R.L. HUDSON & COMPANY

O-RING DESIGN & MATERIALS GUIDE

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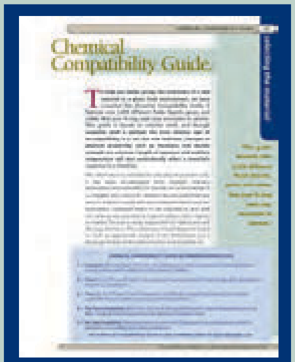
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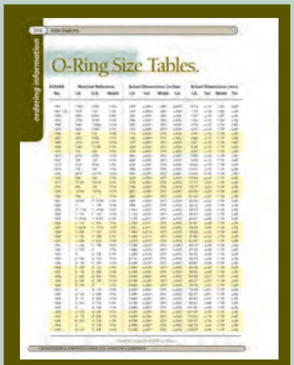

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Using this Design Guide.

This design guide provides data on the most widely used type of seal: the O-ring. As you review the contents, please keep in mind that the many materials and designs featured in this guide are just part of the wide variety of sealing solutions offered by R.L. Hudson & Company.

In order to arrive at the best seals for your projects, you'll need to consider the following factors: the material to be used for the seal; the type of seal application; the conditions under which the seal will have to operate; the seal dimensions; and the construction of the gland into which the seal will be installed. Follow the steps below to design your O-ring seal.

DESIGNING THE BEST O-RING SEAL FOR YOUR APPLICATION

1. Review the discussion of material properties beginning on ***page 18*** to determine which of these factors are most important to your project.
2. For chemical compatibility questions, see the guide starting on ***page 33***.
3. Review the material profiles beginning on ***page 89***.
4. For general information on seal dimensions, see the discussion starting on ***page 177***.
5. Review the discussion of seal environment beginning on ***page 182***.
6. For recommendations regarding gland construction, see the discussion starting on ***page 192***.
7. Review the discussion and dimensions of static and dynamic designs beginning on ***page 198***.

Before you begin, however, you may find it helpful to quickly review a few of the basics. "An O-Ring Primer" (starting on ***page 6***) gives a brief overview of sealing concepts. "Back to Basics" (beginning on ***page 11***) takes a look at why elastomeric materials make good seals.

> **"The many materials and designs featured in this guide are just part of the wide variety of sealing solutions offered by R.L. Hudson & Company."**

An O-Ring Primer.

In industries from aerosol to aerospace, O-rings are the most commonly used seals in the world. Why? Because they are effective, economical, and easy to use.

Although O-ring sealing is a simple concept, there is a lot to consider as you design a seal for a specific application. This guide provides detailed information on the many factors that influence the design of an effective O-ring seal. Here's a quick overview:

> **"The purpose of any seal is to block the clearance gap so that nothing passes through it."**

BLOCKING THE GAP

Any mechanical assembly containing fluids must be designed so that these substances flow only where intended and do not leak into other parts of the assembly (or out of the assembly entirely). Seals are incorporated into mechanical designs to prevent such leakage at the points where different parts of an assembly meet. These meeting points are known as *mating surfaces*, and the space between them is called a *clearance gap*. The purpose of any seal is to block the clearance gap so that nothing passes through it.

ROD & PISTON GLANDS

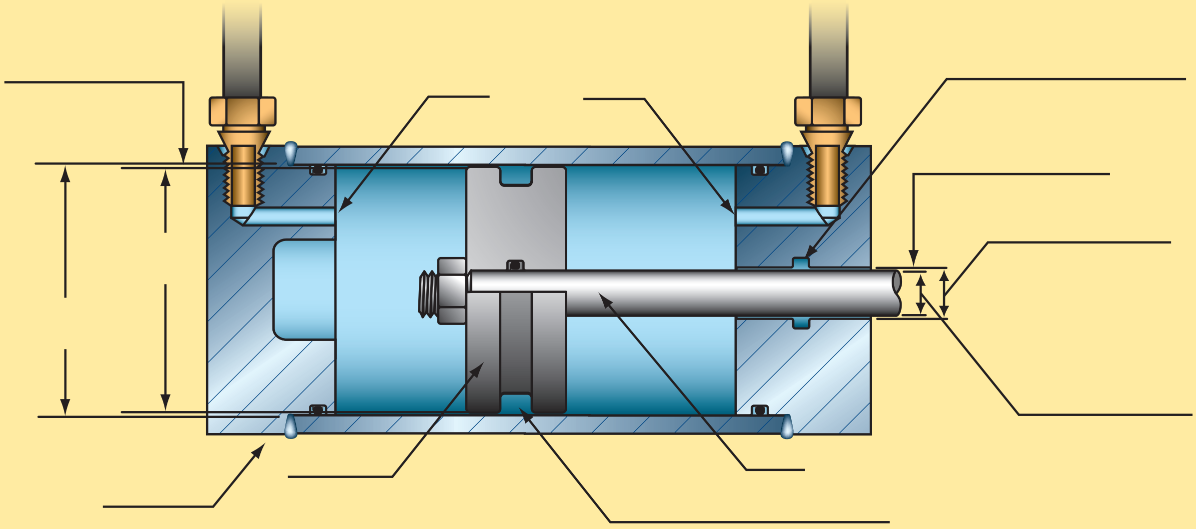


Figure 1: Components of a Rod Gland & a Piston Gland

A number of methods may be used to block the gap, including welding, brazing, soldering, or machining lapped fits. You might also simply squeeze a softer material between the two harder materials of the assembly. This last method describes the function of an O-ring.

IN THE GROOVE

An O-ring seal has two essential parts: the O-ring and the gland. The gland consists of the machined groove into which the O-ring is installed *and* the mating surface to be sealed. The primary components of rod and piston glands are shown in ***Figure 1***.

A seal is effected when an O-ring is squeezed between mating components, thereby creating zero clearance and preventing the escape of fluids through the clearance gap. ***Figure 2*** shows rod and piston O-rings installed. As can be seen, the groove for a rod seal is machined into the housing, whereas the groove for a piston seal is machined into the piston itself. The versatility of O-rings allows them to function effectively in either configuration.

ROD & PISTON SEALS

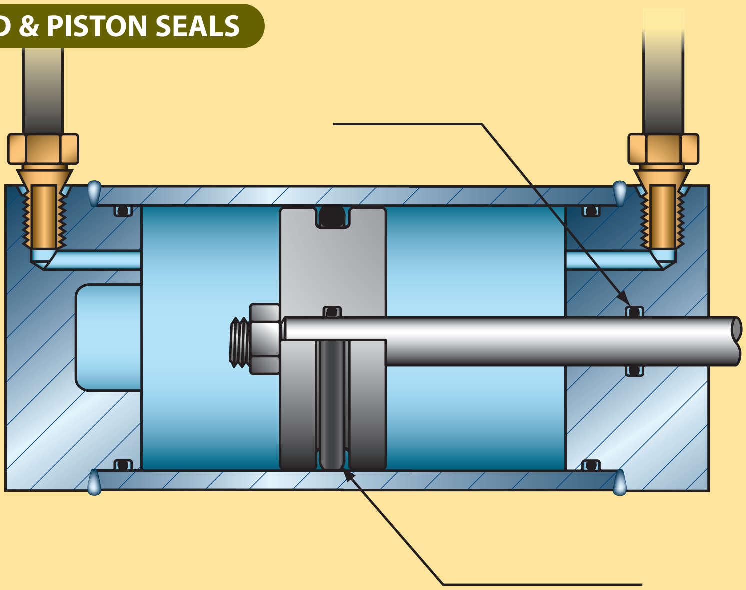


Figure 2: Rod & Piston O-Rings Installed

SEALING YOUR FATE

To better understand how an O-ring seals, think of the O-ring as a highly viscous (thick) "fluid" with very high surface tension. When placed under pressure, the O-ring is forced to "flow" within the groove toward the clearance gap. As the O-ring flows against (and slightly into) the gap, it produces zero clearance and prevents the sealed substance from escaping. ***Figures 3 through 6*** (see next page) illustrate this process.

In ***Figure 3***, the O-ring has been installed but is not under pressure. In ***Figure 4***, the O-ring is under just enough pressure to effect a seal. ***Figure 5*** shows the seal under maximum pressure. The seal is extruding (extending) slightly into the clearance gap but is still functioning effectively. In ***Figure 6***, the pressure has now exceeded the seal's capabilities, forcing it to extrude severely. A leak path forms, and the seal fails.

AN O-RING IN ACTION

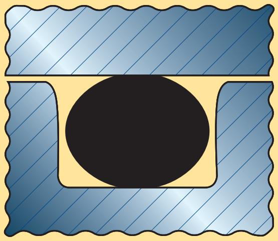


Figure 3: Installed

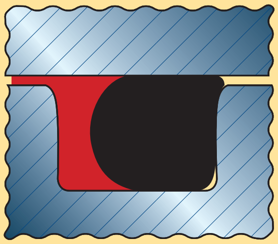


Figure 4: Pressurized

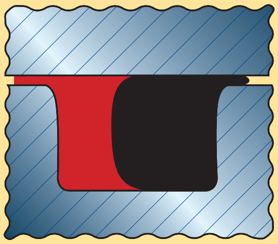


Figure 5: Extruded

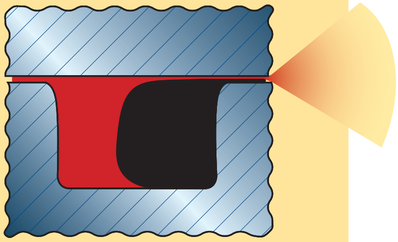


Figure 6: Failed

STAYING IN SHAPE

An important factor in the effectiveness of any O-ring is its *memory*, or ability to remember its shape. The molecular properties of the O-ring are such that it is always trying to regain its original shape despite being squeezed and/or distorted by pressure. This memory function allows a properly designed O-ring seal to block the clearance gap and prevent leakage, all the while resisting extrusion into the gap or otherwise losing its shape. Since an O-ring's memory is directly related to its chemical structure, let's take a closer look at some basic structural concepts next.

Back to Basics.

Anyone designing an O-ring seal must answer a multitude of questions. In a sense, that's really what good design work is all about: determining which questions to ask and where to find the answers. Though the sealing industry has a multitude of exotic terms, a clear understanding of a few basic concepts will help you ask the most pertinent questions and find the most productive answers. To that end, here's a quick review, starting with the building block of all materials, the atom.

AN ATOM IN ACTION

An atom is the smallest unit of an element that 1) retains all the element's distinctive properties and 2) can enter into a chemical reaction. In other words, anything less than an atom of carbon (C) is no longer carbon. A carbon atom can be split into its component parts (see ***Figure 7***), but the resulting subatomic particles (positively-charged protons, non-charged neutrons, and negatively-charged electrons) do not reflect the properties of carbon. Though their number and arrangement vary from element to element, subatomic particles alone tell you nothing about the atoms from which they came. A proton from a carbon atom is identical to an oxygen (O) proton.

> **"A clear understanding of a few basic concepts will help you ask the most pertinent questions and find the most productive answers."**

Subatomic particles are important, however, because they determine one of the defining characteristics of any atom: its *atomic weight*, or the total mass of the protons and neutrons within its nucleus (orbiting electrons are of negligible weight and don't figure into this total). For example, the nucleus of a hydrogen (H) atom contains one proton and no neutrons, so its atomic weight is 1. Carbon is composed of six protons and six neutrons, for an atomic weight of 12.

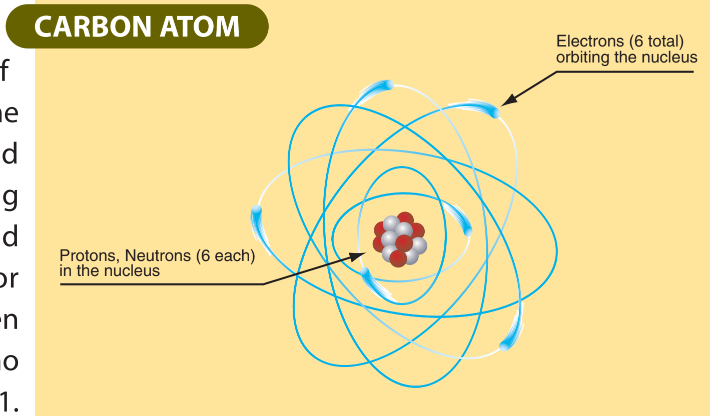


Figure 7: Subatomic Particles

Each individual atom is also distinguishable by the one or more energy bonds it can form with neighboring atoms. This ability to combine is known as *valence*, and the amount of valence varies with each element. For example, an atom of hydrogen has a valence of 1, meaning it can form only one such energy bond. Oxygen has a valence of 2 and carbon has a valence of 4, meaning they can form two and four bonds, respectively. To be more precise, atoms need to form these energy bonds in order to be "satisfied" or "stable." The interaction of differing valences is what allows a group of atoms to join together into a *molecule*.

MOLECULAR MATCHMAKING

The kind of molecule is determined by the exact type and number of atoms. For example, a water molecule is made up of just three atoms: two of hydrogen and one of oxygen. The components of a water molecule are most simply expressed by the well-known chemical formula "H_20" or by the structural diagram: H-O-H (see ***Figure 8***). A water molecule can be considered stable because the valences of each of its atoms are satisfied: the two hydrogen atoms have formed one bond each, and the single oxygen atom has formed the two bonds it needs.

When dissimilar atoms join together (as with water), the resulting molecule is called a *compound*. There are two major types of compounds: *organic* and *inorganic*. Generally speaking, organic compounds contain carbon and inorganic compounds do not, though a handful of carbon-containing compounds (such as metallic cyanides, carbon dioxide, carbides, and carbonates) are studied as part of inorganic chemistry.

WATER MOLECULE

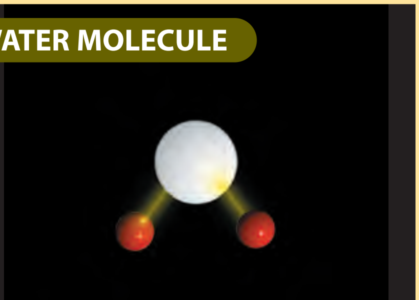


Figure 8: A Simple Inorganic Compound

The specific way in which a molecule is formed depends on which type of compound it is. Inorganic compounds are formed when an atom gives up, or transfers, one of its orbiting electrons to a nearby atom. Thanks to the rules of valence, this electron transfer can help both the donor atom and the recipient atom become more stable. Because the carbon atom has a compact structure, it is much less inclined to give up an electron. It will, however, share an electron with a nearby atom (such as hydrogen) to attain a more stable compound.

As previously stated, each atom has its own atomic weight. When atoms unite to form a molecule, the sum of these atomic weights is then known as the *molecular weight*. For example, a methane molecule (CH_4) combines the atomic weight of one carbon atom (12) with the atomic weight of four hydrogen atoms (1 x 4), for a total molecular weight of 16. In addition to hydrogen, oxygen, and carbon, there are a handful of other atomic elements that form the basis for the majority of raw materials used in the sealing industry. These include nitrogen (N), fluorine (F), silicon (Si), sulfur (S), and chlorine (Cl). The atomic weights and valences of each of these elements are listed in ***Table 1***.

	ELEMENT	ATOMIC WT	VALENCE (ENERGY BONDS)
●	Hydrogen	1	1
●	Carbon	12	4
●	Nitrogen	14	3
●	Oxygen	16	2
●	Fluorine	19	1
●	Silicon	28	4
●	Sulfur	32	2
●	Chlorine	35	1

Table 1: Atomic Elements Most Commonly Used as Building Blocks in the Sealing Industry

LINKS IN THE CHAIN

Small, individual molecules are known as mers, or *monomers* (literally, “single mers”). When conditions are right, these small molecules can chemically “link” together to form long, chainlike structures. The *macromolecules* (giant molecules) that result may incorporate thousands of the original monomers. These long chain macromolecules are therefore known as *polymers* (“many mers”). The linking process itself is called *polymerization*. An example of this process is shown in ***Figure 9***. Methane monomers can combine to form ethane, and eventually, polyethylene. Rubber and plastics are polymer-based materials.

MONOMER TO POLYMER

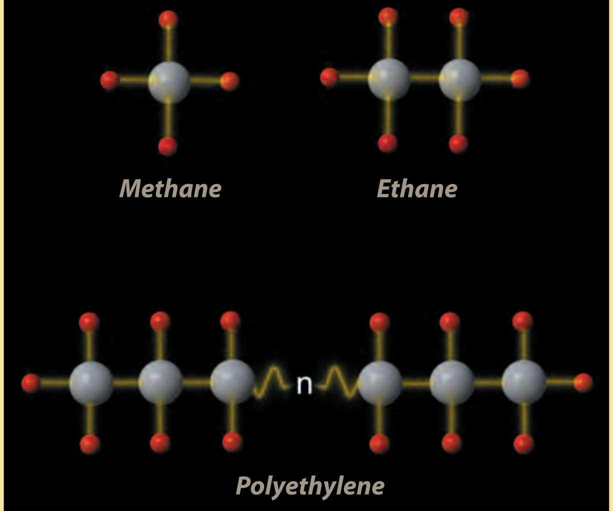


Figure 9: Effect of Polymerization

Changes in physical properties as a result of polymerization are largely a factor of molecular weight. When molecules (each with their own total weight) join to form a polymer, the sum of the molecular weights has a huge impact on the polymer's physical properties. As a general rule, an increase in chain length (and thus molecular weight) also means an increase in strength and *viscosity* (resistance to flow).

Table 2 shows the effects of increased molecular weight. By adding CH_2 groups, the polyethylene molecule goes from a gas (with little or no physical properties) to a liquid, then to a wax. Continued addition of molecules forms a tough solid (of relatively low molecular weight, or LMW) such as is used for plastic grocery bags, then a very tough solid (of high molecular weight, or HMW), and soon an extremely tough, solid plastic (of ultra-high molecular weight, or UHMW) used in abrasion pads and bridge bearings. No matter what its physical state, the molecule is made up of the same two elements, carbon and hydrogen, and is configured the same way. The only difference is the number of molecules (the chain length) and thus the molecular weight. Polymers with higher molecular weights are key in the formulation of high strength materials for extreme applications. In the higher molecular weights, the numbers of carbon and hydrogen atoms are ranges rather than absolute values. The HMW and UHMW polyethylene formulas in ***Table 2*** are averages.

COMMON NAME	CHEMICAL FORMULA	MOLECULAR WT	STATE (RM TEMP)
Methane	CH_4	16	Gas
Ethane	C_2H_6	30	Gas
Propane	C_3H_8	44	Gas
Butane	C_4H_{10}	58	Gas
Pentane	C_5H_{12}	72	Liquid
Kerosene	$C_{17}H_{36}$	240	Liquid
Paraffin Wax	$C_{18}H_{38}$	254	Soft Solid
Hard Wax	$C_{50}H_{102}$	702	Brittle Solid
LMW Polyethylene	$C_{100}H_{202}$	1402	Tough Solid
HMW Polyethylene	$C_{70,000}H_{140,002}$ (avg.)	980,002	Very Tough Solid
UHMW Polyethylene	$C_{220,000}H_{440,002}$ (avg.)	3,080,002	Extr. Tough Solid

Table 2: Changes in Physical Properties as a Result of Polymerization

FORCES OF NATURE

Long polymeric chains (such as those in polyethylene) are held in place by intermolecular forces (known as *van der Waals forces*) and by chain entanglement (as in a bowl of spaghetti). The intermolecular forces are heat-sensitive, so that as a polymer is heated, the molecular motion increases and the attractive forces between the molecules decrease. The polymer chains can then slide past one another.

Some polymers are composed primarily of linear, symmetrical molecules arranged in close proximity to one another. This proximity allows the intermolecular van der Waals forces to be at their strongest, and the polymer will thus be very rigid. These orderly polymers are said to be *crystalline* in structure (see ***Figure 10***). Polyethylene plastic is a good example of a crystalline polymer.

CRYSTALLINE

Figure 10: Linear, Symmetrical Chains

Other polymers are composed mainly of branched, non-symmetrical molecules that cannot fit closely to one another. Because of this increased distance between the molecules, the van der Waals forces will be at their weakest, resulting in a random mass of twisted and entwined polymer chains. These polymers are said to be *amorphous* (see ***Figure 11***).

AMORPHOUS

Figure 11: Random, Non-Symmetrical Chains

Because their intermolecular forces are not very strong, amorphous polymers can be thought of as very viscous (thick) liquids that appear to be solids. Though it is possible to have an amorphous plastic, most plastics are either crystalline or semi-crystalline. Keep in mind that it is common to see tough polymers in which the numerous crystalline segments are surrounded by a few amorphous areas (as in ***Figure 12***). All rubbers or elastomers are amorphous at room temperature.

"COMBO" STRUCTURE

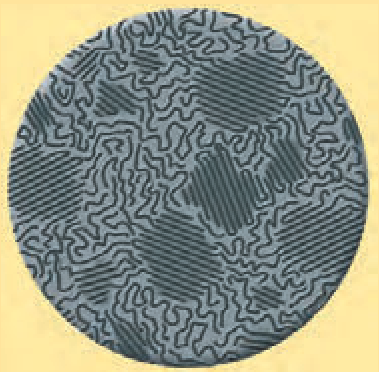


Figure 12: Crystalline Regions Surrounded by Amorphous Regions

Though the term elastomer was initially used to denote a synthetic form of natural rubber, "elastomer" and "rubber" are now more or less synonymous. To be officially considered an elastomer by the American Society for Testing and Materials (ASTM), a polymer must not break when stretched 100%, and it must return to within 10% of its original length within five minutes after being held for five minutes at 100% stretch.

An elastomer is perhaps best described as a visco-elastic material, in that it goes through both a viscous phase and an elastic phase. The visco-elastic behavior of elastomers can be simulated using a spring coupled with a dashpot (damper). The spring illustrates the elastic phase, and the dashpot exemplifies the viscous phase (see ***Figure 13***).

VISCO-ELASTICITY

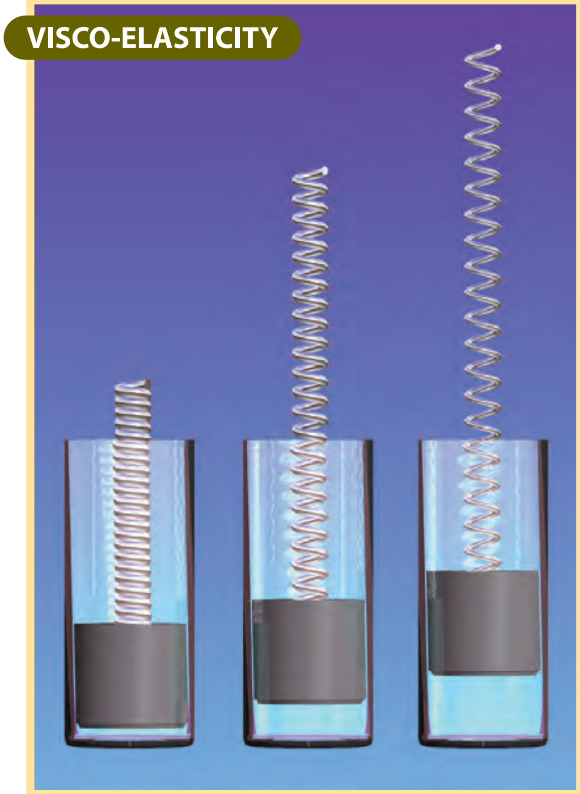


Figure 13: A spring-dashpot combination can illustrate the visco-elastic nature of elastomers.

STATE OF ENTANGLEMENT

But why is an elastomer elastic and resilient, able to undergo high strain and yet recover its original shape? Put simply, it's the tangled nature of its long molecular chains. When pressure (in the form of a compressive load or a stretching force) is applied to the elastomer, the chains rotate around their chemical bonds. This rotation tends to uncoil the entangled mass and straighten the chains. When the pressure is removed, the chains coil up again, reverting to their normal state of entanglement. This tendency to return to its original configuration helps explain an elastomer's rubbery, resilient nature.

Under certain conditions, a few elastomers will have their molecules align and form crystalline regions. In some cases, this can be advantageous. Natural rubber undergoes *strain crystallization*, meaning its entangled macromolecular chains will untangle and align to form crystals as a result of a stretching force. This tendency to strain crystallize gives natural rubber inherently good strength and fatigue properties. In other cases, the tendency to crystallize can be a distinct disadvantage. An elastomer that crystallizes due to cold temperatures becomes harder and less able to stretch.

Because many seals will face potentially detrimental service conditions (such as extreme cold or heat), an elastomer alone is seldom an effective seal material. Other ingredients must often be added to make the elastomer easier to process and to augment its physical and/or chemical traits. These other ingredients may include *fillers* (to reinforce or extend the material), *plasticizers* (to aid flexibility and processibility), *cure activators and accelerators* (to initiate and speed processing), *inhibitors* (to ensure the reaction does not proceed too quickly), *anti-degradants* (to help resist environmental elements like oxygen or ozone), and *pigments* (for colorization). The combination of a base elastomer and additives is called an *elastomeric compound*.

MAKING CONNECTIONS

After a compound has been formulated, it must still be processed into a useful form (such as an O-ring). Under normal conditions, an elastomer's amorphous chain segments are free to move relative to one another. This is not true only when the chains meet mechanical entanglement (as with the spaghetti effect), or when the separate chains are chemically connected. *Vulcanization* (also known as *cure*) is a heat-induced process whereby the long chains of the rubber polymers are permanently cross-linked to one another, thus forming three-dimensional elastic structures (see ***Figure 14***). Aided by curing agents in the original compound, vulcanization transforms soft, weak, non-cross-linked materials into strong elastic products. In addition to making the compound stronger, the vulcanization process is also generally the point at which the material is molded into a useful shape that it retains due to its memory.

EFFECT OF VULCANIZATION

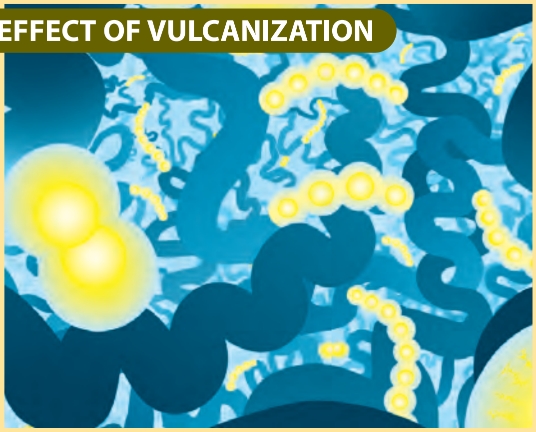


Figure 14: A 3-D Elastic Structure

Though every effort has been made to simplify the preceding discussion, it's important to realize that putting together an elastomeric compound can get quite complex. Decisions made in compounding will ultimately impact the processing and performance of any seals produced from the compound. Depending on the type and degree of additives in use, a single base elastomer can generate hundreds of different compounds, each with unique characteristics. Since choices made during compounding directly determine the properties of an elastomeric seal, let's look at these physical, thermal, and chemical properties next.

Physical Properties.

There are a number of physical properties you should consider when choosing an elastomeric compound for your O-ring application. These include hardness, tensile strength, modulus, elongation, tear resistance, abrasion resistance, compression set resistance, and resilience. The extent to which each of these properties is present in a given material has a huge impact on the material's ability to provide an effective seal.

HARDNESS

Typically defined as resistance to indentation under specific conditions, the hardness of an elastomer is more accurately thought of as two related properties: inherent hardness and processed hardness. As a result of chemical structure, each elastomer has its own inherent hardness. This inherent hardness can be modified (and is typically supplemented) via compounding and vulcanization. Hardness in molded rubber articles (processed hardness) is a factor of cross-link density (and the amount of fillers). The more cross-linking a given material undergoes during vulcanization, the harder the final molded part will be. When judging the potential effectiveness of a molded seal, processed hardness is one of the most common criteria in the rubber industry.

