063	2	6.2	900
GHT	1.6	0.063	2	6.2	900
GHV	1.6	0.063	2	6.2	900
GHW	1.6	0.063	2	6.2	900
GHE	1.6	0.063	2	17.2	2500
GHO	1.6	0.063	2	17.2	2500

PVRC Tightness Factors

The basis for determination of gasket design factors “m” and “Y” used for ASME flange design calculations have been subject to question. Using “m” and “Y” values to calculate required gasket stress only ensures there is sufficient bolt load to seat the gasket and accommodate the internal pressure.

The new gasket factors, developed by ASME’s Pressure Vessel Research Council (PVRC), consider leakage and joint tightness in the design of a bolted flange joint. Gasket tightness is a measure of its ability to control the leak rate of the joint for a given load. A tightness parameter, T_p , has been introduced to define tightness. The new gasket factors are G_b , “a”, and G_s . These factors are calculated using the Room Temperature Tightness (ROTT) test. The ROTT test is a two part test to examine the tightness behavior of a gasket installed in a bolted joint during the initial seating and during the service when bolt loads have been reduced due to fluid pressurization and gasket creep.

Gasket factors G_b and “a” together represent the capacity of the gasket to develop tightness upon initial seating. The combined effect of G_b and “a” is best represented by the value of $S_{Tp} = (G_b \times T_p^a)$. S_{Tp} tells us the minimum gasket seating stress for specified tightness level. Low values of S_{Tp} are favorable. They indicate that the gasket requires low gasket stress levels to insure initial seating. These two factors together are similar to the gasket seating stress factor “Y” in the current ASME Code.

Gasket factor G_s is an independent constant that represents how the gasket will behave in operation. It characterizes the gaskets tightness sensitivity to operating bolt load reductions that can occur due to system pressurization or gasket creep.

For a specified tightness, G_S indicates the minimum operating load needed on the gasket. A low value of G_S may indicate that the gasket is not sensitive to load fluctuation. The “m” factor in the current Code is similar, because it also provides a minimum gasket stress.

The G_b , “a,” and G_S constants for GRAFOIL gaskets are shown in Table XV.

The ROTT test procedures to calculate gasket stress requirement for a degree of tightness has not been approved by ASTM as of February 2002. Approval is expected in the near future. The ROTT test procedure for the required calculations should be obtained from ASTM. The use of the new gasket factors for flange designs has also not been approved by ASME yet. They are expected to be introduced as a non-mandatory appendix in the near future.

This new PVRC procedure for calculating the required gasket stress is a considerable improvement over the procedure used with the “m” and “Y” constants. It still must be remembered that neither procedure takes into consideration the long-term heating effects on the sealability of a gasket, the chemical compatibility of the gasket, or the creep relaxation of the gasket. These parameters must be considered separately.

Table XV PVRC Gasket Constants for GRAFOIL Products

GRADE	G_b		a	G_S	
	<u>N/m²</u>	<u>psi</u>		<u>N/m²</u>	<u>psi</u>
GHB	6.69	970	0.384	0.00034	0.05
GHR	5.62	816	0.377	0.00046	0.066
GHT	5.62	816	0.377	0.00046	0.066
GHV	5.62	816	0.377	0.00046	0.066
GHW	5.62	816	0.377	0.00046	0.066
GHE	9.65	1400	0.324	0.00007	0.01
GHO	9.65	1400	0.324	0.00007	0.01
GHP	6.69	970	0.384	0.00034	0.05

Blowout Tests

The ASTM test for gasket blowout (F-434) only evaluates the gasket to 1000 psi (6.9 MPa) internal pressure. Since GRAFOIL flexible graphite gaskets are often used at much higher pressures, a more stringent 5000 psi (34.5 MPa) test was developed. In this test, a

standard size gasket with 2-5/8" OD and a 1-5/16" ID (6.67 cm OD and a 3.33 cm ID) was used. The test gasket was held between heavy steel flanges that were machined to ASME B16.5 standards. This standard uses a cutting tool with a 1.52 mm (0.06") radius. Serrated-concentric grooves [24 to 40 per inch (9.4 to 15.7 per cm)] are machined in the faces to provide a surface roughness of 125-250 micro-inch.

For the blowout test, flanges are placed in a small 30-ton (27 Mg) press, which is used to hold the flanges together. After the clamping force is applied to the gasket, a partial vacuum is pulled on the inside of the gasket to remove air. The internal pressure is applied with an air-over-water high-pressure pump. The pump is then started and the center of the gasket is filled with water.

The clamping force (gasket unit load) needed for the 5000 psi (34.5 MPa) internal pressure (leak pressure) is 12,500 psi (86.2MPa) for grades GHE and GHR and 10,900 psi (75.1 MPa) for all other grades based on "m" and "Y" values. The internal pressure is increased in 1000 psi (6.9 MPa) increments from 0 psi to 5000 psi (34.5 MPa) with a 30-second hold at each pressure and a one-minute hold at 5000 psi (34.5 MPa). Since creep relaxation does not effect the test results when this method is used, only a short hold period is required. None of the GRAFOIL grade gaskets evaluated "blew out" at 5000 psi (34.5 MPa) internal pressure and the appropriate clamping force.

Appendix 1 GRAFOIL Flexible Graphite Product Grades

Appendix 1 depicts the most common range of catalog sizes that are readily available for your application. GRAFOIL flexible graphite can be rolled, corrugated, wrapped, or molded into a complete range of shapes and densities to fit virtually any fluid sealing design. For special order material not of standard stock, consult with our national sales office at (800) 253-8003, or (216) 529-3777.

Homogeneous Sheet

Grade Designation	Typical Sizes	Description	Typical Applications
GTA (Premium nuclear grade)	Rolls 0.005" (0.127 mm) to 0.030" (0.762 mm) Thick 24" (610 mm) & 39.4" (1.0 m) Width 100' (30.48 m) Long, Tol: ±0.002" (0.05 mm) Thickness ±1/16" (1.6 mm) Width + 2.0' (610 mm)/-0 (0.0 mm) Length	Premium nuclear grade monolithic sheet. Has < 50 ppm max, leachable chlorides, <630 ppm sulfur and max. ash content of 0.5%.	Sheet for fabrication. Used to make Ribbon Pack grade GTR and die molded rings for nuclear valve and pump packings. Used as facing material to make high-purity laminated gaskets, nuclear form-in-place gaskets and thread sealant tape (GTF). Meets the GE Nuclear Specification D50YP12 (Rev 2). Nuclear, fossil fuel, aerospace and electronic applications.
GTB (Standard industrial grade)	Rolls 0.005" (0.127 mm) to 0.060" (1.5 mm) Thick 24" (610 mm), 39.4" (1.0 m), 60" (1524 mm) Width 100' (30.48 m) Long, Tol: ±0.002" (0.05 mm) Thickness ±1/16" (1.6 mm) Width + 2.0' (610 mm)/-0 (0.0 mm) Length	Standard industrial grade monolithic sheet. Meets material portion of MIL-P-24503 B specification. Has <1000 ppm sulfur, and max. ash content of 2.0%. Contains a nonmetallic, inorganic passivating inhibitor to increase the resistance to corrosion and oxidation.	Sheet for fabrication. Used to make industrial Ribbon Pack grade GTZ and die molded rings for industrial valve and pump packings. Used as facing material to make industrial laminated gaskets (GHB, GHL, GHE, GHR, GHO, GHT, GHV, GHW, GHP, GRAFKOTE®), industrial form-in place gaskets, and thread sealant tape (GTH). Used as filler material for spiral wound gaskets. Chemical, petro chemical, refinery, and metallurgical applications.
GTJ (Premium nuclear grade with inhibitor)	Rolls 0.005" (0.127 mm) to 0.030" (0.762 mm) Thick 24" (610 mm) & 39.4" (1.0 m) Width 100' (30.48 m) Long, Tol: ±0.002" (0.05 mm) Thickness ±1/16" (1.6 mm) Width + 2.0' (610 mm)/-0 (0.0 mm) Length	Contains a nonmetallic, inorganic passivating inhibitor to increase the resistance to corrosion and oxidation. Made of grade GTA material.	Sheet for fabrication. Primarily used for nuclear packing and gasketing applications. Used to make nuclear Ribbon Pack GTJ and die molded rings. Used as base grade material for braided flexible graphite used in packing. Meets the GE Nuclear Specification D50YP12 (Rev 2). Nuclear, fossil fuel, aerospace and electronic applications.

Grade Designation	Typical Sizes	Description	Typical Applications
GTK (Standard industrial grade with inhibitor)	Rolls 0.005" (0.127 mm) to 0.030" (0.762 mm) Thick 24" (610 mm), 39.4" (1.0 m), 60" (1524 mm) Width 100' (30.48 m) Long Tol: ±0.002 (0.05 mm) Thickness ± 1/16" (1.6 mm) Width + 2.0' (610 mm)/-0 (0.0 mm) Length	Contains a nonmetallic, inorganic passivating inhibitor to increase the resistance to corrosion and oxidation. Made of grade GTB material.	Sheet used for fabrication. Used in industrial packing and gasketing applications. Can also be used as filler material for spiral wound gaskets. Used to make industrial Ribbon Pack Grade GTK, and die molded rings. Used as base grade material for braided flexible graphite and as filler in spiral wound gaskets. Chemical, petrochemical, refinery, and metallurgical applications.
GTY (Extra thin flexible graphite)	Rolls 0.003" (0.076 mm) Thick 24" (610 mm) Wide 100' (30.48 m) Long Tol: ±0.0006" (0.015 mm) Thickness ± 1/16" (1.6 mm) Width + 2.0' (610 mm)/-0 (0.0 mm) Length	Same properties as monolithic sheet material but made from a finer flake material.	Used in industrial heat sink and aerospace applications. Can also be used as a thinner adhesive backed tape when combined with an adhesive backing.

Adhesive-Backed Sheet

NFT (Adhesive-backed sheet)	Rolls 0.005" (0.127 mm), 0.010" (0.254 mm), 0.015" (0.381 mm), 0.020" (0.508 mm), 0.025" (0.635 mm), 0.030" (0.762 mm) Thick 24" (610 mm) & 39.4" (1.0 m) Wide Can also be slit to width with minimum quantity equal to parent roll width. 100'(30.48 m) Length	Plain or crinkled adhesive-backed GTA grade sheet containing less than 50 ppm leachable chlorides.	Nuclear grade form-in place gasketing and thread sealant tape. Use flat tape for straight runs or as pipe thread sealant and the crinkle for the curved lay. Can be used in applications requiring up to two layers of thickness. Also available in premium nuclear grade GTJ for oxidation and corrosion resistance.
GTH (Adhesive-backed sheet)	Rolls 0.005" (0.127 mm), 0.010" (0.254 mm), 0.015" (0.381 mm), 0.020" (0.508 mm), 0.025" (0.635 mm), 0.030" (0.762 mm) Thick 24" (610 mm) & 39.4" (1.0 m) Wide Can also be slit to width with minimum quantity equal to parent roll width. 100'(30.48 m) Length	Plain or crinkled adhesive-backed GTB grade sheet containing less than 50 ppm leachable chlorides. Bonded to a 0.0015" (0.0381 mm) thick polymer with pressure sensitive adhesive using a siliconized release paper on one side.	Industrial form-in place gasketing and thread sealant tape. Use flat tape for straight runs or as pipe thread sealant and the crinkle for the curved lay. Can be used in applications requiring up to two layers of thickness. Also available in grade GTK for oxidation and corrosion resistance.

Non-Metallic Laminates

Grade Designation	Typical Sizes	Description	Typical Applications
GHA (All Flexible Graphite)	Gasket Sheet 1/32" (0.79 mm), 1/16" (1.59 mm) 1/8" (3.18 mm) Thick Also made to order thickness. 24" (610 mm) Square Tol: ± 10% Thickness +1/2" (12.7 mm), -0" Width +1/2" (12.7 mm), -0" Length	Adhesive-bonded and thermally carbonized laminate made from GTA sheet.	Used in aerospace, chemical, and metallurgical applications where high purity gaskets are required.
GHB (All Flexible Graphite)	Gasket Sheet 1/32" (0.79 mm), 1/16" (1.59 mm), 1/8" (3.18 mm) Thick Also made to order thickness 24" (610 mm) Square Tol: ±10% Thickness +1/2" (12.7 mm), -0" Width +1/2" (12.7 mm), -0" Length	Adhesive-bonded and thermally carbonized laminate made from GTB Sheet.	Used in elevated temperature industrial applications where outgassing of adhesives could present a problem. Vacuum, chemical, and metallurgical applications.
GHL (All Flexible Graphite)	Gasket Sheet 1/16" (1.59 mm), 1/8" (0.3 mm) Thick 24" (610 mm), 39.4" (1.0 m), 60" (1524 mm) Square Tol: ±10% Thickness ±1/8" (3.18 mm) Width ±1/8" (3.18 mm) Length Rolls: 1/16" (1.59 mm) Thick 24" (610 mm), 39.4" (1.0 m) Width 100' (30.48 m) Length ±1/8" (3.18 mm) Width +5.0' (1.52 m)/-0' Length	Industrial laminate made from adhesively bonding monolithic GTB sheet.	Used in industrial applications where outgassing of adhesives is not a problem and a metallic or nonmetallic interlayer is not needed. Chemical and metallurgical applications.
GHP (Polymer insert)	Gasket Sheet 1/32" (0.79 mm), 1/16" (1.59 mm), 1/8" (3.8 mm) Thick 24" (610 mm), 39.4" (1.0 m), 60" (1524 mm) Square Tol: ±10% Thickness ±1/8" (3.18 mm) Width ±1/8" (3.18 mm) Length Rolls: 0.030" (0.76 mm), 0.060" (1.52 mm) Thick 24" (610 mm), 39.4" (1.0 m) Wide 25' (7.62 m), 50' (15.24m), 100' (30.48 m) Lengths Tol: ±10% Thickness ±1/8" (3.18 mm) Width +5.0' (1.52 m)/-0' Length	GTB sheet thermally bonded on each side of a 0.0015" (0.0381 mm) thick polymer interlayer.	General purpose industrial laminate having low seating stress. Used as an economical high volume gasket for the OEM (Original Equipment Manufacturers) markets. Especially suitable where metallic inserted gaskets cannot be used. Also used as a filler material for spiral wound gaskets.

Grade Designation	Typical Sizes	Description	Typical Applications
GRAFKOTE [®] (Polyester coating on GRAFOIL Flexible Graphite)	Gasket Sheet on a Roll 1/32" (0.79 mm), 1/16" (1.59 mm) Thick 100' (30.5 m) and 500' (152.3 m) Lengths Tol: ±10% Thickness ± 1/8" (3.18 mm) Width + 5.0' (1.52 m) /-0' (0.0 m) Length	Polyester film thermally bonded to GTB sheet. Polyester film can be bonded to one side or both sides as desired.	Used where lower seating stress and handleability are needed. Very easy to cut "in house" and can be used for economical, high volume gaskets for the OEM markets.
GHW (Woven glass fiber insert)	Gasket Sheet 1/32" (0.79 mm), 1/16" (1.59 mm), 1/8" (0.3 mm) Thick 40" (1016 mm) x 60" (1524 mm) Sheet 60" (1524 mm) x 60" (1524 mm) Sheet Tol: ±10% Thickness ±1/8" (3.18 mm) Width ±1/8" (3.18 mm) Length	GTB sheet thermally bonded to a high temperature woven glass fiber interlayer	Used where lower seating stress and handleability are needed. Very easy to cut "in house" as an emergency replacement gasket. Used where metal inserted gasket are not acceptable.
UCAR-323 [®] (PTFE and a high temp woven glass fiber interlayer)	Gasket Sheet 1/32" (0.79 mm), 1/16" (1.59 mm), 1/8" (3.18 mm) Thick 36" (914 mm) X 48" (1219 mm) Sheet Tol: ±10% Thickness ±1/8" (3.18 mm) Width ±1/8" (3.18 mm) Length	PTFE gasketing material with a unique advanced composite construction comprised of a high temperature woven glass fiber interlayer.	Used where GRAFOIL flexible graphite cannot be used because of material compatibility and is an ideal replacement for existing PTFE gasket applications which experience high temperature thermal cycling and excessive creep relaxation at elevated temperature.

Metal Inserted Laminates

GHE (0.004" 316L/ 316 SS tanged metal insert)	Gasket Sheet 1/32" (0.79 mm), 1/16" (1.59 mm), 1/8" (3.18 mm) Thick 24" (610 mm), 39.4" (1.0 m), 60" (1.5 m) Square 39.4" (1.0 m) X 78.8" (2.0 m) Sheet Tol: ±10% Thickness ±1/4" (6.35 mm) Width ±1/4" (6.35 mm) Length Rolls: 1/32" (0.79 mm), 1/16" (1.59 mm) Thick 39.4" (1.0 m) Width 100' (30.5 m), 200' (61 m), 500' (152.4 m) Length Tol: ±10% Thickness ±1/4" (6.35 mm) Width +5' (1.52 m)/-0' Length	GTB sheet mechanically bonded to a 0.004" (0.10 mm) 316/316L SS tanged metal.	Industrial gasketing, used where higher seating stress, greater blowout resistance, and improved handleability are needed. Also used in applications where of an adhesive could pose a problem Recommended for use in cyclic applications where fatigue is a controlling condition. Will make a high-strength, corrosion-resistant, one piece gasket for ASME 150 and 300 class flanges. Chemical, petrochemical and refinery applications.
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Grade Designation	Typical Sizes	Description	Typical Applications
GHR (0.002" 316/ 316L SS flat foil)	Gasket Sheet 1/32" (0.79 mm), 1/16" (1.59 mm), 1/8" (3.18 mm) Thick 24" (610 mm), 39.4" (1.0 m) and 60" (1.5 m) Square 39.4" (1.0 m) X 78.8" (2.0 m) Sheet Tol: ±10% Thickness ±1/8" (3.18 mm) Width + 3/4" (19.1 mm)/-1/8" (3.18 mm) Length Rolls: 1/32" (0.79 mm), 1/16" (1.59 mm), 1/8" (3.18 mm) Thick 39.4" (1.0 m) Width 100' (30.5 m), 250' (76.2 m), 500' (152.4 m) Length Tol: ±10% Thickness ±1/8" (3.18 mm) Width +5' (1.52 m)/-0' Length	GTB sheet adhesively bonded to a 0.002" (0.05 mm) thick flat 316/316L SS foil.	Industrial gasketing used where ease of cutting, and large one piece gaskets are required. Stainless steel interlayer aids in providing improved handleability and blowout resistance. Recommended or heat exchangers with pass partitions. Will make a high-strength, corrosion- resistant one-piece gasket for ASME 150 and 300 class flanges. Chemical, petro- chemical and refinery applications.
GHV (0.015" 316/ 316L SS insert)	Gasket Sheet 1/16" (1.59 mm), 1/8" (3.18 mm) Thick 24" (610 m), 39.4" (1.0 m) Square Tol: ±10% Thickness ±1/4" (6.35 mm) Width and Length	GTB sheet adhesively bonded to a 0.015" (0.38 mm) thick flat 316/316L SS metal.	Industrial gasketing having a stainless steel interlayer which provides handleability and blowout resistance. Will make a high-strength, corrosion-resistant, one-piece gasket for ASME 150 and 300 class flanges. Excellent replacement for flexible graphite coated corrugated metal gaskets. Chemical, petrochemical and refinery applications.
GHT (0.002" C-276 flat foil insert)	Gasket Sheet 1/32" (0.79 mm), 1/16" (1.59 mm), 1/8" (3.18 mm) Thick 24" (610 m) Square Tol: ±10% Thickness ±1/8" (3.18 mm) Width ±1/8" (3.18 mm) Length	GTB sheet adhesively bonded to a 0.002" (0.05mm) thick alloy C-276 flat foil interlayer.	Industrial gasketing having an alloy C-276 interlayer which provides improved handleability and blowout resistance especially where 316 SS cannot be used such as chlorine service. Will make a high-strength, corrosion- resistant, one-piece gasket for ASME 150 and 300 class flanges. Chemical, petrochemical, refinery, and metallurgical applications.

Grade

Designation

Typical Sizes

GHO (0.005" C-276 tanged metal insert)
 Gasket Sheet
 1/32" (0.79 mm), 1/16" (1.59 mm),
 1/8" (3.18 mm) Thick
 24" (610 mm) Square
 Tol: ±10% Thickness
 ±1/4" (6.35 mm) Width
 ±1/4" (6.35 mm) Length

Description

GTB sheet mechanically bonded to a 0.005" (0.13 mm) thick C-276 tanged metal interlayer.

Typical Applications

Industrial gasketing having an alloy C-276 interlayer which provides handleability and blowout resistance. Used especially where 316 SS cannot be used such as chlorine service. Also used in applications where outgassing of an adhesive could pose a problem. Will make a high-strength, corrosion-resistant, one-piece gasket for ASME 150 and 300 class flanges. Chemical, petrochemical, refinery, and metallurgical applications.

Thread Sealant Paste

GTS®
 (Thread sealant paste)

Tubes
 Available in 125 gram, net wt squeezable tubes, 12 tubes per carton.

Premium nuclear grade thread sealant paste made of a colloidal mixture of graphite flake and a proprietary carrier.

Nuclear certifiable, will meet GE Nuclear Specification D50YP12 (Rev 2). Has many industrial applications as well, such as bolt thread lubricant / antiseize compound.

**Appendix 2 Chemical Compatibility of Materials
with Homogeneous GRAFOIL Sheet**

Graphite is one of the most thermally stable and chemically resistant materials known to man. GRAFOIL flexible graphite is manufactured employing a process that introduces no organic or inorganic elastomeric binders, fillers, or other potentially fugitive ingredients that could limit its thermal and chemical stability.

GRAFOIL flexible graphite is resistant to attack from nearly all organic and inorganic fluids with the exception of highly oxidizing chemicals and concentrated, highly oxidizing mineral acids such as nitric or sulfuric acids. GRAFOIL flexible graphite is an extremely chemically resistant material. The classes of organic chemicals that should not be used with GRAFOIL flexible graphite are those that are highly oxidizing, such as nitrates, persulfates, perbenzoate, and peroxides. Unacceptable compatibility for inorganic chemicals would include molten sodium or potassium hydroxide and chlorine dioxide.

If these chemicals are used in a critical or dangerous process, we always recommend their evaluation in a test loop since we do not have control over the environment or process in which the GRAFOIL flexible graphite gaskets are used.

It is much easier to list the chemicals which GRAFOIL flexible graphite is not compatible with instead of listing all of the chemicals it is compatible. Table XVI lists the strong oxidizers in which GRAFOIL flexible graphite would not be compatible and Table XVII lists the vast majority of chemicals which are compatible and could possibly come in contact with GRAFOIL flexible graphite during industrial use.

Table XVI Strong Oxidizers

(not recommended with GRAFOIL flexible graphite)

Aqua Regia	Bromine (dry)	Calcium Chlorate
Calcium Hypochlorite*	Calcium Nitrate	Chlorazotic Acid
Chlorine Dioxide*	Chlorine Trifluoride	Chloric Acid
Chloroazotic Acid	Chloronitrous Acid	Chromates
Chromic Acid	Chromic Anhydride	Chromium
Chromium Trioxide*	Dichloropropionic Acid*	Dichromates
Hydrogen Dioxide	Hydrogen Peroxide**	Lime Nitrate
Lime Saltpeter	Molten Alkaline	Nitrates
Nitric Acid*	Nitric Oxide	Nitrocalcite

Nitrohydrochloric Acid	Nitromuriatic Acid	Norge Niter
Norwegian Saltpeter	Oleum (Fuming Sulfuric Acid)	Oxygen*(above +600°F)
Ozone	Perchloric Acid	Permanganate solutions
Persulfates	Perbenzoates	Perborates
Peroxide	Potassium Bichromate	Potassium Chlorate
Potassium Chromate	Potassium Dichromate	Potassium Nitrate
Sodium Chlorite*(over 4%) Acid*	Sodium Hypochlorite*	Sodium Peroxide Sulfuric
	Sulfur Trioxide*	

*GRAFOIL flexible graphite may be acceptable in specific temperature/concentration ranges. Call Graftech to discuss your specific application.

** See special limitation notes on page 31.

Table XVII is a listing for many of the chemicals which are chemically compatible with GRAFOIL flexible graphite. The information has been taken from various sources of information.

Again, if these chemicals are used in a critical or dangerous process, we always recommend their evaluation in a test loop, since we do not have control over the environment or process in which the GRAFOIL gaskets are used.

Care must be taken of what combinations of GRAFOIL flexible graphite, interlayer material, chemicals, temperature and concentration are used together. The combination may not be compatible.

Table XVII Chemicals which are compatible with GRAFOIL Flexible Graphite

Chemical Reagents

Acetaldehyde	Alcohol
Acetate Solvents	Alcohol (Ethyl)
Acetic Acid	Aldehyde
Acetic Anhydride	Alkanes
Acetone	Alkyl Acetone
Acetone, Dry	Alkyl Alcohol
Acetylene Gas	Alkyl Amine
Acidaldehyde	Alkyl Arylsulphonics
Acrylonitrile	Alkyl Benzene
Air, Instrument	Alkyl Chloride
Air, Plant	Alkylate, Light
Air, Process	Alum
Air, Starting	Alum Solution

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Aluminum Chloride	Asphalt
Aluminum Fluoride	Barium Carbonate
Aluminum Hydroxide (Boehmite)	Barium Chloride (Aqueous)
Aluminum Sulfate	Barium Hydroxide
Aluminum Sulphate, Aqueous	Barium Nitrate (Aqueous)
Amine	Barium Sulfate
Amine, Fat Condensate	Barium Sulfide
Ammonia	Beer
Ammonia Liquid	Beer Wort
Ammonia, Anhydrous	Beet Juice
Ammonia, Aqua	Beet Pulp
Ammonia, Aqueous	Beet Sugar Solution
Ammonia, Gas (Dry)	Benoic Acid Sol
Ammonium Bicarbonate	Benzaldehyde
Ammonium Bifluoride	Benzene
Ammonium Bisulfate	Benzene Hexachloride
Ammonium Carbonate	Benzoic Acid
Ammonium Chloride	Benzol
Ammonium Hydroxide	Benzyl Sulfonic Acid
Ammonium Nitrate	Black Liquor
Ammonium Persulfate	Bleach Solution (0-25% conc. @R.T.)
Ammonium Phosphate	Boiler Feed Water
Ammonium Sulfate	Borax (Sodium Borate)
Ammonium Thiocyanate	Borax Solution
Amyl Acetate	Boric Acid
Amyl Alcohol	Boric Acid, Aqueous
Amyl Nitrate	Boron Trichloride
Aniline	Brine Calcium
Aniline Hydrochloride	Brine, Calcium & Sodium Chloride
Aniline Hydrochlorine	Brine, Chloride PH8
Anti-Foaming Agent	Brine & Magnesium Chloride
Aromatic Fuels	Brine, Sea Water
Aniline Hydrochloride	Bromo Methane
Arsenic Acid	Bunker C Fuel Oil
Arsenic Trichloride	Butadiene

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Butane	Caustic Zine Chloride
Butane (LPG)	Chloracetone
Butanol	Chloral Hydrate
Butyl Acetate	Chloride of Lime
Butyric Acid	Chloride of Zinc
Butyl Alcohol	Chlorinated Solvents
Butylamine	Chlorine
Butyl Caritol	Chlorine (Dry and Wet)
Butylene	Chlorine Water
Butylene (Butene) (Ethylethylene)	Chloroacetic Acid
Butyl Phthalate	Chlorobenzene
Calcium Carbonate	Chloroethylbenzene
Calcium Chloride	Chloroform
Calcium Hydroxide	Chloropicrin
Calcium Hypochlorite	Chlorosulfonic Acid
Calcium Magnesium Chloride	Citric Acid
Calcium Phosphate	Citric Acid, Aqueous
Calcium Sulfate	Cocoa Butter
Cane Juice	Coconut Acid, Fatty
Carbolic Acid	Coconut Oil
Carbonate of Soda	Cod Liver Oil
Carbon Bisulfide	Condensate (Water)
Carbon Dioxide	Cooling Water
Carbon Disulfide	Copper Acetate
Carbonic Acid	Copper Ammonium Acetate
Carbonic Acid, Aqueous	Copperas
Carbon Monoxide	Copper Cyanide
Carbon Tetrachloride	Copper Nitrate
Carbon Tetrachloride (Anhydrous)	Copper Sulfate
Catsup	Corn Oil
Caustic	Creosol, META
Caustic Cyanogen	Cresols
Caustic Potash	Creosote (Coal Tar)
Caustic Soda	Cresylic Acid
Caustic Strontia	Crude Oil
Caustic Sulfide	Cupric Chloride

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Cupric Sulfate	Dinitrochlorobenzene & Styrene
Cupros Ammonia Acetate	Dinitrotoluene
Cutting Oil	Diethyl Phthalate
Cyanogen in Water	Diethyl-Amine
Cyclohexene	Diphenyl
Cyclohexanone	Dow Corning Silicone Fluid
DDT Solution (Kerosine Solv)	Dowtherm (All Types)
DDT Solution (Toluene Solv)	Dye Wood Liquor
De-Butanizer Reflux	Esso Therm 500
De-Ethanizer Charge	Ethane
Demineralized Water	Ethanol (Ethyl Alcohol)
Denatured Alcohol	Ethanolamine
De-Propanizer Reflux	Ether
Diacetone Alcohol	Ethyl Acetate
Dibromoethyl Benzene	Ethyl Acrylate
Dibutyl Amine	Ethyl Alcohol (Ethanol)
Dibutyl Cellusolve Adipate	Ethyl Benzoate
Dibutyl Phthalate	Ethyl Cellosolve
Dibutylether	Ethyl Chloride
Dichlorobenzene	Ethyl Chlorocarbonate
Dichloroethane	Ethyl Chloroformate
Diesel Fuel	Ethyl Chlorohydrin
Diethanolamine (Dea)	Ethylene (Ethene)
Diethyl Carbonate	Ethylene Chloride
Diethyl Ether	Ethylene Chlorohydrin
Diethylamine	Ethylene Diamine
Diethylene Glycol	Ethylene Bromide
Diethylene Triamine	Ethylene Dichloride
Di-Isobutyl Ketone	Ethylene Glycol (anti-freeze)
Di-Isopropyl Ketone	Ethylene Oxide
Dimethyl Formaldehyde	Ethylene Oxide & Freon 12
Dimethyl Hydrazene	Ethylene Trichloride
Dimethyl Phthalate	Ethyl Ether (Ethyl Oxide)
Dimethyl Terephthalate	Ethyl Formate
Dinitrochlorobenzene	Ethyl Hexanol

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Ethyl Mercaptain-water	Gasoline Aromatic
Ethyl Oxide	Gasoline Hi-Test w/Mercaptan, H ₂ S
Ethyl Pyridine	Gelatin
Fatty Acids	Glaubers Salt
Fatty Acids, Oleic	Glycerine (Glycerol)
Ferric Chloride	Glycols
Ferric Chloride (Aqueous)	Grease
Ferric Nitrate	Glue Sizing
Ferric Sulfate (Aqueous)	Green Sulphate Liquor
Ferrous Chloride	Halon
Ferrous Sulfate	Heat Transfer Fluids (Petroleum-Oil Based)
Flourolube	Helium
Fluoboric Acid	Heptane
Fluorine	Hexachloro Acetone
Fluosilicic Acid	Hexane
Folic Acid	Hexanol
Formaldehyde (Methanol)	Hexene (Butylethylene)
Formalin	Hexone
Formic Acid	Hexyl Alcohol (Hexanol)
Freon 11 & Refrig. Oil	Hops
Freon 113 & Refrig. Oil	Hydrazine
Freon 114 & Refrig. Oil	Hydrobromic Acid
Freon 12 & Refrig. Oil	Hydrochloric Acid
Freon 121 & Refrig. Oil	Hydrocyanic Acid
Freon 22 & Refrig. Oil	Hydroflouric Acid
Freons, Liquid	Hydrogen
Fruit Acid	Hydrogen Chloride
Fruit Juices	Hydrogen Fluoride
Fuel Oil	Hydrogen Sulfide
Fuel Oil #6	Hydrogen Sulfide-water
Fuel Oil, Acidic	Hypochlorous Acid
Furfural	Hydrogen Chloride
Furnace Oil	Insecticides (Aromatic)
Gas Oil	Insecticides (Nonaromatic)
Gasoline	Iodine
Gasoline 100 & 130 Oct.	Iodoform

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Iso-Octane	Lithium Chloride (Aqueous)
Isobutane	Lye, Caustic
Isobutyl Alcohol	Lye, Salty
Isobutyl Methyl Ketone	Magnesium Chloride (Bischofite)
Isobutylene	Magnesium Hydroxide (Brucity)
Isodecane	Magnesium Sulfate (Epsom Salt)
Isopentane	Magnesium Sulfate (Aqueous)
Isopropanol	Magnesium Sulfite (Aqueous)
Isopropyl Acetate	Maleic Anhydride
Isopropyl Alcohol	Maleic Hydrazide
Isopropyl Chloride	Manganese Chloride (Aqueous)
Isopropyl Ether	Manganese Sulfate (Aqueous)
Isopropylamine	Marsh Gas (Methane)
Isopropyl Acetone	Marsh, Anti-Biotic Fermentation, No Solvent
JP-3	Marsh, With Solvent
JP-4	Mayonnaise
JP-5	MEA (Monoethanolamine)
JP-6	MEA- With Copper Sulfate
JP-X	Melamine Resins
Kerosene	Mercaptan
Ketones	Mercuric Chloride
Lacquer (MEK Sol)	Mercury
Lacquer Thinners	Mercury Salts
Lactic Acid	Mercury Vapors
Lard (Animal Fat)	Mesityl Oxide (Ketone)
Latex	Methane (Marsh Gas)
Lavender Oil	Methanol (Methyl Alcohol)
Lead Acetate (Liquid)	Methyl Acetate
Lead Nitrate	Methyl Acrylate
Lead Sulphamate	Methyl Alcohol (Methanol)
Lindol	Methyl Bromide (Bromomethane)
Linseed Oil	Methyl Butyl Ketone
Liquor, Steep	Methyl Cellosolve
Liquor, Sulphate	Methyl Chloride (Chloromethane)
Lithium Bromide Brine	Methyl Chloride (Anhydrous)