Unfortunately, hardness is also one of the least consistent concepts in that the most-used measurement scales have only limited comparability. There is no single "universal hardness" unit, so it is often impossible to draw a clear and easy correlation between readings on two different scales, even when the samples being measured are absolutely identical. There are currently two hardness tests that predominate in the rubber industry: Shore durometer and International Rubber Hardness Degrees (IRHD).

"The extent to which each of these properties is present in a given material has a huge impact on the material's ability to provide an effective seal."

HARDNESS TESTERS

Figure 15: Some instruments can generate both durometer and IRHD readings.

Because Shore Instruments led the way in the marketing of durometer gauges, the words "Shore" and "durometer" have become virtually synonymous within the rubber industry. Now a division of Instron Corporation, Shore Instruments offers a wide range of durometer scales conforming to the ASTM D 2240 standard. These scales are designed to gauge hardness in everything from textile windings to plastics to foam. Rubber hardness is most often measured via a Shore Type A or Type D durometer. Since there is more than one scale, you should always be specific as to which scale is being applied in a given situation, e.g. "95 Shore A" or "46 Shore D." The full range of durometer scales and the materials they are most commonly used on are listed in ***Table 3***.

DUROMETER SCALE	MOST COMMONLY USED ON
Type A	All O-Ring Compounds
Type B (not commonly used)	Moderately Hard Rubber
Type C (not commonly used)	Medium Hard Rubber and Plastics
Type D	Hard Rubber; Polyurethane; Thermoplastic Elastomers (TPEs)
Type DO	High Density Textile Windings
Type O	Soft Rubber; Medium Density Textile Windings
Type OO	Sponge Rubber and Plastics; Low Density Textile Windings
Type OOO	Plastic Foams
Type T	Medium Density Textile Windings

Table 3: Guide to Durometer Scale Selection

The Shore A durometer is a portable and adaptable device which uses a frustum (truncated) cone indentor point and a calibrated steel spring to gauge the resistance of rubber to indentation. When the durometer is pressed against a flat rubber sample, the indentor point is forced back toward the durometer body. This force is resisted by the spring. Once firm contact between the durometer point and the sample has been made, a reading is taken within one second unless a longer time interval is desired. Five readings are typically taken, then an average value calculated. The amount of force the rubber exerts on the indentor point is reflected on a gauge with an arbitrary scale of 0 to 100. Harder substances generate higher durometer numbers. A reading of 0 would be indicative of a liquid, whereas 100 would indicate a hard plane surface (e.g. steel or glass).

That said, it's important to note that readings of less than 10 or more than 90 Shore A are not really considered reliable.

Materials harder than 90 Shore A (e.g. some polyurethanes and plastics) are more accurately measured on a Shore Type D durometer, which utilizes a stiffer spring and a sharp 30° angle indentor point. The majority of O-ring materials have readings between 40 and 90 Shore A. ***Table 4*** includes approximate conversions for several of the most-used durometer scales.

TYPE A	TYPE B	TYPE C	TYPE D	TYPE O	TYPE OO
100	85	77	58		
95	81	70	46		
90	76	59	39		
85	71	52	33		
80	66	47	29	84	98
75	62	42	25	79	97
70	56	37	22	75	95
65	51	32	19	72	94
60	47	28	16	69	93
55	42	24	14	65	91
50	37	20	12	61	90
45	32	17	10	57	88
40	27	14	8	53	86
35	22	12	7	48	83
30	17	9	6	42	80
25	12			35	76
20	6			28	70
15				21	62
10				14	55
5				8	45

Table 4: Conversions for Durometer Hardness Scales

Though most standard O-rings are either 70 or 90 Shore A, the application will always govern the necessary hardness. Softer compounds offering less resistance may be perfectly fine for low-pressure seals, but high-pressure seals will likely require a harder, more extrusion-resistant material. Making decisions about a property such as hardness often entails compromise in order to ensure the long-term usefulness of the seal. For example, a relatively hard compound may resist being extruded under high pressure, but its use can also lead to increased frictional buildup in dynamic seals. Increased friction leads to increased heat, which can, in turn, degrade the seal and decrease its useful life span.

It is also important to realize that measuring the hardness of a rubber sample is an imprecise art (see ***Figure 16***). Depending on both the specific gauge in use and the expertise of its operator, it is possible (even probable) that the same sample will yield two or more different readings. The rate at which the durometer is applied to the sample, the force used, the amount of time that elapses before taking the reading, and the temperature of the specimen at the time of testing can all impact a test result. For this reason, all durometer readings normally include a tolerance of ± 5 points, but sometimes even this may not be enough to fully anticipate all of the variances to be seen in testing. Technological advances have reduced many of the discrepancies, but sometimes at the expense of the simplicity and portability that initially made durometers popular. It is generally a good idea to test a given specimen several times and average the results to ensure accuracy.

Despite the long-standing close association between "Shore" and "durometer," be aware that there are other companies which market high-quality durometers. These include Rex Gauge Company and PTC Instruments. Microhardness testers have also been developed for use on samples that are too small or too irregularly shaped to be accurately gauged by standard durometers.

DUROMETER USE

Figure 16: An average of several readings is preferable.

The other widely-used test, International Rubber Hardness, utilizes a spherical indentor and a dial gauge calibrated in International Rubber Hardness Degrees (IRHD). Though not as common in the United States as abroad, all IRHD testers are designed to conform to the ASTM D 1415 standard.

TENSILE STRENGTH

Typically noted in either pounds per square inch (psi) or megapascals (MPa), tensile strength is the amount of force required to break a rubber specimen. To convert from MPa to psi, simply multiply the MPa figure by 145. For example, 14

MPa converts to 2,030 psi. Converting from psi to MPa is just a matter of dividing the psi number by 145.

To better understand tensile strength, first recall that there are intermolecular forces (known as *van der Waals forces*) helping to hold long polymer chains in place. These forces are at their weakest when, due to structural irregularities, the molecules cannot fit closely together, resulting in a non-regimented, amorphous structure. Some polymers, however, have their constituent molecules aligned in very regular patterns. The combination of this regularity and the intermolecular forces may be enough to "fit" the chains into a rigid, crystalline pattern.

Tensile strength largely depends on an elastomer's ability to partially strain crystallize when stretched. With greater crystallization comes increased strength and resistance to stress. Natural rubber is an example of an elastomer with a very regular chain structure that strain crystallizes. As a result, natural rubber has high tensile strength. Of course, the temporary nature of strain crystallization allows natural rubber to regain its original shape once the stress is removed. An elastomer with inherently poor tensile strength, such as styrene butadiene, can be improved through the addition of highly particulate reinforcing agents. Silica and carbon black are common reinforcing agents. Be aware that the majority of dynamic applications will require an elastomeric compound with tensile strength of at least 1000 psi (6.9 MPa).

TENSILE SPECIMEN

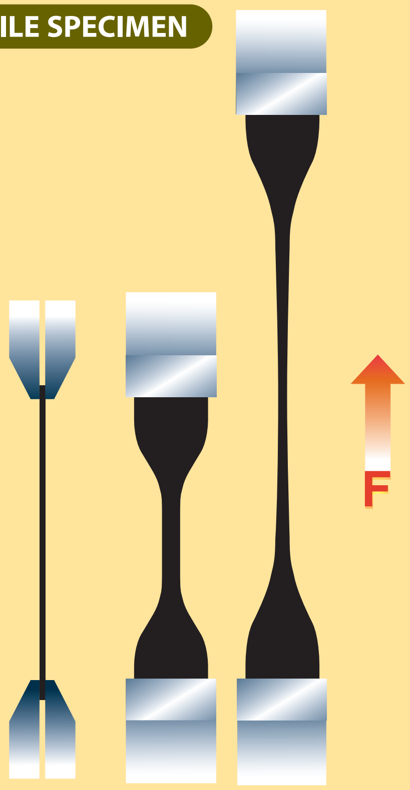


Figure 17: Molded Dumbbell

Per ASTM D 412, a compound's tensile strength is generally tested using a molded dumbbell (see **Figure 17**). The dumbbell is placed in the grips (jaws) of a tensile tester (see **Figure 18**). The best-known tester is Instron, but tensiTECH and others are also used. When the tester is activated, the dumbbell is pulled steadily at a rate of 20 inches per minute until it breaks. The force being exerted on the sample at the time of rupture is said to be the sample's tensile strength. Minimum tensile strength is often used as both a qualification criterion when specifying a new material and as a control criterion (with a ± 15% production tolerance) when testing batches of mixed material.

MODULUS

Perhaps the best single gauge of a compound's overall toughness and extrusion resistance, modulus is the force (stress) in pounds per square inch (psi) required to produce a certain elongation (strain). This elongation might be 50%, 100%, or even 300%, though 100% is the most widely used figure for testing and comparison purposes. Industry literature typically refers to 100% elongation as "M100" (or modulus 100). Compounds with a higher modulus are more resilient and more resistant to extrusion. Generally speaking, the harder a compound, the higher its modulus. Because it is basically a measure of tensile strength at a particular elongation (rather than at rupture), modulus is also known as tensile modulus or tensile stress.

TENSILE TESTER

Figure 18: Stretching a Sample

As described in ASTM D 412, modulus is typically gauged simultaneously with tensile strength on the same dumbbell specimen shown in ***Figure 17***. As the specimen is being stretched, the tester records the psi (for example, 836.7) needed to achieve a given elongation (for example, 100%). This figure in psi is considered to be the sample's modulus at that elongation. Minimum modulus is typically used as a qualification criterion when specifying a new material. It can also serve as a control criterion (with a ± 25% production tolerance) when testing finished parts.

ELONGATION

Elongation is the percentage increase in original length (strain) of a rubber specimen as a result of tensile force (stress) being applied to the specimen. Elongation is inversely proportional to hardness, tensile strength, and modulus. That is, the greater a material's hardness, tensile strength, and modulus, the less it will elongate under stress. It takes more force to stretch a hard material having high tensile strength and high modulus than to stretch a soft material with low tensile strength and low modulus.

Ultimate elongation is the elongation at the moment the specimen breaks. Per ASTM D 412, ultimate elongation is generally noted along with tensile strength and modulus during tensile testing. Some elastomeric materials are much more forgiving in this area than others. Natural rubber can often stretch up to 700% before breaking. Fluorocarbons typically rupture at about 300%. Keep in mind that these figures highlight relative failure modes only and are not acceptable seal installation values.

Overstretching can doom an O-ring, so elongation is an important installation factor, especially as gland and seal dimensions decrease. What might be a small percentage increase in a larger seal can be a large increase in a smaller seal. For example, an OR-150 seal has a nominal inside diameter (I.D.) of 2 7/8". If stretched 1/16", it is elongated roughly 2%. On the other hand, an OR-102 seal has a 1/16" nominal I.D. If stretched 1/16", it is elongated 100%. Since a given amount of elongation can mean vastly different things, elongation is truly relative to a seal's initial size. Though elongation is seldom a problem, installing small diameter, high durometer, and low elongation seals can be problematic in some instances.

TEAR INITIATION

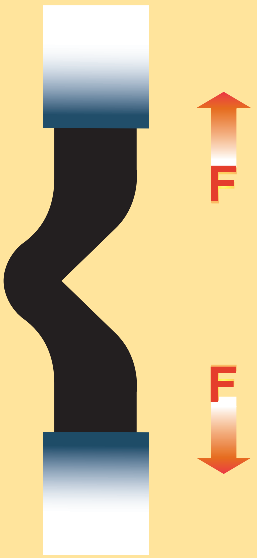


Figure 19: Unnicked 90° Angle

TEAR RESISTANCE

Noted in kilonewtons per meter (kN/m) or pound force per inch (lbf/in.), tear resistance (or tear strength) is resistance to the growth of a cut or nick in a vulcanized (cured) rubber specimen when tension is applied. Tear resistance is an important consideration, both as the finished article is being removed from the mold *and* as it performs in actual service.

Tear resistance can be gauged via the same ASTM D 412 apparatus used in the testing of tensile strength, modulus, and elongation. As described in ASTM D 624, different specimen types can be used to measure both tear initiation (resistance to the start of a tear, see ***Figure 19***) and tear propagation (resistance to the spread of a tear, see ***Figure 20***). Either way, the sample is placed in the tester's grips, which then exert a uniform pulling force until the point of rupture. This force may then be divided by the specimen's thickness to arrive at the tear resistance for that particular sample. Three separate samples are typically tested and an average calculated.

TEAR PROPAGATION

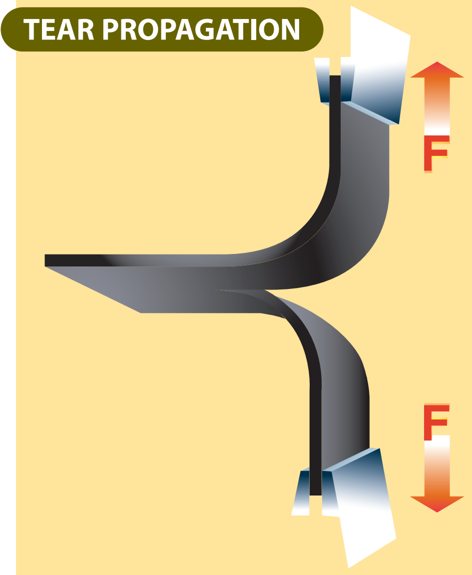


Figure 20: Slit ("Trouser") Specimen

Though epichlorohydrin, natural rubber, and polyurethane all have excellent tear resistance, many materials are not very strong in this area. Silicone and fluorosilicone have notably poor tear resistance. Though it might seem logical, it is in fact a common misconception that hardness automatically equals good tear resistance. Compounds whose tear resistance is less than 100 lbf/in. are most at risk for installation damage, especially in designs featuring non-smooth areas (as with burrs, slots, threads, etc.) and/or sharp, non-radiused (non-rounded) corners. Once damaged, materials with poor tear resistance will quickly fail in service. This is especially true for dynamic seals. Poor tear resistance is linked to poor abrasion resistance.

ABRASION RESISTANCE

Measured as a loss percentage based on original weight, abrasion resistance is the resistance of a rubber compound to wearing away by contact with a moving abrasive surface. Whereas the cutting or nicking of a seal's surface is an instantaneous event, abrasive rubbing or scraping is much more of a progressive phenomenon that develops over time. Seals in motion are most susceptible to abrasion. Hard compounds tend to exhibit less abrasive wear than soft compounds, but use of a harder compound can also increase friction in dynamic seals, and increased friction generates seal-degrading heat.

Because of the many potential variables (including heat fluctuation and surface contamination), abrasion resistance is hard to accurately measure. Testing typically involves the uniform application of an abrasive material (such as sandpaper) to the surface of a sample. ASTM standards describe three different abraders: D 1630 relies on a National Bureau of Standards (NBS) abrader (see ***Figure 21***); D 2228 uses a Pico abrader (see ***Figure 22***); and D 3389 (also known as Taber Abrasion) employs a double-head abrader and a rotary platform (see ***Figure 23)***. Regardless of the specific test method, the relative amount of sample material that is lost due to abrasion is a good indication of abrasion resistance.

NBS ABRADER

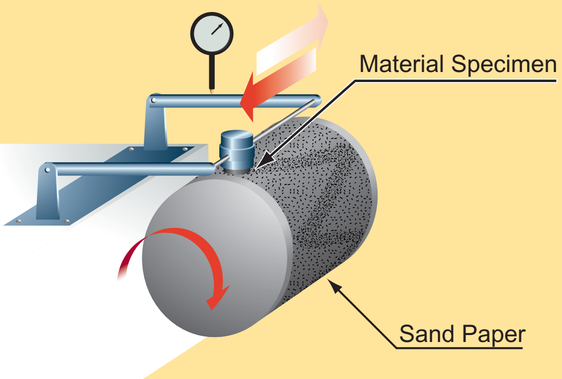


Figure 21: Rotating Drum

Generally speaking, hydrocarbon-based elastomers tend to offer better abrasion resistance than fluorocarbon elastomers. Polyurethane offers the most outstanding abrasion resistance, while carboxylated nitrile and hydrogenated nitrile offer abrasion resistance that is superior to other hydrocarbon-based elastomers.

COMPRESSION SET

Compression set is the end result of a progressive stress relaxation, which is the steady decline in sealing force that results when an elastomer is compressed over a period of time. In terms of the life of a seal, stress relaxation is like dying, whereas compression set is like death. The effects of compression set on an O-ring's cross-section can be seen in ***Figure 24***.

PICO ABRADER

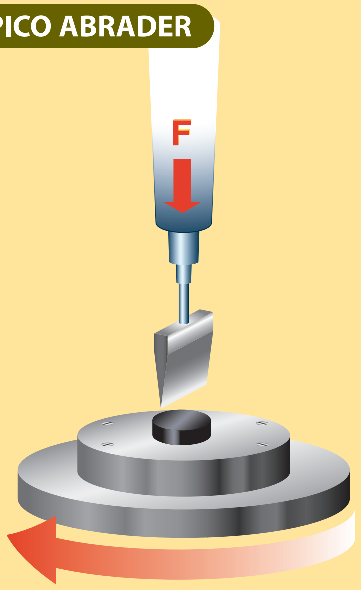


Figure 22: Rotating Platform

Though it is very difficult to accurately quantify stress relaxation, compression set is easy to measure. ASTM D 395 details compression set testing for rubber that will be compressed in air or liquid media. Two methods are described ("A" for constant force; "B" for constant deflection), but the basic methodology is substantially the same. Testing generally involves use of cylindrical disk compression set test buttons (0.49" thick by 1.14" diameter). In lieu of buttons, die-cut plied (stacked) samples (0.070" thick by 1.14" diameter) may be substituted. The buttons or plied samples are placed between steel plates. In method A (see ***Figure 25***), the plates are then forced together using either a calibrated spring or a pre-defined external force. In method B (see ***Figure 26***), a bolt-tightened device and steel spacers are used. Either way, compression (normally 25% of original thickness) is held for a given time (e.g. 22 hours) at a specific temperature (e.g. 100° C), these last two variables based on anticipated service conditions.

TABER ABRADER

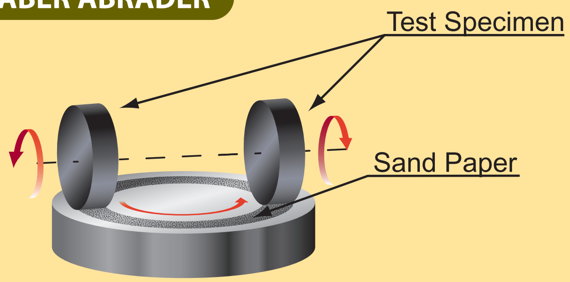


Figure 23: Rotating Samples

COMPRESSION SET

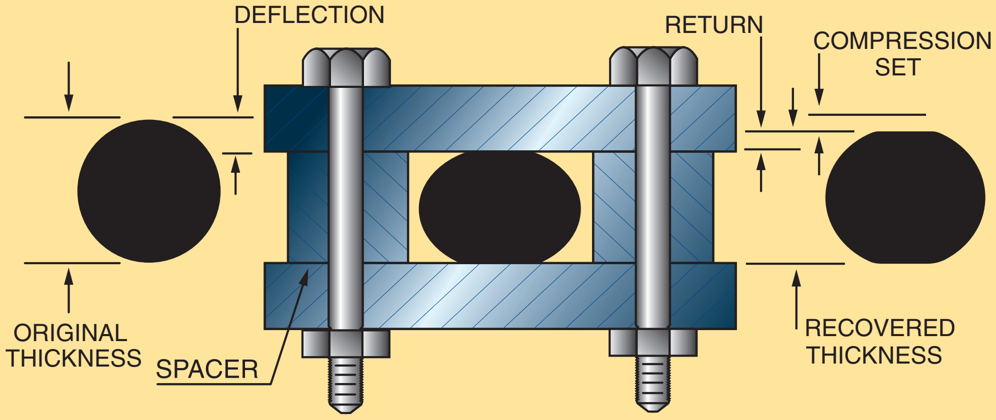


Figure 24: Effects of Compression Set on an O-Ring's Cross-Section

After removal from the compression device and a 30-minute cooling period, the specimens are measured using a dial micrometer. Compression set can then be calculated as either a percentage of original specimen thickness or as a percentage of original deflection.

Though a high degree of compression set is to be avoided, other service variables (such as inadvertent fluid swell or the intentional application of greater squeeze) may compensate. Seals are most likely to fail when there is both high compression set and shrinkage. ***Table 5*** (next page) shows how several of the most commonly used materials respond to increasing temperatures. For more information on compression set, see ***page 256***.

RESILIENCE

As detailed in ASTM D 2632, resilience (also known as

CONSTANT FORCE

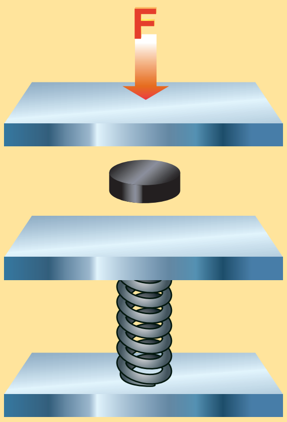


Figure 25: Compression Set Test Method A

CONSTANT DEFLECTION

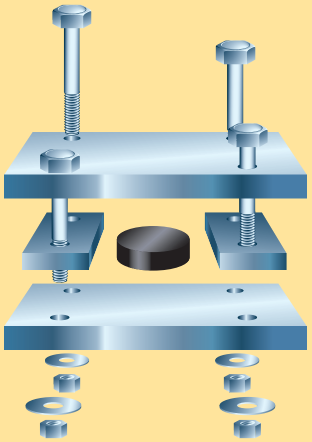


Figure 26: Compression Set Test Method B

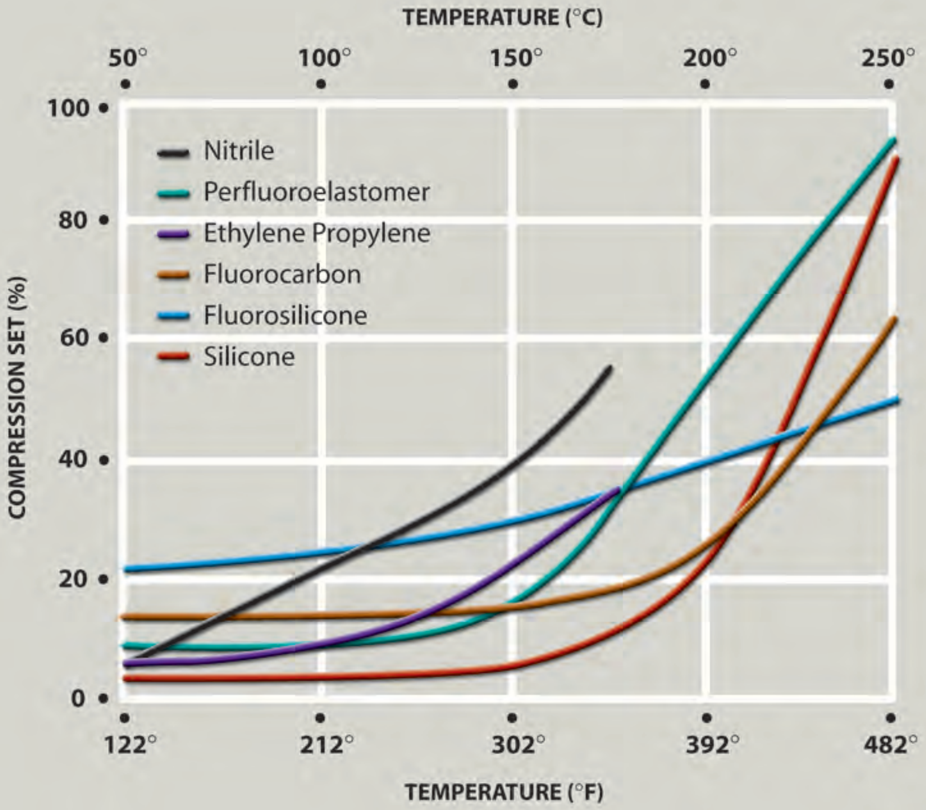


Table 5: Compression Set in Increasing Temperatures

rebound) refers to a compound's ability to regain its original size and shape after temporary deformation. Resilience testing typically involves the dropping of a small weight onto a test specimen (such as a compression set button, see ***Figure 27***). The extent to which the weight bounces back is then noted as a percentage of the initial drop height. A highly resilient material (one that can rapidly regain its dimensions) might engender a 70% rebound value, but values in the range of 40 to 50% are more typical for the majority of elastomers tested. Though compounding may improve an elastomer in this area, it can also detract from good resilience, which is largely an inherent property. As a general rule, resilience is most critical in dynamic seals.

RESILIENCE

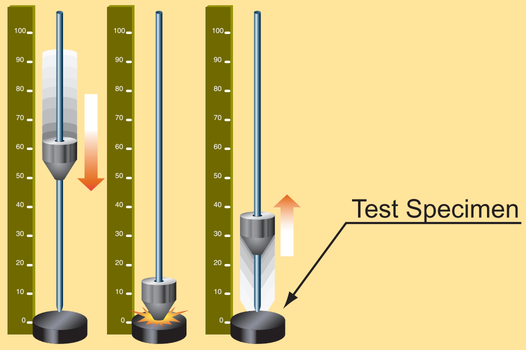


Figure 27: Bashore Resilience Testing

As important as they are, the physical properties of a given material are not the end of the story. Chemical properties are also critical, so let's take a closer look at them next.

Chemical Properties.

In addition to the physical properties discussed in the preceding section, there are also a couple of very important chemical properties you should consider when choosing an elastomeric compound. Primarily, the material must be chemically compatible with the substance(s) to be sealed. You must also anticipate any volume changes that the compound may undergo as a result of contact with system fluids.

COMPATIBILITY

As used by the sealing industry, the term *compatibility* refers to a seal material's resistance to having its chemical (and, by extension, its physical) properties degraded (either temporarily or permanently) as a result of contact with a liquid or gas. Because "likes dissolve likes," the true key to compatibility between the seal and the fluid(s) being sealed is dissimilar chemical structure. For example, an O-ring seal made from an oil-derived material can be severely compromised when put in contact with oils or fuels. The most likely result: excessive swelling of the O-ring, resulting in failure of the seal (see ***Figure 28***).

"Because 'likes dissolve likes,' the true key to compatibility between the seal and the fluid(s) being sealed is dissimilar chemical structure."

In addition to being resistant to the primary system fluid, the seal must also be resistant to any and all additives which may be encountered during the course of operation. For example, oil-field applications often utilize film-forming amine inhibitors to coat tubular goods and help prevent metal corrosion. Unfortunately, amine inhibitors act as curing agents for some fluorocarbon elastomers, causing seal hardening and failure. In such an application, an O-ring would need to be resistant to the fluid(s) being sealed and to the added amine inhibitors in order to provide an effective and long-lasting seal.

EVIDENCE OF INCOMPATIBILITY

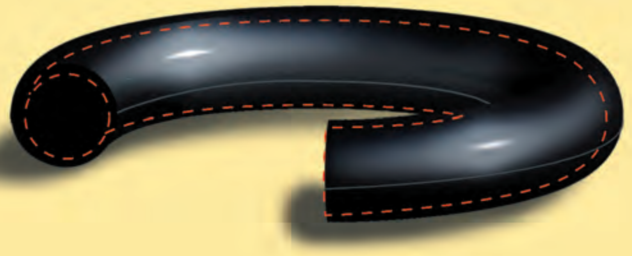


Figure 28: O-Ring Swell

Even if they do not degrade the elastomeric compound directly, some fluids degrade surfaces adjacent to the seal (as with metal corrosion), thus reducing the effectiveness of the seal itself. You should also keep in mind that while some compounds formulated from a particular polymer may be okay for use in a given fluid, not all compounds of that polymer will be appropriate for use in that fluid. Since a compound's properties are a direct result of its interactive constituents (e.g. reinforcing agents, plasticizers, etc.), each unique formulation should be tested under actual service conditions to accurately determine its appropriateness for an application.