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Methyl Cyclopentane	Nitrochloroform
Methyl Dichloride	Nitrobenzene
Methyl Ether	Nitrobenzine
Methyl Ethyl Ketone (MEK)	Nitroethane
Methyl Formate	Nitromethane
Methyl Isobutyl Ketone	Nitrogen Gas
Methyl Isopropyl Ketone	Nitropropane
Methylene Chloride (Dichloromethane)	Oakite
Methylene Dichloride	Oil & Ammonia
Milk	Oil, Animal, Bone
Milk of Lime	Oil, Animal, Cod
MIL F-25558 (RJ-1)	Oil, Animal, Lard
MIL H-5606 (HFA)	Oil, Animal, Menhadden
MIL H-5606 (J43)	Oil, Animal, Neatsfoot
MIL L-7808	Oil, Animal, Sperm
MIL O-8200 (Hydr)	Oil, Animal, Whale
MIL O-8515	Oil, Bunker 'C'
Mine Water	Oil, Coal Tar
Mineral Spirits	Oil, Creosote, Sweet
Miscella 20% Soya Oil	Oil, Crude, Sweet
Mobiltherm	Oil, Diesel, #2D
Molasses	Oil, Diesel, #3D
Monochlorobenzene	Oil, Diesel, #4D
Monoethanolamine (MEA)	Oil, Diesel, #5D
Naphtha	Oil, Essential
Naphtha Crude	Oil, Fed. Spec #9170, #9250
Napthalene	#9370, #9500
Natural Gas Liquid	Oil, Fed. Spec #10, #20, #30
Neatsfoot Oil	Oil, Fed. Spec SAE 20, 30, 40, 50, 60,
Nickel Acetate	70, 90, 140, 250
Nickel Chloride	Oil, Fuel #1, #2, #3, #5A, #5B, #6
Nickel Cobalt Sulfate, 5% H ₂ SO ₄	Oil, Insulating
Nickel Salts	Oil, Kerosene
Nickle Sulfate	Oil, Lean
Nicotine Sulfate	Oil, Linseed (Raw)

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Oil, Lubricating #8	Petroleum Ether
Oil, Lubricating Diesel #9110	Phenol (Carbolic Acid)
Oil, Mineral Lard Cutting, Fed. Spec. #1	Phenol, Formaldehyde Mix
Oil, Mineral Lard Cutting, Fed. Spec. #2	Phenyl Acetic Acid
Oil, Navy Spec., Navy II	Phidolene
Oil, Quenching	Phosphoric Acid
Oil, Rich	Phosphorous Trichloride
Oil, Turbine Lube	Photographic Developers
Oil, Vegetable, Castor	Phthalic Anhydride
Oil, Vegetable, China Wood	Phthalic Esters
Oil, Vegetable, Coconut	Picric Acid, Molten
Oil, Vegetable, Corn	Picric Acid, Water Solution
Oil, Vegetable, Cottonseed	Plasticizer
Oil, Vegetable, Linseed (Raw)	Plating Solutions (Not Chrome)
Oil, Vegetable, Olive	Poly Glycols
Oil, Vegetable, Palm	Poly Vinyl Acetate
Oil, Vegetable, Peanut	Potable Water
Oil, Vegetable, Rape Seed	Potash (Plant Liquor)
Oil, Vegetable, Rosin	Potash Alum
Oil, Vegetable, Sesame	Potash, Sulfide
Oil, Vegetable, Soya Bean	Potassium Bicarbonate
Olefin, Crude	Potassium Bromide
Oleums	Potassium Carbonate
Orthodichloro Benzene	Potassium Chloride
Oxygen, Liquid and Gaseous (below 600°F)	Potassium Cyanides
Paracymene	Potassium Hydroxide
Paradichlorobenzene	Potassium Perfluoro Acetate
Paraffin, Liquid	Potassium Permanganate
Pectin, Liquor	Potassium Phosphate
Penicillin, Liquid	Potassium Sulfate
Pentachlorophenol	Potassium, Bicarbonate
Pentane	Propane
Pentasol	Propiolactone, Beta
Perchloroethylene	Propionaldehyde
Petrolatum	Propyl Alcohol

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Propylene (Propane)	Sodium Phosphate, Tribasic
Propylene Glycol	Sodium Plumbite
Propylene Oxide	Sodium Silicate
Pulp Stock	Sodium Sulfate
Pyridine	Sodium Sulfide
Pyrogallic Acid	Sodium Tetraborate
Pyroligneous Acid	Sodium Thiosulfate
Raffinate	Solvasol 1, 2, 3, 73, 74
Refrigerants 11, 12, and 134A	Sorbitol
Sal Ammoniac (Ammonium Chloride)	Stannic Chloride
Salt Cake	Starch
Salt Water	Steam
Sea Water	Steam, Superheated
Sewage	Stearic Acid & Oleic
Shellac	Steric Acid (Octadecandic Acid)
Silicone Oils and Greases	Stoddard Solvent
Silver Nitrate	Strontium Nitrate
Skydrol 500, 7000	Styrene (Monomer) (Vinylbenzene)
Soap, Liquors	Sulfate of Lime
Soap, Solutions	Sulfide of Hydrogen
Sodium Acetate	Sulfide of Sodium
Sodium Aluminate	Sulfite Pulp
Sodium Bicarbonate	Sulfur Chloride
Sodium Bisulfate	Sulfur Dioxide
Sodium Bisulfite	Sulfur Monochloride
Sodium Borate	Sulphonated Fatty Alcohol
Sodium Chloride	Sulphonated Vegetable Oils
Sodium Chloride Sol (Salt)	Sulphuric Chlorohydrin
Sodium Cyanamide	Syrup
Sodium Hydroxide	Tall Oil
Sodium Hydrosulfite	Tallow
Sodium Metasilicate	Tannic Acid
Sodium Perborate	Tanning Liquors
Sodium Phosphate, Dibasic	Tar & Ammonia w/Water
Sodium Phosphate, Meta	Tar, Bituminous
Sodium Phosphate, Mono	

**Table XVII (continued) Chemicals which are compatible
with GRAFOIL Flexible Graphite**

Chemical Reagents

Tar, Pine	Water, Borated
Tartaric Acid, Aqueous	Water, Brackish
Terephthalic Acid	Water, Clean Untreated
Tetrachloroethane	Water, Condensate
Tetrachloroethylene	Water, Cooling Tower
Tetrahydrofuran	Water, Deaerated
Tetraphenyl	Water, Distilled
Therminol (All Types)	Water, Fresh
Therminol #1, 2 & 3	Water, Heavy
Titanium Tetrachloride	Water, Hot
Toluene (Toluol) (Methylbenzene)	Water, Mine
Tomato Pulp	Water, River
Toxaphene	Water, s/Sol. Oil
Trichlorobenzene	Water, Salt & Sea, Solution
Trichloroethane	Water, Soapy
Trichloroethylene	Whiskey
Trichloronitromethane	White Liquor
Tricresylphosphate	White Water, Paper Mill
Triethylamine	Wine
Trifluorovinylchloride	Wood Pulp (Stock)
Trisodium Phosphate	Wood Vinegar
Turpentine	Wort (Beer Wort)
Ucon (All types)	Xylene (Dimethylbenzene)
Urea	Yeast
Varnish, Aromatic	Zeolite Treated Water
Varnish, Non-Aromatic	Zinc Ammonium Chloride
Vegetable Juices	Zinc Chloride
Vetrocoke Solution	Zinc Cyanide
Vinegar	Zinc Nitrate
Vinyl Chloride	Zinc Phosphate
Vinyl Pyridine	Zinc Sulfate
Vinylidene Chloride	
Water, Boiler Feed	

Appendix 3 Comparative Chemical Resistance Chart of Gasket Metals to Various Corrosive Media

The charts on the following pages will serve as a rough guide in the selection of the proper interlayer alloy for a given type of corrosive service. The main value of this data is in narrowing down the choice of alloy to be used in the gasket laminate. In the tables, the effects of complicating factors such as aeration, galvanic action, contamination and erosion are not taken into account. In some instances, the data was compiled from the availability of only a few sources.

For these reasons, the information in the tables is not to be construed as a recommendation either for or against using any alloy as a gasket interlayer under any given conditions. The only reliable method for making a final choice of a material is actual field testing of the alloy. Special attention should be made as to what combinations of GRAFOIL flexible graphite and metallic interlayer materials are used in respect with the chemical media when used together. The combination in a laminate form may not be compatible.

A – Good Resistance
U – Unsatisfactory

B – Moderate Resistance
- No Data Available

C – Poor Resistance

Media	Aluminum	Copper	Inconel	Monel	Nickel	316SS	Steel	Hastelloy
			600	400	200			C276
Acetic Acid - Room Temp	A	A	B	B	B	A	U	A
Acetic Anhydride-Rm Temp	A	A	B	B	A	A	B	A
Acetone	A	A	A	A	A	A	A	A
Alum Chloride-Rm Temp	U	B	-	B	B	U	U	C
Alum Fluoride-Rm Temp	B	B	-	B	B	U	B	-
Aluminum Sulfate	B	B	B	B	B	A	U	A
Ammonia (Anhydrous)	A	A	A	B	B	A	B	A
Ammonium Chloride	U	U	A	B	B	B	B	A
Ammonium Hydroxide	B	U	A	U	U	A	A	A
Ammonium Nitrate	A	U	B	U	U	A	A	A
Ammonium Phosphate	A	B	B	B	B	A	U	A
Ammonium Sulfate	U	B	B	B	B	A	A	A
Amyl Acetate	A	A	A	A	A	A	B	A
Aniline	B	A	B	B	B	A	A	A
Barium Chloride	B	B	A	-	B	A	B	A
Beer	A	A	A	A	A	A	A	A
Benzene	A	A	A	A	B	A	A	A
Benzol	A	A	B	A	B	A	A	A
Borax	A	A	A	A	-	A	A	A
Boric Acid	A	A	B	B	B	A	U	-

Appendix 3 (continued)

A – Good Resistance

B – Moderate Resistance

C – Poor Resistance

U – Unsatisfactory

- No Data Available

Media	Aluminum	Copper	Inconel	Monel	Nickel	316SS	Steel	Hastelloy
			600	400	200			C276
Bromine	A	A	A	A	A	U	U	A
Butyl Alcohol	A	A	A	A	A	A	A	A
Calcium Carbonate	A	A	A	A	A	A	A	A
Calcium Chloride	B	A	A	B	B	A	A	A
Calcium Hydroxide	B	A	B	B	B	B	A	A
Calcium Hypochlorite	U	U	U	U	B	A	U	A
Carbolic Acid	A	A	B	B	B	A	U	A
Carbon Tetrachloride	B	B	A	A	A	A	U	A
Chlorine-Dry	A	A	A	A	A	U	A	A
Chlorine-Wet	U	U	B	B	B	U	U	A
Chromic Acid	B	U	B	U	U	A	-	A
Citric Acid	A	A	B	B	B	A	U	A
Copper Chloride	U	U	U	U	U	B	B	-
Copper Sulfate	U	B	B	B	B	A	U	A
Creosote (Coal Tar)	B	A	B	B	B	A	A	A
Crude Oil	A	B	-	B	-	A	A	A
Ether	A	A	B	B	B	A	A	A
Ethyl Acetate	A	A	A	A	A	A	A	A
Ethyl Chloride	B	A	-	B	B	A	A	C
Ferric Chloride	U	U	U	U	U	U	U	A
Ferric Sulfate	B	B	U	U	U	A	U	A
Formaldehyde	B	A	A	A	A	A	B	C
Formic Acid	U	A	B	B	B	A	U	A
Fuel Oil(Acid)	B	B	U	B	U	B	B	A
Furfural	A	A	B	A	B	A	A	A
Gasoline	A	A	A	A	A	A	A	A
Glue	A	A	A	A	A	A	A	A
Glycerin	A	A	A	A	A	A	A	A
Hydrobromic Acid	U	U	U	U	U	U	U	A
Hydrochloric Acid <100° F	U	U	U	U	U	U	U	A
Hydrochloric Acid >100° F	U	U	U	U	U	U	U	C
Hydrocyanic Acid	A	C	-	B	-	A	B	-
Hydrofluoric Acid	U	U	A	A	A	U	U	C
Hydrofluosilicic Acid	-	U	B	-	B	U	U	-

Appendix 3 (continued)

A – Good Resistance

B – Moderate Resistance

C – Poor Resistance

U – Unsatisfactory

- No Data Available

Media	Aluminum	Copper	Inconel	Monel	Nickel	316SS	Steel	Hastelloy
			600	400	200			C276
Hydrogen Peroxide	A	C	B	B	B	A	U	A
Hydrogen Sulfide	A	A	B	B	B	A	U	A
Kerosene	A	A	A	A	A	A	A	A
Lactic Acid	B	A	B	U	U	B	U	A
Linseed Oil	A	B	A	A	A	A	A	A
Lye (Caustic)	U	B	A	A	A	A	A	-
Manganese Carbonate	A	A	B	B	B	A	-	-
Manganese Chloride	U	B	B	B	B	A	U	-
Magnesium Carbonate	B	A	A	A	A	A	-	-
Magnesium Chloride	B	B	A	A	A	A	B	A
Magnesium Hydroxide	U	A	A	A	A	A	A	A
Magnesium Nitrate	A	B	B	B	-	A	B	A
Magnesium Sulfate	A	A	B	B	B	A	A	C
Methylene Chloride	U	U	U	U	U	U	B	-
Mercuric Chloride	U	U	U	U	U	U	U	C
Mercury	U	U	A	B	B	A	A	A
Muriatic Acid	U	U	U	U	U	U	U	A
Nitric Acid-Diluted	U	U	U	U	U	A	U	A
Nitric Acid-Concentrated	A	U	U	U	U	A	U	U
Nitrous Acid	B	B	B	-	-	A	-	-
Nitrous Oxide	A	A	U	A	U	-	B	-
Oleic Acid	A	A	A	B	B	A	B	A
Oxalic Acid	B	A	B	B	B	A	U	A
Petroleum Oils-Crude	A	U	A	A	A	A	A	A
Phosphoric Acid	U	B	B	B	B	A	U	A
Picric Acid	A	C	U	U	U	A	A	-
Potassium Bromide	B	A	B	A	B	A	B	A
Potassium Carbonate	B	A	B	A	B	A	B	C
Potassium Chloride	B	B	B	B	B	A	A	A
Potassium Cyanide	U	U	B	B	B	A	A	-
Potassium Hydroxide	U	U	B	A	A	A	B	C
Potassium Sulfate	A	A	B	B	B	A	A	-
Potassium Cyanide	U	U	B	B	B	A	A	-
Sea Water	B	B	B	B	B	A	B	A

Appendix 3 (continued)

A – Good Resistance

B – Moderate Resistance

C – Poor Resistance

U – Unsatisfactory

- No Data Available

Media	Aluminum	Copper	Inconel	Monel	Nickel	316SS	Steel	Hastelloy
			600	400	200			C276
Sewage	B	B	-	-	-	A	B	A
Silver Nitrate	U	U	B	U	U	A	U	-
Soaps	B	B	A	A	A	A	A	-
Sodium Bicarbonate	B	A	A	A	A	A	B	A
Sodium Bisulfate	B	B	B	B	B	A	U	C
Sodium Bromide	B	A	B	B	B	A	B	-
Sodium Carbonate	B	A	B	B	B	A	A	A
Sodium Chloride	B	A	A	A	A	A	A	A
Sodium Hydroxide	U	B	A	A	A	A	A	A
Sodium Hypochlorite	U	U	U	U	U	A	U	A
Sodium Nitrate	A	A	A	B	B	A	A	C
Sodium Peroxide	A	B	B	B	B	A	B	C
Sodium Phosphate	A	A	B	B	B	A	B	A
Sodium Silicate	B	A	-	B	-	A	A	A
Sodium Sulfate	A	A	B	B	B	A	A	A
Sodium Sulphide	U	U	B	-	B	-	A	A
Soy Bean Oil	A	A	-	B	-	A	-	-
Steam	A	B	A	A	A	A	A	A
Stearic Acid	A	A	B	B	B	A	B	-
Stannic Chloride	U	U	B	B	B	A	-	-
Sulfur Chloride	U	A	-	B	B	U	B	-
Sulfur Dioxide-Dry	A	A	A	A	A	A	A	A
Sulfuric Acid - <10% - Cold	B	B	U	B	B	B	U	A
Sulfuric Acid - <10% - Hot	U	U	U	B	U	U	U	A
Sulfuric Acid- 10-50% -Cold	U	U	U	B	U	U	U	A
Sulfuric Acid- 10-50% - Hot	U	U	U	U	U	U	U	C
Sulfuric Acid-Fuming	A	U	U	U	U	A	B	C
Sulfurous Acid	B	U	U	U	U	B	A	A
Sulfur-Molten	A	U	A	U	U	A	A	U
Tannic Acid	B	A	B	B	B	A	U	A
Tartaric Acid	B	A	B	B	B	A	U	A
Vinegar	B	B	A	A	A	A	B	A
Zinc Chloride	U	B	B	B	B	U	B	A
Zinc Sulfate	B	A	B	B	B	A	B	A

Appendix 4 Thermal and Electrical Conductivity of GRAFOIL Flexible Graphite Sheet

The intrinsic properties of materials we call thermal and electrical conductivity are very poor approximations of what happens in energy transfer models which include more than one component. In fact, with polished surfaces at low load, an aluminum sheet may transmit only 1% of the energy from a source to a collector that would be predicted using *k*, the thermal conductivity.

For graphite to a temperature of 1400°C (2552°F), the product of thermal conductivity and the electrical resistivity (the reciprocal of the conductivity) at a given temperature is a straight line function of 1/*K*

Because of this relationship, anything that effects the electrical conductivity also effects the thermal conductivity.

Thermal Conductivity

Thermal Conductivity (*k*) is a property measured within a material.

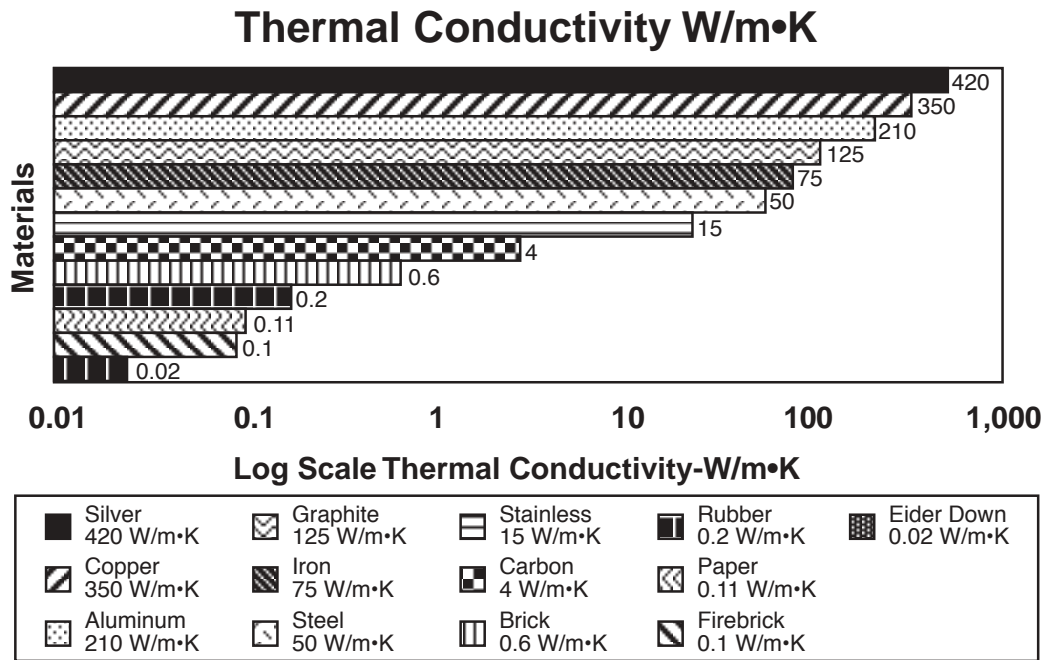
The thermal conductivity of a material is defined as the quantity of heat transferred within that material per unit area per unit temperature gradient. This is written:

$$k = \frac{WL}{A\Delta T}$$

where *k* is the thermal conductivity, *W* is the heat transferred per unit time, *A* is the area at right angles to the direction of heat flow, *L* is the length of the sample along which the heat flows, and ΔT is the temperature differential along that length.

Some handbook values for *k* are shown in Figure 19. Thermal conductivity (in W/mK) ranges from 0.02 for a down comforter, to 0.2 for paper, to 15 for stainless steel, to 210 for aluminum, and to 420 for silver.

Figure 19 Thermal Conductivities



Heat Transmission

Overall heat transmission coefficient (U) is a property having identical units to thermal conductivity but measured on a composite structure.

When measuring energy (heat) transfer through a composite structure, the thermal resistance (R) can be looked upon as a series resistance, and every change in thermal resistance must be included. For example, there are five components to model heat transmission from one aluminum block to another: (1) aluminum, (2) the aluminum oxide surface coating, (3) contact fluid (gas or liquid) separating imperfect surfaces, (4) the aluminum oxide surface coating, and (5) aluminum.

$$k_{comp} = U = \frac{1}{R_T} = \frac{1}{R_1 + R_2 + R_3 + R_4 + R_5}$$

The heat transmission for aluminum to aluminum may be less than 1% of the k depending upon the surface condition and pressure at the contacting surfaces.

Metals used in gasket and flange construction generally have stable oxide surface coatings. The oxide and/or the “fluid” layer (that is, the point-to-point contact between two less than perfect surfaces) presents most of the resistance to heat flow.

Flexible graphite has low contact resistance and, like gold, does not have a stable oxide coating.

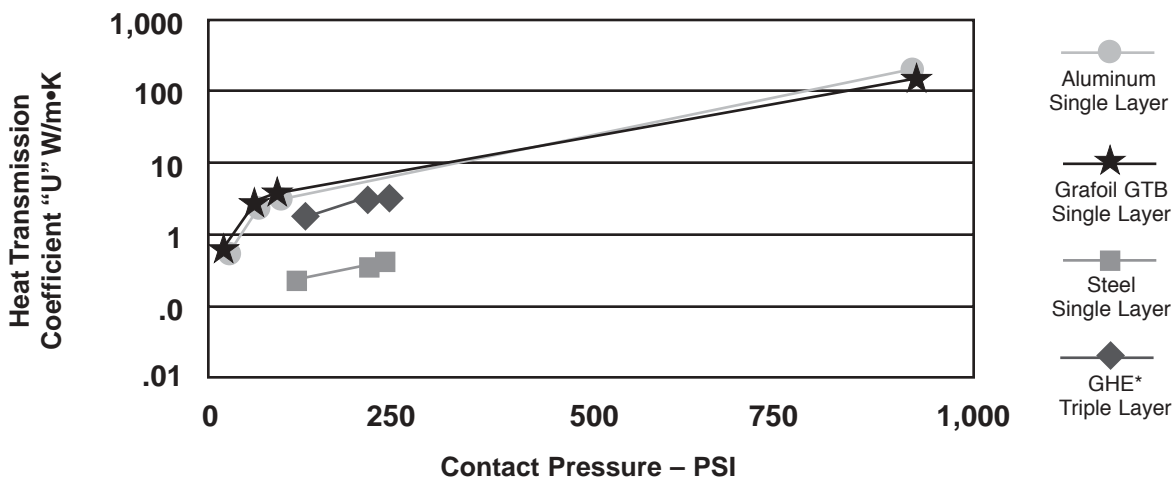
For a GRAFOIL Grade GHR gasket with a metal interlayer, there are 13 thermal resistors in the heat transmission model: five from the above paragraph plus (6) GRAFOIL sheet (7) point-point contact resistance, (8) metal oxide, (9) metal, (10) metal oxide, (11) contact resistance, (12) GRAFOIL sheet, and (13) contact resistance. For this system,

$$U = \frac{1}{R_T} \text{ where } R_T \text{ equals the total of the 13 resistances}$$

Contact resistance is changed by load on the system for two major reasons: (1) the air gap is lessened, and (2) the metal oxide layer (insulation) is damaged so there are fewer resistances in series.

Figure 20 shows overall heat transfer through single-layer samples of aluminum, GRAFOIL sheet, and steel, with a sample of Grade GHE included for comparison. Based on k (the thermal conductivity within a material), steel and aluminum are 8 and 40 times higher in through the thickness thermal conductivity than GRAFOIL sheet. However, the U (overall heat transmission) for GRAFOIL sheet is better than aluminum and 10 times better than steel at moderate load. The conformance of GRAFOIL flexible graphite on both sides of tanged stainless steel results in Grade GHE conducting heat more like GRAFOIL flexible graphite than steel.

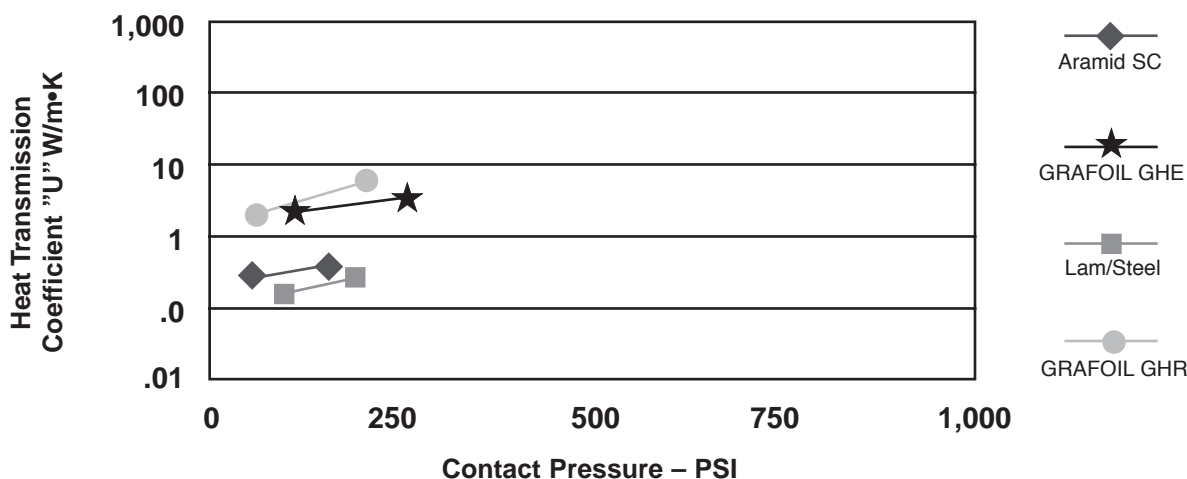
Figure 20 U-Heat Transfer Overall Heat Transmission Coefficients ‘U’ Values



*GHE=GRAFOIL GTB-perforated steel-GRAFOIL GTB measured at points only-Graftech system

Figure 21 shows four different gaskets that have been clamped between a loaded heat source and calorimeter. The x-axis is the clamping load (50–200 psi) (.34–1.4 MPa). The y-axis is log scale showing energy transfer through the gaskets. The gasket samples were GRAFOIL GHE, GRAFOIL GHR, aramid fiber-reinforced with metal foil interlayer, and three layers of stainless steel.

Figure 21 Variation of Heat Transmission with Load



Note that heat transmission increases with increasing load and that GRAFOIL GHR is better at transferring energy at higher load than GRAFOIL GHE. This is probably due to the tangs or protrusions resulting from the perforations keeping the GRAFOIL facing from conforming as well to the mating surfaces. The three layers of uncoated stainless steel are poorest at transferring energy, possibly because the surfaces are rigid and non-conforming and provide few points of contact and lots of “fluid” resistance.

If the data is extended to a load of 200 psi (1.4 MPa) and GRAFOIL GHR conducts one unit of energy, the GRAFOIL GHE would conduct 0.5 units, aramid 0.08 units, and laminated steel only 0.07 units of energy.

Electrical Contact Resistance

The term electrical contact resistance refers to the resistance occurring between any two contact points in electrical applications. This contact resistance is dependent upon a number of variables, including the nature of the materials involved, the pressure at the contact, the nature of the surfaces making the contact, and the quality of the contact surfaces.

Data are shown in Table XVIII for electrical contact resistance between manufactured graphite and other materials. In general, a greater than 10-fold reduction in resistance is achieved as clamping load is raised from 25 to 1000 psi (0.17–6.9 MPa).

Table XVIII Typical Electrical Contact Resistance of Graphite

Contact Resistance (ohm/in ²)					
Pressure (psi)	Graphite to Graphite	Graphite to Copper	Graphite to Steel	Graphite to Brass	Graphite to Aluminum
25	0.000473	0.000704	0.01309	0.00092	0.0448
75	0.000261	0.000424	0.00694	0.00034	0.0159
150	0.000175	0.000315	0.00438	0.00021	0.0067
250	0.000101	0.000237	0.00282	0.00016	0.0043
400	0.000064	0.000162	0.00177	0.00010	0.0020
750	0.000036	0.000075	0.00086		
1000	0.000031	0.000055	0.00074		

The values must be considered as typical only since the absolute electrical contact resistance for any given situation will depend upon the individual pieces and their exact surface condition.

Table XIX is a list of conversion factors; if you do not like the units reported, for example, W/m•K, and prefer “cal” units, multiply “W” by 0.002389 to convert.

Table XIX Thermal Conductivity Conversion Factors

	cal•cm/sec•cm ² •K	W/m•K	BTU•ft/hr•ft ² •°F
cal•cm/sec•cm ² •K	1	418.6	242
W/m•K	0.002389	1	0.578
BTU•ft/hr•ft ² •°F	0.004135	1.730	1

Appendix 5 General Gasket Design Guidelines for the Use of GRAFOIL Flexible Graphite

What is a gasket?

A gasket is a material or combination of different materials usually combined or “laminated” with one another, and placed between two stationary members of a flanged connection for the specific purpose of preventing a liquid or gaseous leak into the atmosphere.

The gasket material selected must be chemically compatible with the internal medium, compatible with the metallic valves, piping and pumps, and able to withstand the application temperatures and pressures.

Gaskets are used to provide the sealing element in flanged connections and should not be used to correct any design flaws or shortcomings within the engineered piping system.

How does a gasket function?

A gasket provides a seal in a flanged connection by flowing into the imperfections of the mating surfaces. This is done by the exertion of external forces on the gasket surface, which compress the gasket material, causing it to flow. The combination of contact stress between the gasket and the flanged connection and the densification of the gasket material prevents the escape of the confined liquid or gas from the assembly.

When a gasket is compressed, it must be capable of overcoming two main types of flanged imperfections. It must be able to flow into minor flange surface imperfections and it must be capable of withstanding non-parallel flanges, distortions and deep surface scorings caused by continued maintenance of the flanged connections.

Therefore, sufficient force must be available for pre-load to initially seat the gasket. In order to ensure the maintenance of the seal throughout the life expectancy of the assembly, sufficiently high stresses must remain on the gasket surface to ensure that the leakage does not occur over time.

The resultant bolt load on the gasket materials should always be greater than the hydrostatic end force acting against it in order to effect a seal. The hydrostatic end force is the force produced by the internal pressure that acts to separate the flanges from each other.

Gasket Selection

Not much thought was given to gasketing applications, testing or differentiation prior to the decade of the 60's when asbestos gasketing was predominantly the sealing material of choice by virtue of availability. Compressed asbestos sheet was considered the performance standard for nonmetallic gasketing materials used in valves and flanges. Asbestos was well known and dependable material with many years of operating data.

The 1980's brought significant changes to the way everyone thought about and used gasketing materials. Gasketing and bolted joint behavior became a focal point when in the United States, and elsewhere around the world, asbestos became suspect as a health hazard. Instantly, users began the search for nonasbestos materials and at the same time, environmental regulations got tougher. Suddenly, flanged connections were looked at as a source of fugitive emissions and by and large, gasket users and manufacturers alike were caught off guard by the impact of this asbestos issue.

As the availability of asbestos gaskets decreased, a multitude of substitute products claiming comparable performance to asbestos appeared in the market. Every manufacturer of gasketing material began producing alternative asbestos-free materials whose room temperature and short-term properties were almost identical to asbestos. Users of these new products saw varying degrees of success and some notable failures, especially for elevated temperature services where detailed long term performance data was lacking. It now became very clear that there were no meaningful testing standards or qualification procedures for these new materials due to years of inattention while asbestos was the standard.

All of the claims of the so-called nonasbestos gasketing materials were made largely on short-duration, in-house quality type property testing. End users became alarmed when they experienced disappointing performance, including some major failures resulting in loss of life and property.

Currently, new gasket materials and combinations of materials are being manufactured regularly as the trend for asbestos substitutes and tighter gaskets improve. This rapidly changing environmental climate together with higher performance needs continue to make gasket selection a challenge.

There are many factors that effect the sealability of a flanged connection so the selection of a gasket material must be such that:

1. The material will withstand the pressures exerted upon the gasket. This includes the tensile, crush strength, resilience and the amount of seating stress required to effect an initial seal.
2. The gasket must satisfactorily resist the entire temperature range in which it will be exposed to. This includes the heat resistance, thermal conductivity, creep relaxation at elevated temperatures and thermal cycling of the gasket.

One of the most important considerations in the selection of a gasket material is its response to elevated temperature service. Tensile strength, blowout resistance, creep relaxation, recovery, and general sealability are all affected by increases in temperature. This has become more and more clear to end users in recent years who attempt to replace the old compressed asbestos gasketing from their facilities.

Many of the asbestos substitutes consist of a clay or other inorganic base material which is added as a filler for improved strength, flexibility, and improved processing. Aramid, acrylic, glass, and cellulose fibers have been added as well, but not to the same degree in which the asbestos fiber contributed to the overall composition of the gasket material. Only glass has the heat resistance of asbestos, but it lacks the intertwining compressible structure of asbestos.