There is no single ASTM test to determine "chemical compatibility." Rather, compatibility is understood to be a wider concept incorporating changes (or the lack thereof) in a number of material properties, each with their own test methods. Hardness, tensile strength, modulus, and elongation can all be compromised if a compound is not compatible with (resistant to) a given fluid. Perhaps the most visible evidence of chemical incompatibility is a change in the material's volume.

VOLUME CHANGE

Volume change is either the increase (swell, as in ***Figure 28***) or decrease (shrinkage, as in ***Figure 29***) in the volume of a specimen which has been in contact with a fluid. This contact may range from occasional "splashing" to constant immersion. Any resulting volume change can range from minor (indicating there is a relative compatibility between the fluid and the specimen) to major (indicative of incompatibility). Volume change is typically noted as a percentage of the original volume. For example, a specimen that swells to twice its original volume is said to have undergone a 100% increase.

EVIDENCE OF INCOMPATIBILITY

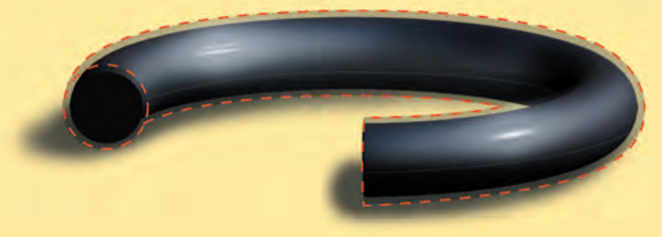


Figure 29: Shrinkage Due to Plasticizer Extraction

An elastomeric seal typically becomes softer as a result of swell, whereas shrinkage generally hardens the seal. A slightly swollen seal is, in most cases, still functional. A limited amount of swell may even compensate for other variables, such as compression set. Shrinkage, on the other hand, can exacerbate an already-existing compression set problem. With some of its soluble components (such as plasticizer) having been extracted by system fluid, an O-ring seal that has undergone shrinkage is more prone to leaks.

As described in ASTM test method D 471, volume change testing typically employs ASTM and Industry Reference Material (IRM) oils, as well as ASTM Reference Fuels, Service Liquids, and Type IV Reagent Water. Regardless of the liquid in use, testing involves immersing a material sample (of known properties) in the liquid for a specific period of time (e.g. 70 hours) at a specific temperature (e.g. 100° C ± 2°), both variables based on the conditions expected in service. Material deterioration (if any) is then determined based on changes in physical properties, including volume.

Thermal Properties.

Most physical and chemical properties are impacted when an elastomeric compound meets high or low temperatures, especially if the exposure is for a prolonged period. Affected properties can include hardness, tensile strength, modulus, elongation, compression set, and volume. Because O-rings often face extreme heat or extreme cold (and in some cases, both extremes), there are important thermal properties you must consider. These include high and low temperature effects, coefficient of thermal expansion, and the Gough-Joule effect.

> **"Because O-rings often face extreme heat or extreme cold, there are important thermal properties you must consider."**

HIGH TEMPERATURE EFFECTS

Unless specially formulated, elastomers will typically soften when first exposed to high temperatures. Extended heat exposure can cause irreversible changes in tensile strength and elongation, as well as alterations in the chemical makeup of a seal such that it hardens and cracks. This hardening is the result of additional cross-linking, plasticizer evaporation, and/or oxidation. ***Table 7*** shows how high temperatures impact a handful of the most-used materials.

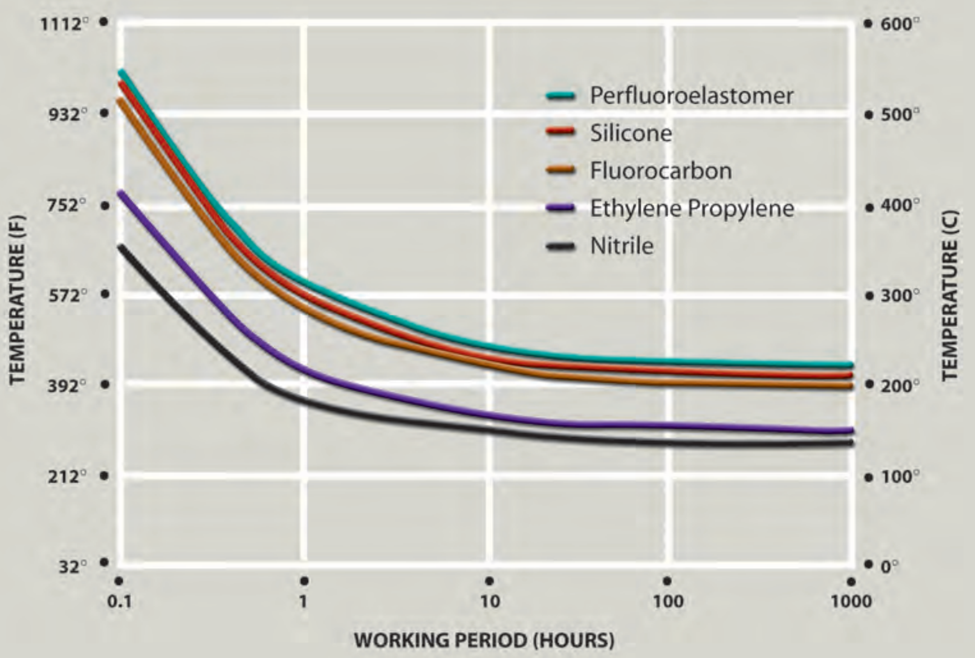


Table 7: Material Performance in High Temperatures

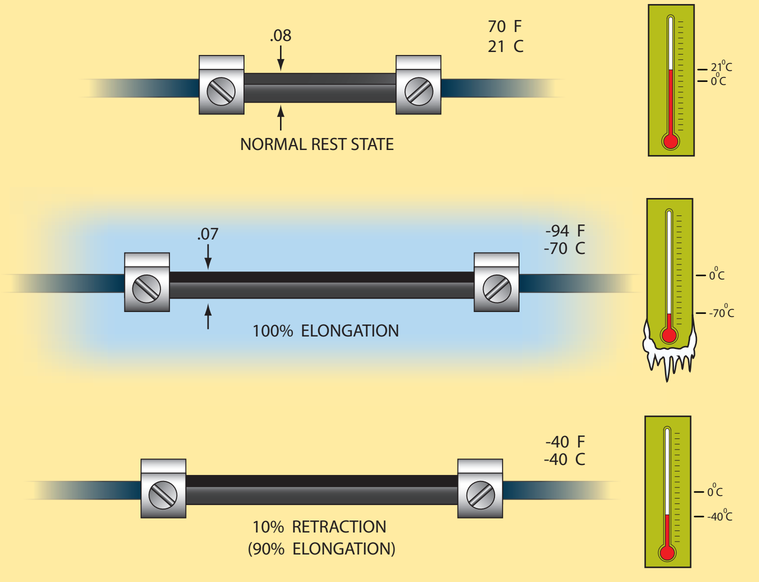
There are four different ASTM test methods related to high temperature effects. All are designed to gauge the amount of material degradation that results from exposure to a heated environment. The main difference between these tests is the device used to keep pressure and heat on the specimen. D 454 uses an air-pressure chamber to mimic the degrading effects of heat and air. D 572 utilizes a similar oxygen-pressure chamber to simulate deterioration by heat and oxygen. D 573 details testing in an air oven, and D 865 describes heat and air testing within a test tube enclosure.

LOW TEMPERATURE EFFECTS

Unlike the changes that result from exposure to high temperatures, changes brought about by low temperature exposure are generally not permanent and can often be reversed once heat returns. For example, extended exposure to low temperatures will increase an elastomer's hardness, but the material will soften again when the temperature rises. Perhaps the most important consideration related to low temperatures involves seals which must also work in a low-pressure environment. Unless the selected seal compound is sufficiently soft and resilient, the combination of low temperature (which can cause shrinkage and hardening of the seal) and low service pressure (which will not help hold the seal against the mating surface) can cause leakage and failure.

There are two main tests related to low temperature effects. The first is described in ASTM D 2137 (Method A) as a way to measure the *brittleness point*, or the lowest temperature at which a sample will not fracture or crack when struck once. The second test is described in ASTM D 1329. More commonly known as a *TR-10*, this temperature retraction test (see ***Figure 30***) is considered by many within the rubber industry to be the most useful indicator of a material's low temperature performance.

LOW TEMPERATURE TESTING



-40° C is the TR10 Value of this sample

Figure 30: Temperature Retraction, or "TR-10"

In a nutshell, the TR-10 measures material resilience. Samples are frozen in a stretched state, then gradually warmed until they lose 10% of this stretch (i.e. retract by 10%). The results of such tests are believed to provide a good basis for evaluating the effects of crystallization and the impact of low temperatures on visco-elastic properties. TR-10 results are generally thought to be consistent with the capabilities of most dynamic seals. Static seals can often function at 15° F / 8° C below the TR-10 temperature.

COEFFICIENT OF THERMAL EXPANSION

Coefficient of thermal expansion may be either linear or volumetric. The coefficient of linear thermal expansion is the change in length per unit of length for a 1° rise in temperature. The coefficient of volumetric thermal expansion is the change in volume divided by the product of the original volume and the change in temperature. In solids, the coefficient of volumetric expansion is three times the coefficient of linear expansion.

Because elastomeric compounds have much higher coefficients of expansion than steel or aluminum (i.e. than the materials from which many glands are made), thermal expansion may cause an already tight seal to swell and overfill the gland as temperatures rise. Glands have even been known to rupture under the force exerted by an expanding seal. Conversely, a seal design that provides only minimal squeeze in a low temperature setting cannot look to thermal effects for help in tightening the seal.

MATERIAL RETRACTION

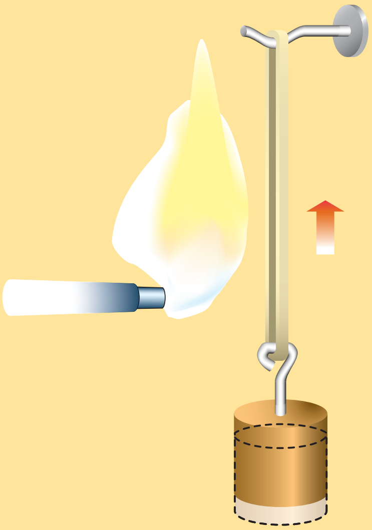


Figure 31: Gough-Joule Effect

GOUGH-JOULE EFFECT

The Gough-Joule effect (see ***Figure 31***) is actually two related phenomena. First, unlike many materials, rubber heats up when stretched quickly. Second, rubber that is held stationary at one end and stretched under a given load will actually retract if localized heat is applied. This is true because the rubber's stressed macromolecular chains are trying to regain a less-stressful state. The Gough-Joule effect is perhaps most important in rotary seal designs, where excessive installed stretch in conjunction with system heat can cause an O-ring to retract, seizing the rapidly rotating shaft and dooming the design.

With these physical, chemical, and thermal properties in mind, let's now look more specifically at the relative strengths and weaknesses of the most commonly used O-ring materials.

Material Profiles.

The following profiles of the most commonly used O-ring materials are intended to serve as general guidelines only. Inherent strengths and weaknesses are noted, but keep in mind that these properties may be enhanced or diminished through compounding. Selecting the best material for a given application will inevitably require both comparison *and* compromise. You should always test final formulations (the base material and all additional modifying agents) in actual service conditions *prior* to field use.

* Non Oil-Resistant Material

"Selecting the best material for a given application will inevitably require both comparison *and* compromise."

Butyl Rubber.

ASTM D 1418 Designation: IIR

ASTM D 2000, SAE J200 Type / Class: AA, BA

STANDARD COLOR: Black

TRADE NAMES:

- **Exxon Butyl® (Exxon Chemicals)**
- **Polysar® (Bayer Corp.)**

RELATIVE COST: Medium

GENERAL TEMPERATURE RANGE: -50° to +250° F

> **"Butyl offers excellent resistance to gas permeation."**

An unsaturated copolymer of isobutylene and isoprene (thus the designation IIR), butyl rubber has two defining traits: (1) it is composed entirely of petroleum, limiting its usefulness around hydrocarbons (since "likes dissolve likes"); and (2) it offers excellent resistance to gas permeation, making it ideal for vacuum seals. Though ethylene propylene is now used rather than butyl for a number of applications, butyl is still used in some aircraft hydraulic systems. Butyl offers stronger resistance to sunlight and ozone than isoprene alone; presence of the saturated isobutylene in the polymer chain makes this possible (see ***Figure 32***). Butyl also resists heat, chemicals, and abrasion.

IIR

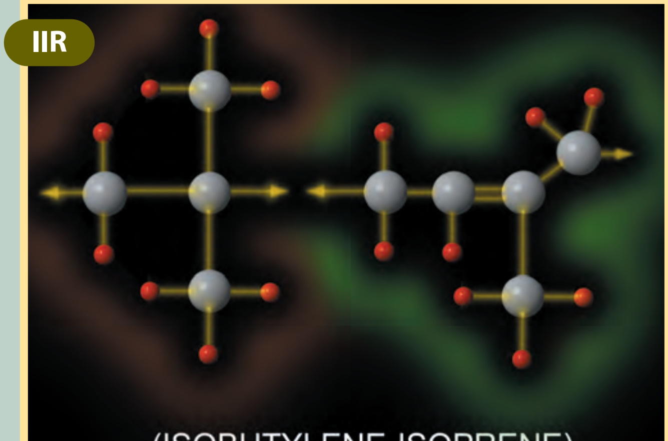


Figure 32: Molecular Structure of Butyl Rubber

IIR PERFORMS WELL IN:

- Hot water & steam (up to 250° F, 121° C)
- Phosphate ester type hydraulic fluids (e.g. Skydrol®, Fyrquel®, Pydraul®)
- Silicone fluids & greases

IIR DOES NOT PERFORM WELL IN:

- Mineral oil & grease
- Hydrocarbon oil & fuel

Chloroprene.

ASTM D 1418 Designation: CR

ASTM D 2000, SAE J200 Type / Class: BC, BE

STANDARD COLOR: Black

TRADE NAMES:

- **Baypren® (Bayer Corp.)**
- **Neoprene® (DuPont Dow Elastomers)**

RELATIVE COST: Medium

GENERAL TEMPERATURE RANGE: -40° to +250° F

Chemically known as polychloroprene but often referred to by the trade name Neoprene®, chloroprene was one of the first synthetic materials developed as an oil-resistant substitute for natural rubber. Neoprene's molecular structure closely mirrors that of natural rubber, with the exception that a chlorine atom has replaced a methyl (CH_3) sidegroup (see ***Figure 33***). Presence of a chlorine atom in each repeating unit increases the compound's polarity and improves its resistance to hydrocarbon fluids despite the presence of a double bond in the main chain. Because the chlorine atom essentially deactivates the double bond, chloroprene is more resistant to oxygen, ozone, and UV light than similarly unsaturated polymers.

Due to the similarity of their structures, natural rubber and chloroprene are generally comparable in their good strength, abrasion resistance, resilience, elongation, and strain crystallization characteristics. Both also offer a similar low fatigue property, low heat build up, low temperature flexibility, and high bondability. Chloroprene surpasses natural rubber in its resistance to aging, heat, oils, ozone, and solvents. Chloroprene has also gained FDA approval for use in the food and beverage industries.

> **"Chloroprene was one of the first synthetic materials developed as an oil-resistant substitute for natural rubber."**

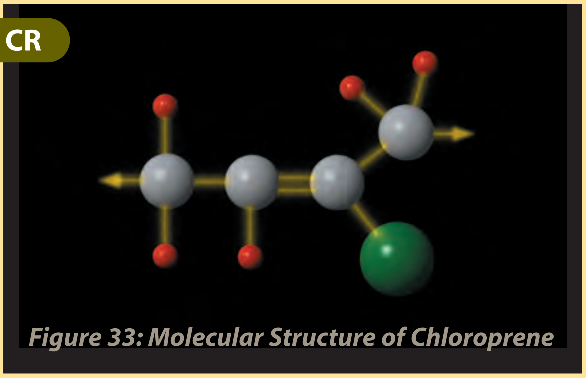


Figure 33: Molecular Structure of Chloroprene

CR PERFORMS WELL IN:

- High aniline point petroleum oils
- Mild acids
- Refrigeration seals (resistance to Freon® & ammonia)
- Silicone oil & grease
- Water

CR DOES NOT PERFORM WELL IN:

- Hydrocarbons (aromatic, chlorinated, nitro)
- Ketones (MEK, acetone)
- Phosphate ester fluids
- Strong oxidizing acids

Chlorosulfonated Polyethylene.

ASTM D 1418 Designation: CSM

ASTM D 2000, SAE J200 Type / Class: CE

STANDARD COLOR: Black

TRADE NAME:

- **Hypalon® (DuPont Dow Elastomers)**

RELATIVE COST: Medium

GENERAL TEMPERATURE RANGE: -20° to +250° F

Best known by the trade name Hypalon®, chlorosulfonated polyethylenes (see ***Figure 34***) are valued for their attractive combination of physical resilience and chemical resistance to corrosives, heat, oil, oxygen, ozone, and weather. Both heat resistance and low temperature flexibility can be augmented through use of lower amounts of chlorine, but oil resistance is only fair in such formulations. Higher chlorine levels lead to greater oil resistance at the expense of the heat resistance and low temperature flexibility. CSM can also be compounded to retain permanent bright colors. On the down side, CSM suffers from poor compression set resistance.

> **“Chlorosulfonated polyethylenes are valued for their attractive combination of physical resilience and chemical resistance.”**

CSM

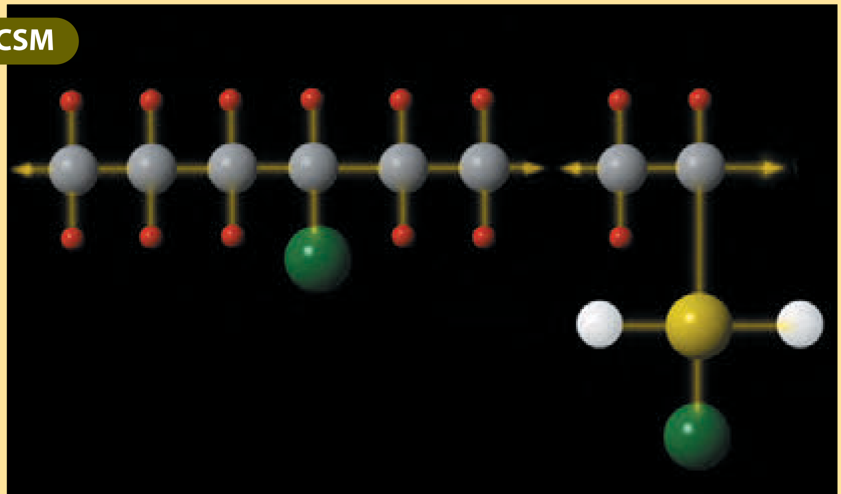


Figure 34: Molecular Structure of Chlorosulfonated Polyethylene

CSM PERFORMS WELL IN:

- Acids
- Alkalies
- Silicone oil & grease
- Water & water solvents
- Refrigerants (high chlorine compounding lends Freon® resistance)
- Ozone

CSM DOES NOT PERFORM WELL IN:

- Aldehydes
- Esters
- Ethers
- Hydrocarbons (aromatic, chlorinated, nitro)
- Ketones

Epichlorohydrin.

ASTM D 1418 Designations: CO, ECO, GECO

ASTM D 2000, SAE J200 Type / Class: CH

STANDARD COLOR: Black

TRADE NAME:

- **Hydrin® (Zeon Chemicals, L.P.)**

RELATIVE COST: Medium

GENERAL TEMPERATURE RANGE: -55° to +275° F

Epichlorohydrin is an oil resistant compound available in three formulations: as a homopolymer (CO), as a copolymer of epichlorohydrin and ethylene oxide (ECO, see ***Figure 35***), and as a terpolymer of epichlorohydrin, ethylene oxide, and a cure site monomer (GECO).

Epichlorohydrin combines low gas and solvent permeability with high resistance to hydrocarbon oils and fuels. Epichlorohydrin is very resistant to weathering and ozone due to complete saturation within the polymer chain.

Epichlorohydrin also remains stable during low to high temperature cycling. Because it exhibits less sub-zero stiffness, epichlorohydrin is often used in place of nitrile and chloroprene (Neoprene®) for applications requiring resistance to low temperatures. Epichlorohydrin has only fair compression set resistance at high temperatures (i.e. 250° to 275° F).

> **"Epichlorohydrin combines low gas and solvent permeability with high resistance to hydrocarbon oils and fuels."**

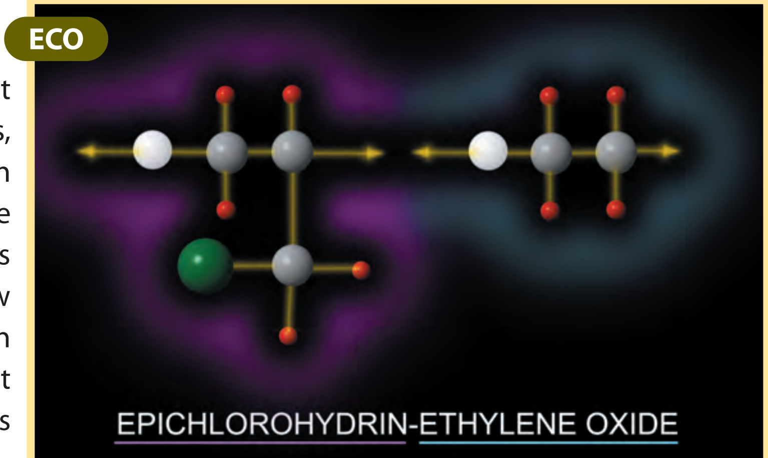


Figure 35: Molecular Structure of Epichlorohydrin

EPICHLOROHYDRIN PERFORMS WELL IN:

- Aliphatic hydrocarbons
- Mineral oil & grease
- Silicone oil & grease
- Ozone

EPICHLOROHYDRIN DOES NOT PERFORM WELL IN:

- Aldehydes
- Brake fluids
- Esters
- Hydrocarbons (chlorinated, nitro)
- Ketones
- Peroxides

Ethylene Acrylic.

ASTM D 1418 Designation: AEM

ASTM D 2000, SAE J200 Type / Class: EE, EF, EG

STANDARD COLOR: Black

TRADE NAME:

- **Vamac® (DuPont Dow Elastomers)**

RELATIVE COST: Medium

GENERAL TEMPERATURE RANGE: -40° to +300° F

Better known as Vamac®, ethylene acrylic is a copolymer of ethylene and methyl acrylate. Vamac also has a third, acid-containing monomer to cure the polymer chain's active groups (see ***Figure 36***). Vamac offers exceptional resistance to ozone, sunlight, and heat, as well as low gas permeability and moderate oil swell resistance. Flex life is good, as are tear, abrasion, and compression set properties.

"Vamac offers exceptional resistance to ozone, sunlight, and heat."

AEM PERFORMS WELL IN:

- Alkalies
- Dilute acids
- Glycols
- Water
- as power steering & automatic transmission seals

AEM DOES NOT PERFORM WELL IN:

- Aromatic hydrocarbons (benzene, toluene, xylene)
- Brake fluids
- Gasoline
- Ketones
- Phosphate esters
- Strong acids

AEM

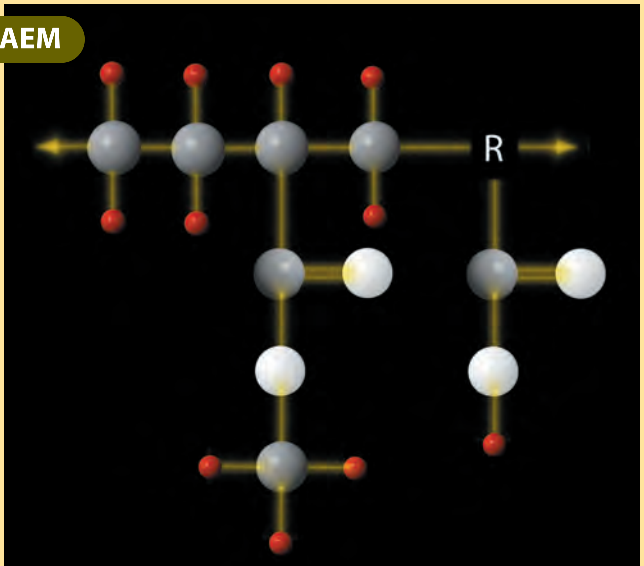


Figure 36: Molecular Structure of Ethylene Acrylic

Note: The "R" in the carboxyl cure site monomer denotes an alkyl group, a (typically aliphatic) organic structure.

Ethylene Propylene.

ASTM D 1418 Designations: EPM, EPDM

ASTM D 2000, SAE J200 Type / Class: AA, BA, CA, DA

STANDARD COLOR: Black

TRADE NAMES:

- **Buna EP® (Bayer Corp.)**
- **Keltan® (DSM Copolymer, Inc.)**
- **Nordel® (DuPont Dow Elastomers)**
- **Royalene® (Uniroyal, Inc.)**
- **Vistalon® (Exxon Chemicals)**

RELATIVE COST: Low

GENERAL TEMPERATURE RANGE: -65° to +300° F

Ethylene propylene is a copolymer of ethylene and propylene (EPM), or, in some cases, a terpolymer due to the addition of a diene monomer (EPDM). This additional diene monomer can be important because it includes unsaturation to facilitate sulfur crosslinking (see ***Figure 37***).

"Ethylene propylene is primarily valued for its outstanding resistance to phosphate ester type hydraulic fluids, as well as for its typical temperature range."

In use since 1961, ethylene propylene is primarily valued for its outstanding resistance to Skydrol® and other phosphate ester type hydraulic fluids (including Pydraul® and Fyrquel®), as well as for its typical temperature range (-65° to +300° F, -54° to +149° C).

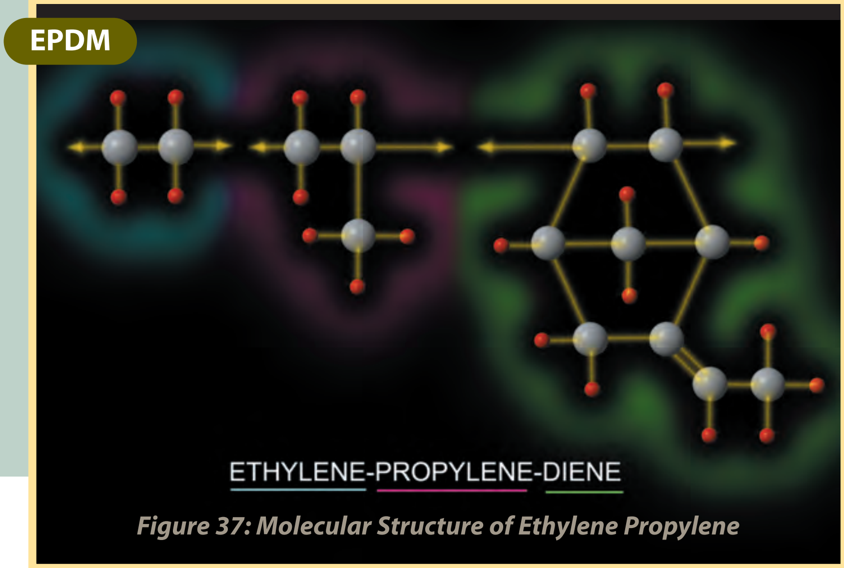


Figure 37: Molecular Structure of Ethylene Propylene

Ethylene propylene is also known for its good resistance to weathering thanks to saturation within its chemical backbone.

EPM PERFORMS WELL IN:

- Alcohols
- Automotive brake fluids
- Dilute acids & dilute alkalies
- Ketones (MEK, acetone)
- Silicone oils & greases
- Steam (up to 400° F, 204° C)
- Water

EPM DOES NOT PERFORM WELL IN:

- Aliphatic & aromatic hydrocarbons
- Di-ester based lubricants
- Halogenated solvents
- Petroleum oils

Fluorocarbon.

"Fluorocarbons make excellent general purpose O-rings due to their exceptional resistance to chemicals, oil, and temperature extremes."