Some of the proposed substitutes are equal or even better than asbestos at room or moderately elevated temperatures, however, they tend fail mechanically when temperatures are raised. Elastomeric bonded sheet materials consist of a base polymer with the addition of vulcanizing agents, fillers, chopped fibers, pigments and various additives. Table XX shows the temperature limits of various elastomeric compounds.

Table XX Temperature Limits of Polymers

Base Polymer	Temperature Limits
Natural Rubber (NR)	-50 to 120°C (-60 to 250°F)
Neoprene (CR)	-50 to 110°C (-60 to 230°F)
Nitrile (NBR)	-50 to 120°C (-60 to 250°F)
Butyl (IIR)	-40 to 150°C (-40 to 300°F)
Viton (FDM)	-20 to 200°C (-4 to 392°F)
Ethylene Propylenediene (EPDM)	-50 to 150°C (-60 to 300°F)
Styrene Butadiene (SBR)	-50 to 120°C (-60 to 250°F)
Silicone	-70 to 250°C (-95 to 480°F)

3. The gasket must withstand corrosive attack from the confined medium. This is the chemical resistance and workable pH range of the gasket material.

Included in Appendix 3 - Comparative Chemical Resistance Chart of Gasket Metals to Various Corrosive Media - are some general recommendations for metallic materials against various corrosive media. Although this chart gives general recommendations, there are many additional factors that have an influence on the corrosion resistance of a particular semi-metallic material at operating conditions. Among them are:

- The concentration of the corrosive agent can be tricky and will have an effect on the gasket selection. A full 100% concentration of a corrosive agent may not necessarily be more corrosive than those of dilute proportions, and of course, the reverse is also true.
- The purity of the corrosive agent is another factor to consider. For example, a solution of dissolved oxygen in what one would consider pure water, may cause a rapid oxidation in steam service generation equipment at high temperatures.
- The temperature of the corrosive agent will accelerate the corrosive attack. In general, higher temperatures of corrosive agents will cause this to occur.

As a consequence of the above three influential factors that have an influence on the corrosion resistance, it is often necessary to “field test” materials for resistance to corrosion under normal operating conditions to determine if the material selected will have the required resistance to corrosion. The only reliable method for making a final choice of a materials is actual field testing of the alloy with the chemical medium.

4. In addition to the above, considerations associated with the decision as to which grade or style of gasket to use for a particular joint also includes:
 - As a replacement for a 1/16" thick asbestos composition gasket, is a joint design review needed?
 - Ease of installation.
 - Availability.
 - Purchase price of the gasket.
 - Basic design considerations.

Gasket Composition

Gaskets can be categorized into three main segments or styles; nonmetallic, semimetallic and metallic types. It should be noted that the mechanical characteristics, performance and seating stresses of a gasket will vary, depending upon the type of gasket selected and the materials from which it is manufactured. Although the mechanical properties are an important factor when considering a gasketing material, the primary selection of a gasket is influenced by the temperature and pressure of the media to be contained together with the corrosive nature of the application.

There are many factors that effect the performance of a flanged connection and a gasket is nothing more than another variable in the “big picture” equation. In addition to the gasket properties, the overall application detail and parameters listed in Table XXI should be considered as well.

Table XXI Joint Performance Factors

The Joint	The Fastener	The Service Loads & Environmental Factors
Material Factors Configuration Surfaces Holes Gaskets	Material Factors Shape Factors Surfaces Special Features	Types Direction Dynamics Temperature Stress Relaxation
The Tools	The Assembly Process	Post Assembly Relaxation
Type of Tool Power Source Type of Control Capacity, Speed Repeatability Ease of Use	Joint Condition Fastener Condition Tool Condition Use of Tools Interrelationships Preparation Assembly Procedure	Stress Friction Losses Alignment Conforming Resistance Deformation

Nonmetallic gaskets are usually composed of compressed sheet materials that are used in low pressure class applications. They are particularly suitable for a wide range of general and corrosive chemical and steam applications. The products listed in Table XXII are typically referred to as soft sheet gasketing materials.

Table XXII Nonmetallic GRAFOIL Laminates

Nonmetallic	Composition
GHL	All GRAFOIL laminate
GHP	GRAFOIL flexible graphite and 0.0015" thick polymer
GHW	GRAFOIL flexible graphite and 0.0025" thick glass fiber
GRAFKOTE	GRAFOIL flexible graphite and 0.0015" thick polymer coated surface
UCAR 323	PTFE and woven glass fiber

A semimetallic gasket usually consists of both nonmetallic and metallic materials. The metal generally provides the strength, and blow out resistance while the nonmetallic facing material provides resilience and sealing. These gaskets can be used for high pressure and high temperature applications.

Table XXIII Semimetallic GRAFOIL Laminates

Semimetallic	Composition
GHR	GRAFOIL and 0.002" thick 316 stainless steel
GHE	GRAFOIL and 0.004" thick 316 stainless steel tang
GHV	GRAFOIL and 0.015" thick 316 stainless steel
GHT	GRAFOIL flexible graphite and 0.002" thick alloy C-276 foil
GHO	GRAFOIL and 0.004" thick alloy C-276 tang

Semimetallic gaskets also include GRAFOIL flexible graphite filled spiral wound and double jacketed gaskets.

Table XXIV Spiral Wound and Double Jacketed GRAFOIL Gaskets

Nonmetallic Filler	Application Use
GTA	High Purity Spiral Wound Gaskets
GTB	Spiral Wound Gaskets
GTJ	High Purity Spiral Wound Gaskets with Corrosion/Oxidation Inhibitor
GTK	Spiral Wound Gaskets with Corrosion/Oxidation Inhibitor
GHP	Spiral Wound Gaskets, Double Jacketed Gasket
GHL	Spiral Wound Gaskets, Double Jacketed Gaskets

Metallic gaskets can be fabricated from a single metal or a combination of metallic materials in a variety of shapes and sizes. These gaskets are generally suited for very high temperatures and pressure applications. Very high loads are required to seat an all-metallic gasket and they are usually found in the form of ring type joints, lens rings, welded gaskets and clamp joints.

Basic Design Factors for Gaskets

Gasket Material Selection:

Of the three main segments or styles of gaskets, the semimetallic gaskets are by far the most widely used for industrial gasketing, typically in 150 and 300 class service. For higher class service applications, it is usually recommended to use a spiral wound or a double jacketed gasket utilizing GRAFOIL flexible graphite GTB as a filler material.

Under certain special conditions where a spiral wound or double jacketed gasket would not be suitable for an application, semimetallic gasket grade GHE has been used successfully in applications as high as 1,500 psig (10.3 MPa) and with coincident temperatures up to 650°F (343°C). It is normally recommended to consult with the manufacturer for these applications over and above 300 class flanges.

Application Operating Condition Considerations:

Internal pressures, coincident temperatures, the operating pressure and/or temperature variations in magnitude and frequency and fatigue should be considered when designing a flanged joint. In addition to design pressures and temperatures, the internal media being sealed will add additional restraints to the gasket selection and joint design process. The question of chemical compatibility with the gasket facing material and with any other combinations of materials should also be considered. The metal used in the windings of a spiral wound gasket or the metal used as the jacket must be considered for chemical compatibility as well.

One must also consider: 1) the nature of the fluid or gaseous media and the consequence of leakage from a health, safety and environmental standpoint, 2) the cost of a possible shutdown to replace the gasket, 3) if a metal or metal-reinforced gasket would generally be considered desirable, 4) if the joint design should be of the confined type (e.g. male/female, tongue and groove) to further provide blowout protection, and 5) if the gasket should be made from a fire safe material.

Considerations to the history of the joint should not be overlooked. How does the proposed replacement of the gasket compare with the gasket that has given reliable, leak-free service? How about unreliable, leak-prone service? If the later case prevails, does a careful review of the joint system design indicate that a gasket change alone will rectify the problem? The gasket is an important part of, but only a part of, the complete joint system.

The question of which type of gaskets are appropriate to use in gasketed joints needs further clarification of the application itself. Thermal cycling, thermal shocks, vibration and erosion need to be considered when designing a flanged connection.

Surface Finish and Flatness:

Relative to the mechanical condition of the joint in question, considerations must be made to the surface finish of both the gasket contact surfaces and the flatness of these surfaces. GRAFOIL flexible graphite can seal against a wide range of surface finishes from polished (5 microinch) to rough (500 microinch). The ideal surface finish is in the range of 125 to 250 microinch. For new designs, the surface finish should be specified accordingly. In all cases, the lay of the surface finish shall be either spiral (phonographic) or concentric. Any radial scratches across the gasket contact surface are not acceptable. Sometimes the surface finish of the gasket contact faces of ANSI flanges approaches 500 microinch, and if so, re-machining to a smoother finish is not necessary. GRAFOIL gaskets will conform to and seal either concentric or spiral (phonographic) serrated surfaces as well as smooth surface flanges. Serrations can have either a “u” cut or a “v” cut shaped cross section. Serrations can be from 0.005” (0.13 mm) to 0.015” (0.38 mm) in depth and from 20 to 50 serrations per inch. Gaskets must be thick enough to completely fill the serration depth when the gasket is compressed.

The flatness of the flange surface is essential to good gasketing practice. If gasketed surfaces are perfectly flat under operating conditions, then the average unit load on the gasket is also the minimum unit load. If the flange surface is not flat while in service, the gasket unit load can be less at some point or points than the amount required to seal operating or test pressures.

In general, if a 0.001” (0.03 mm) thick feeler gage cannot be inserted anywhere around the circumference of the flange faces when they are brought together, then a gasket as thin as 0.015” (0.38 mm) can be used to seal this flange. If this criteria cannot be met or if the flanges warp under loaded conditions, then a thicker gasket is required.

Flange Design:

Paying attention to details of flange design is critical when designing a gasket for a jointed connection. The very configuration of the flange, the available bolt load and construction materials all have an effect on the gasket selection. The basic dimensions of a gasket are taken from the flange configuration and the total bolt load available are the basis for calculating whether the gasket will seal or not. Then the possibility of corrosion enters the picture when looking at the compatibility between the flange and the gasketing material.

If corrosion is a possibility, Graftech Inc. recommends using one of our inhibited grades (GTB, GTK, GTJ) as the gasket facing.

When a jointed connection is designed for service, there are basically three forces that become critical in affecting the sealing characteristics of a gasket.

End Force	This is the pressure of the confined gases or liquids which tend to separate the flange faces.
Gasket Unit Load	This comes from the available bolting or other means which applies force upon the flange faces to compress the gasket.
Internal Pressure	This is the force which can move, permeate or bypass the gasket.

In taking the three above factors into consideration, one of the most important hurdles to overcome is the initial pre-load force applied to the jointed connection. This force must be enough to seat the gasket to the flange faces and it must be enough to compress and conform the gasket material into any surface imperfections or misalignment. It must also be sufficient enough to compensate for the internal pressures acting against the flange assembly, commonly referred to as the hydrostatic end force. Lastly, the applied force must be sufficient enough to maintain a correct amount of residual load upon the jointed connection. Call Graftech's Applied Technology team to assist you in determining the correct loads to seal a GRAFOIL gasket.

Ease of Installation:

One should consider the location and position of the joint and the associated gasket handling requirements, and raise these questions; How will the gasket be centered and held in position? Should a male/female or tongue and groove facing be provided to minimize installation problems in the field? Consider the weather conditions. Will the tendency of the gasket to flex and/or bend create installation problems under the expected access and environmental conditions? Will working (e.g. joint access) conditions detract from the likelihood of getting a proper level of uniform pre-load on the bolts? Will a tube bundle have to be removed or will major vessel sections be separated (with attendant pipe spool removal or separation) to replace a gasket?

It is likely that in many cases the ease of handling and/or replacement will be the dominant consideration(s) in the gasket selection for a particular joint.

Grafter recommends using a light spray of 3M Super 77 adhesive to hold a gasket in the correct position, if necessary, while assembling a joint. Do not use tape to hold a gasket in position.

Availability:

One needs to consider if the gasket is readily available from plant stores or from a local supplier? Must the gasket be ordered from an out-of-town gasket manufacturer, thus requiring significant lead time to obtain in time for the outage? Can overtime/hotshot transport of a gasket be used to expedite the delivery?

In estimating the total cost associated with a gasket replacement, one must consider the unit shutdown costs, labor to dismantle the equipment, gasket cost, and labor to reassemble and leak test the joint.

Almost always, the purchase price of the gasket itself, even the most expensive, is a very small percentage of the total cost of installing the gasket. Therefore, the gasket which initially costs more, but withstands handling abuse better, is easier to install, and is more forgiving of joint and joint make-up deficiencies (and hence less likely to need retorquing or replacement), often proves to be the most economical choice over the long run.

Gasket Thickness and Wall Thickness:

In general, the thinner the gasket the better within the flange flatness and roughness limits. The thickness difference between the original and the replacement gaskets is generally not a major consideration in that swapping out a 1/16" for another 1/16" thick gasket is recommended. In many cases, the use of a 1/16" thick gasket to replace a 1/8" can also be recommended unless there is a fixed gap or space that must be filled by the gasket. The practice of using two 1/16" thick gaskets of any kind to fill unwanted space or to make an easy initial seal is generally not recommended. Also recognize that GRAFOIL gaskets may compress more and therefore be thinner under load than many asbestos or non-asbestos gaskets.

The gasket wall thickness, being the width of the gasket measured from the ID to the OD, usually opens up the discussion to controversy and past practices. Studies have shown only a very weak correlation between GRAFOIL gasket width and sealability. Handleability and flange size constraints usually dictate the gasket width. Very narrow width (1/4" or less) GHR or GHE gaskets that are cut with a steel rule die may require flattening after punching to reduce the rollover of the insert metal around the edges of the gasket. Typical gasket widths are often based on the nominal joint diameter.

Table XXV Typical Gasket Width

Nominal Joint Diameter	Typical Gasket Width
≤ 24"	1/2"
> 24" < 48"	3/4"
> 48" < 96"	1"
> 96"	1 1/4"

“m” Factor and “Y” Stress:

Most engineers define the leakage behavior of pressure vessel gaskets in terms of two gasket factors found in Section VIII of the ASME Boiler and Pressure Vessel Code. These are typically called the “m” or maintenance factor and the “Y” or minimum seating stress factor. These factors were intended by the ASME Boiler Code authors to be used for flange design, not for prediction or explanation of leakage or to define assembly bolt loads. However, these gasket factors did manage to at least provide a clue to the relationship between assembly or working stress on the gasket and a reasonable leak-free behavior. The “m” and “Y” factors are built around the premise that a gasket is either leaking or is leak-free.

The “Y” stress factor is the initial gasket stress or surface pressure required to pre-load or seat the gasket to prevent leakage in the joint without any internal pressure. We know that the actual seating stress is a function of the flange surface finish, gasket material, gasket density, gasket thickness, fluid or gas to be sealed and the allowable leak rate. The need for varied “Y” values is determined by variables such as rough or irregular flange finish, the ease or harshness of containing fluids and the specified allowable leak rates in the joint.

Appendix II, Section VIII, of the Boiler Code under paragraph VA-49 makes the statement; “the “m” factor is a function of the gasket material and construction.” Another interpretation of “m” is the ratio of the residual gasket contact pressure to the internal pressure required for a gasket material not to leak. It can be viewed as the safety margin above the internal pressure required to affect a gasket seal. Two things must occur in order to maintain a satisfactory ratio of gasket contact pressure to the internal pressure. The flanges must be sufficiently rigid to prevent unwanted unloading of the gasket due to flange rotation when the internal pressure is introduced and the bolts must be adequately pre-stressed. The Boiler Code recognizes the importance of pre-stressing the bolts sufficiently to withstand the hydrostatic test pressure. Appendix S, in the Code, discusses this problem in greater detail.

We know from experience that when the system is pressurized, the contact pressure on the gasket material is reduced, depending upon the elastoplastic behavior of the gasket and its relationship to the elasticity of the joint. So therefore, the contact pressure on the gasket must generally be larger than the internal pressure in the system.

The ratio of contact pressure to contained pressure is called the “m” factor, and may be different for various types of gaskets as suggested below.

Table XXVI “m” Factor and “Y” Seating Stress for Various Gasket Materials

Gasket Material	Thickness	ASME “m” Factor	ASME “Y” Stress (psi)
Asbestos with suitable binder	1/8"	2.0	1,600
Spiral Wound Metal with asbestos filler	1/8"	2.50-3.0	10,000
Asbestos and elastomer	1/8"	2.0	1,600
Sheet PTFE	1/32"	2.0	2,700
Expanded PTFE	Any	1.5-2.0	2,500
UCAR 323	Any	3.0	2,200
GRAFOIL Flexible Graphite Grades GHR, GHW, GHP, GHV, GRAFKOTE, GHL, GHT	Any	2.0	900
GRAFOIL Flexible Graphite Grades GHE, GHO	Any	2.0	2,500

The “m” and “Y” factors, respectively, claim to define the amount of assembly stress which must be applied to a gasket and the amount of residual stress that must be provided to prevent the gasket from leaking after the system has been pressurized. Both of these gasket stresses – initial seating stress and the in-service stress – are equally important.

Bolt Loading:

Consideration must be given to the effective stretching length of the bolts. Is the effective stretching length such that the joint will be unacceptably sensitive to expected bolt load relaxation due to embedment losses? Although GRAFOIL flexible graphite has the most favorable creep relaxation characteristics of any gasket material available today, there will still be some creep relaxation of the gasket and the other highly stressed parts in the bolted joint.

When an axial tensile load (stress) is applied to a bolt in a bolted-joint system, the bolt will stretch just as any elastic material will. The amount of stretch (ΔL) is directly proportional to the effective stretching length. In a bolted-joint system, we use the distance between mid thickness of the nuts as the effective stretching length. Also, the bolt strain ΔL over L is proportional to the tensile load (stress) on it, with the constant of proportionality being the modulus of elasticity, E . This is know as Hooke’s Law.

Bolts in most customer-designed joints should be pre-loaded to 2 times the ASME Code allowable stress at room temperature. This factor is derived by using a factor of 1.5 for the hydrostatic test condition and a factor of 1.3 to cover for the pre-load losses due to gasket, thread, nut-to-flange, etc., embedment. This 1.3 factor is also intended to cover the fact that the actual response of the flanged system to the loading departs somewhat from the theoretical analysis model. Combining these factors, the total pre-load factor becomes $1.5 \times 1.3 = 1.95$, say 2.

The amount a bolt stretches is given by the following:

$$\Delta L \text{ (in)} = \frac{\text{Stress on bolt Root Area (psi)} \times \text{Effective Stretching Length (in)}}{\text{Modulus of Elasticity (psi)}}$$

When we have additional losses in a joint system which occur over time while the joint is in service, such as reduction of gasket thickness, this reduces the amount of stretch in the bolt, ΔL , in proportion to the loss of thickness. By rearranging the above formula, and solving for stress on bolt,

$$\text{Stress on Bolt (psi)} = \frac{\Delta L \text{ (in)} \times \text{Modulus of Elasticity (psi)}}{\text{Effective Stretching Length (in)}}$$

The resultant stress must be equal to or greater than the stress value used to design the flange system, adjusted for embedment losses; otherwise the system will leak.

As an example, assume a SA-193, GR-B7 bolt with an effective stretching length of seven inches. The modulus of elasticity is 29.7×10^6 psi and the Code allowable design stress is 25,000 psi. The recommended initial pre-load would be $2 (25,000) = 50,000$ psi, and the bolt stretch would be $\frac{50,000 \times 7}{29.7 \times 10^6} = 0.012$ ".

$$\frac{50,000 \times 7}{29.7 \times 10^6}$$

Assuming the total design embedment loss does take place, the resulting initial stretch in the bolt will reduce to 0.012/1.3 or approximately 0.009 inches. If the gasket has an additional loss in thickness during operation of 0.001 inches, the final bolt stress is $(0.009 - 0.001) \times 29.7 \times 10^6 / 7 = 33,900$ psi which is comfortably above the design value of 25,000 psi. Therefore, this joint would not be expected to leak during normal operation but very likely would leak during a subsequent hydrotest at 1.5 X MAWP since the theoretical required bolt pre-stress would be approximately 1.5 X 25,000 or 37,500 psi.

Obviously, the sensitivity to embedment loss can be reduced by increasing the effective stretching length of the bolts, which in turn can be accomplished by adding a segmented backing ring behind each flange (this is considered better practice than either adding washers or a heavy tube over each bolt at the back of the flanges). For example, had the effective stretching length of the bolts in the above example been 12 inches instead of seven inches, the comparative values in the above example would be as follows:

Table XXVII Bolt Length Comparison

	Effective Stretching Length = 7"	Effective Stretching Length = 12"
Initial Bolt Stress	50,000 psi	50,000 psi
Initial Bolt Stretch	0.012"	0.020"
Residual Bolt Stress After 0.003" embedment loss	38,000 psi	42,600 psi
Residual Bolt Stress After additional 0.001" embedment loss (0.004" total)	33,900 psi	40,100 psi

This sensitivity analysis clearly shows the advantages of a relatively long stretching length, and, conversely, illustrates the disadvantages of joints with relatively short bolts. Clearly, there are occasions when adding backing rings are needed to ensure reliable, leak-free performance.

ASME Boiler and Pressure Vessel Code Criteria

Section VIII of the ASME Boiler & Pressure Vessel Code establishes the necessary criteria for flange design and relates to the traditional “m” (maintenance factor) and “Y” (minimum seating stress) values. Overall, these defined values have proven very successful in actual applications.

The initial bolt load required to seat a gasket sufficiently to hold any pressure at all is defined in this equation:

$$W_{m2} = \pi b G Y$$

The “b” in this formula is defined as the effective gasket width, G is the gasket diameter at the effective width, and “Y” is defined as the minimum seating stress in psi that depends upon the type of gasket (see Table XXIX for a complete list of symbols and definitions). It should be noted that these are suggested values for “Y”, not mandatory.

The required operating bolt load must be at least sufficient, under the most severe operating conditions, to contain the hydrostatic end force and in addition, to maintain a residual compression load on the gasket that is sufficient to assure a tight joint. ASME defines this bolt load in the following equation:

$$W_{m1} = \frac{\pi G^2 P}{4} + 2 b \pi G m P$$

Where P = internal design pressure and where m = maintenance factor for the gasket material. This equation states the minimum required bolt load for operating conditions and is the sum of the hydrostatic end force plus a residual gasket load on the contact area of the gasket times a factor times internal pressure. Stated another way, this equation requires the minimum bolt load be such that it will maintain a residual unit compressive load on the gasket area that is greater than internal pressure when the total load is reduced by the hydrostatic end force.

After W_{m1} and W_{m2} are calculated, the minimum required bolt area A_m is determined as follows:

$$A_{m1} = \frac{W_{m1}}{S_b} \quad \text{where } S_b \text{ is the allowable bolt stress at operating temp, and}$$

$$A_{m2} = \frac{W_{m2}}{S_a} \quad \text{where } S_a \text{ is the allowable bolt stress at ambient temp}$$

Then A_m is equal to the greater of A_{m1} or A_{m2} as follows:

$A_m = A_{m1}$ if A_{m1} is greater or equal to A_{m2} , or

$A_m = A_{m2}$ if A_{m2} is greater or equal to A_{m1}

Bolts are then selected so that the actual bolt area A_b is equal to or greater than A_m

$A_b = (\text{Number of Bolts}) \times (\text{Minimum Cross-Sectional Area of Bolt in Square In})$

A_b greater than or equal to A_m

At this point, it is important to realize that the gasket must be capable of carrying the entire compressive force applied by the bolts when pre-stressed unless provisions are made to utilize a compression stop in the flange design or by the use of a compression gauge ring.

The maximum unit load S_g (max) on the gasket bearing surface is equal to the total maximum bolt load in pounds divided by the actual sealing area of the gasket in square inches.

For Spiral Wound Gaskets it would be:

$$S_g \text{ (max)} = \frac{A_b S_a}{\frac{\pi [(OD - 0.125)^2 - (ID)^2]}{4}}$$

For all other types of gaskets it would be:

$$S_g \text{ (max)} = \frac{A_b S_a}{\frac{\pi [(OD)^2 - (ID)^2]}{4}}$$

Except as noted, the following symbols and definitions below are those given in Appendix II of the ASME Boiler and Pressure Vessel Code, Section VIII.

Table XXVIII Notation Symbols and Definitions

Symbol	Description
A_b	Actual total cross-sectional area of bolts at root of thread or section of least diameter under stress, square inches.
A_m	Total required cross-sectional area of bolts, taken as the greater of A_{m1} or A_{m2} , square inches.
A_{m1}	Total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for the operating conditions.
A_{m2}	Total cross-sectional area of bolts at root of thread or section of least diameter under stress, required for gasket seating.
b	Effective gasket or joint-contact surface seating width, inches.
b_o	Basic gasket seating width, inches.
G	Diameter at location of gasket load reaction.
ID	Inside Diameter.
m	Gasket maintenance factor.
N	Width, in inches, used to determine the basic gasket seating width b_o , based upon the possible contact width of the gasket.
OD	Outside Diameter.
P	Design pressure, psi.
S_a	Allowable bolt stress at ambient temperature, psi.
S_b	Allowable bolt stress at operating temperature, psi.
W_{m1}	Required bolt load for operating conditions, pounds.
W_{m2}	Minimum required bolt load for gasket seating, pounds.
Y	Gasket or joint-contact surface unit seating load, minimum design seating stress, psi.

PVRC Design Calculations

Through many years of research and development, the PVRC (Pressure Vessel Research Council) has conceived a new philosophy that addresses the mechanisms of sealing which will ultimately, benefit the gasket manufacturers, pressure vessel designers and the operators of pressure vessels in general. This diligent effort encompassed hundreds of actual gasket tests over the past 25 years on a wide range of gasket styles and materials to arrive at a methodology to improve upon the current “m” & “Y” factors as we know them today.

The results of their effort is a methodology which recommends the minimum levels of gasket assembly stress to fulfill the operational requirements of the user. The new procedure is similar to the existing ASME Section VIII calculation, except it incorporates new gasket factors (G_b), (a), (G_s) and (T_p) to replace the traditional “m” & “Y” gasket factors.

The suitability of the traditional “m” and “Y” factors, in use since the early 40’s, has been questioned over the years and although they were defined by most engineers to assume leakage behavior of pressure vessel gaskets, they had no real bearing on leakage as we know of it today. They were basically intended by the Code authors to be used solely for the design of flanged connections, and not supposed to be used to predict or explain leakage, nor to define assembly bolt loads. The “m” and “Y” did however, at least provided some insight for the engineers to the relationship between assembly or working stress on the gasket and a leak-free behavior.

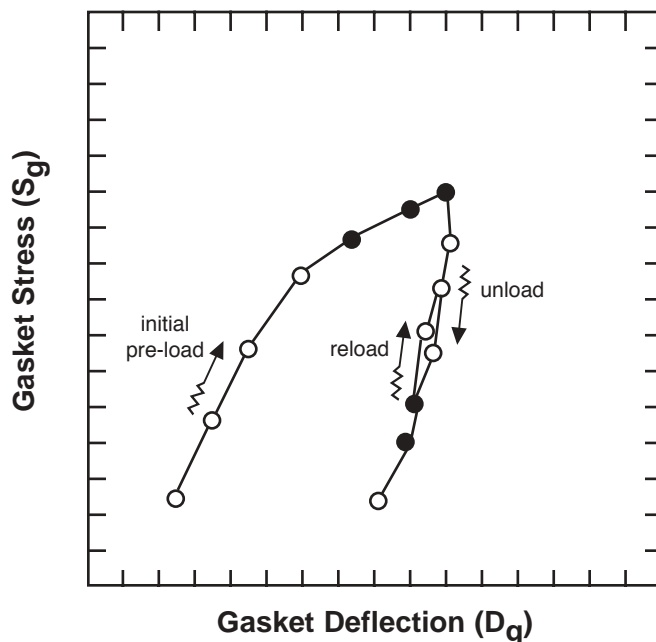
Knowing the questionable validity of the existing gasket constants, the ASME Subcommittee on Design made a request of the PVRC of the Welding Research Council in New York City, to investigate the revision of the traditional “m” and “Y” values. With this task in mind, the PVRC initiated an exploratory program and has continued since its introduction in 1974.

The traditional “m” and “Y” factors only considered the gasket material, but the PVRC findings showed very clearly that there are other variables, including the acceptable leak rate, the contained fluid, the gasket stress achieved at assembly, the internal pressure, and the flange surface finish. There is no question that the work done by the PVRC has provided a better understanding of all the variables which affect the reliability of a bolted gasket joint.

(G_b) and (a) represent the initial gasket compression characteristics and relate to bolt behavior, while (G_s) represents the unloading characteristics which typically are associated with operating behavior. (T_p) is also related and means tightness parameter.

In the PVRC tests, data is obtained simultaneously on the mechanical and leak behavior of the gasket material. After the gasket is first loaded, a partial seating stress to the gasket is made and a leak test is conducted at that point. After loading the gasket to some maximum seating stress, the gasket would be unloaded and again, checked for a leak rate. By the end of a given test series, the leak rate will have been checked at all of the points shown in Figure 22. In some tests, the gasket is loaded and unloaded at several different initial stresses. After the initial unloading and reloading cycles, the seating stress is raised, followed by further unloading and reloading tests.

Figure 22 Gasket Deflection



The data generated by testing gaskets under a variety of conditions and with a variety of contained fluids is best summarized by the use of a dimensionless parameter called a “tightness parameter” defined as follows:

$$T_p = \frac{P}{P^*} \left(\frac{L_{rm}^*}{L_{rm} D_t} \right)^a$$

where

T_p	the tightness parameter (dimensionless)
P	the contained pressure (psig or MPa)
P^*	reference atmospheric pressure (14.7 psi or 101.3 kPa)
L_{rm}	mass leak rate (lb/hr•in, mg/sec•mm)
L^*_{rm}	reference mask leak rate (0.2 lb/hr•in, 1 mg/sec•mm) which is keyed to a normalized reference gasket of 5.9 in (150 mm) outside diameter.
a	experimentally determined exponent (e.g., 0.5 if the contained fluid is a gas, 1.0 if it's a liquid).
D_t	gasket OD (in, mm)

A tightness parameter of 100 means that it takes a contained pressure of 100 atmospheres (1470 psi or 10.1 MPa) to create a total leak rate of about 1 mg/sec from a gasket having a 5.9" (150mm) outer diameter. Note that the tightness parameter is expressed in terms of mass leak rate rather than a volumetric leak rate. This allows the lumping together of test data representing a variety of test fluids which could be gaseous or liquid. Since mass leak rates are rather difficult to visualize, the following tables list some equivalents in terms of volumetric leak rates and some bubble equivalents for gaseous leaks.

Table XXIX Volumetric Equivalents For 1mg/sec at Room Temperature

Contained fluid	ml/sec	pt/hr
Water	1×10^{-3}	0.008
Nitrogen	0.86	6.5
Helium	6.02	45.8

Leak rate (ml/sec)	Volume equivalent	Bubble equivalent
10^{-1}	1 ml/10 sec	Steady stream
10^{-2}	1 ml/100 sec	10/ sec
10^{-3}	3.6 ml/hr	1/sec
10^{-4}	1 ml/3 hr	1 in 10 sec

The PVRC also felt that it is necessary to define "acceptable leak rates" in terms of tightness. Three levels of tightness were developed, called economy, standard, and tight as listed on the following page.

Mass leak rate per unit diameter (L_{rm})

Tightness Classification	(mg/sec•mm)	(lbm/hr•in)	Constant C	Tightness parameter pressure ratio (T_{pmin} / P_r)
T1 - Economy	1/5	1/25	1/10	0.18257
T2 - Standard	1/500	1/2480	1	1.8257
T3 - Tight	1/50,000	1/248,000	10	18.257

Economy might be used for a low-pressure water line. Standard would be the most common choice and tight might often be required to combat fugitive emissions.

New Gasket Factors

Figure 23 Actual Stress vs Tightness Parameter

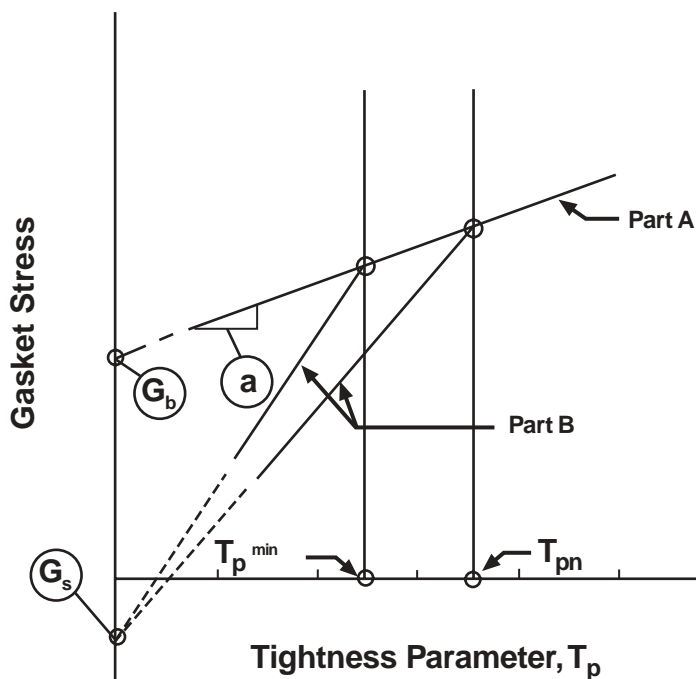


Figure 23 is an idealized approximation of the chart shown in Figure 22, only this time, it has linear regression lines to replace the actual loading and unloading curves from the test data.

Notice the three gasket factors (G_b), (a) and (G_s).

- G_b the intercept of the upper portion of the loading curve with the gasket stress axis.
- a the slope of the upper portion of the loading curve.
- G_s the intercept of all unloading lines with the gasket stress axis.