ASTM D 1418 Designation: FKM

ASTM D 2000, SAE J200 Type / Class: HK

STANDARD COLORS: Black, Brown, Green

TRADE NAMES:

- **DAI-EL® (Daikin Industries)**
- **Dyneon®, previously Fluorel® (Dyneon)**
- **Tecnoflon® (Ausimont USA, Inc.)**
- **Viton® (DuPont Dow Elastomers)**

RELATIVE COST: High

GENERAL TEMPERATURE RANGE: -15° to +400° F

Also referred to as fluoroelastomers, fluorocarbon compounds are thermoset elastomers containing fluorine (see ***Figure 38***). Fluorocarbons make excellent general purpose O-rings due to their exceptional resistance to chemicals, oil, and temperature extremes (-15° to +400° F). Specialty compounds can further extend the low temperature limit down to about -22° F for dynamic seals and about -40° F in static applications.

FKM

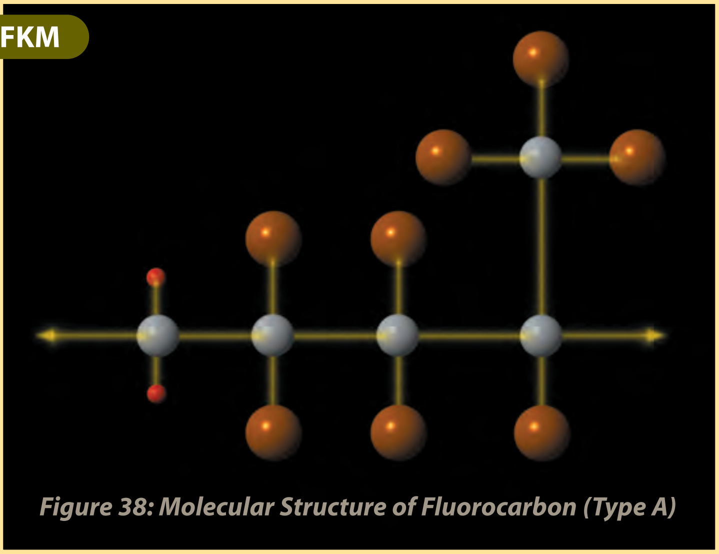


Figure 38: Molecular Structure of Fluorocarbon (Type A)

Fluorocarbons usually have good compression set resistance, low gas permeability, and resistance to ozone and sunlight. Over the last five decades, this remarkable combination of properties has prompted the use of FKM seals in a variety of demanding sectors. Though they were initially formulated for use in aerospace applications, FKM compounds are now widely used in the automotive, appliance, fluid power, and chemical processing industries.

Three main factors contribute to the remarkable heat (see ***Table 8***) and fluids resistance of fluorocarbon compounds. First, there are extremely strong bonds between the carbon atoms comprising the polymer backbone and the attached (pendant) fluorine atoms. Under most circumstances, these bonds cannot be broken, and thus the polymer is not prone to undergo chain scission (division of the macromolecular chains into smaller, weaker, more susceptible segments).

Second, fluorocarbons feature a high fluorine-to-hydrogen ratio. In other words, fluorine (rather than hydrogen) atoms fulfill the majority of the available bonds along the material's carbon backbone. Polymers with a high level of fluorination have proven to be extremely stable. A stable compound is less inclined to react to, or be broken down by, its environment.

Third, the carbon backbone is fully saturated. That is, it contains only single bonds between the carbon atoms. It does not contain any of the covalent double bonds present in unsaturated compounds. Since double bonds are the focus for chemical attack, the saturated structure of fluorocarbons renders them impervious to harmful agents (such as oxygen, ozone, and UV light) that typically degrade unsaturated materials.

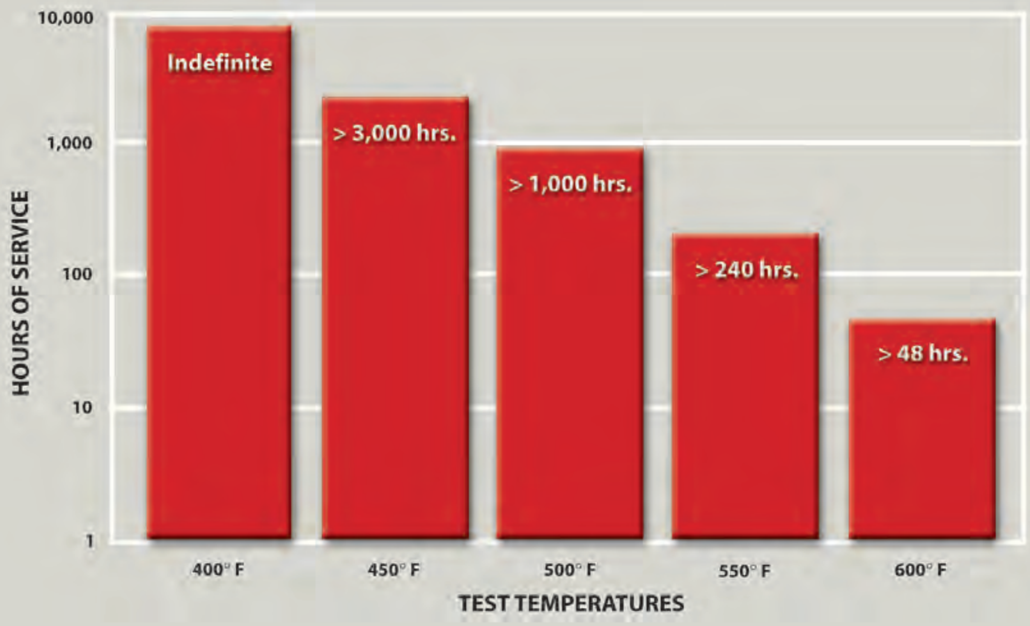


Table 8: Heat Resistance of FKM

FKM PERFORMS WELL IN:

- Acids
- Aircraft engine applications
- Gasoline (& alcohol blends)
- Hard vacuum applications
- Low outgassing applications
- Petroleum products
- Silicone fluids & greases
- Solvents

FKM DOES NOT PERFORM WELL IN:

- Amines
- Hot chlorosulfonic acid
- Hot hydrofluoric acid
- Hydrocarbons (nitro)
- Ketones
- Low molecular weight esters & ethers
- Fireproof hydraulic fluids (e.g. Skydrol®)

Depending on the specific needs of your application, there are a number of different fluorocarbon formulations available for use. Though they may share some common characteristics, these different types are distinguished by their processing and end-use properties. Perhaps the most well-known fluorocarbon manufacturer is DuPont Dow Elastomers, to the point that the trade name for their compound, Viton®, is often used as if it were a generic term for FKM. In the interests of simplicity, the following descriptions of some of the most common FKM formulations will make use of the DuPont "type" names.

The original commercial fluorocarbon, ***Viton A***, is the general-purpose type and is still the most widely used. Viton A is a copolymer of vinylidene fluoride (VF_2) and hexafluoropropylene (HFP). Generally composed of 66% fluorine, Viton A compounds offer excellent resistance against many automotive and aviation fuels, as well as both aliphatic and aromatic hydrocarbon process fluids and chemicals. Viton A compounds are also resistant to engine lubricating oils, aqueous fluids, steam, and mineral acids.

Viton B fluorocarbons are terpolymers combining tetrafluoroethylene (TFE) with VF_2 and HFP. Depending on the exact formulation, the TFE partially replaces either the VF_2 (which raises the fluorine level to approximately 68%) or the HFP (keeping the fluorine level steady at 66%). Viton B compounds offer better fluids resistance than the Viton A copolymers.

Viton GF fluorocarbons are tetrapolymers composed of TFE, VF_2, HFP, and small amounts of a cure site monomer. Presence of the cure site monomer allows peroxide curing of the compound, which is normally 70% fluorine. As the most fluid resistant of the various FKM types, Viton GF compounds offer improved resistance to water, steam, and acids.

Viton GFLT fluorocarbons are similar to Viton GF, except that perfluoromethylvinyl ether (PMVE) is used in place of HFP. The "LT" in Viton GFLT stands for "low temperature." The combination of VF_2, PMVE, TFE, and a cure site monomer is designed to retain both the superior chemical resistance and high heat resistance of the G-series fluorocarbons. In addition, Viton GFLT compounds (typically 67% fluorine) offer the lowest swell and the best low temperature properties of the types discussed here (see ***Table 9***). Viton GFLT can seal in a static application down to approximately -40° F. A brittle point of -50° F can be achieved through careful compounding.

	VITON A	**VITON B**	**VITON GF**	**VITON GFLT**
PERCENT FLUORINE	**66**	**68**	**70**	**67**
FUEL SWELL (70 hrs. at 23° C):				
Fuel C, % volume	+5	+4	+3	+3
Methanol, % volume	+70	+22	+3	+5
LOW TEMPERATURE FLEXIBILITY:				
TR-10, °C/°F	-17/1	-14/7	-6/21	-24/-11
COST/POUND*	$20	$20	$25	$55

* At time of publication

Table 9: Comparison of Standard Fluorocarbons to Specialty Type GFLT

Fluorosilicone.

"Fluorosilicones combine the best properties of fluorocarbons and silicones."

ASTM D 1418 Designation: FVMQ

ASTM D 2000, SAE J200 Type / Class: FK

STANDARD COLOR: Blue

TRADE NAMES:

- **FE® (Shincor Silicones)**
- **FSE® (General Electric)**
- **Silastic LS® (Dow Corning Corp.)**

RELATIVE COST: High

GENERAL TEMPERATURE RANGE: -70° to +350° F

Fluorosilicone is the common name for fluorovinylmethyl silicone rubber (see ***Figure 39***). Fluorosilicones combine the best properties of fluorocarbons and silicones. Fluorosilicones resist solvents, fuel, and oil (similar to fluorocarbons). They also have high and low temperature stability (as with silicones). Fluorosilicones are resilient, with low compression set characteristics. Though widely used in aerospace fuel systems and auto fuel emission controls, fluorosilicones are really only good as static seals. High friction tendencies, limited strength, and poor abrasion resistance disqualify them from dynamic uses.

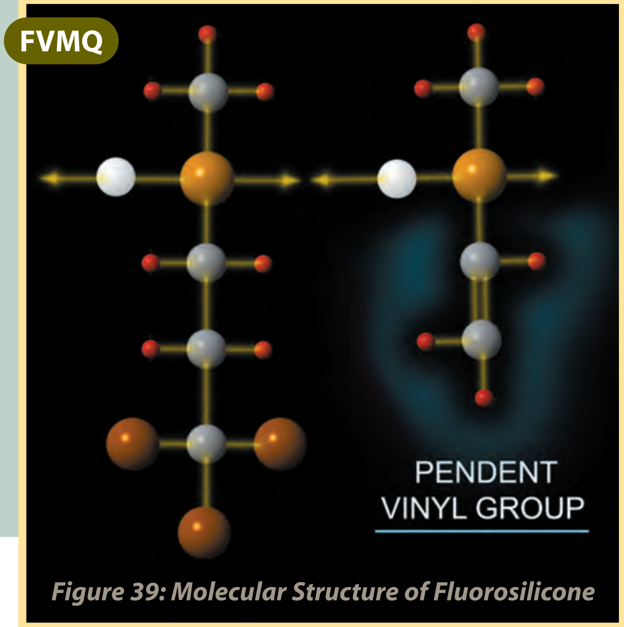


Figure 39: Molecular Structure of Fluorosilicone

FVMQ PERFORMS WELL IN:

- Hot air
- Hydrocarbons (aromatic, chlorinated)
- Ozone
- Sunlight

FVMQ DOES NOT PERFORM WELL IN:

- Brake fluids
- Hydrazine
- Ketones

Hydrogenated Nitrile.

ASTM D 1418 Designation: HNBR

ASTM D 2000, SAE J200 Type / Class: DH

STANDARD COLORS: Black, Green

TRADE NAMES:

- **Therban® (Bayer Corp.)**
- **Zetpol® (Zeon Chemicals, L.P.)**

RELATIVE COST: High

GENERAL TEMPERATURE RANGE: -25° to +300° F

Though the double bonds within nitrile's butadiene segments are needed for cross-linking (see **page 109**), they are also the main attack sites for heat, chemicals, and oxidation. As part of an ongoing effort to engineer more resistant compounds, a new class of nitrile was developed in the 1980s. Initially known as highly saturated nitrile (HSN), this class is now more commonly called hydrogenated nitrile butadiene rubber (HNBR), or just hydrogenated nitrile (see ***Figure 40***).

> **"As part of an ongoing effort to engineer more resistant compounds, a new class of nitrile was developed in the 1980s."**

As you might guess, hydrogenated nitrile results from the *hydrogenation* of standard nitrile. Hydrogenation is the process of adding hydrogen atoms to the butadiene segments. Adding hydrogen greatly reduces the number of carbon-to-carbon double bonds that would otherwise be weak links in the polymer chain. Why are double bonds weak? It stems from *valence*, or the ability of an atom to form one or more energy bonds with neighboring atoms. A carbon atom can form four distinct covalent bonds. Because carbon has this valence of four, it is most "satisfied" when it has actually formed four single bonds (a state known as saturation) rather than two single bonds and a double bond. A satisfied, saturated atom is more stable, so a compound composed largely of saturated carbons is less reactive and more resistant to chemical attack.

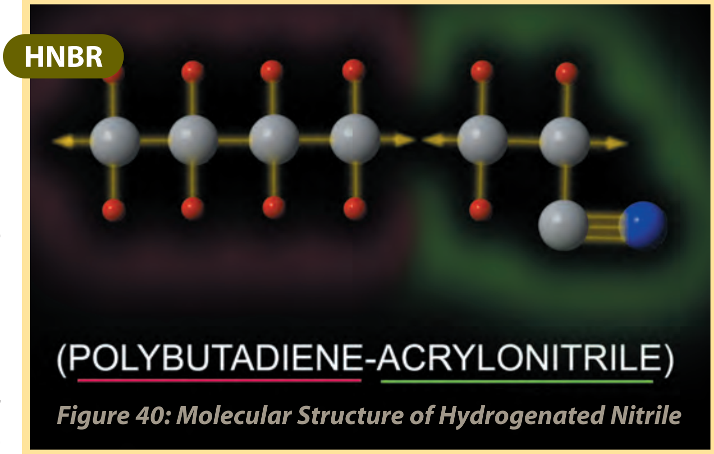


Figure 40: Molecular Structure of Hydrogenated Nitrile

As shown in ***Figure 40***, HNBR's main chain is primarily composed of highly saturated hydrocarbons and acrylonitrile (ACN). Thanks to their saturation, the hydrocarbon segments impart heat, chemical, and ozone resistance. Keep in mind that increased hydrogenation and heat resistance make HNBR more likely to creep (cold flow). Increased hydrogenation also leads to decreased low temperature elasticity. As with standard nitrile, the ACN content of HNBR imparts toughness, as well as fuel and oil resistance. This ACN content can be modified for specific uses. There are also a few remaining unsaturated butadiene segments (typically well under 10%) to facilitate peroxide curing or, in some instances, sulfur vulcanization. Peroxide-cured HNBR has improved thermal properties and will not continue to vulcanize like sulfur-cured nitriles.

Since its introduction, HNBR has proven itself in a variety of applications. Deeper and deeper oil wells require materials that can resist heat, crude oil, hydrogen sulfide (H_2S), amine-based corrosion inhibitors, steam, and the detrimental effects of explosive decompression. HNBR meets these needs and is used for a variety of products, including O-rings, packings, wellhead seals, drill bit seals, blowout preventors, and drill pipe protectors.

HNBR is used in automotive air conditioning systems where R134a refrigerant gas has replaced the chlorofluorocarbon (CFC)-containing R12 refrigerant. HNBR is used in fuel parts due to its increased resistance to sour gasoline and ozone. It is used in oil line parts because of its resistance to elevated temperatures, oil additives, and copper-containing metal sludge.

HNBR is also finding wider use as an alternative to fluorocarbon rubber (FKM) in shaft seals. Why the switch? The hardness of the mineral fillers - primarily calcium sulfate ($CaSO_4$) and barium sulfite ($BaSO_3$) - used to improve fluorocarbon's wear properties can cause grooving of the metal shaft, eventually providing a leak path that leads to seal failure. With other materials, carbon black (which is not as abrasive as the mineral fillers) might be substituted, but carbon black is not sufficient to give fluorocarbon good abrasion resistance. On the other hand, HNBR has excellent abrasion resistance, making it a viable alternative to FKM. HNBR also has better low temperature properties and tear resistance than fluorocarbon.

HNBR PERFORMS WELL IN:

- Automotive applications (as O-rings, timing belts, fuel injector seals, fuel hose, shaft seals, diaphragms, and in air conditioning systems)
- Oil field applications (as O-rings, well-head seals, drill-bit seals, packers, drill-pipe protectors)

HNBR DOES NOT PERFORM WELL IN:

- Esters
- Ethers
- Hydrocarbons (chlorinated)
- Ketones

Natural Rubber.

“Natural rubber was the sole O-ring polymer before the development of synthetic elastomers in the 1930s.”

ASTM D 1418 Designation: NR

ASTM D 2000, SAE J200 Type / Class: AA

STANDARD COLOR: Black

TRADE NAMES: Too numerous to list.

RELATIVE COST: Low

GENERAL TEMPERATURE RANGE: -60° to +220° F

Polyisoprene vulcanized from the latex of the Hevea brasiliensis tree, natural rubber was the sole O-ring polymer before the development of synthetic elastomers in the 1930s. Though its use has since sharply declined, natural rubber offers many excellent characteristics, including low heat build up, high resilience and elongation, good abrasion resistance, and low temperature flexibility.

Natural rubber has both high tensile strength and good tear strength due to its tendency to strain crystallize. It also undergoes low compression set. Its chief drawback is its poor resistance to either oils or solvents. The double bond in its main polymer chain (see ***Figure 41***) also makes natural rubber susceptible to attack by oxygen, ozone, and UV light.

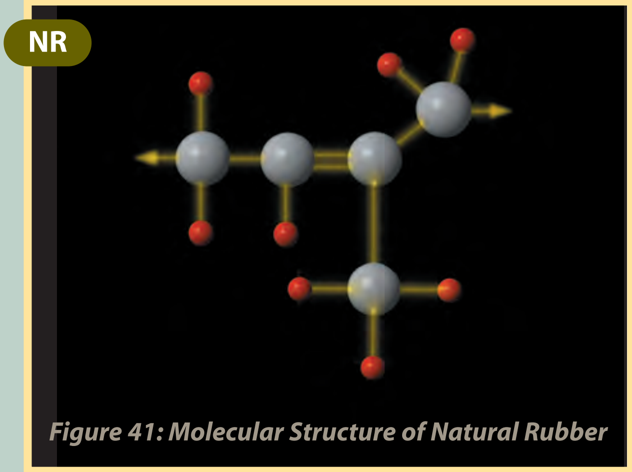


Figure 41: Molecular Structure of Natural Rubber

NR PERFORMS WELL IN:

- Alcohols
- Organic acids
- and as non-hydraulic seals

NR DOES NOT PERFORM WELL IN:

- Aromatic, aliphatic, or halogenated hydrocarbons
- Ozone
- Petroleum oils

Nitrile (Buna N).

ASTM D 1418 Designations: NBR, XNBR

ASTM D 2000, SAE J200 Type / Class: BF, BG, BK, CH

STANDARD COLOR: Black

TRADE NAMES:

- **Krynac® (Polysar International, USA)**
- **Nipol® (Zeon Chemicals, L.P.)**
- **Nysyn® (Copolymer Rubber & Chemical Corp.)**
- **Paracril® (Uniroyal, Inc.)**

RELATIVE COST: Low

GENERAL TEMPERATURE RANGE: -40° to +225° F

Nitrile rubber is the most commonly used elastomer for O-rings and other sealing devices. Also known as Buna N, nitrile (see ***Figure 42***) is a copolymer of butadiene and acrylonitrile (ACN). The name Buna N is derived from <u>bu</u>tadiene and <u>na</u>trium (the Latin name for sodium, the catalyst used in polymerizing butadiene). The “N” stands for acrylonitrile.

> **“Nitrile rubber is the most commonly used elastomer for O-rings and other sealing devices.”**

The butadiene segment imparts elasticity and low temperature flexibility. It also contains the unsaturated double bond that is the site for crosslinking, or vulcanization. This unsaturated double bond is also the main attack site for heat, chemicals, and oxidation.

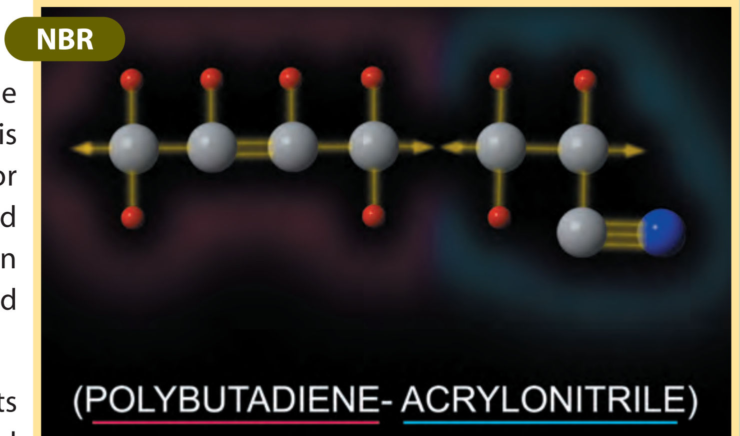


Figure 42: Molecular Structure of Nitrile

The acrylonitrile segment imparts hardness, tensile strength, and abrasion resistance, as well as fuel and oil resistance. Heat resistance and gas impermeability are also improved through increased ACN content, which typically ranges from 18% to 45%. A standard, general-purpose nitrile compound usually contains 34% ACN.

The relationship between the ACN content, volume swell in ASTM # 3 oil, and the brittle point of the elastomer is illustrated in ***Table 10***.

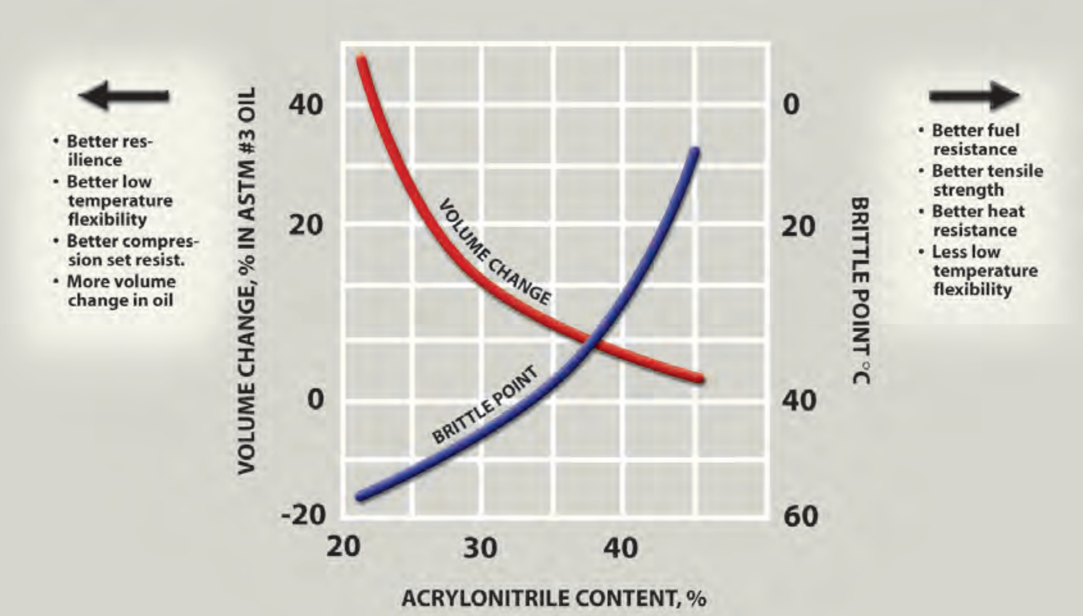


Table 10: Relationship Between ACN content, Volume Swell in ASTM # 3 Oil, and Brittle Point

General-purpose nitrile compounds with a 34% ACN content have a recommended temperature range of -40° to +225° F (-40° to +107° C). The low temperature flexibility can be improved by reducing the ACN content. Nitrile compounds with an ACN content of 18% to 20% remain flexible at temperatures down to -65° F (-54° C).

Unfortunately, compounding ingredients and polymers that offer the best low temperature properties are usually adversely affected by high temperatures. A general-purpose compound is cured with sulfur, but as the ambient temperature in an application exceeds +225° F, free sulfur in the compound finds other unsaturated double bonds and forms additional crosslinks. This results in compression set and hardening of the compound. To improve high temperature properties, a peroxide cure system and/or mineral fillers must be used. Peroxide-cured compounds have both better high temperature properties (up to +275° F, +135° C) and improved compression set characteristics, but they are also more difficult to process and more expensive than sulfur-cured compounds.

Nitrile compounds outperform most other elastomers due to high tensile strength, as well as excellent abrasion, tear, and compression set resistance. Nitriles also have very good aging properties under severe conditions. Because of the double bonds present in the polybutadiene parts of the chemical backbone, nitrile compounds have poor resistance to ozone, sunlight, and weathering. They should not be stored near ozone-generating electric motors or equipment.

NBR PERFORMS WELL IN:

- Petroleum oils & fuels
- Silicone oils & greases
- Ethylene glycol
- Dilute acids
- Water (below 212° F)

NBR DOES NOT PERFORM WELL IN:

- Aromatic hydrocarbons (benzene, toluene, xylene)
- Automotive brake fluid
- Halogen derivatives (carbon tetrachloride, trichloroethylene)
- Ketones (MEK, acetone)
- Phosphate ester hydraulic fluids (Skydrol®, Pydraul®)
- Strong acids

Carboxylated nitrile rubber compounds (XNBR) provide even better strength properties, especially abrasion resistance. Carboxylated nitriles are produced by the inclusion of carboxylic acid groups on the polymer during polymerization. These carboxylic acid groups provide extra “pseudo” crosslinks, producing harder, tougher compounds with higher abrasion resistance, modulus, and tensile strength than standard nitriles. Carboxylated nitriles are, however, less flexible at low temperatures and less resilient than non-carboxylated compounds. Also, the “pseudo” crosslinks (being ionic in nature) are thermally sensitive. As temperatures increase, the ionic bonds lose strength.

Other nitrile variations are possible, including internally lubricated compounds with improved friction and wear properties, as well as Food and Drug Administration (FDA) and National Sanitation Foundation (NSF) formulations for food and potable water applications (see ***page 143***).

Perfluoroelastomer.

ASTM D 1418 Designation: FFKM

ASTM D 2000, SAE J200 Type / Class: JK, HK

STANDARD COLOR: Black

TRADE NAMES:

- **Aegis® (International Seal - FNGP)**
- **Chemraz® (Greene, Tweed & Company)**
- **Kalrez® (DuPont Dow Elastomers)**

RELATIVE COST: Very High

GENERAL TEMPERATURE RANGE: -25° to +575° F

> **"The fully-fluorinated monomers contained in perfluoroelastomers are the reason they exhibit superior chemical resistance."**

Most commercial perfluoroelastomers are terpolymers of tetrafluoroethylene (TFE), perfluoromethylvinyl ether (PMVE), and a cure site monomer (CSM). The fully-fluorinated monomers contained in perfluoroelastomers are the reason they exhibit superior chemical resistance (see ***Figure 43***). As with fluorocarbon elastomers, the bonds between carbon and fluorine atoms are extremely strong, making the chemical structure virtually unbreakable. Also, polymers with high levels of fluorine (as opposed to hydrogen) have proven to be more stable and less chemically reactive. Perfluoroelastomers also enjoy immunity from chemical attack due to saturation along the polymer's backbone. There are no double bonds to be attacked by degradants such as oxygen, ozone, UV light, or harsh chemicals.