These PVRC gasket constants G_b , a and G_s are based on the interpretation of leakage test data and define the leak behavior of a gasket. (G_b) represents the loading of the gasket. The (a) represents the slope of the loading of the gasket as the gasket stress changes. The (a) constant describes the rate at which the gasket develops tightness with increasing stress. (G_s) represents the unloading of the gasket.

Low values of “ G_b ” and “ a ” indicate that the gasket requires low levels of gasket stress for initial seating. A low value for G_s indicates less sensitivity to unloading or a material which can tolerate the unloading better. The test data is best summarized by use of a dimensionless parameter called a “tightness parameter”, represented by T_p , expressed in terms of mass leak rate.

T_p is the pressure (in atmospheres) required to cause a helium leak of 1 mg/sec for a 150mm (5.9”) OD gasket in a jointed connection. A tightness parameter of 100 would mean that it takes an internal pressure of 1,470 psi (10.1 MPa) to create a total leak rate of about 1 mg/s from a 5.9” OD (150 mm) gasket. A leak rate of 0.01 mg/s at 1,470 psi would mean a tenfold increase in the tightness parameter to $T_p = 1,000$. Conversely, a tenfold decrease in the T_p will result in 100 times more leakage from the gasket at the same stress and internal pressure. T_p is proportional to pressure and inversely proportional to the square root of leak rate. A higher value of T_p indicates a tighter joint.

It is estimated that a new nonmandatory Appendix will appear in the revised ASME Code in the near future.

Although the three new gasket constants are intended primarily for the use of flange designers, they have been used by people trying to analyze existing flanges or trying to decide how much torque to apply to the flange bolts. More than likely, they will continue to be used until some other way to relate assembly preload and/or working loads on the gasket are developed.

Table XXX Bolt Torque Requirements for GRAFOIL GHR & GHE ASME B16.21 Gaskets

Class 150							Minimum Seating Force			Minimum Seating Force			Recommended gasket load
pipe size (in)	bolt size (in)	# bolts	gasket/flange raised face OD (in)	gasket ID (in)	gasket area (in ²)	Max internal pressure (psi)	GHR total force (lbs)	GHR tension/bolt (lbs)	GHR torque/bolt (ft·lbs)	GHE total force (lbs)	GHE tension/bolt (lbs)	GHE torque/bolt (ft·lbs)	Torque required to develop 5000 psi net gasket stress (ft·lbs)
0.5	0.5	4	1.38	0.84	0.941	275	1518	379	3	3024	756	6	9
0.75	0.5	4	1.69	1.06	1.360	275	2216	554	5	4393	1098	8	13
1	0.5	4	2	1.31	1.793	275	2972	743	6	5842	1461	11	17
1.25	0.5	4	2.5	1.66	2.743	275	4575	1144	9	8966	2242	16	26
1.5	0.5	4	2.88	1.91	3.647	275	6080	1520	11	11918	2980	21	34
2	0.625	4	3.62	2.38	5.840	275	9697	2424	22	19046	4762	43	68
2.5	0.625	4	4.12	2.88	6.814	275	11677	2920	26	22584	5646	50	79
3	0.625	4	5	3.5	10.009	275	17166	4292	38	33188	8298	73	117
3.5	0.625	8	5.5	4	11.186	275	19684	2461	22	37591	4699	42	66
4	0.625	8	6.19	4.5	14.182	275	24947	3119	28	47650	5956	53	83
5	0.75	8	7.31	5.56	17.680	275	32326	4041	45	60628	7579	83	131
6	0.75	8	8.5	6.62	22.314	275	41838	5230	58	77558	9695	107	167
8	0.75	8	10.62	8.62	30.207	275	59870	7484	83	108226	13529	149	220
10	0.875	12	12.75	10.75	36.895	275	78485	6540	81	137546	11462	141	220*
12	0.875	12	15	12.75	49.013	275	106217	8852	109	184678	15390	188	287
14	1	12	16.25	14	53.429	275	119845	9988	143	205375	17115	245	369
16	1	16	18.5	16	67.706	275	153517	9595	138	261901	16369	234	353
18	1.125	16	21	18	91.845	275	203223	12702	200	350249	21891	347	433
20	1.125	20	23	20	101.265	275	233303	11666	185	395410	19771	313	388
24	1.25	20	27.25	24	130.752	275	314094	15705	275	523403	26171	458	684
*maximum torque limited by stress limit of bolting, not by stress limit of gasket material													
Class 300							Minimum Seating Force			Minimum Seating Force			Recommended gasket load
pipe size (in)	bolt size (in)	# bolts	gasket/flange raised face OD (in)	gasket ID (in)	gasket area (in ²)	Max internal pressure (psi)	GHR total force (lbs)	GHR tension/bolt (lbs)	GHR torque/bolt (ft·lbs)	GHE total force (lbs)	GHE tension/bolt (lbs)	GHE torque/bolt (ft·lbs)	Torque required to develop 5000 psi net gasket stress (ft·lbs)
0.5	0.5	4	1.38	0.84	0.941	720	2602	651	5	4108	1028	8	9
0.75	0.625	4	1.69	1.06	1.360	720	3820	955	9	5997	1500	14	17
1	0.625	4	2	1.31	1.793	720	5168	1292	12	8038	2010	18	22
1.25	0.625	4	2.5	1.66	2.743	720	7980	1995	18	12372	3093	28	34
1.5	0.75	4	2.88	1.91	3.647	720	10603	2651	31	16441	4111	46	56
2	0.625	8	3.62	2.38	5.840	720	16877	2110	19	26226	3279	30	36
2.5	0.75	8	4.12	2.88	6.814	720	20643	2581	30	31550	3944	44	54
3	0.75	8	5	3.5	10.009	720	30360	3795	42	46382	5798	64	79
3.5	0.75	8	5.5	4	11.186	720	35237	4405	49	53144	6643	73	90
4	0.75	8	6.19	4.5	14.182	720	44654	5582	62	67356	8420	93	113
5	0.75	8	7.31	5.56	17.680	720	58874	7360	81	87177	10898	120	146
6	0.75	12	8.5	6.62	22.314	720	77024	6419	71	112745	9396	104	125

Class 300 (Continued)							Minimum Seating Force			Minimum Seating Force			Recommended gasket load
pipe size (in)	bolt size (in)	# bolts	gasket/flange raised face OD (in)	gasket ID (in)	gasket area (in ²)	Max internal pressure (psi)	GHR total force (lbs)	GHR tension/bolt (lbs)	GHR torque/bolt (ft·lbs)	GHE total force (lbs)	GHE tension/bolt (lbs)	GHE torque/bolt (ft·lbs)	Torque required to develop 5000 psi net gasket stress (ft·lbs)
8	0.875	12	10.62	8.62	30.207	720	112739	9395	116	161094	13425	165	195
10	1	16	12.75	10.75	36.895	720	151727	9483	136	210789	13175	189	224
12	1.125	16	15	12.75	49.013	720	206677	12918	205	285139	17822	282	334
14	1.125	20	16.25	14	53.429	720	235924	11797	187	321454	16073	255	300
16	1.25	20	18.5	16	67.706	720	303278	15164	266	411664	20584	361	423
18	1.25	24	21	18	91.845	720	398245	16594	291	545272	22720	398	468
20	1.25	24	23	20	101.265	720	463276	19304	338	625383	26058	457	536
24	1.5	24	27.25	24	130.752	720	631836	26327	545	841145	35048	725	844

Gasket Installation Methodology

In any gasketed bolted joint system, the assembly of the components is just as important to the performance of the system as the selection of the gasket itself.

A gasket will normally provide a reliable seal if recommended installation procedures are followed. However, in most cases, the performance of any gasket is not entirely dependent on the gasket, but on a combination of variables which are outside the normal control of the gasket material manufacturer. Any leakage in a gasketed joint is not necessarily an indication of a faulty gasket, but rather, a faulty joint. A faulty joint could be the result of improper joint assembly or bolting procedures, damaged flanges, gasket failure, or a combination of many variables that comprise the bolted joint assembly.

To ensure that the optimum quality of a seal is achieved, there are certain assembly procedures that should be employed. The following procedure should be employed each and every time a gasket is installed.

Recommended Installation Methods for GRAFOIL Flexible Graphite Gasketing Materials

1. All joint components must be cleaned and thoroughly inspected before assembly.
 - A. Gasket-bearing surface areas of both joint faces.
 - Remove most of, if not all, traces of old gasket material. Small amounts of GRAFOIL Flexible Graphite left on the flange faces will not harm the installation as long as the large chunks of flexible graphite are removed. GRAFOIL Flexible Graphite can seal against itself!

- Inspect for scratches, nicks, gouges, burrs. Scratches that run radially across the facing are of particular concern.
- Check surfaces for flatness, both radially and circumferentially.
- Carefully clean up any defects. This may require remachining of the gasket-bearing surfaces. Consult with the Process Vessel Engineer prior to removing defects if remachining will require removal of more than 0.010" (0.25 mm) from the gasket-bearing surface.

B. Stud or Bolt-Washer-Nut Assembly

- Stud, bolt and nut threads - inspect threads for damage, rust, corrosion, burrs or thread damage. Replace any damaged components (refer to vessel drawings for replacement specifications).
- Nut bearing surfaces - inspect for scores and burrs. Replace any questionable nuts.
- Washer Surfaces - inspect for damage; replace questionable parts.

C. Nut-bearing/washer-bearing surfaces of flanges.

- Inspect for scores, burrs, etc.; remove protrusions by filing. Spot facing may be appropriate for heavily scored surfaces. Heavy paint must be removed.

2. Install a new gasket; do not reuse old gasket.

- Gasket must comply with gasket size and specification shown on the vessel drawing. Check that the gasket's type, style and materials are correct.
- Carefully examine the new gasket for manufacturing defects or shipping damage. The gasket should remain flat and horizontal until immediately prior to assembly.
- For all gasket types, be sure that the gasket lines up evenly all the way around (is concentric with) the flange ID.
- To hold the gasket in place, use a very light dusting of a spray adhesive such as 3-M Type 77. Do not use tape. Do not use additional adhesive on self adhesive gaskets or crinkle tapes.
- For special three-ply corrugated metal gasket styles, be sure that the washer side is placed downward in the groove or female facing.
- Do not use any gasket compounds and under no circumstances, do not force the gasket into position as damage may result.

3. Place flanges in position.

- Mate the male and female type joints carefully to avoid damage to the corners of the male facing during initial contact.
- Be sure that heat exchanger partitions fit into grooves in the tubesheet if present.

4. Lubricate studs and nuts.

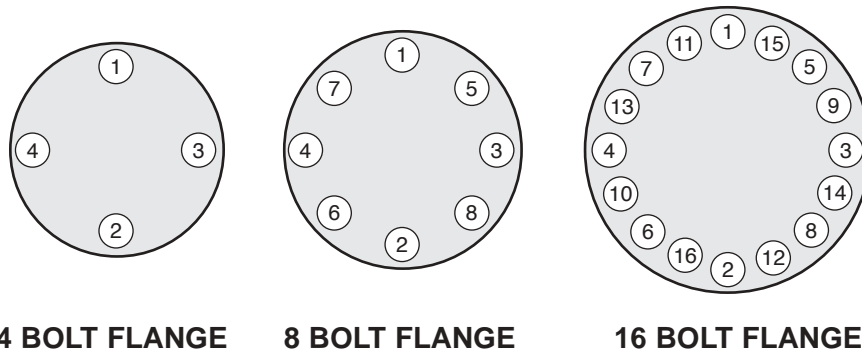
- Liberally coat all thread engagement surfaces and bearing face of the nuts with a lubricant judged to be suitable for the operating temperature and fluid service. This is done in order to reduce and control the friction between the load bearing surfaces.
- The use of molybdenum disulfide or similar nickel based compounds are recently receiving a great deal of attention as far as environmental concerns. There are now a variety of different lubrication materials on the market such as the GRAFOIL GTS Thread Sealant Paste. (See Appendix 1 for more information of GRAFOIL GTS Thread Sealant Paste and how it can be used as a bolt lubricant as well as a thread sealant paste.)

5. Install nuts hand tight, making sure that all nut threads are engaged. You are now ready to generate the required bolting stresses on the joint.

6. Tighten the joint.

- In order to achieve and maintain a leak tight seal on a bolted flange connection, it is very important to provide adequate bolt stress to meet both the operating and the hydrostatic test conditions. The correct level of bolt stress can be determined as detailed under the section headed "ASME Boiler and Pressure Vessel Code Criteria." One of the major causes of joint leakage is from the inability to adequately achieve the correct level of stress required for the flanged connection.
- Start tightening, using a rotating cross-pattern sequence as shown in the following examples. Use a torque wrench or other method to insure loading levels are correct.

4 - 8 - and 16 Bolt Flange Bolting Sequence Pattern



- The first round should be 30% followed by increments of 60%, 90%, and 100% of the final torque value. See Table XXX for minimum and recommended torque values for standard ASME class 150 & class 300 GRAFOIL gaskets. This table comprises the use of “m” and “Y” values. The recommended torque values are calculated at a 5000 psi gasket stress. The torque values are based on clean and well lubricated bolting and nut-bearing surfaces.

WARNING:

Nuts must be tightened in the sequence and incremental steps indicated. If this is not done, the flanges may become cocked relative to each other, resulting in joint leakage. This is particularly true the smaller the flange bolt circle and the fewer the number of bolts. By following the above sequence, reasonably even compression of the gasket will be achieved.

- After final torque is reached, tighten the bolts in a rotational order in a clockwise direction followed by a round in the counterclockwise direction.
- Repeat the rotational clockwise and counterclockwise rotations after a minimum dwell time of four (4) hours. (A large percentage of embedment loss occurs during the first few hours after initial tightening.) Because of the varying frictional conditions of neighboring bolts and the fluctuations in stress levels of bolts which occur as the bolts are individually tightened around the flange, the final level of stress in all of the bolts around the flange can vary considerably. Tests have shown that the final stress levels around the flange can vary as much as +/- 20% from the average, even under ideal conditions.
- Apply the required leak test. If the joint leaks at low pressure, carefully disassemble the joint and determine the problem. If the joint shows minimal leakage at test pressure, the joint should be retighten to two times the Code allowable stress for the stud material (50,000 psi for SA-193, GR-B7 studs). If the joint still leaks, consult Process Vessel Engineering.

Table XXXI Torque Values to Obtain 50,000 psi Tensile Stress for Various Size Bolts (for SA-193, GR-B7 alloy steel bolts)

Nominal Bolt Size	Torque (ft•lbs)
5/8"	100
3/4"	185
7/8"	285
1"	435
1 1/8"	560
1 1/4"	875
1 3/8"	1190
1 1/2"	1545
1 5/8"	2000
1 3/4"	2500
1 7/8"	3085

Table XXXII Common Gasket Factors for PVRC Design Calculations

Type	Material	G _b (psi)	a	G _s (psi)
Sheet Gaskets GHR	GRAFOIL flexible graphite & 0.002" SS Foil	816	0.377	0.066
Sheet Gaskets GHE	GRAFOIL flexible graphite & 0.004" SS Tang	1400	0.450	0.01
Sheet Gaskets GHO	GRAFOIL flexible graphite & 0.004" Tang C-276	1400	0.450	0.01
Sheet Gaskets GHL	All GRAFOIL flexible graphite	970	0.384	0.05
Sheet Gaskets GHV	GRAFOIL flexible graphite & 0.015" SS Sheet	1750	0.274	0.0123
Sheet Gaskets GHW	GRAFOIL flexible graphite & 0.0025" E-Glass Insert	816	0.377	0.066
Sheet Gaskets GHP	GRAFOIL flexible graphite & 0.0005" Polyester	970	0.384	0.05
Sheet Gaskets GHT	GRAFOIL flexible graphite & 0.002" C-276 Foil	816	0.377	0.066
Sheet Gaskets GRAFKOTE	GRAFOIL flexible graphite & 0.0005" Polyester facing	970	0.384	0.05
Spiral Wound Stainless Steel	PTFE Filler	4500	0.140	70
Spiral Wound Stainless Steel	GRAFOIL flexible graphite Filler	2300	0.237	13
Spiral Wound Stainless Steel	Asbestos Filler	3400	0.300	93
UCAR 323	PTFE and Glass Filler	5	0.921	0.078
Corrugated Metal Jacket	Corrugated Metal with Metal Jacket	8500	0.134	230

Note: All of the data presented in this table is based on the most current available published information. Values are subject to further review or alteration since the PVRC continues to refine its data reduction techniques.

Torque Required to Produce Bolt Stress

(Load in Pounds on Stud Bolts when Torque Loads are Applied) The torque required on a bolt to produce a certain required stress in bolting is greatly dependent upon a number of conditions.

- Diameter of bolt
- Number of, and type of threads on the bolt
- Material of bolt
- Condition of the nut bearing surfaces
- Lubrication of the bolt threads and nut bearing surfaces

It is generally understood that it is the users responsibility to follow prescribed ASME Code calculations, and to ensure that a sufficient amount of pre-load is applied to withstand the internal pressure, properly seat the gasket, and compensate for any bolt relaxation.