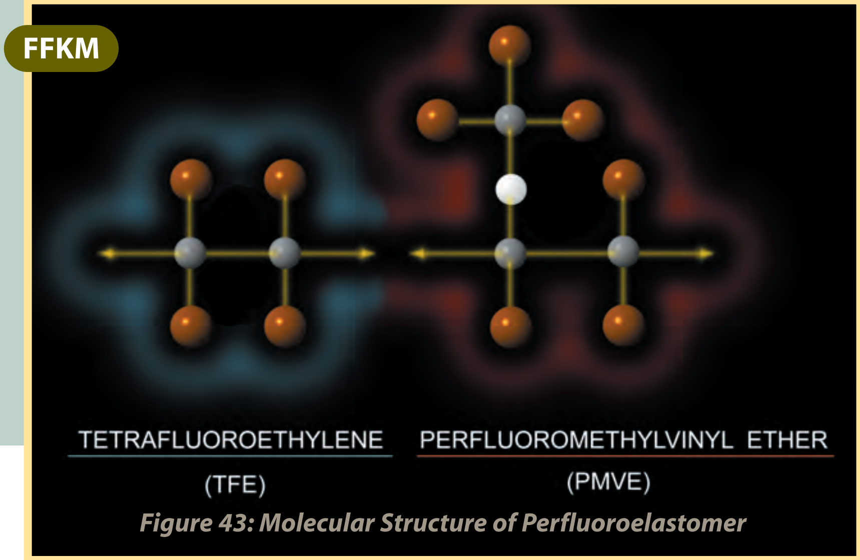


Figure 43: Molecular Structure of Perfluoroelastomer

Perfluoroelastomers can trace their lineage back to the late 1960s, when chemists at DuPont pioneered what came to be known as Kalrez®. In so doing, they combined the chemical resistance of Teflon® and the elasticity of Viton® into a fully-fluorinated polymer that could be cross-linked. Differences in perfluoroelastomer performance are often due to the manner in which the material is cross-linked. In the early days, perfluoroelastomer compounds made use of bisphenol cross-links (like those still seen in current copolymer fluoroelastomers). Bisphenol curing works fine for fluoroelastomers, but it became clear that these bisphenol cross-links were causing perfluoroelastomers to undergo a high degree of compression set. As a result, in the mid-80s DuPont developed compound 4079. This new perfluoroelastomer formulation utilized high temperature triazine cross-links. Compression set was reduced, and, as an added bonus, thermal properties were enhanced, allowing the material to stay resilient even in temperatures approaching 600° F, 316° C (see ***Table 11***).

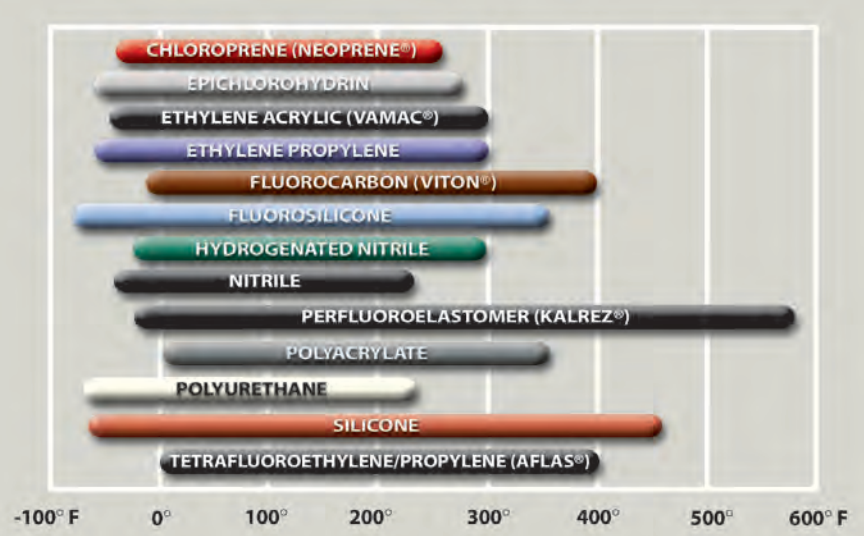


Table 11: FFKM's Thermal Properties Compared to Other Materials

Because of the presence of aggressive chemicals and the need to exclude microcontaminants, seals used in the manufacturing of integrated circuits (ICs) must withstand harsh fluids while resisting extraction. Perfluoroelastomers like Kalrez (which is resistant to over 1,600 solvents, chemicals, and plasmas) have found wide use within the semiconductor industry (see **page 144**). Kalrez seals are also common in the oil exploration and refining industries, as well as in chemical processing and transportation seals. Be aware that Kalrez's vulnerability to compression set generally increases as temperatures go up. Despite its overall chemical resistance, Kalrez can swell when in contact with uranium hexafluoride, fully halogenated Freon®, and some fluorinated solvents. Kalrez should not be exposed to molten or gaseous alkali metals.

As instrumental as they were to the development and acceptance of perfluoroelastomer compounds, the DuPont personnel were not the only ones on the case. At about the same time that DuPont was finding new success with triazine cross-links, another company was experimenting with peroxide cure systems. Greene, Tweed & Company started producing Chemraz® parts based on an imported peroxide cross-linked perfluoroelastomer.

Chief among Chemraz's virtues is its outstanding overall chemical compatibility. Chemraz compounds are resistant to almost every chemical compound, including fuels, ketones, esters, alkalines, alcohols, aldehydes, and both organic and inorganic acids. Chemraz also has very good resistance to compression set, and it offers outstanding steam resistance. Chemraz has an upper temperature limit of about 450° F (232° C). As with Kalrez, Chemraz has found a place in the demanding semiconductor industry. Greene, Tweed prepares Chemraz compounds in a state-of-the-art clean room to ensure purity from the very beginning.

Not to be outdone, International Seal Company (now known as International Seal - FNGP) launched a perfluoroelastomer program in 1996. They developed their compound – known as Aegis® – with an eye toward providing a cost-competitive (yet still high performance) alternative to Kalrez and Chemraz. The 1998 merger of International Seal with Freudenberg-NOK provided significant improvements in both the technology and the processing of perfluoroelastomers. Some of IS-FNGP's perfluoroelastomer compounds are cross-linked using peroxide; some are not.

In 1999, IS-FNGP introduced five new Aegis compounds specifically tailored to the semiconductor industry, and each of these "SC" perfluoroelastomers is environment-specific. For example, SC1001 is a low compression set compound intended primarily for wet chemical applications. SC1011 is used mainly in dry process, vacuum, and plasma environments. SC1090 is the cleanest grade and is useful for both wet chemical and plasma projects. SC1070 is a high temperature formulation (viable up to 572° F, 300° C) intended for low-pressure chemical vapor deposition and furnace applications. With high temperature resistance comparable to SC1070, SC1071 is suited for aggressive plasma environments. New Aegis compounds are also being developed in response to industry needs. As a matter of fact, IS-FNGP offers a wide range of seal materials (produced in a class 100/1000 clean room) specifically designed to provide both the high purity and the extraordinary chemical resistance demanded by the semiconductor industry.

Aegis seals are also commonly used in chemical and petroleum processing, analytical instruments, automotive systems (fuel and oil), and spray painting systems. The main advantages of Aegis compounds over Kalrez and Chemraz: less compression set and higher strength at a lower cost.

FFKM PERFORMS WELL IN:

- Most chemical & petrochemical situations

FFKM DOES NOT PERFORM WELL IN:

- Uranium hexafluoride
- Fully halogenated Freon®
- Some fluorinated solvents

Polyacrylate.

ASTM D 1418 Designation: ACM

ASTM D 2000, SAE J200 Type / Class: DF, DH

STANDARD COLOR: Black

TRADE NAME:

- **HyTemp™ (Zeon Chemicals, L.P.)**

RELATIVE COST: Medium

GENERAL TEMPERATURE RANGE: 0° to +350° F

> **"Polyacrylate offers good resistance to petroleum fuels and oils."**

Polyacrylate is a copolymer (ethyl acrylate, see ***Figure 44***) which offers good resistance to petroleum fuels and oils. The auto industry uses polyacrylate O-rings as seals in automatic transmissions and power steering designs. Resistant to flex cracking, polyacrylate also resists damage from oxygen, sunlight, and ozone (due to main chain saturation).

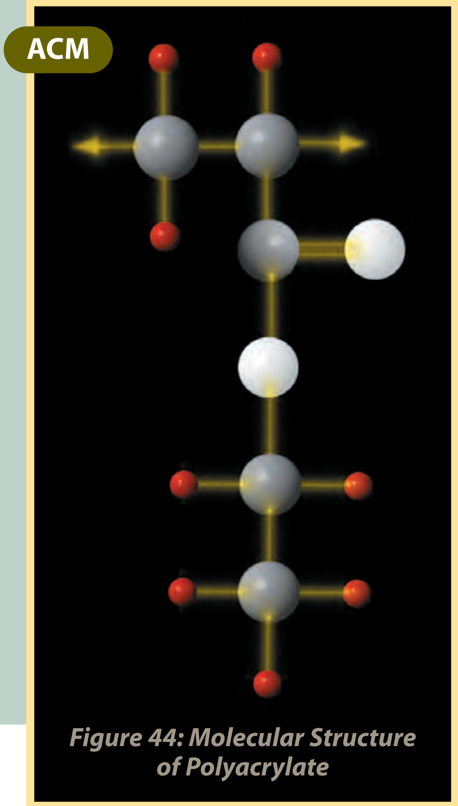


Figure 44: Molecular Structure of Polyacrylate

Use of a butyl acrylate instead of an ethyl acrylate rubber can greatly improve low temperature flexibility. Changing the R group from C1 (methyl) to C8 (octyl) can shift the brittle point by as much as 60° C. Though it is marginally more resistant to hot air than nitrile, polyacrylate falls short in strength and compression set resistance, as well as in resistance to water and low temperatures.

ACM PERFORMS WELL IN:

- Automatic transmission fluid
- Hot oils
- Type A power steering fluid

ACM DOES NOT PERFORM WELL IN:

- Alcohol
- Alkalies
- Brake fluids
- Glycols
- Hydrocarbons (aromatic, chlorinated)

Polyurethane.

ASTM D 1418 Designations: AU, EU

ASTM D 2000, SAE J200 Type / Class: BG (Millable)

STANDARD COLOR: Translucent Yellow

TRADE NAMES:

- **Adiprene® (Uniroyal, Inc.)**
- **Estane® (B.F. Goodrich)**
- **Millthane® (TSE Industries)**
- **Morthane® (Morton International, Inc.)**
- **Pellethane® (Dow Chemical)**
- **Texin® (Bayer Corporation, Plastics Division)**
- **Vibrathane® (Uniroyal, Inc.)**

RELATIVE COST: High

GENERAL TEMPERATURE RANGE: -65° to +225° F

“Polyurethane is the toughest, most extrusion-resistant, and most abrasion-resistant of all elastomeric sealing materials.”

Polyurethane is the toughest, most extrusion-resistant, and most abrasion-resistant of all elastomeric sealing materials. Polyurethane O-rings can withstand pressures up to 5,000 psi with a .010” extrusion gap. Polyurethane is also very resistant to explosive decompression and has excellent properties over a wide temperature range. Polyurethane O-rings are used in a wide variety of products, including quick-disconnect hydraulic fittings, hydraulic cylinders and valves, pneumatic tools, CO_2 firearms, or for applications requiring extreme abrasion or extrusion resistance.

There are three primary components of any polyurethane mixture. The first is a low molecular weight (400-6000) hydroxyl-containing molecule with two or more hydroxyl groups per chain. Such a molecule is known as a *polyol*. This polyol has a low T_g (Glass Transition temperature) and is usually low melting (less than 70° C), thus lending the polyurethane compound a degree of rubber-like softness and flexibility.

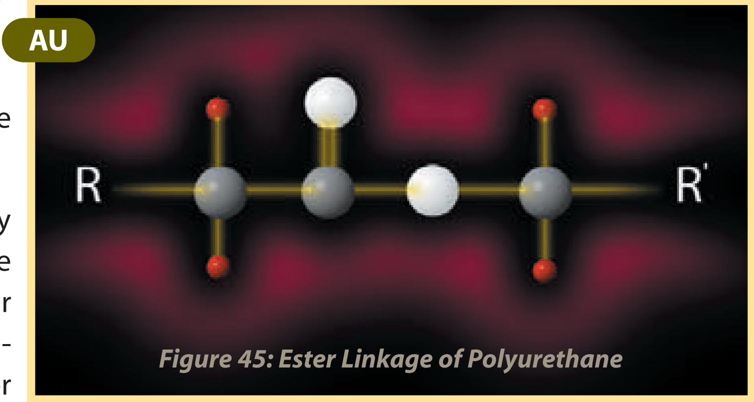


Figure 45: Ester Linkage of Polyurethane

There are three main polyols in use today, each of which bestows different properties or levels of resistance on a polyurethane compound. Polyester polyols are the most widely used due to their good tear and abrasion resistance, as well as their resistance to oil and long-term heat. Polyester-based polyurethanes (designated under ASTM D1418 as AU, see ***Figure 45***) are, however, highly susceptible to degradation as a result of contact with the combination of heat and water (humidity). The ester linkage (with an oxygen pendent to the polymer backbone) is highly susceptible to hydrolytic attack, resulting in chain scission (division of the polymer chain into smaller, weaker segments). Over time, the polyurethane becomes soft and cheesy. This deterioration may take two years or more, but in hot, humid climates the material can degrade in a matter of weeks. Polyester urethanes are also subject to microbial (bacterial and fungal) attack in certain environments.

Polycaprolactone polyols, a special sub-group of polyesters, are the best choice for compounds to be molded into O-rings and other seals. Polycaprolactones have a reduced number of ester groups (the moisture attack sites) compared to the same molecular weight of standard (adipate) ester polyols. Polycaprolactones thus offer better water resistance than standard polyesters. They also provide better oil and thermal resistance than the polyethers.

Polyether-based polyurethanes (designated as EU, see ***Figure 46***) are of two very distinct types: polypropylene ether polyols (PPG type) and polytetramethylene ether glycol (PTMEG type). With its oxygen located within the polymer backbone (rather than pendent to it as in an ester linkage), the ether linkage is better protected from hydrolytic attack. The ether structure is also more mobile, allowing ether-based compounds to have better low temperature properties than polyesters. Polyethers do not perform well in petroleum-based oils or solvents, and they are not as good as polyesters when exposed to long-term heat. The PPG type polyurethanes have reduced mechanical properties (such as abrasion resistance), whereas the PTMEG type is very close to esters in many mechanical properties (particularly in harder formulations above 80 Shore A). PTMEG-based

EU

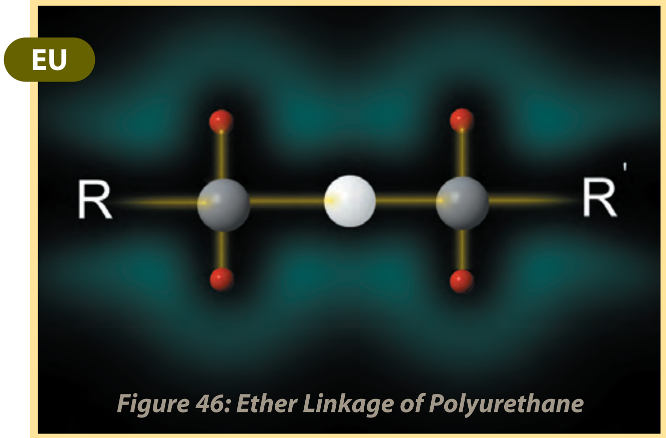


Figure 46: Ether Linkage of Polyurethane

polyurethanes have the highest resilience of any common formulation and are thus preferred where dynamic properties are paramount. For very soft formulations (less than 60 Shore A), esters are almost always superior to any ether in mechanical properties.

The second primary component in any polyurethane is a *diisocyanate*, and the thermal properties of polyurethane are closely tied to the diisocyanate in use. The three diisocyanates that are most widely used in the production of polyurethane O-rings are MDI, TODI, and PPDI. MDI (diphenylmethane diisocyanate) is the workhorse of the polyurethane industry. As such, it is widely used in thermoplastic polyurethanes (TPUs). A complex molecule that is environmentally safer than other diisocyanates, MDI is one of the few diisocyanates used in formulations meeting NSF, FDA, USDA, and USP guidelines.

TODI (dimethylbiphenyl diisocyanate) polyurethanes have outstanding thermal properties (up to 225° F) and compression set resistance. TODI is rather costly, however, and difficult to obtain, being sole sourced from Japan.

PPDI (para-phenylene diisocyanate) polyurethanes offer outstanding dynamic properties, resilience, and heat resistance (up to 275° F). Unfortunately, PPDI is very expensive (approximately $30 per pound).

Though other strategies are possible, the most popular method of polyurethane mixing combines a diisocyanate with one of the aforementioned polyols. The result is known as a pre-polymer, and this liquid or waxy solid is then combined with the third main polyurethane component: a chain extender. This extender acts much like a cross-linking or vulcanizing agent used to cure rubber.

In contrast to the polyols, the combination of diisocyanates and chain extenders have crystalline structures. Their presence gives the compound a degree of plastic-like hardness and rigidity. The toughness of polyurethane elastomers is almost entirely due to phase separation of the crystalline areas from the polyol segments in the polymer chain. The softening of the polyurethane as temperature is raised is dependent on the melting point of these crystalline hard segments.

Polyurethane O-rings are usually processed in one of three ways: 1) as a compression-molded millable gum, 2) as a molded castable thermoset, or 3) as an injection-molded thermoplastic. Millable gum O-rings have somewhat better abrasion and extrusion resistance than those made from standard hydrocarbon elastomers, but compression set can sometimes be a problem as temperatures increase. The recommended upper temperature limit for millable gum polyurethanes is about 200° F. Millable gum polyurethanes offer good low temperature flexibility, as well as resistance to sunlight, ozone, hydrocarbon fuels, and petroleum-based oils. As already noted, these properties will depend on the polyol and diisocyanate in use.

Processed much like rubber, millable gum polyurethanes develop hardness and modulus primarily through the addition of fillers. (Phase separation, while present, is secondary.) There are limits, however, as to how much both hardness and modulus can be improved. Millable gums rely on chemical crosslinks (actually, covalent bonds) to hold the macromolecular chains together. R.L. Hudson & Company offers a variety of millable gum polyurethanes (both polyether-based and polyester-based) in 70, 80, and 90 Shore A. These are typically either black or natural (translucent yellow, see ***Figure 47***), but other colors and hardness levels can be formulated with the addition of pigments and fillers.

TOUGH TO TOP

Figure 47: Polyurethane O-Rings

Cast, thermoset polyurethanes offer the best balance of properties. In addition to tensile strength, abrasion resistance, and extrusion resistance, cast polyurethanes have heat resistance up to 225° F. Cast polyurethanes outperform millable gum polyurethanes in compression set resistance and elongation. Cast polyurethanes offer strong resistance to aliphatic solvents, alcohols, ether, petroleum products, and mineral-based oils. They can also be used around weak acids, weak bases (ether-types only), and mixtures with less than 80% aromatic constituents. O-rings molded from cast polyurethanes cost slightly more than those made from millable gums.

Rather than through the fillers required by millable gums, cast polyurethanes gain their hardness and modulus as a result of phase separation between the hard and soft segments in the polymer chains. Agglomeration of the hard segments (diisocyanate and chain extender) provides large pockets of crystalline particles. These particles act much like the reinforcing fillers used in rubber or millable gums. The polymer chains themselves are held together by hydrogen bonds. Though they are not individually as strong as the covalent bonds in millable gums, these hydrogen bonds are present in numbers great enough to become a significant source of strength and rigidity for the material.

High performance cast, thermoset polyurethanes combine polycaprolactone and TODI. This beneficial combination provides excellent heat and compression set resistance. These compounds also have much better resistance to hydrolysis (chemical decomposition as a result of contact with water) than polyester-based polyurethanes. R.L. Hudson & Company offers two standard polyurethane O-ring compounds, one at 70 Shore A and the other at 92 Shore A. Both proprietary compounds are recommended for continuous service up to 200° F and intermittent use up to 250° F. On the low temperature side, they are generally good in static applications down to -65° F. Instead of using commercial urethanes, our materials are reacted at the plant. This allows us to provide a wide variety of specialty compounds ranging from 60 to 95 Shore A.

Though very widely used, injection-molded polyurethane O-rings have historically offered the least-favorable properties, but times are changing. A new PPDI-based compound offers an excellent combination of dynamic properties, resilience, heat resistance (up to 275° F), and compression set resistance. This new material crosses into the property domain only previously achievable using cast urethanes. Our PPDI-based compound is available in 92 Shore A. The only real drawback to injection-molded O-rings: gate marks left on the seal's O.D. can become leak paths, but these can often be adjusted to avoid contact with a mating surface.

Silicone.

ASTM D 1418 Designations: MQ, PMQ, VMQ, PVMQ

ASTM D 2000 / SAE J200 Type / Class: FC, FE, GE

STANDARD COLOR: Red

TRADE NAMES:

- **Baysilone® (Bayer Corp.)**
- **KE® (Shincor Silicones)**
- **Silastic® (Dow Corning Corp.)**
- **Silplus® (General Electric)**
- **Tufel® (General Electric)**

RELATIVE COST: Medium

GENERAL TEMPERATURE RANGE: -65° to +450° F

> **"Silicones are primarily based on a strong sequence of silicon and oxygen atoms rather than a long chain of carbon atoms."**

Though carbon and hydrogen are part of their chemistry, silicones are primarily based on a strong sequence of silicon and oxygen atoms (see ***Figure 48***) rather than a long chain of carbon atoms (as with many hydrocarbons). This silicon-oxygen backbone is much stronger than a carbon-based backbone, making silicones more resistant to extreme temperatures (-65° to +450° F, -54° to +232° C), chemicals, and shearing stresses.

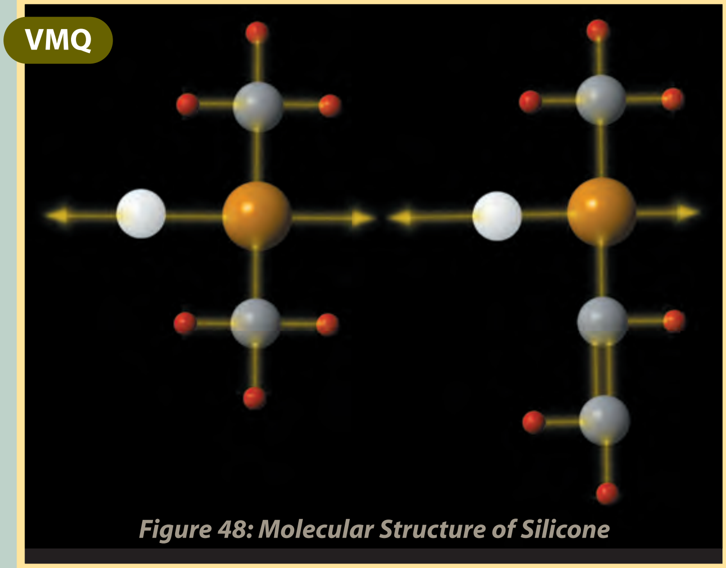


Figure 48: Molecular Structure of Silicone

Due to saturation in the polymer's main chain, silicones are very resistant to oxygen, ozone, and UV light. Of course, this same saturation also demands that the material be peroxide cured since it is not possible to sulfur cure a saturated polymer. In addition to being generally inert (non-reactive), silicones are odorless, tasteless, non-toxic, and fungus resistant. They also have great flexibility retention and low compression set.

There are four different silicone formulations in use today. Standard methyl silicone is known simply as MQ. By replacing a small number (typically less than 1%) of the pendent methyl (CH_3) groups in MQ with vinyl (CH_2CH) groups, you arrive at what is known as vinyl methyl silicone, or VMQ (see ***Figure 48***). VMQ compounds tend to have better cure properties and undergo lower compression set than standard MQ.

Replacing 5% to 10% of the methyl groups with ringed phenyl (C_6H_5) groups results in phenyl methyl silicone, or PMQ. PMQs have better low temperature properties than MQ or VMQ. Finally, adding some of the aforementioned vinyl groups to PMQ results in phenyl vinyl methyl silicone, or PVMQ.

Silicones are not well suited for dynamic use due to their high friction characteristics, low abrasion resistance, and poor tear and tensile strength. Many silicones also suffer from above average mold shrinkage. Though they can be utilized in high aniline point oils, silicones are considered non-resistant to petroleum oils. Silicones swell considerably in both aliphatic and aromatic hydrocarbon fuels unless a special compound is formulated. Silicones are also very gas permeable.

SILICONE PERFORMS WELL IN:

- Engine & transmission oils (mineral oils)
- Ozone
- Dry heat

SILICONE DOES NOT PERFORM WELL IN:

- Petroleum oils & fuels
- Ketones (MEK, acetone)
- Steam
- Concentrated acids

Styrene Butadiene (Buna S).

ASTM D 1418 Designation: SBR

ASTM D 2000, SAE J200 Type / Class: AA, BA

STANDARD COLOR: Black

TRADE NAMES: Too numerous to list.

RELATIVE COST: Low

GENERAL TEMPERATURE RANGE: -50° to +212° F

Also known as Buna S, or GRS (Government Rubber Styrene), styrene butadiene is a copolymer of styrene and butadiene (see ***Figure 49***). Though SBR's low strength properties require the addition of reinforcing agents to make the compound stronger, SBR was widely used as the synthetic substitute for natural rubber during World War II. Like natural rubber, SBR is non oil-resistant.

SBR's use since WWII has sharply declined, though it is still used in automobile tire production and in assorted molded rubber goods. SBR is unsuitable for some applications because the double bond in the polymer backbone invites attack by oxygen, ozone, and UV light.

> **"SBR is used in automobile tire production and in assorted molded rubber goods."**

SBR PERFORMS WELL IN:

- Water
- Alcohol
- Silicone oil & grease
- Automotive brake systems

SBR DOES NOT PERFORM WELL IN:

- Petroleum oils & fuels
- Strong acids
- Aromatic, aliphatic, or halogenated hydrocarbons
- Mineral oils

SBR

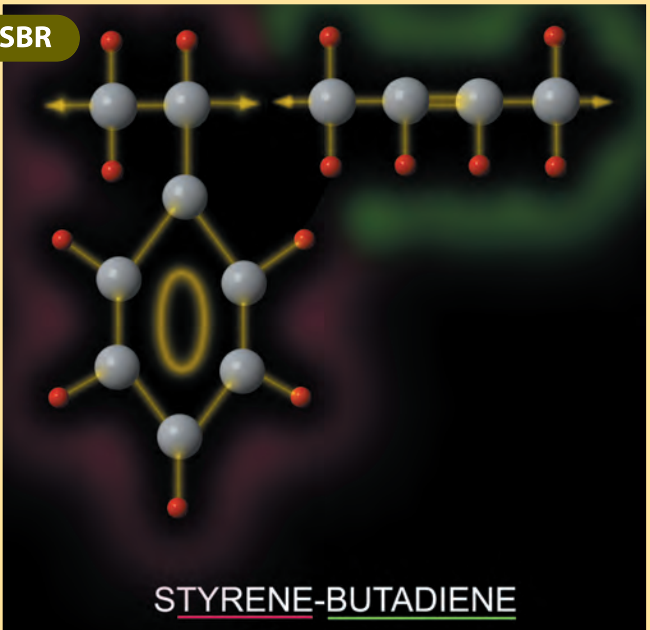


Figure 49: Molecular Structure of Styrene Butadiene

Tetrafluoroethylene.

ASTM D 1418 Designation: FEP

ASTM D 2000, SAE J200 Type / Class: None

STANDARD COLOR: White

TRADE NAMES:

- **Algoflon® (Ausimont USA, Ltd.)**
- **Polyflon® (Daikin Industries, Ltd.)**
- **Teflon® (DuPont)**

RELATIVE COST: High

GENERAL TEMPERATURE RANGE: -300° to +500° F

Poly**t**etra**f**luoro**e**thylene (PTFE) is a completely fluorinated polymer produced when the monomer tetrafluoroethylene (TFE) undergoes free radical vinyl polymerization. As a monomer, TFE is made up of a pair of double-bonded carbon atoms, both of which have two fluorine atoms covalently bonded to them. Thus the name: "tetra" means there are four atoms bonded to the carbons, "fluoro" means those bonded atoms are fluorine, and "ethylene" means the carbons are joined by a double bond as in the classic ethylene structure. (Ethylene has hydrogen atoms attached to the carbons, as in ***Figure 50***, but TFE has fluorine in place of the hydrogen, as in ***Figure 51***.) When TFE polymerizes into PTFE, the carbon-to-carbon double bond becomes a single bond and a long chain of carbon atoms is formed, as in ***Figure 52***. This chain is the polymer's backbone.

> **"The inability of other materials to stick to PTFE makes it perfect for applications requiring a low coefficient of friction."**

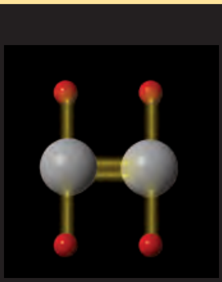


Figure 50: Ethylene

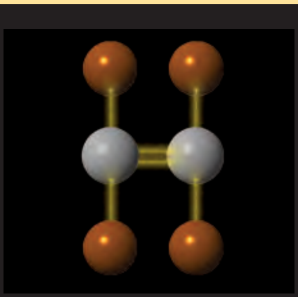


Figure 51: Tetrafluoroethylene

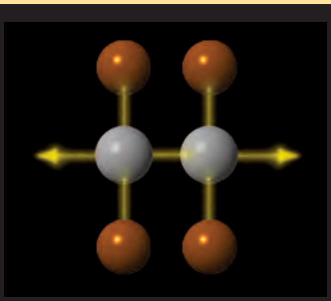


Figure 52: Polytetrafluoroethylene

With a ratio of four fluorine atoms to every two carbon atoms, the backbone is essentially shielded from contact. It's almost impossible for any other chemical to gain access to the carbon atoms. Even if an agent *could* gain access, the carbon-to-fluorine bonds have high bond disassociation energy, so they're almost unbreakable. This makes PTFE the most chemically resistant thermoplastic polymer available. PTFE is inert to almost all chemicals and solvents, allowing PTFE parts to function well in acids, alcohols, alkalies, esters, ketones, and hydrocarbons. There are only a few substances harmful to PTFE, notably fluorine, chlorine trifluoride, and molten alkali metal solutions at high pressures.

PTFE is also very slippery. By its very nature, the fluorine in PTFE repels everything. As part of a molecule, fluorine is decidedly "anti-social." Anything getting close is repelled, and repelled molecules can't stick to the PTFE surface. This makes PTFE perfect for applications requiring a low coefficient of friction. The only thing slicker than PTFE is ice! Because they are essentially self-lubricating, PTFE parts are ideal for applications in which external lubricants (such as oils and greases) can't be used.

PTFE can withstand a wide range of temperatures (-300° to 500° F, -184° to 260° C). Because it's non-flammable and doesn't dissipate heat, PTFE is often used as a thermal insulator (as in welding equipment). At the other extreme, PTFE is widely used in very cold environments (such as space). Other important properties include resistance to both weathering and water absorption. PTFE can also act as an electrical insulator.

Because of its chemical inertness, PTFE cannot be cross-linked like an elastomer. Therefore it has no memory and is subject to *creep* (also known as *cold flow*). Creep is the increasing deformation of a material under a constant compressive load. This can be both good and bad. A little bit of creep allows PTFE seals to conform to mating surfaces better than most other plastic seals. Too much creep, however, and the seal is compromised. Compounding fillers are used to control unwanted creep, as well as to improve wear, friction, and other properties.

Keep in mind that PTFE fillers don't act like elastomer fillers, which become chemically bonded to the elastomer. With polytetrafluoroethylene, the high shear modulus fillers are encapsulated and bound by the low shear modulus PTFE.

PTFE FILLERS

1. Glass is the most common filler for PTFE. Widely used in hydraulic piston rings, glass gives good wear resistance, low creep, and good compressive strength. Glass also has excellent chemical compatibility. The major disadvantage is that glass-filled PTFE compounds are abrasive to mating surfaces, especially in rotary applications.

2. Molybdenum disulfide (MoS_2) improves wear resistance and further lowers the coefficient of friction. "Moly" is typically combined with other fillers (such as glass and bronze).

3. Carbon (powder or fiber) imparts excellent compression (low deformation under load) and wear resistance, good thermal conductivity (heat dissipation), and low permeability. Carbon-filled PTFE compounds are not as abrasive as glass-filled compounds, but they are still more abrasive than polymer-filled compounds. Carbon-filled compounds have excellent wear and friction properties when combined with graphite. Carbon fiber lends better creep resistance than carbon powder, but fiber is more expensive.

4. Graphite is a crystal modification of high purity carbon. Its flaky structure gives great lubricity and decreased wear. Graphite is often combined with other fillers (especially carbon and glass).

5. Bronze (a copper-tin alloy) lends excellent wear resistance and thermal conductivity. Bronze-filled materials have higher friction than other filled PTFE compounds, but that can be improved by adding moly or graphite. Bearing and piston ring applications often use compounds containing 55% bronze - 5% moly. Bronze-filled compounds have poorer chemical resistance than other PTFE compounds.

6. Stainless steel supplies high wear resistance and load bearing capability, along with better chemical resistance than bronze-filled PTFE. Stainless steel is especially good in steam service.

7. Wollastonite (calcium silicate) is a mineral filler giving properties similar to glass (minus the abrasiveness). The FDA has approved it for food service.

8. PPS (polyphenylene sulfide, trade name Ryton®) was the first polymeric material used to improve PTFE's wear and abrasion properties. PPS-filled compounds also exhibit excellent deformation and extrusion resistance, making them good for use in back-up rings.

9. Ekonol® is a thermally stable aromatic polyester. When blended with PTFE, it produces a composite material with excellent high temperature and wear resistance. Ekonol® will not wear mating metal surfaces, making it good for rotary applications. Ekonol®-filled materials are also good for food service.

10. Polyimide is another polymeric filler offering superior wear and abrasion resistance. Polyimide-filled PTFE compounds have about the lowest friction properties of all filled PTFE materials, so they're great in non-lubricated (dry) applications. They will not abrade mating surfaces (even soft materials like brass, stainless steel, aluminum, and plastic). Polyimide is one of the most expensive PTFE fillers, however.

Other fillers include calcium fluoride (CaF_2), which is specifically used in hydrofluoric acid (HF) service, and alumina (Al_2O_3), which can improve the mechanical properties of compounds destined for high voltage applications. Alumina-filled compounds are very abrasive.

Because it does not possess a good elastic memory at or below normal temperatures, PTFE may need to be heated to facilitate installation. PTFE has poor cut resistance, so extra care must be taken not to damage seals during installation.

Tetrafluoroethylene Propylene.

ASTM D 1418 Designation: FEPM

ASTM D 2000, SAE J200 Type / Class: HK

STANDARD COLOR: Black

TRADE NAMES:

- **Aflas® (Asahi Glass)**
- **Dyneon BRF® (Dyneon)**
- **Viton VTR® (DuPont Dow Elastomers)**

RELATIVE COST: High

GENERAL TEMPERATURE RANGE: 0° to +400° F

"TFE/P provides a unique combination of chemical, heat, and electrical resistance."

The FEPM designation was originally directed at copolymers of tetrafluoroethylene (TFE) and propylene (P) such as is shown in ***Figure 53***. TFE/P provides a unique combination of chemical, heat, and electrical resistance. Chemically, TFE/P resists both acids and bases, as well as steam, amine-based corrosion inhibitors, hydraulic fluids, alcohol, and petroleum fluids. TFE/P is also resistant to ozone and weather. TFE/P typically retains its remarkable chemical resistance even in high temperatures (short exposures up to 450° F, 232° C), and tests have shown that electrical resistance actually improves with heat exposure. Nor do physical properties suffer; tensile strength typically approaches 2,500 psi.

FEPM

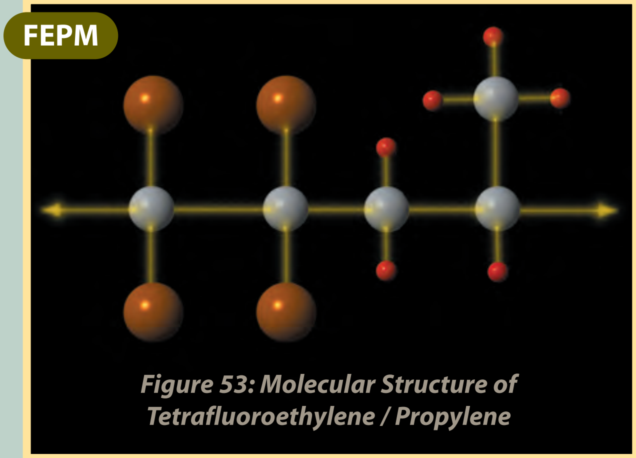


Figure 53: Molecular Structure of Tetrafluoroethylene / Propylene

The first TFE/P compound to be commercially marketed was Aflas (a product of Asahi Glass). In a sense, Aflas defined the initial boundaries for base-resistant materials. Different grades of Aflas have different molecular weights. Most molded and extruded products are made from Aflas 150P, which has a molecular weight of about 130,000. In comparison, Aflas 100H has a molecular weight of 200,000 and is typically used where high pressures are to be sealed, such as in oil field applications. TFE/P compounds are also widely used in the chemical processing, automotive, and aerospace industries. As shown in ***Table 12***, TFE/P compounds are not as good as standard FKM-A (e.g. Viton A) compounds in terms of hydrocarbon resistance, but TFE/P surpasses FKM-A in resistance to strong bases, amines, and polar solvents.

Though it was the first, Aflas is not the only base-resistant fluoroelastomer on the market. DuPont Dow also offers a wide range of excellent materials in this area. Despite being marketed under the same trade name (Viton) as their FKM "cousins," these base-resistant types more closely resemble the FEPM formulations previously discussed. Viton VTR-7480 is a copolymer of tetrafluoroethylene and propylene. Its chemical and processing properties are analogous to those of Aflas 150P, making Viton VTR-7480 suitable for both molded and extruded goods. Viton VTR-7512 is also a TFE/P copolymer, in this case similar to Aflas 100H. With its higher molecular weight (relative to Viton VTR-7480), Viton VTR-7512 is more extrusion resistant and good in higher pressures.

	FKM-A	**TFE/P**	**ETP**
Hydrocarbons			
• Aliphatic	Excellent	Good	Excellent
• Aromatic	Good	Poor	Excellent
Strong bases, amines	Moderate	Excellent	Excellent
Polar solvents (e.g. acetone, MEK)	Poor	Moderate	Excellent

Table 12: Comparison of Fluorinated Materials

The DuPont engineers continue to expand and refine their line of fluoroelastomers in response to the needs of industry. For example, automotive powertrain applications are making greater demands on seal compounds. Increasingly aggressive lubricants and higher temperatures are testing even the best materials.

In response, DuPont developed two new base-resistant Viton materials. These latest additions were unveiled at the Society of Automotive Engineers 2000 World Congress in Detroit. The first of these, Viton TBR-501C, is a terpolymer combining TFE/P with a low level of vinylidene fluoride (VF_2). The "TBR" in the name refers to its "total base resistance." It is completely resistant to highly basic lubricant additives. Viton TBR-501C also has excellent high temperature resistance and outstanding processibility.

The other new addition, Viton IBR-401C, is a terpolymer combining TFE/P with a higher level of VF_2 (roughly three times as much as is in Viton TBR-501C). The "IBR" refers to its "intermediate base resistance." It is not as base-resistant as Viton TBR-501C, but it still offers a good balance of base and hydrocarbon resistance, as well as excellent processibility.

In both the IBR and the TBR types, presence of the VF_2 does three things. First, it improves the materials' low temperature properties. Second, it also improves the materials' resistance to swelling in hydrocarbon oils, though this improvement comes at the expense of base resistance. That's why Viton IBR-401C has less base resistance than Viton TBR-501C; the IBR material has a greater VF_2 content. Third, the VF_2 allows both these materials to be bisphenol cured rather than peroxide cured (the norm for TFE/P copolymers). Bisphenol curing makes for easier processing and lower scrap rates.

You may encounter instances in which none of the materials already discussed quite meet the needs of an application, especially if you require good low temperature properties in partnership with both base resistance and low swell in hydrocarbons. Viton specialty type GFLT may work, but you might also consider Viton ETP (also known as Viton Extreme). The "ETP" is short for ethylene, tetrafluoroethylene, and perfluoromethyl vinyl ether (PMVE). The Viton ETP formulations (such as ETP-500 and ETP-900) offer the most comprehensive fluids resistance (including resistance to strong bases, amines, and polar solvents) of all the Viton types. They also combine outstanding resistance to hydrocarbons (including fuels) and high temperature resistance (equal to standard FKM compounds) with good low temperature flexibility and good processibility. As you can see in ***Table 12***, Viton ETP surpasses both standard FKM-A and TFE/P in resistance to hydrocarbons, strong bases, amines, and polar solvents.

FEPM PERFORMS WELL IN:

- Numerous acids & bases
- Amines
- Brake fluids
- Petroleum fluids
- Phosphate esters
- Steam

FEPM DOES NOT PERFORM WELL IN:

- Aromatic fuels
- Ethers
- Ketones
- Toluene

Military Specifications.

"The military community has established a number of specifications relevant to the sealing industry."

FLUIDS

Specification	Polymer	Description
MIL-L-2104	Nitrile	Oil, Engine
MIL-S-3136	Nitrile	Standard Test Fluids, Hydrocarbon
MIL-L-3150	Nitrile	Oil, Preservative
MIL-G-3278	Fluorosilicone	Aircraft Grease
MIL-O-3503	Nitrile	Oil, Preservative
MIL-G-3545	Nitrile	Hi-Temperature Grease
MIL-G-4339	Nitrile	Soluble Oil
MIL-G-4343	Nitrile	Pneumatic System Grease
MIL-J-5161	Nitrile	Jet Fuel, Reference
MIL-F-5566	Ethylene Propylene	Isopropyl Alcohol
MIL-G-5572	Nitrile	Fuel, Aircraft Reciprocating Engine, Grades 80/87, 91/96, 100/130, 115/145 Aviation Gas
MIL-H-5606	Nitrile	Hydraulic Fluid, Petroleum Base, Aircraft and Ordnance
MIL-T-5624	Nitrile	Jet Fuel JP-4, JP-5
MIL-L-6081	Nitrile	Jet Engine Oil
MIL-L-6082	Nitrile	Lubricating Oil, Aircraft Reciprocating Piston Engine
MIL-H-6083	Nitrile	Hydraulic Fluid, Preservative
MIL-L-6085	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Synthetic Di-ester Base Fluid
MIL-A-6091	Ethylene Propylene	Denatured Ethyl Alcohol
MIL-L-6387	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Synthetic Di-ester Base Lubricating Oil
MIL-C-7024	Nitrile	Aircraft Calibrating Fluid
MIL-H-7083	Ethylene Propylene	Hydraulic Fluid, Hydrolube
MIL-G-7118	Nitrile	Actuator Grease
MIL-G-7187	Nitrile	Grease, Graphite

Table 14: Military Fluid Specifications

FLUIDS

Specification	Polymer	Description
MLO-7277	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Hydraulic Fluid, Petroleum Base, Hi-Temp.
MIL-G-7421	Fluorosilicone	Grease, Extreme Low Temp.
MLO-7557	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Hydraulic Fluid, Petroleum Base, Hi-Temp.
MIL-G-7711	Nitrile	Grease, General Purpose
MIL-L-7808	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Lubricating Oil, Aircraft Turbine Engine, Synthetic Di-ester Base
MIL-L-7870	Nitrile	Lubricating Oil, Low Temp, General Purpose
MIL-C-8188	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Corrosion Preventive Oil, Synthetic Base
MLO-8200	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Hydraulic Fluid, Aircraft and Missile, Silicate-Ester Base
MIL-H-8446	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Hydraulic Fluid, Silicate-ester Base (MLO-8515)
MLO-8515	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Hydraulic Fluid, Silicate-ester Base (MIL-H-8446)
MIL-L-9000	Nitrile	Lubricating Oil, Diesel
MIL-L-9236	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Synthetic Lubricating Oil, Turbine
MIL-E-8500	Ethylene Propylene	Ethylene Glycol, Technical, Uninhibited
MIL-G-10924	Nitrile	Automotive Grease
MIL-H-13910	Ethylene Propylene	Hydraulic Fluid, Non-petroleum Auto. Brake
MIL-L-15017	Nitrile	Oil, hydraulic

Table 14: Military Fluid Specifications

FLUIDS

Specification	Polymer	Description
MIL-G-15793	Nitrile	Grease, Instrument
MIL-F-16884	Nitrile	Fuel Oil, Diesel, Marine
MIL-F-17111	Nitrile	Power Transmission Fluid
MIL-L-17331	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Lubricating Oil, Non-corrosive, Steam Turbine
MIL-H-19457	Ethylene Propylene	Fire Resistant Hydraulic Fluid (phosphate-ester base)
MIL-L-21260	Nitrile	Lubricating oil, Engine, Preservative
MIL-S-21568	Ethylene Propylene	Silicone Fluid, Dimethyl Polysiloxane
MIL-H-22251	Ethylene Propylene	Hydrazine Solution, 22%
MIL-L-23699	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Lubricating Oil, Aircraft Turbine Engine, Synthetic Base
MIL-G-23827	Nitrile	Grease, Aircraft and Instrument
MIL-G-25013	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Bearing Grease, Extreme High Temp.
MIL-G-25537	Nitrile	Aircraft, Helicopter Oscillating Bearing Grease
MIL-F-25558	Nitrile	Fuel, Ram Jet (RJ1)
MIL-C-25576	Nitrile	Rocket and Ram Jet Fuel (RP1)
MIL-F-25656	Nitrile	Jet Fuel, Grade JP6
MIL-L-25681	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Oil, Moly Disulphide, Silicone Base High Temperature
MIL-G-25760	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Bearing Grease, Wide Temp. Range
MIL-P-27402	Ethylene Propylene	Propellent, Aerozine-50
MIL-H-27601	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Hydraulic Fluid, Petroleum Base, High Temperature, Flight Vehicle
MIL-L-46167	Nitrile	Lubricating Oil, Int. Comb. Engine, Arctic

Table 14: Military Fluid Specifications

FLUIDS

Specification	Polymer	Description
MIL-H-46170	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Hydraulic Fluid, Rust Inhibited, Fire Resistant, Synthetic
MIL-F-81912	Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Fuel, Expendable, Turbine Engine
MIL-F-82522	Nitrile	Fuel, Ramjet Engine, T-H Dimer Grade RJ-4
MIL-T-83133		Turbine Fuel, Aviation, Kerosene Type, Grade JP-8
MIL-H-83282	Nitrile, Fluorocarbon, Perfluoroelastomer, Tetrafluoroethylene Propylene	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft

Table 14: Military Fluid Specifications

RUBBER

Specification	Durometer (± 5)	Polymer	Temperature (° F)	Description
ZZ-R-765E Classes 1a, 1b, 2a, 2b Grade 40	40	Silicone	-103 to 437	Resists low and high temps, Low compression set
Classes 1a, 1b, 2a, 2b Grade 50	50	Silicone	-103 to 437	Resists low and high temps, Low compression set
Classes 1a, 1b Grade 70	70	Silicone	-103 to 437	Resists low temps, Low compression set
Classes 2a, 2b Grade 70	70	Silicone	-80 to 437	Resists high temps, Low compression set
Classes 2a, 2b Grade 80	80	Silicone	-80 to 437	Resists high temps, Low compression set
MIL-G-1149C				
Type I, Class 1	50	Chloroprene	-20 to 212	Gasket materials, synthetic
Type II, Class 2	70	Styrene Butadiene	-20 to 212	Gasket materials, synthetic
MIL-R-3533B Type I, Grade B	70	Nitrile	-20 to 158	Synthetic rubber sheets, strips, and molded shapes
MIL-P-5315B	70	Nitrile	-65 to 160	O-ring; resists hydrocarbon fuels (jet fuels)
MIL-P-5510C	90	Nitrile	-45 to 160	Gasket, Straight thread tube fitting boss
MIL-R-6855D Class 1, Grade 60	60	Nitrile	-65 to 212	Synthetic rubber sheets, strips, molded, or extruded; resists fuel, petroleum oil
Class 2, Type B Grade 70	70	Chloroprene	-65 to 212	Synthetic rubber sheets, strips, molded, or extruded; resists petr. oil, weather, ozone
MIL-R-7362D Types I, II			-65 to 275	Sheet, molded, and extruded; resists synthetic oil(di-ester base lubricant)

Table 15: Military Rubber Specifications

RUBBER

Specification	Durometer (± 5)	Polymer	Temperature (° F)	Description
MIL-G-21569B Class I	70	Nitrile	Room Temp to 194	Gasket, cylinder liner seal, synthetic
Class II	70	Silicone	Room Temp to 194	Gasket, cylinder liner seal, synthetic
MIL-P-25732C	75	Nitrile	-65 to 275	Preformed packing, resists petr. hydraulic fluid
MIL-R-25988 Type 1, Class 1 Grade 60	60	Fluorosilicone	-90 to 350	Resists oil, fuel, air, hydraulic fluid
Grade 70	70	Fluorosilicone		Resists oil, fuel
Grade 80	80	Fluorosilicone		Resists oil, fuel
Type 1, Class 3 Grade 75	75	Fluorosilicone		Resists oil, fuel
MIL-P-82744	80	Ethylene Propylene	-65 to 250	Preformed packing, otto fuel compatible
MIL-R-83248C (Type 1) Class 1	75	Fluorocarbon	-15 to 400	Resists high temp. fluids and comp. set
Class 2	90	Fluorocarbon	-15 to 400	Resists high temp. fluids and comp. set
MIL-R-83485 Grade 80	75	Fluorocarbon		Improved low temp. performance
MIL-P-83461B	75	Nitrile	-65 to 275	Preformed packing, resists petr. hydr. fluid

Table 15: Military Rubber Specifications

AMS & NAS Specifications.

AMS…

Aerospace

Material

Specification

NAS…

National

Aerospace

Standard

RUBBER

Specification	Durometer (± 5)	Polymer	Temperature (° F)	Description
AMS3201	40	Nitrile		Resists dry heat
AMS3205	50	Nitrile		Resists low temps
AMS3208	50	Neoprene		Resists weather
AMS3209	70	Neoprene	-40 to 225	Resists weather
AMS3212	60	Nitrile		Resists aromatic fuels
AMS3238	70	Butyl		Resists phosphate esters
AMS3240	40	Neoprene		Resists weather
AMS3301	40	Silicone	-85 to 400	General use
AMS3302	50	Silicone	-85 to 400	General use
AMS3303	60	Silicone	-85 to 400	General use
AMS3304	70	Silicone	-85 to 400	General use
AMS3305	80	Silicone	-85 to 400	General use
AMS3307	70	Silicone		Low comp. set, Non oil-resist.
AMS3325	60	Fluorosilicone		Resists fuel, oil
AMS3326	60	Fluorosilicone		Resists fuel, oil
AMS3337	70	Silicone		Resists very low temps
AMS3345	50	Silicone		
AMS3357	70	Silicone		Resists comp. set and lubricating oil
AMS7257	75	Perfluoroelas.		Resists high temps
AMS7259	90	Fluorocarbon		Resists high temp. fluid, Very low comp. set
AMS7267	75	Silicone		Resists high temps, Low comp. set
AMS7268	70	Silicone		Resists high temps, Low comp. set
AMS7271	65	Nitrile	-67 to 300	Resists phosphate esters
AMS7272	70			Resists synth lubricants
AMS7276	75	Fluorocarbon		Resists high temp. fluid, Very low comp. set
NAS1613	80	EPDM		O-ring, resists phosphate esters

Table 16: AMS & NAS Rubber Specifications

RUBBER

Specification	Durometer (± 5)	Polymer	Temperature (° F)	Description
AMS-P-5315	70	Nitrile		O-ring, resists hydrocarbon fuels
AMS-P-5510	90	Nitrile		Gasket, straight thread tube fitting boss
AMS-R-6855	60, 70	Nitrile, Chloroprene		Synth rubber, resists synth oil
AMS-R-7362	70	Nitrile		Rubber, resists synth oil
AMS-P-25732	75	Nitrile		Preformed packing, resists petroleum hydraulic fluid
AMS-R-25988	55-85	Fluorosilicone		Resists oil, fuel
AMS-R-83248	70-95	Fluorocarbon		Resists high temp fluid, comp. set
AMS-P-83461	75			Preformed packing, resists petroleum hydraulic fluid
AMS-R-83485	75	Fluorocarbon		Resists low temps

Table 16: AMS & NAS Rubber Specifications

Special Considerations.

Though we have already discussed a variety of general use applications, there are a number of situations which will require special materials or quality assurance testing. Careful consideration should be made in each of these instances to find the most appropriate compound and/or testing procedure.

FUEL SERVICE

Designing an effective fuel service seal is not easy. Taken together, there are literally hundreds of hydrocarbons, trace metals, and additives (such as oxygenates, corrosion inhibitors, and detergents) in any given gallon of gasoline. Variances in crude oil processing and changes in the fuel during storage further complicate the picture.

> **"There are literally hundreds of hydrocarbons, trace metals, and additives in any given gallon of gasoline."**

Though the variables are numerous, seal engineers are primarily concerned with two factors. The first is aromatic content. Aromatic hydrocarbons (those containing ringed carbons, such as benzene, toluene, and xylene) are used along with other additives (such as alkylates) to boost octane ratings in unleaded fuels. Higher ratings generally translate to increased engine efficiency. Unfortunately, aromatic hydrocarbons also cause greater elastomer swell compared to aliphatic hydrocarbons (those with straight-chain carbons, such as paraffins, olefins, and acetylenes) or other fuel constituents. The higher the aromatic content, the greater the potential swell. Since greater swell is linked to increased degradation of physical properties in elastomeric parts, aromatic content is one major concern.

The other major concern is the level of oxygenated additives (oxygenates), particularly alcohols and ethers. As with aromatic hydrocarbons, oxygenated additives raise octane numbers. Gasoline blends containing alcohols and ethers also extend the fuel supply and cut down on pollutants. The additional oxygen atoms they provide allow cleaner engine combustion, thus producing less carbon monoxide (CO). Use of reformulated fuels containing oxygenated additives has been ordered by the Environmental Protection Agency (EPA) for cities with poor air quality. But oxygenates can be problematic for the seal designer. The presence of oxygenated additives in certain concentrations can make gasoline much more aggressive toward elastomeric compounds. This heightened aggression dramatically increases the likelihood that seals will be degraded to the point of failure.

The composition of fuels can thus have a number of effects on elastomers. As already noted, substantial volume change (most commonly elastomer swell) is a primary concern. Volume change is typically accompanied by changes in physical properties, including hardness, tensile strength, modulus, and elongation. Resistance to tearing and to compression set are also impacted as a result of volume change. Increasing swell means hardness and these other physical properties will decrease.

The elastomer's resistance to fuel permeation is another major consideration, particularly in sealing applications. Even if permeability isn't a problem, the elastomer may face chemical attack from "sour" fuel. Often seen in fuel-injected automotive systems, soured fuel results when oxygen combines with hydrogen to form what are known as hydroperoxides (O_2H groups). These hydroperoxides later break into free radicals which, because they have at least one unpaired electron, are "anxious" to chemically react. A prime target: the elastomer's chemical backbone. Depending on the circumstances, free radicals can cause the elastomer to become too soft (due to the breaking of chemical bonds, known as *reversion*) or too brittle (due to unwanted crosslinking; see ***Figure 54***). Either way, the elastomer is compromised.