Table XXXIII Bolt Torque Required to Produce Bolt Stress

Alloy Steel Stud Bolts

Nominal Diameter of Bolt (Inches)	Number of threads (Per Inch)	Diameter at Root of Thread (Inches)	Area at Root of Thread Sq. Inch	Stress					
				30,000 PSI		45,000 PSI		60,000 PSI	
				Torque Ft/Lbs	Compression Lbs	Torque Ft/Lbs	Compression Lbs	Torque Ft/Lbs	Compression Lbs
1/4"	20	.185	.027	4	810	6	1215	8	1620
5/16"	18	.240	.045	8	1350	12	2025	16	2700
3/8"	16	.294	.068	12	2040	18	3060	24	4080
7/16"	14	.345	.093	20	2790	30	4585	40	5580
1/2"	13	.400	.126	30	3780	45	5670	60	7560
9/16"	12	.454	.162	45	4860	68	7290	90	9720
5/8"	11	.507	.202	60	6060	90	9090	120	12120
3/4"	10	.620	.302	100	9060	150	13590	200	18120
7/8"	9	.731	.419	160	12570	240	18855	320	25140
1"	8	.838	.551	245	16530	368	24795	490	33060
1 1/8"	8	.963	.728	355	21840	533	32760	710	43680
1 1/4"	8	1.088	.929	500	27870	750	41805	1000	55740
1 3/8"	8	1.213	1.155	680	34650	1020	51975	1360	69300
1 1/2"	8	1.338	1.405	800	42150	1200	63225	1600	84300
1 5/8"	8	1.463	1.680	1100	50400	1650	75600	2200	100800
1 3/4"	8	1.588	1.980	1500	59400	2250	89100	3000	118800
1 7/8"	8	1.713	2.304	2000	69120	3000	103680	4000	138240
2"	8	1.838	2.652	2200	79560	3300	119340	4400	159120
2 1/4"	8	2.088	3.423	3180	102690	4770	154035	6360	205380
2 1/2"	8	2.338	4.292	4400	128760	6600	193140	8800	257520
2 3/4"	8	2.588	5.259	5920	157770	8880	236655	11840	315540
3"	8	2.838	6.324	7720	189720	11580	284580	15440	379440

Reference Crane Co. (Page 383, Crane No. 60 Valve Catalog.)

Table XXXIII reflects the results of many tests to determine the relation between bolt torque and bolt stress. These values are based on steel bolting being well lubricated with a mixture of oil and graphite.

Table XXXIV Various Metallic Gasket Materials Information

Material	Description	Temp Range ° C (° F)	Hardness Value (Brinell)	Comments
Carbon Steel	Commercial Quality. Sheet Forged or Rolled Steel. Often referred to as Soft Iron	-50 to 540 ° C (-58 to 1,000 ° F)	120 max	For general applications.
316 SS	An 18-12 Chromium/ Nickel Austenitic SS, containing approx. 2% molybdenum content for high temp strength.	815 ° C max (1,500 ° F)	160 max	Excellent corrosion resistance. Subject to stress corrosion cracking and intergranular corrosion in the presence of certain media.
316L SS	Variation of 316, carbon content reduced to 0.03% max.	815 ° C max (1,500 ° F)	160 max	Reduced possibilities of stress corrosion cracking and intergranular corrosion due to reduced carbon content.
304 SS	An 18-8 chromium/ nickel austenitic SS.	540 ° C max (1,000 ° F)	160 max	Excellent corrosion resistance. Subject to stress corrosion cracking and intergranular corrosion at elevated temps.
304L SS	Variation of 304, carbon content reduced to 0.03% max.	540 ° C max (1,000 ° F)	160 max	Reduced possibilities of stress corrosion cracking and intergranular corrosion due to reduced carbon content.
321 SS	An 18-10 chromium /nickel austenitic SS with a titanium addition	870 ° C max (1,600 ° F)	160 max	Subject to stress corrosion and reduced possibilities of intergranular corrosion.

Material	Description	Temp Range ° C (° F)	Hardness Value (Brinell)	Comments
347 SS	An 18-10 chromium/ nickel austenitic SS with the addition of columbium.	870 ° C max (1,600 ° F)	160 max	Similar properties as 321, high temp resistance.
410 SS	An 12-9 chromium/ nickel ferritic SS.	850 ° C max (1,560 ° F)	160 max	Excellent high temp strength/corrosion properties, excellent resistance to oxidation, nitriding and carburisation.
Alloy 400	A 67% Nickel/30% copper alloy steel.	820 ° C max (1,500 ° F)	150 max	High resistance to hydrofluoric acid.
Alloy C276	A nickel/chromium/ molybdenum alloy steel.	1,093 ° C max (2,000 ° F)	210 max	Excellent corrosion resistance to both oxidizing and reducing media and chlorine.
Aluminum	Commercially pure wrought aluminum.	425 ° C max (800 ° F)	Approx 35	Excellent ductility and workability.
Brass	Commercial copper/ zinc alloy.	260 ° C max (500 ° F)	Approx 60	General corrosion resistance.
Copper	Commercially pure copper.	315 ° C max (600 ° F)	Approx 80	General corrosion resistance.

Table XXXV
Pressure-Temperature ratings
of carbon-steel and 304L/316L
Stainless-Steel flanges

Working pressures for material group number 1.1, carbon steel are listed first, then material class number 2.3, types 304L/316L stainless steels. This table was excerpted from the American Society of Mechanical Engineers (ASME)/American National Standards Institute Inc. (ANSI) B16.5 – 1996 standard.

		Working pressure by Classes in psig	
Temperature, °F		150	300
-20 to	100	285/230	740/600
	200	260/195	675/505
	300	230/175	655/455
	400	200/160	635/415
	500	170/145	600/380
	600	140/140	550/360
	650	125/125	535/350
	700	110/110	535/345
	750	95/95	505/335
	800	80/80	410/330
	850	65/65	270/320
	900	50/--	170/--
	950	35/--	105/--
	1,000	20/--	50/--

The Search For Better Gasket Testing

The performance of substitute gasket materials for the replacement of asbestos, especially at elevated temperatures, is not well documented. Information is lacking on their limitations and on the appropriate ways in which they are used. The result has been a significant number of gasket failures of the asbestos-free sheet gasket materials in the fields of the various industries who use gasketing materials.

Since the early 1970's, a major research program aimed at solving the problem of leakage of gasketed flanged joints has been undertaken by the Pressure Vessel Research Council (PVRC). The program had the following goals:

- better understand the sealing mechanism.
- develop more meaningful gasket design factors.
- develop a standard leakage test procedure at room temperature.
- develop a design procedure to minimize leakage of gasketed flanged joints.

The following acronyms represent an update of the recent tests in the area of gasket testing, specifically on the testing of flexible graphite, elastomeric sheet gaskets and fugitive emissions gasket characteristics.

Acronym	Full Name	Description
AHOT	Aged Hot Operational Tightness test	This hot tightness test serves gasket users and producers for product qualification. AHOT/HOTT tests evaluates the sealing performance of gasketing products exposed to simulated long term service conditions (exposure periods of several days to weeks or months).
ARLA	Aged Relaxation Leakage Adhesion test	Measures the weight loss of a gasket, creep relaxation, leakage, and adhesion to the flange surfaces under thermal exposure in an air oven. Similar to the ATRS test, but uses ring gaskets so leakage can be measured.
ATRS	Aged Tensile Relaxation Screen test	Dumbbell-shaped test specimens are tested for creep during and tensile strength after up to 42 days of exposure to 750°F (400°C).

EHOT	Emission Hot Operational Tightness Test	A room-temperature leakage test followed by a 3-day HOTT test, followed by an elevated-temperature leakage test.
FIRS	FIRe Simulation screening test	Specimen subjected to 1200°F (649°C) for 30 min, then tested for tensile strength and relaxation properties.
FITT	simulated FIre Tightness Test	Gasket subjected to 1200°F (649°C) for 15 min. The leak rate is measured during and after the test.
HATR	High temperature Aged Tensile Relaxation test	Conducted at 1100°F (593°C). Relaxation screen test (up to 1050°F)
HBOT	Hot Blow-Out Test	Same as the HOTT/AHOT test and then gauges for blow-out resistance under extreme relaxation conditions.
HOTT	Hot Operational Tightness Test	Gasket tested for leak tightness and blowout resistance under contained pressure, gasket stress, and temperatures (up to 800°F) (450°C).
ROTT	ROom Temperature Tightness test	Determines gasketing product constants (G_D , "a", and G_S) for their use in the proposed ASME Code Bolted Joint Revised Rules

The goal of the PVRC is to develop the technology for standardized performance testing methods and criteria. It is hoped that these developments will lead to the adoption of standard performance tests by national standard bodies, such as the ASTM.

Graftech Inc. financially supports, and is actively involved with the research efforts of the ASME's Pressure Vessel Research Council (PVRC) to update the current gasket design methodology. The PVRC has conceived a new philosophy that addresses the mechanisms of sealing that will benefit gasket manufacturers, vessel designers and the operators of pressure vessels. This has taken many years of research and development involving hundreds of actual gasket tests. The new design factors are anticipated to appear in upcoming revisions of the ASME Boiler and Pressure Vessel Code.

Appendix 6 Glossary of Terms/Definitions Relative to Gasketing

AMBIENT TEMPERATURE: The temperature of the atmosphere or medium surrounding the gasket in service.

ANISOTROPIC: That having different properties according to the direction of measurement.

ANSI: Abbreviation for American National Standards Institute.

API: Abbreviation for American Petroleum Institute.

AQUEOUS SOLUTIONS: Any fluid solution containing water. (See further discussion under pH.)

ASH: Residual product following oxidation of the base carbon as determined by prescribed methods.

ASME: Abbreviation for American Society of Mechanical Engineers.

ASTM: Abbreviation for American Society for Testing and Materials.

BEATER ADD (BEATER SATURATED): A manufacturing process for making nonmetallic sheet employing a paper-making process, using Fourdrinier or cylinder-type paper machines.

BINDER: A substance, usually an organic material, used to bond layers of a gasket.

BSS: Abbreviation for British Standard Specification

BSI: Abbreviation for British Standards Institute

BURST: A rupture caused by internal pressure.

CALENDER: A machine equipped with two or more rolls, which is used for forming sheet gasket materials.

CARBON: An element, atomic number 6, symbol C, molecular weight 12.01115, which exists in several allotropic forms.

COKE: A carbonaceous solid produced from coal, petroleum, or other materials by thermal decomposition with passage through a plastic state.

COLD FLOW: The continued deformation without additional stress, usually a natural property of the material. Also see CREEP,

COMPRESSED SHEET: A gasketing material primarily containing fibers, rubber, and fillers manufactured on a special calender, known as a “sheeter” in such a manner that the compound is “built up” under high load, on one roll of the “sheeter”, to a specified thickness.

COMPRESSIBILITY: The quality or state of being compressible. In the case of gasketing, deformation of thickness when subjected to a compressive stress for a period of time at a prescribed temperature.

COMPRESSION SET: The deformation that remains in gasketing after it has been subjected to, and released from, a specific compressive stress for a period of time at a prescribed temperature.

COMPRESSIVE STRENGTH: A property of solid material that indicates its ability to withstand a uniaxial compressive load.

CREEP: A transient stress-strain condition in which the strain increases as the stress remains constant.

CREEP RELAXATION: A transient stress-strain condition in which the strain increases concurrently with the decay of stress.

DENSITY: The ratio of mass of a body to its volume or mass per unit volume.

DIELECTRIC STRENGTH: The measure of a product’s ability to resist passage of a disruptive discharge produced by electric voltage.

DIN: Abbreviation for Deutsche Industrie Normen. English translation is German Industry Standard. Is one of the European equivalents to ASTM.

ELASTIC UNIT: The extent to which a body may be deformed and yet return to its initial shape after removal of the deforming force.

ELASTOMER: Any of various elastic substances resembling rubber. These man-made rubbers (also called polymers) are produced by the combination of monomers. See also *RUBBER*.

EXTRUSION: Permanent displacement of part of a gasket into a gap.

FATIGUE: The weakening or deterioration of a material caused by cyclic or continuous application of stress.

FLANGE: The rigid members of a gasketed joint that contact the sides or edges of the gasket.

FLANGED JOINT: See *GASKETED JOINT*, which is the preferred term.

FLEX LIFE: The number of cyclic bending stresses a material can withstand before failure.

FLEXURAL STRENGTH: A property of solid material that indicates its ability to withstand a flexural or bending load.

FULL-FACE GASKET: A gasket covering the entire flange surface extending beyond the bolt holes.

GASKET: A deformable material, which when clamped between essentially stationary faces, prevents the passage of matter through an opening or joint.

GASKETING: Material in any form from which gaskets may be cut, formed, or fabricated.

GASKETING SHEET: Refers to a specific flat form of gasketing material from which gaskets are cut and/or fabricated.

GASKETED JOINT: The collective total of all members used to effect a gasketed seal between two separate pipes or vessels. Includes the bolts, flanges & gaskets used together to form the joint.

GRADE: The designation given a material by a manufacturer such that it is always reproduced to the same specifications established by the manufacturer.

HOMOGENEOUS: Products that are of uniform composition throughout.

HARDNESS: The resistance of a material to deformation, particularly permanent deformation, indentation, or scratching.

ID: Abbreviation for Inside Diameter.

IMPREGNATION: Partial filling of the open pore structure with another material.

ISO: The abbreviation for International Standards Institute.

JIS: The abbreviation for Japanese Industrial Standard.

JOINT: The connection between rigid members of a fluid container.

JOINTING: Common term in Europe for gasketing.

LEAK: The passage of matter through interfacial openings or passageways, or both, in the gasket.

LEAKAGE RATE: The quantity, either mass or volume, of fluid passing through and/or over the faces of gaskets in a given length of time.

MAINTENANCE “m” FACTOR: The factor that provides the additional pre-load capability in the flange fasteners to maintain sealing pressure on a gasket after the internal pressure is applied to the joint.

MANUFACTURED CARBON: A bonded granular carbon body whose matrix has been subjected to a temperature typically between 900 and 2400°C.

MANUFACTURED GRAPHITE: A bonded granular carbon body whose matrix has been subjected to a temperature typically in excess of 2400°C and whose matrix is thermally stable below that temperature.

MSS: Abbreviation for Manufacturers Standardization Society of the valve and fittings industry.

OD: Abbreviation for Outside Diameter.

O-RING: An elastomeric seal of homogeneous composition molded in one piece to the configuration of a torus with circular cross-section or more simply, a round ring with a round cross-section.

PACKING SHEET: See *Gasketing Sheet*, which is the preferred term.

PERMANENT SET: The amount by which an elastic material fails to return to its initial form after deformation.

PERMEABILITY: The quality or condition of allowing passage of fluid through a material.

PLASTICIZER: A compounding ingredient which can change the hardness, flexibility, or plasticity of an elastomer.

POROSITY: The percentage of the total volume of a material occupied by both open and closed pores.

PRESS CURE: A method of vulcanizing rubber by use of heated platens, which can be brought together and separated by hydraulic pressure or mechanical action, between which sheet can be cured under pressure.

PTFE: The abbreviation for polytetrafluoroethylene plastic.

PSI: The abbreviation for pounds per square inch.

PT VALUE: A numerical value resulting from the multiplication of the internal pressure (psi) by the temperature of the fluid being sealed. Used only as a rough safety guide for limited gasket usage.

QPL: Military abbreviation for Qualified Products List.

RECOVERY (GASKETING): The percent decrease in deformation following release of a compressive load as defined in ASTM Standard F-36.

SEALABILITY: The measure of fluid leakage through and/or across both faces of a gasket. Measured either by using ASTM F-37, ROTT, or DIN 3535 standard test procedures.

SPRINGBACK: Expressed as a percent, the distance a gasket recovers from an initial compressive load.

STRAIN: The deformation of a gasket specimen under the action of applied force or stress.

STRESS: The intensity of the load at a point in the gasket specimen.

STRESS-RELAXATION: A transient stress-strain condition in which the stress decays as the strain remains constant. (This condition is encountered in grooved-face gasketing joints in which metal-to-metal contact occurs. This condition is also approached in flat-face gasketing joints when the bolt is practically infinitely rigid.)

STRESS-STRAIN: The relationship of load and deformation in a gasket under stress. In most nonmetallic gasketing, this is commonly the relationship of compressive load and compression (strain).

SURFACE FINISH: The geometric irregularities in the surface of a solid material. Measurement of surface finish shall not include inherent structural irregularities unless these are the characteristics being measured.

TENSILE STRENGTH: A property of solid material that indicates its ability to withstand a uniaxial tensile load (pulling).

THRESHOLD OF OXIDATION: That temperature at which one square meter of 70 lbs/ft³ (1.12 mg/m³) density, 15 mil (.38 mm) thick GRAFOIL will lose 1% of its weight in 24 hours.

VOID: An unfilled space enclosed within an apparently solid body.

WORKING PRESSURE: The maximum operating pressure encountered during normal service.

YIELD “Y” FACTOR: The minimum design seating stress on the gasket in either psi or megapascals that is required to provide a sealed joint with no internal pressure in the joint.