"SOUR" FUEL EFFECT

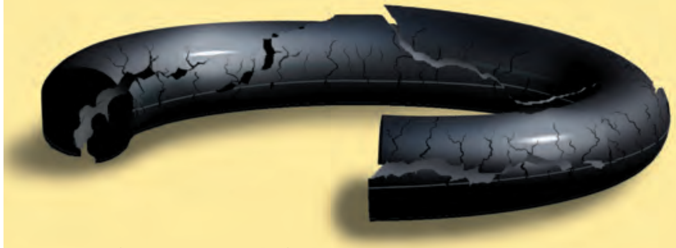


Figure 54: Embrittlement can be caused by unwanted crosslinking.

Additionally, compounds used in fuel systems must be able to withstand temperature extremes. Unless properly anticipated, high temperatures can contribute to other effects, especially elastomer swell and compression set. Low temperatures can be troublesome in dynamic applications.

Because fuel service can have such wide-ranging effects on elastomers, the American Society for Testing and Materials (ASTM) developed test method D 471 as a way to gauge the effects of fuels and other liquids on elastomeric samples.

Samples are exposed to a fluid (e.g. Reference Fuel A) for a specific period of time (e.g. 70 hours) at a set temperature (e.g. 23° C). After exposure, the sample's properties (e.g. hardness, tensile strength, elongation, and volume) are measured and compared with the properties as recorded prior to testing. Decisions can then be made as to the suitability of a particular compound for use with a given fuel.

ASTM Reference Fuels A through K have been specifically selected to test compounds in contact with gasolines or diesel fuels. Which tests are called for depends on which fluid(s) the elastomer will encounter. For example, Reference Fuel A is a 100% isooctane fluid which mirrors the shrinking or low-swell effects of gasolines composed primarily of aliphatic hydrocarbons. If the compound in question will be used around gasolines with a very high aliphatic content, then a test using Reference Fuel A is a good idea. Reference Fuel B is a 70% isooctane-30% toluene mixture. The toluene content lends the mixture a level of aromaticity, enabling Reference Fuel B to approximate the swelling effects of commercial gasolines. The ASTM Reference Fuels are listed in ***Table 17***.

Peroxide-curable, high fluorine content fluorocarbon rubber (FKM) is currently the most common choice for fuel service. High fluorine content fluorocarbons traditionally have poor low temperature resistance, but Type GFLT fluorocarbons have improved low temperature properties similar to Type GLT in combination with fluid resistance analogous to Type GF. In lieu of fluorocarbon, some nitrile (NBR) compounds may be suitable, provided they have a high acrylonitrile (ACN) content to bolster fuel resistance. Epichlorohydrin rubber (ECO) is also used for fuel service, but it does not

Reference Fuel Type	Composition (Volume %)
A	Isooctane (100)
B	Isooctane (70), Toluene (30)
C	Isooctane (50), Toluene (50)
D	Isooctane (60), Toluene (40)
E	Toluene (100)
F	Diesel Fuel, Grade 2 (100)
G	Fuel D (85), anhydrous denatured ethanol (15)
H	Fuel C (85), anhydrous denatured ethanol (15)
I	Fuel C (85), anhydrous methanol (15)
K	Fuel C (15), anhydrous methanol (85)

Table 17: ASTM Reference Fuels

perform as well as fluorocarbon or nitrile, especially in sour fuel hydroperoxides.

FOOD & BEVERAGE USES

The U.S. Food and Drug Administration (FDA) has compiled a "white list" of materials that it deems acceptable for use in food and beverage industry seals. This list can be found in Title 21 of the Code of Federal Regulations, Section 177.2600. To meet FDA requirements, materials must be both non-toxic and non-carcinogenic. Elastomers that appear most often in white list compounds include silicone, fluorocarbon, nitrile, ethylene propylene, and chloroprene.

Founded over fifty years ago as the National Sanitation Foundation, NSF International fosters public safety and environmental protection by developing standards, certifying services, and testing products. For example, rubber compounds designed to come into contact with potables (such as drinking water) can be submitted to NSF for water extraction analysis and many other tests. The most well known tests are NSF 51 for articles contacting food and NSF 61 for articles contacting water. Materials passing such tests are certified as meeting NSF standards. NSF does both stand-alone and component testing, meaning they evaluate articles by themselves and as parts of larger designs.

R.L. Hudson & Company offers a number of NSF 61-certified compounds. These include ***N1030-70 (nitrile)***, ***E3030-70 (ethylene propylene)***, and ***S5030-70 (silicone)***.

GAS PERMEATION

Several factors can affect the degree to which a seal is gas permeable. Use of lubrication decreases permeability, as does applying greater squeeze. Use of harder compounds and smaller cross-sections can also help reduce permeability. Butyl rubber allows the least gas permeation. Tetrafluoroethylene (PTFE), chloroprene, epichlorohydrin, polyurethane, nitrile, and fluorocarbon are also good choices. Silicone and fluorosilicone allow the most gas permeation.

In applications involving pressures of 500 psi or higher, compressed gases enter through flaw sites on the seal's surface and fill the O-ring's micropores until equilibrium is reached. During an equilibrium shift (as during decompression), the gases expand, creating blisters in lower durometer O-ring compounds and fractures in harder compounds (see ***Figure 55***). Instances of such "explosive decompression" can be reduced through careful choice of materials. Harder, high shear modulus compounds have the most resistance to explosive decompression because they have the strength to dissipate the fracture energy as it propagates through the O-ring. For contact with carbon dioxide (CO_2), such as in air guns, polyurethane is definitely the best choice. For more on explosive decompression, see ***page 258***.

PLASTIC SURFACES

Because plastic parts are being used more and more as alternatives to metal components, you should be aware that sealing against a plastic surface may present some special problems. The hardness or chemical makeup of an O-ring can cause fine surface cracks to form in adjacent plastic parts. This "crazing" of the plastic is often the result of ester *plasticizers* (chemical substances added to increase softness, provide low temperature flexibility, and improve processing) in the O-ring compound and may ultimately cause the plastic part to fail. Ethylene propylene, chloroprene (Neoprene®), nitrile, and silicone have all been used successfully in conjunction with plastics such as Noryl® (modified polyphenylene oxide, or PPO), Cycolac T® (ABS thermoplastic), and Lexan® (thermoplastic polycarbonate).

HIGH PRESSURE DANGER

Figure 55: Failure due to explosive decompression.

SEMICONDUCTOR INDUSTRY

Because of the aggressive chemicals in use and the need to exclude microcontaminants, the semiconductor industry offers some real challenges. Seals used in the production of integrated circuits (ICs) must withstand harsh fluids while resisting extraction. Several companies have developed fully-fluorinated compounds for use in wet chemical, dry chemical, vacuum, and plasma applications. These companies include DuPont (Kalrez® Ultrapure); Greene, Tweed (Chemraz®); and International Seal-FNGP (Aegis®).

For example, each of the Aegis "SC" perfluoroelastomers is environment-specific. SC1001 is a low compression set compound intended primarily for wet chemical applications. SC1011 is used mainly in dry process, vacuum, and plasma environments. SC1090 is the cleanest grade of Aegis and is intended for both wet chemical and plasma projects. SC1070 is a high temperature formulation (viable up to 572° F, 300° C) intended for low-pressure chemical vapor deposition and furnace applications. With high temperature resistance comparable to SC1070, SC1071 can handle aggressive plasma.

Regardless of the manufacturer, it's important to note that black, carbon-filled compounds are most susceptible to having parts of their chemical make-up extracted by system fluids. This "leaching" of the material leads to seal shrinkage and may result in seal failure. For this reason, white or clear compounds making use of other fillers (such as barium sulfate or PTFE) are typically used in applications where shrinkage is a big concern. Fluorocarbons (such as Viton®), fluorosilicones, and ethylene propylene are also used in semiconductor production. Fluorosilicones and EPDM are seeing less use, however, because they do not function as cleanly as either perfluoroelastomers or fluorocarbons.

UNDERWRITERS LABORATORIES

The Underwriters Laboratories test and approve a wide variety of commercial and industrial products submitted by more than 40,000 manufacturers and product developers worldwide. The formal submission process begins by contacting a client advisor, who helps direct the submission toward an appropriate project engineer. The submission itself consists of several items, including a product sample, written description, statement of intended use, list of possible variations, list of components and materials (including alternates), diagrams and/or pictures, any manuals that will accompany the final product, applicant contact information, desired listing information (pending approval), and results of any prior testing by either UL or other testing services. The project engineer uses these items to oversee both initial testing and follow-up reviews.

Included among the products that Underwriters Laboratories typically review are elastomeric compounds formulated for specific uses. The Recognized Component Directory lists all the compounds tested and approved by UL. Available for purchase from UL, this annual directory includes characteristic information (such as hardness, tensile strength, and elongation) on numerous materials in various product categories (such as "Gaskets and Seals"). Thanks to the diversity of our factories, R.L. Hudson & Company can provide you with a wide variety of UL-approved compounds.

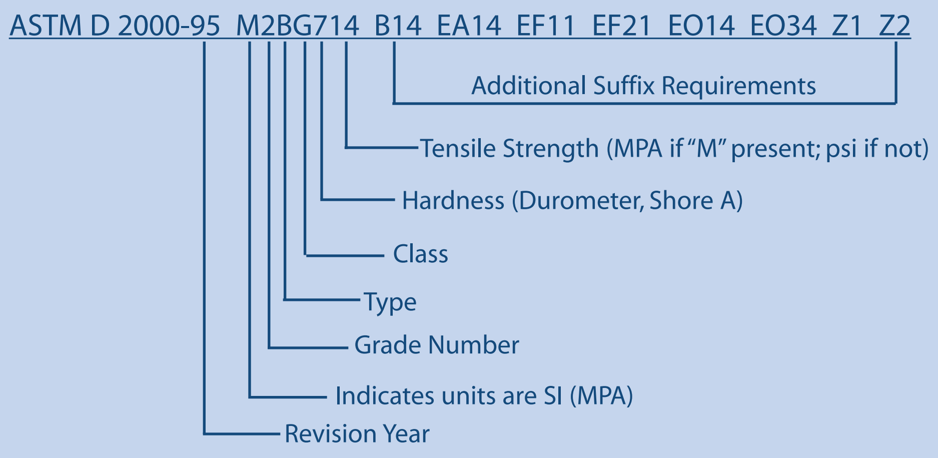
Understanding ASTM D 2000 / SAE J200.

Having discussed the properties and uses of the most common elastomer types, the question then becomes: How can these properties be succinctly specified when an existing compound is being selected or when a new compound must be formulated?

In order to provide guidance in the selection of vulcanized rubber materials, and to provide a method for specifying these materials by the use of a simple line call-out specification, the American Society for Testing and Materials (ASTM) and the Society of Automotive Engineers (SAE) established ASTM D 2000 / SAE J200. Though these standards are virtually identical, J200 finds its widest use within the automotive industry. D 2000 is the more common tool among rubber manufacturers. Specifying your elastomer choice via a standardized line call-out is a good idea because it allows the flexibility of using different manufacturers' compounds while ensuring that the material quality and performance stay consistent.

D 2000 is based on the premise that the properties of all rubber products can be arranged into characteristic material designations. These designations are determined by types, based on resistance to heat aging, and classes, based on resistance to swelling. Here is the line call-out, or specification, for "N470," a 70 (Shore A) durometer nitrile:

> **"Specifying your elastomer choice via a standardized line call-out is a good idea because it allows the flexibility of using different manufacturers' compounds while ensuring that the material quality and performance stay consistent."**


ASTM D 2000-95 M2BG714 B14 EA14 EF11 EF21 EO14 EO34 Z1 Z2

ASTM D 2000-95 M2BG714 B14 EA14 EF11 EF21 EO14 EO34 Z1 Z2

This line call-out contains the following:

A. The document name (ASTM D 2000-95). The two-digit number following the hyphen indicates the revision year (in this case, 1995).

B. The letter "M" may or may not be present. Since it is present in our example, the units of measure in the line call-out (and in any other documentation, such as a test report) are understood to be stated in SI (metric) units. For example, tensile strength is in megapascals (MPa). If the "M" was not present, English units would be in use. For example, tensile strength would be in pounds per square inch (psi).

C. The Grade Number defines specific added test requirements which are desirable in cases where the basic requirements do not always sufficiently ensure an acceptable material. Grade 1 indicates that only the basic requirements are compulsory; no suffix requirements are permitted. All other grades and test requirements are listed in Table 6 of the D 2000 document. In our example, the material is Grade 2.

D. The Type is based on changes in tensile strength of not more than 30%, elongation of not more than -50%, and hardness of not more than ±15 points after heat aging for 70 hours at a given temperature. The temperatures at which these materials shall be tested for determining type are listed in ***Table 18***. In our example, the material is Type B, which corresponds to a 100° C test temperature.

Type	Test Temperature (° C)
A	70
B	100
C	125
D	150
E	175
F	200
G	225
H	250
J	275
K	300

Table 18: Basic Requirements for Establishing Type by Temperature

ASTM D 2000-95 M2BG714 B14 EA14 EF11 EF21 EO14 EO34 Z1 Z2

E. The Class is based on the material's resistance to swelling in Industry Reference Material (IRM) 903 Oil (now used in lieu of ASTM Oil # 3, which was discontinued due to requirements by the Occupational Safety and Health Administration). Testing involves immersion for 70 hours at the temperature previously determined from ***Table 18*** (100° C), after which swell is calculated. Limits of swelling for each class are shown in ***Table 19***. In our example, the material is Class G, indicating a maximum swell of 40%. Be aware that ASTM Oil Number 3 and IRM 903 Oil are similar but *not* identical, so complete equivalency among results is not possible. For information on converting ASTM oil swell values to IRM values, please refer to ASTM Emergency Standard ES 27-94. ***Table 20*** below lists the D 2000 material designations (type and class) and the elastomers most often used for each.

Class	Volume Swell (Maximum %)
A	No requirement
B	140
C	125
D	100
E	80
F	60
G	40
H	30
J	20
K	10

Table 19: Basic Requirements for Establishing Class by Volume Swell

Material Designation	Most-Used Elastomer(s)
AA	Natural Rubber
BA	Ethylene Propylene
BC	Neoprene®
BE	Neoprene®
BF	Nitrile
BG	Nitrile, Polyurethane
BK	Nitrile
CA	Ethylene Propylene
CH	Nitrile
DA	Ethylene Propylene
DF	Polyacrylate
DH	Polyacrylate
EF	Vamac®
FC	Silicone
FE	Silicone
FK	Fluorosilicone
GE	Silicone
HK	Viton®

Table 20: Material Designations & Most-Used Elastomers

ASTM D 2000-95 M2BG714 B14 EA14 EF11 EF21 EO14 EO34 Z1 Z2

F. The next three digits (in this case, "714") specify the hardness and tensile strength. The first digit indicates Shore A durometer. For example, 7 for 70 ±5. The next two numbers indicate the minimum tensile strength, i.e. 14 for 14 MPa. Remember, this will be in SI units if the letter "M" is in the call-out, and English units if not. To convert to psi, simply multiply the MPa number by 145. In this case, 14 MPa would convert to 2,030 psi.

MPa X 145 = psi

psi / 145 = MPa

G. Suffix letters and suffix numbers follow the hardness and tensile strength specifications to provide for additional testing requirements. The meaning of each suffix letter is shown in ***Table 21***. For example, the "B" of "B14" specifies a compression set test. Suffix letters are typically followed by two suffix numbers. The first number always indicates the test method, and the second indicates the test temperature. The suffix numbers are covered by Tables 4 and 5 of the D 2000 document. For example, the "1" specifies a 22-hour compression set test as detailed in D 395 (Method B) for solid test specimens, and the "4" specifies testing at 100° C. Keep in mind that in some cases, the second suffix number may be two digits, which means you might see something like "F110." F110 would indicate a 3-minute low temperature resistance test as detailed in ASTM D 2137 (Method A) and conducted at a temperature of -65° C.

A	Heat Resistance
B	Compression Set
C	Ozone or Weather Resistance
D	Compression Deflection Resistance
EA	Fluid Resistance (Aqueous)
EF	Fluid Resistance (Fuels)
EO	Fluid Resistance (Oils & Lubricants)
F	Low Temperature Resistance
G	Tear Resistance
H	Flex Resistance
J	Abrasion Resistance
K	Adhesion
M	Flammability Resistance
N	Impact Resistance
P	Staining Resistance
R	Resilience
Z	Any Special Requirement (e.g. "Resistance to Marking")

Table 21: The Meaning of Suffix Letters

That's all there is to understanding the D 2000 / J200 call-out system. It is one of the most versatile specifications in the rubber industry. In addition to helping you specify compounds, familiarity with the system will also help you make sense of material test reports. Let's take a closer look at a sample report next.

Anatomy of a Test Report.

Many manufacturers provide material test reports (also known as technical reports or specification sheets) as a service to aid their customers. These reports show the performance of a cured rubber compound when subjected to a variety of standardized ASTM tests. Provided these tests mirror the anticipated service conditions, you can use them to make an informed decision regarding the compound's suitability for your application.

> **"Provided these tests mirror the anticipated service conditions, you can use them to make an informed decision regarding the compound's suitability for your application."**

To help you better understand just how much test reports can tell you, let's take a closer look at a sample report (see ***pages 156 & 157***) whose subject is the same 70 (Shore A) durometer nitrile compound that we dealt with in "Understanding ASTM D 2000 / SAE J200." As we go through the report line by line, you'll find references to many of the most commonly used ASTM tests. Keep in mind, however, that not every report you see will (or should) cover all of these tests. We're including them here simply to help you get better acquainted with as many tests as possible.

A. This first line tells you the absolute basics: you are looking at a test report on "N470," a nitrile compound that has a durometer hardness of 70 (Shore A).

B. The next item lists all of the ASTM specifications to which the N470 material conforms. Each of these are defined individually during the course of the report, but for now, just recall from "Understanding ASTM D 2000 / SAE J200" that each line call-out entry corresponds to a particular test. For example, "EA14" is an ASTM D 471 70-hour water resistance test conducted at 100° C.

C. "Original properties" are the initial attributes of the material. Information in this and all subsequent entries is broken into two columns: the "specification" (what is required to be acceptable) and the properties (or response) of the "N470" nitrile. There are six different original properties on this report: 1) Hardness, 2) Tensile Strength, 3) Elongation, 4) Modulus at 100%, 5) Tear Resistance, and 6) Specific Gravity. Note that specific gravity (S.G.) is not specified on the report; rather, it is a reported figure to be used as a quality control criterion. The S.G. of N470 (1.25) is understood relative to water's S.G. of 1.00. Compound N470 is 25% heavier than water.

D. The first test on this report is "heat resistance" (also known as heat aging or air aging). Per the line call-out, our nitrile is a Grade 2 "BG" compound. This would normally send you to the D 2000 or J200 documents, where you would turn to the "BG Materials" section of Table 6 and see data similar to that shown in ***Table 22*** below. You'll see that "A14" is the suffix designation for "heat resistance" as

	Suffix Requirements	**Grade 1**	**Grade 2**	**Grade 3**	**Grade 4**	**Grade 5**	**Grade 6**	**Grade 7**	**Grade 8**
A14	Heat resistance, Test Method D 573, 70 h at 100° C:								
	• Change in hardness, max, points				± 5	+15	+15		
	• Change in tensile strength, max, %				±15	-20	-20		
	• Change in ultimate elongation, max, %				-15	-40	-40		
B14	Compression set, Test Methods D 395, Method B, max, %, 22 h at 100° C		25	50	50	25	25	25	
B34	Compression set, Test Methods D 395, Method B, max, %, 22 h at 100° C		25			25	25		
C12	Resistance to ozone, Test Method D1171, quality retention rating, min, %			*	*				
EA14	Water resistance, Test Method D 471, 70 h at 100° C:								
	• Change in hardness, points		±10					±10	
	• Change in volume, %		±15					±15	
EF11	Fluid resistance, Test Method D 471, Reference Fuel A, 70 h at 23° C:								
	• Change in hardness, points		±10					±10	
	• Change in tensile strength, max, %		-25					-25	
	• Change in ultimate elongation, max, %		-25					-25	
	• Change in volume, %		-5 to +10					-5 to +10	
EF21	Fluid resistance, Test Method D 471, Reference Fuel B, 70 h at 23° C:								
	• Change in hardness, points		0 to -30					0 to -30	
	• Change in tensile strength, max, %		-60					-60	
	• Change in ultimate elongation, max, %		-60					-60	
	• Change in volume, %		0 to +40					0 to +40	
EO14	Fluid resistance, Test Method D 471, No. 1 Oil, 70 h at 100° C:								
	• Change in hardness, max, points		-5 to +10	-7 to +5	-7 to +5	-5 to +15	-5 to +15	-5 to +15	
	• Change in tensile strength, max, %		-25	-20	-20	-25	-25	-25	
	• Change in ultimate elongation, max, %		-45	-40	-40	-45	-45	-45	
	• Change in volume, %		-10 to +5	-5 to +10	-5 to +5	-10 to +5	-10 to +5	-10 to +5	
EO34	Fluid resistance, Test Method D 471, No. 3 Oil, 70 h at 100° C:								
	• Change in hardness, points		-10 to +5	-10 to +5	-10 to +5	0 to -15	0 to -20	-10 to +5	
	• Change in tensile strength, max, %		-45	-35	-35	-45	-45	-45	
	• Change in ultimate elongation, max, %		-45	-40	-40	-45	-45	-45	
	• Change in volume, %		0 to +25	+16 to +35	0 to +6	0 to +35	0 to +35	0 to +25	
F16	Low-temperature brittleness, Test Methods D 2137, Method A, 9.3.2, nonbrittle after 3 min at -35° C							pass	
F17	Low-temperature brittleness, Test Methods D 2137, Method A, 9.3.2, nonbrittle after 3 min at -40° C		pass				pass		
F19	Low-temperature brittleness, Test Methods D 2137, Method A, 9.3.2, nonbrittle after 3 min at -55° C			pass	pass	pass			

* Values not yet established.

Table 22: Sample suffix and grade requirements.

gauged by ASTM D 573, a 70-hour test conducted at 100° C.

Why, then, is A14 not listed among the additional suffix requirements in this material's line call-out? It is omitted from the call-out because there are no A14 specifications for Grade 2 BG compounds. In ***Table 22***, the Grade 2 column across from row A14 is empty, so the heat resistance specifications column in our sample report is blank. When there are no specifications, a material cannot be said to "conform" to a given test, and the corresponding suffix designation is not listed in the call-out. We've chosen to include heat resistance on this report because it is a common test used to gauge resistance to oxidation and thermal attack over time. You'll no doubt see it regularly on test reports, and it will likely be specified in three properties: 1) Hardness Change, 2) Tensile Change, and 3) Elongation Change.

E. The second test is "compression set" (B14 in the line call-out) as determined by ASTM D 395, a 22-hour test conducted at 100° C. This report lists one property specification related to compression set: Percent of original deflection, which is specified at a 25% maximum. In this instance, the N470 test specimen takes a 14% set. Be aware that a number of factors other than the compound itself can greatly affect compression set results, including the test temperature and the sample thickness.

IN THE LAB

Figure 56: Testing is the best way to predict performance.

F. The third test is "water resistance" (EA14 in the line call-out) as determined by ASTM D 471, a 70-hour test conducted at 100° C. This report lists two property specifications related to water immersion: 1) Hardness Change and 2) Volume Change.

G. The next four tests gauge fuel and oil resistance (EF11, EF21, EO14, and EO34 in the line call-out). In each case, there are four property specifications: 1) Hardness Change, 2) Tensile Change, 3) Elongation Change, and 4) Volume Change. Per J200 / D 2000, EF 11 is the suffix designation for ASTM D 471, a 70-hour test conducted at 23° C using Reference Fuel A. That's good to know, but you're probably wondering what EF11 and the other fluid resistance tests can really tell you about a compound.

Put simply, fluid resistance tests give you an indication of how the compound will react when brought in contact with fuels and oils. In most cases, the primary concern is swelling, though compound degradation is also common. Recall that volume changes (either swell or shrinkage) are typically accompanied by changes in physical properties, including hardness, tensile strength, modulus, elongation, tear resistance, and compression set.

Reference Fuel Type	Composition (Volume %)
A	Isooctane (100)
B	Isooctane (70), Toluene (30)
C	Isooctane (50), Toluene (50)
D	Isooctane (60), Toluene (40)
E	Toluene (100)
F	Diesel Fuel, Grade 2 (100)
G	Fuel D (85), anhydrous denatured ethanol (15)
H	Fuel C (85), anhydrous denatured ethanol (15)
I	Fuel C (85), anhydrous methanol (15)
K	Fuel C (15), anhydrous methanol (85)

Table 23: ASTM Reference Fuels

ASTM Reference Fuels A through K (see ***Table 23***) have been specifically selected to test compounds in contact with gasolines or diesel fuels. Which tests are called for depends on which fluid(s) the seal will encounter. For example, Reference Fuel A (used in the EF11 test) is a 100% isooctane fluid which mirrors the shrinking or low-swell effects of gasolines composed primarily of straight-chain aliphatic (rather than ringed aromatic) hydrocarbons. If the compound in question will be used around gasolines with a very high aliphatic content, then an EF11 test is a good idea. Reference Fuel B (used in the EF21 test) is a 70% isooctane-30% toluene mixture. The toluene content lends the mixture a level of aromaticity, enabling Reference Fuel B to more closely approximate the swelling effects of commercial gasolines.

The other two fluid resistance tests on this report are based on shrinking or swelling in lubricating oils rather than fuels. EO14 is the suffix designation for another ASTM D 471 test, this one lasting 70 hours and conducted at 100° C using Number 1 Oil. EO14 is commonly used to gauge elastomer shrinkage. The time and temperature requirements for EO34 are identical to EO14, with the exception that Industry Reference Material (IRM) 903 is used rather than Number 1 Oil. EO34 is a common tool for gauging elastomer swell. As with the Reference Fuels, the choice of oils in testing is not arbitrary. Rather, Number 1 Oil and IRM 903 are used because they have an aniline point similar to the aniline point of a fluid to be found in service.

The *aniline point* is the lowest temperature at which equal volumes of aniline (an oily, colorless, and poisonous organic liquid derived from benzene) and the oil will completely dissolve in one another. The aniline point is actually a good measure of the aromatic content, or the amount of unsaturated hydrocarbons present in the oil. The higher the level of unsaturants, the more easily the organic aniline can "step in" to combine with the oil, and thus the aniline point will be low. A low aniline point is important because it translates to a higher potential for swelling certain rubber compounds.

Number 1 Oil has the highest aniline point (124° C ± 1°) of the ASTM test oils, meaning it typically causes the least amount of rubber swell. As is clear by looking at the EO14 volume change specification (-10% to +5%), Number 1 Oil actually has the potential to cause more shrinkage than swell. Testing with Number 1 Oil is thus a common tool for gauging oil-induced shrinkage due to plasticizer extraction. IRM 903, on the other hand, has the lowest aniline point (70° C ± 1°) among the test oils and typically causes the greatest swell. Be aware that IRM 903 is used in lieu of the now-obsolete Number 3 Oil for EO34 testing.

DATA ON DEMAND

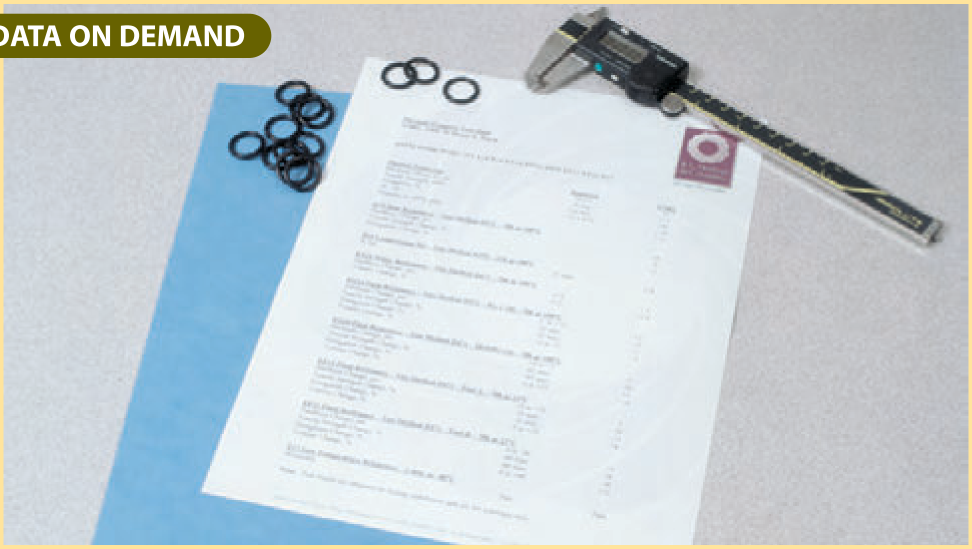


Figure 57: R.L. Hudson & Company is happy to provide test reports upon request.

H. The eighth test is "impact brittleness" (also known as low-temperature brittleness; Z1 in the line call-out). Note that this is a three-minute test conducted at -25° C. Per ASTM D 2137 (Method A), low temperature tests are normally conducted at -35° C, -40° C, or -55° C. For example, if this test had been conducted at -40° C, F17 would have been noted in the line call-out. Because this test was conducted at a non-standard temperature (-25° C), it is noted in the line call-out using a special "Z" suffix. (Per D 2000 / J200, special suffix requirements begin with a "Z" and must be specified in detail, including test methods.) Our report has one specification related to Z1, which is conducted on a pass-fail basis only: No cracks in the material after it is struck once. N470 passes this test.

On some reports, you may also see a "temperature retraction" TR-10 listing. Though TR-10 is not covered by a D 2000 suffix, ASTM D 1329 does detail TR-10 as a way to gauge a compound's crystallization and visco-elastic properties at low temperatures. In this case, specification is for the material to remain viable at -25° C. N470 passes this test. For more on TR-10 testing, see "Low Temperature Effects" on ***page 87***.

I. The ninth test is another special stipulation required by the user of the material (Z2 in the line call-out). In our example, "Z2" is "resistance to marking." There is one specification related to this test, which is conducted on a pass-fail basis only: Non-marking by the material. That is, the compound should not leave any mark when wiped on white paper with a 0.03 MPa contact pressure. N470 passes this test.

In some instances, a Z suffix may be used for something as basic as a hardness reading, as with the specification for a 75 (Shore A) durometer fluorocarbon. Because the line call-out system only allows three digits for both durometer and tensile strength (as with "714" indicating a 70 durometer material with a tensile strength of 14 MPa), it is not possible to specify a 75 durometer material in this way. A special Z suffix would be needed.

TEST REPORT

A. Compound: N470 Nitrile 70 Durometer

B. Conformance to: ASTM D 2000-95, M2BG714, B14, EA14, EF11, EF21, EO14, EO34, Z1, Z2

C.	**ORIGINAL PROPERTIES**	**SPECIFICATION**	**N470**
	Hardness, Durometer A	70 ± 5	70
	Tensile Strength, MPa	14 min	15.9
	Elongation, %	250 min	370
	Modulus @ 100%, MPa	11 min	12.1
	Tear Resistance, kN/m	20 min	35
	Specific Gravity	-	1.25
D.	A14 - HEAT RESISTANCE - 70 hrs @ 100° C		
	Hardness Change, Points	-	+2
	Tensile Change, %	-	+14
	Elongation Change, %	-	-11
E.	B14 - COMPRESSION SET - 22 hrs @ 100° C		
	% of Original Deflection	25 max	14
F.	EA14 - WATER RESISTANCE - 70 hrs @ 100° C		
	Hardness Change, Points	± 10	-2
	Volume Change, %	± 15	+3
G.	EF11 - ASTM FUEL A - 70 hrs @ 23° C		
	Hardness Change, Points	± 10	-2
	Tensile Change, %	-25 max	-10
	Elongation Change, %	-25 max	-10
	Volume Change, %	-5 to +10	+1

	SPECIFICATION	N470	
EF21 - ASTM FUEL B - 70 hrs @ 23° C			G.
Hardness Change, Points	0 to -30	-10	
Tensile Change, %	-60 max	-56	
Elongation Change, %	-60 max	-45	
Volume Change, %	0 to +40	+26	
EO14 - ASTM OIL # 1 - 70 hrs @ 100° C			
Hardness Change, Points	-5 to +10	+2	
Tensile Change, %	-25 max	+21	
Elongation Change, %	-45 max	-2	
Volume Change, %	-10 to +5	-5	
EO34 - IRM903 OIL - 70 hrs @ 100° C			
Hardness Change, Points	-10 to +5	-4	
Tensile Change, %	-45 max	+7	
Elongation Change, %	-45 max	-3	
Volume Change, %	0 to +25	+7	
Z1 - LOW TEMPERATURE - 3 mins @ -25°			H.
Impact Brittleness	No cracks	Pass	
TR-10	-25° C	-25° C	
Z2 - RESISTANCE TO MARKING			I.
Marking by the material on white paper when wiped at 0.03 MPa contact pressure	Non-marking	Pass	

Batch Testing & Cure Date.

When one of our suppliers mixes or buys a batch of rubber, a batch number is automatically assigned. But before it can be molded into usable parts (such as O-rings), the batch must be tested to make sure it is a "good batch," i.e. that its physical properties meet specifications. Batch testing is vital in ensuring consistency among finished parts.

To test a batch of rubber's physical properties, a sample of the material is molded into 6" x 6" x .070" slabs. These slabs are then cut into the various shapes needed to test for hardness, tensile strength, modulus, elongation, and compression set. All of these tests are described in the Physical Properties section of "Selecting the Material."

Specific gravity is also often measured, though more as a check on compounding consistency than as a physical test. Per ASTM D 792, specific gravity (or relative density) compares the weight of a molded sample to the weight of an equal volume of water. Specific gravity (SG) is noted without units. If a material is twice as heavy as water, its specific gravity is 2. Using the specific gravities of previously-molded compounds for comparison (e.g. a material may have an SG of 0.86, or less than that of water), a manufacturer can see if a sample is consistent with prior batches.

If the tested physical properties of a batch of rubber meet all specifications, the batch is approved for production of O-rings or other articles. If the properties are not satisfactory, the batch must either be reworked (broken down and reformulated) or scrapped. Scrapping an entire batch of rubber and starting over can be very costly and is thus a last resort. But even if the compound's physical properties are acceptable, it must still meet processing requirements in order to be ready for use in a specific molding facility.

> **"Batch testing is vital in ensuring consistency among finished parts."**

TOOLS FOR TESTING

At one time, the Mooney Viscometer was the most common tool used to determine the processing characteristics for a given batch of rubber. Many compounders still use the Mooney to verify viscosity (which is indicative of molecular weight) when obtaining raw polymer stock. This works because a compound's resistance to being moved by the Mooney's internal rotor is directly linked to its viscosity. The viscometer's previous role as the chief indicator of processing traits, however, has now been usurped by the rheometer.

There are two main types of rheometers currently in use: the ODR and the MDR. The older of these, the Oscillating Disk Rheometer (ODR, see ***Figure 58***), builds on the Mooney Viscometer's rotor-based design. An ODR gauges the amount of torque (twisting force in pounds per inch, lb./in, or decinewtons per meter, dN/m) needed to oscillate a rotor within the rubber sample. Whereas a viscometer rotor relies on full rotation, the ODR rotor only moves back and forth across a small arc. This oscillation is less degrading to the material than in the viscometer, where destruction of the sample is typical.

ODR test results are also more reflective of actual cure conditions because constant high pressure and the desired vulcanization temperature are maintained on the sample. As testing progresses, the sample begins to behave in predictable ways. Viscosity briefly drops as the sample first heats up, but the chemical reaction soon starts. The rubber becomes more viscous due to crosslinking of the macromolecular chains. As a result, the amount of torque that is required to internally shear (deform) the sample increases. Using this increasing torque as a gauge, the ODR plots a *cure curve* (see ***Table 24, next page***) illustrating the state of cure for a given time and temperature.

ODR

Figure 58: Oscillating Disk Rheometer

Though the Monsanto ODR was for many years the most-used rheometer, a more recent development is the Moving Die Rheometer (MDR). Whereas the ODR uses an embedded rotor to torque the rubber sample, an MDR holds the sample between a pair of heated dies (metal plates forming a cavity). As one of the dies moves across a small arc, the other die gauges the reaction torque generated in the sample. This again results in a cure curve that can show the optimum cure time for the desired blend of properties. Since the MDR does not insert a rotor into the sample, many molders feel the MDR is less intrusive to the curing process and thus more objective and accurate than the ODR.

DETERMINING CURE TIMES

Whether generated by an ODR or an MDR, a cure curve is essentially "torque versus time (at a given temperature)." The torque value is a direct indication of the sample's shear modulus (resistance to shearing deformation). A number of processing characteristics can also be read, including the minimum pressure needed to make the material flow properly into the mold cavity, *scorch time* (prior to vulcanization), *optimum cure time* (typically 85 to 95% of maximum cure), and *maximum cure* (prior to over cure). Keeping the initial cure slightly below the maximum helps avoid over cure by allowing leeway for any necessary *post cure* (controlled continuation of vulcanization to finish cure, drive off byproducts, and stabilize) or inadvertent *after cure* (uncontrolled continuation of vulcanization after heat is removed).

Though specific vulcanization questions can be answered via a cure curve, rheometers also help molders address more general concerns about processibility and consistency. No matter what the cure curve says, "optimum" cure time is

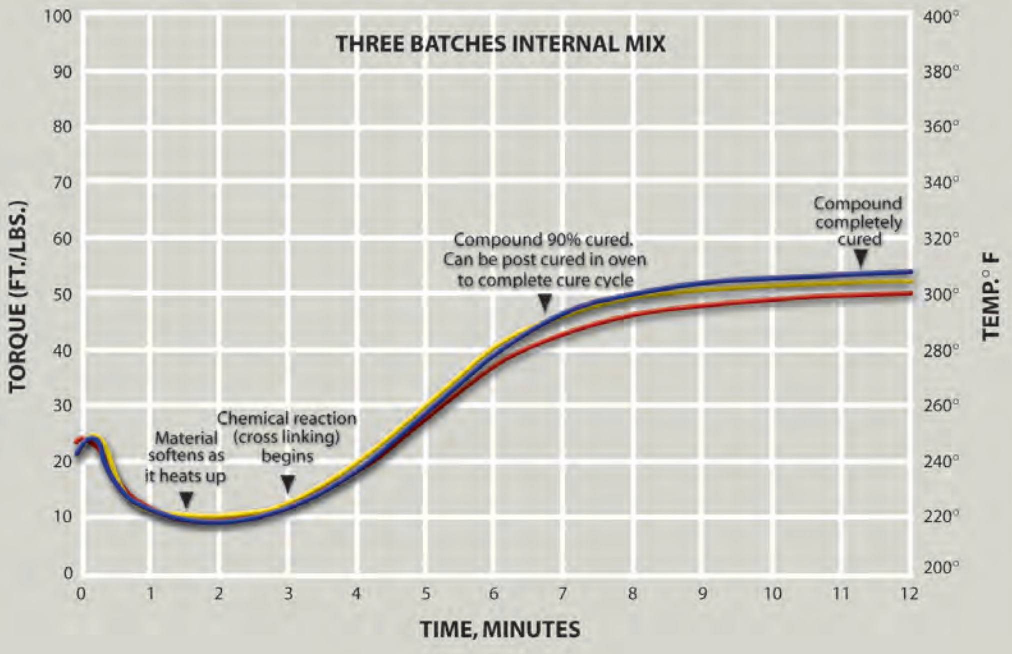


Table 24: ODR-Plotted Cure Curve

largely a matter of economics. There is no "universal" cure time for a compound. A batch of rubber may have different cure times if given to different molders, depending on their capabilities.

The old adage about time being money is especially true when it comes to *cycle time* (the time between a given point in one molding cycle and the same point in the next cycle; e.g. loading of raw stock, through molding and unloading of finished parts, then to reloading; see ***Figure 59***). Generally speaking, the longer the cycle time, the more expensive the process and the more costly the part. As a cost-cutting measure, manufacturers may increase mold temperature to decrease cure time. A 20° F boost can cut cure time in half, but this is not always advantageous. Sometimes the ratio of the time the mold is open (for unloading and reloading) to the time the mold is closed and in the press allows the mold temperature to dip below what is needed for full vulcanization. Partially-vulcanized, unusable parts can result.

Again, consistency among different batches of the same material is always a concern. The cure curve can serve as a "fingerprint" for a given batch of rubber. By comparing cure curves, it is possible to see if the properties present in one batch are present in another. Because wasted processing can be costly in terms of both time and money, compounding errors are much more economically spotted in batch testing than in subsequent stages of quality control, such as vulcanizate testing.

GOING TO PRESS

Figure 59: Multiple cavity mold in use.

ASSIGNING CURE DATES

Quality control is aided by the batch number that was initially assigned to the rubber. This number follows the batch as it makes its way through the manufacturing process. When the batch (or a portion of it) is molded, a *cure date* is also assigned. This cure date consists of the quarter and year in which the parts are molded. For example, all parts molded in January, February, or March of 2001 have a cure date of 1Q01. Parts molded in October, November, or December of 2000 have a cure date of 4Q00. Both the batch number and cure date stay with the part through to the end user, thus assuring that complete traceability is maintained.

Quality Assurance.

We are proud to say that R.L. Hudson & Company is a preferred supplier of fluid sealing devices and custom-molded rubber, plastic, and polyurethane products for a diverse group of manufacturers. As such, we have attained a worldwide reputation with commercial establishments as an organization committed to customer satisfaction.

Recognizing that quality is not only conformance to established acceptance standards, R.L. Hudson & Company is dedicated to being responsive to the ever-changing needs of our customers. Additionally, one of our prime objectives is to seek out continuous improvement so as to cost effectively provide our customers with a product line of the highest available quality.

In accordance with global Quality Assurance's movement toward one unified International Standard, it is our policy to assure process integrity by operating to a Quality System defined by ISO 9001.

As part of this system, we established our own in-house Quality Assurance department (see ***Figure 60***) whose sole purpose is to oversee the inspection of the products we offer, including O-ring seals. We feel strongly that having our own Quality Assurance department is a wise investment in the ultimate success of our customers' applications.

What follows is an overview of the ten most common types of O-ring surface imperfections, along with the maximum acceptable measurements (both military and industrial) in each case.

> **"Our objective is to seek out continuous improvement so as to cost effectively provide our customers with a product line of the highest available quality."**

ATTENTION TO DETAIL

Figure 60: A Voyager 1000 video imaging system is just part of our Quality Assurance capabilities.

Backrind.

Backrind is typified by a longitudinal recess (shaped like a wide-angle "U" or "W") found at the parting lines on the seal's OD and/or ID (see Figure 61). This recess may sometimes exist on the entire circumference of the O-ring. Backrind can result from the thermal expansion of material over a sharp mold edge. It can also be caused by premature curing of the material.

BACKRIND

Figure 61: Found on the OD and/or ID.

"Backrind is typified by a longitudinal recess found at the parting lines."

AS568A	**O-Ring Width**		**Military (per MIL-STD 413C)**		**Industrial (per RMA)**	
Series	**Inches**	**Millimeters**	**Inches**	**Millimeters**	**Inches**	**Millimeters**
000	< .100	< 2.54	.000	.000	.005 wide .003 deep	.127 wide .076 deep
100	.100-.134	2.54-3.42	.005 wide .003 deep	.127 wide .076 deep	.007 wide .003 deep	.178 wide .076 deep
200 & 300	.135-.268	3.43-6.81	.006 wide .004 deep	.152 wide .102 deep	.008 wide .004 deep	.203 wide .102 deep
400	.269-.281	6.82-7.14	.010 wide .005 deep	.254 wide .127 deep	.015 wide .005 deep	.381 wide .127 deep

Table 25: Maximum Amount of Acceptable Backrind

Excessive Trimming (Buffing).

Excessive trimming is typified by a flattened area on the seal's OD and/or ID (see Figure 62). This flattening results in an out-of-tolerance (ID to OD measurement) condition. Keep in mind that problems can result even if "excessive" trimming is avoided. Imperfect trimming or buffing to remove flash can result in a much coarser seal surface. Both excessive trimming and buffing are the result of improper removal of flash.

"Excessive trimming is typified by a flattened area on the seal's OD and/or ID."

EXCESSIVE TRIMMING

Figure 62: On the OD and/or ID.

AS568A Series	Minimum Cross-Section Inches	Millimeters
000	.067	1,70
100	.100	2,54
200	.135	3,43
300	.205	5,20
400	.269	6,84

(Note: The "maximum amount of acceptable trimming" is defined as the minimum allowable cross-section for each O-ring series. It is the same for both military and industrial applications.)

Table 26: Minimum Cross-Sections

Flow Marks.

Flow marks are shallow, thread-like recesses in the surface of the seal (see Figure 63). Flow marks are typically curved and have rounded edges. Flow marks result from improper flowing and premature curing of the material in the mold.

FLOW MARKS

Figure 63: Typically curved, with round edges.

> “Flow marks are shallow, thread-like recesses in the surface of the seal.”

AS568A	O-Ring Width		Military (per MIL-STD 413C)		Industrial	
Series	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters
000	< .100	< 2.54	.002 deep .060 long	.05 deep 1.52 long	NOT AVAILABLE	
100	.100-.134	2.54-3.42	.002 deep .060 long	.05 deep 1.52 long		
200	.135-.204	3.43-5.20	.002 deep .180 long	.05 deep 4.57 long		
300	.205-.268	5.21-6.81	.002 deep .180 long	.05 deep 4.57 long		
400	.269-.281	6.82-7.14	.002 deep .180 long	.05 deep 4.57 long		

Table 27: Maximum Amount of Acceptable Flow Marks

Foreign Material.

Foreign material may be any superfluous material (such as dirt, grit, and particulate matter) embedded in the seal (see Figure 64). Foreign material also refers to any residual indentation in the seal resulting from the removal of such unwanted matter. Contamination of the material, either prior to or during molding, is the cause.

> **"Foreign material may be any superfluous material embedded in the seal."**

Figure 64: Embedded in the seal.

AS568A	**O-Ring Width**		**Military (per MIL-STD 413C)**		**Industrial (per RMA)**	
Series	**Inches**	**Millimeters**	**Inches**	**Millimeters**	**Inches**	**Millimeters**
000	< .100	< 2.54	Non Visible	Non Visible	.005 wide .003 deep	.127 wide .076 deep
100	.100-.134	2.54-3.42	.005 wide .003 deep	.127 wide .076 deep	.008 wide .003 deep	.203 wide .076 deep
200	.135-.204	3.43-5.20	.007 wide .004 deep	.178 wide .102 deep	.010 wide .004 deep	.254 wide .102 deep
300	.205-.268	5.21-6.81	.010 wide .005 deep	.254 wide .127 deep	.015 wide .006 deep	.381 wide .152 deep
400	.269-.281	6.82-7.14	.015 wide .006 deep	.381 wide .152 deep	.020 wide .006 deep	.508 wide .152 deep

Table 28: Maximum Amount of Acceptable Foreign Material

Mismatch.

Mismatch is an inequality between the cross-sectional radius of one half of the O-ring and the radius of the other half (see Figure 65). Mismatch is caused by dimensional differences in the mold halves.

MISMATCH

Figure 65: Unequal radii.

"Mismatch is an inequality between one half of the O-ring and the other half."

AS568A Series	O-Ring Width Inches	O-Ring Width Millimeters	Military (per MIL-STD 413C) Inches	Military (per MIL-STD 413C) Millimeters	Industrial (per RMA) Inches	Industrial (per RMA) Millimeters
000	< .100	< 2.54	.003	.076	.003	.076
100	.100-.134	2.54-3.42	.004	.102	.004	.102
200	.135-.204	3.43-5.20	.005	.127	.005	.127
300	.205-.268	5.21-6.81	.006	.152	.006	.152
400	.269-.281	6.82-7.14	.006	.152	.006	.152

Table 29: Maximum Amount of Acceptable Mismatch

Mold Deposit Indentations.

Mold deposit indentations are irregularly-shaped depressions with a rough texture found on the seal's surface (see Figure 66). Mold deposit indentations are caused by an accumulation of hardened deposits on the inner surface of the mold cavity.

"Mold deposit indentations are irregularly-shaped depressions with a rough texture."

MOLD DEPOSIT INDENTATIONS

Figure 66: Visible on the seal's surface.

AS568A Series	O-Ring Width Inches	O-Ring Width Millimeters	Military (per MIL-STD 413C) Inches	Military (per MIL-STD 413C) Millimeters	Industrial (per RMA) Inches	Industrial (per RMA) Millimeters
000	< .100	< 2.54	.010 wide .003 deep	.254 wide .076 deep	.015 wide .003 deep	.381 wide .076 deep
100	.100-.134	2.54-3.42	.015 wide .003 deep	.381 wide .076 deep	.020 wide .003 deep	.508 wide .076 deep
200	.135-.204	3.43-5.20	.020 wide .004 deep	.508 wide .102 deep	.025 wide .004 deep	.635 wide .102 deep
300	.205-.268	5.21-6.81	.025 wide .004 deep	.635 wide .102 deep	.030 wide .005 deep	.762 wide .127 deep
400	.269-.281	6.82-7.14	.030 wide .005 deep	.762 wide .127 deep	.040 wide .006 deep	1.016 wide .152 deep

Table 30: Maximum Amount of Acceptable Mold Deposit Indentation

Non-Fill

Non-fill is a random and irregular surface indentation with a coarser texture than the unaffected portions of the O-ring surface (see Figure 67). Non-fill results from imperfect flow of the seal material within the mold, and/or incomplete filling of the mold, and/or air trapped in the mold.

> **"Non-fill is a random and irregular surface indentation."**

NON-FILL

Figure 67: Random surface indentations.

AS568A	O-Ring Width		Military (per MIL-STD 413C)		Industrial (per RMA)	
Series	**Inches**	**Millimeters**	**Inches**	**Millimeters**	**Inches**	**Millimeters**
000	< .100	< 2.54	None	None	None	None
100	.100-.134	2.54-3.42	.010 wide .002 deep	.254 wide .051 deep	.030 wide .003 deep	.762 wide .076 deep
200	.135-.204	3.43-5.20	.015 wide .003 deep	.381 wide .076 deep	.030 wide .004 deep	.762 wide .102 deep
300	.205-.268	5.21-6.81	.025 wide .003 deep	.635 wide .076 deep	.040 wide .004 deep	1.016 wide .102 deep
400	.269-.281	6.82-7.14	.040 wide .003 deep	1.016 wide .076 deep	.050 wide .004 deep	1.270 wide .102 deep

Table 31: Maximum Amount of Acceptable Non-Fill

Off-Register.

Off-register results in an obvious misalignment of the O-ring "halves" (see Figure 68). Off-register results from a lateral shift of one of the mold cavity plates in relation to its mating plate.

"Off-register results in an obvious misalignment of the O-ring 'halves.'"

Figure 68: Misaligned "halves."

AS568A	O-Ring Width		Military (per MIL-STD 413C)		Industrial (per RMA)	
Series	**Inches**	**Millimeters**	**Inches**	**Millimeters**	**Inches**	**Millimeters**
000	< .100	< 2.54	.003	.076	.003	.076
100	.100-.134	2.54-3.42	.004	.102	.004	.102
200	.135-.204	3.43-5.20	.005	.127	.005	.127
300	.205-.268	5.21-6.81	.006	.152	.006	.152
400	.269-.281	6.82-7.14	.006	.152	.006	.152

Table 32: Maximum Amount of Acceptable Off-Register

Parting Line Indentations.

Parting line indentations are shallow recesses (typically shaped like a saucer, though sometimes triangular) found at the seal's parting line on the OD and/or ID (see Figure 69). The parting line usually divides the indentation in half. Parting line indentations are the result of a deformity in the edge of the mold at the parting line.

PARTING LINE INDENTATIONS

Figure 69: Found on the OD and/or ID.

> "Parting line indentations are shallow recesses found at the seal's parting line."

AS568A	O-Ring Width		Military (per MIL-STD 413C)		Industrial (per RMA)	
Series	Inches	Millimeters	Inches	Millimeters	Inches	Millimeters
000	< .100	< 2.54	.010 wide .003 deep	.254 wide .076 deep	.015 wide .003 deep	.381 wide .076 deep
100	.100-.134	2.54-3.42	.015 wide .003 deep	.381 wide .076 deep	.020 wide .003 deep	.508 wide .076 deep
200	.135-.204	3.43-5.20	.020 wide .004 deep	.508 wide .102 deep	.025 wide .004 deep	.635 wide .102 deep
300	.205-.268	5.21-6.81	.025 wide .005 deep	.635 wide .127 deep	.030 wide .005 deep	.762 wide .127 deep
400	.269-.281	6.82-7.14	.030 wide .006 deep	.762 wide .152 deep	.040 wide .006 deep	1.016 wide .152 deep

Table 33: Maximum Amount of Acceptable Parting Line Indentation

Parting Line Projection.

Parting line projection is a continuous ridge of material found at the seal's parting line on the OD and/or ID (see Figure 70). Excessive flash is a thin, film-like formation extending beyond the parting line projection. Parting line projection can result when mold wear results in enlarged corner radii. Excessive flash can result from separation of the mold plates or improper (inadequate) trimming of the seal following removal from its mold cavity.

> "Parting line projection is a continuous ridge of material found at the seal's parting line."

PARTING LINE PROJECTION

Figure 70: Found on the OD and/or ID.

AS568A	O-Ring Width		Military (per MIL-STD 413C)		Industrial (per RMA)	
Series	Inches	Millimeters	High Max Inches	High Max Millimeters	High Max Inches	High Max Millimeters
000	< .100	< 2.54	.003	.076	.003	.076
100	.100-.134	2.54-3.42	.003	.076	.004	.102
200	.135-.204	3.43-5.20	.004	.102	.005	.127
300	.205-.268	5.21-6.81	.005	.127	.006	.152
400	.269-.281	6.82-7.14	.006	.152	.007	.178

Table 34: Maximum Amount of Acceptable Parting Line Projection

Aging & Shelf Life.

As they age, O-rings and other rubber products can undergo changes in physical properties. They may even become unusable due to excessive hardening, softening, cracking, crazing, or other surface degradations. These changes may be the result of a single factor or a combination of factors, such as the action of oxygen, ozone, light, heat, humidity, oils, water, or other solvents. Detrimental effects can be minimized, however, by proper storage conditions.

"Detrimental effects can be minimized by proper storage conditions."

TEMPERATURE

The optimum storage temperature is between 40° F and 80° F. High temperatures accelerate the deterioration of rubber products. Heat sources should be arranged so that the temperature of stored items never exceeds 120° F. Low temperature effects are neither as damaging nor as permanent, but rubber articles will stiffen. Care should be taken to avoid distorting them at temperatures below 30° F.

HUMIDITY

Expressed as a percentage, *relative humidity* is the ratio of the amount of water vapor present in the air to the greatest amount that could be present at a given temperature. Ideally, the relative humidity in the storage area should be below 75%. Very moist or very dry conditions must be avoided. Where ventilation is necessary, keep it to a minimum. Condensation cannot be allowed to occur. Some materials, such as polyester-based polyurethanes, are hygroscopic (they absorb moisture from the air). This moisture attacks the polymer's chemical backbone, resulting in *chain scission* (division of the polymer chain into smaller, weaker segments). Over time, the material becomes soft and cheesy. In humid environments, this can occur in a matter of weeks unless precautions are taken.

OUR WAREHOUSE

Figure 71: Proper storage conditions prolong the lives of molded products.

LIGHT

O-rings and other rubber products should always be protected from light, especially natural sunlight. Strong artificial light with a high ultraviolet (UV) content is also dangerous. Regardless of the source, UV rays can cause chain scission. Use of polyethylene bags stored inside large cardboard containers is recommended. Alternatively, polyethylene-lined craft bags also offer good protection.

OXYGEN AND OZONE

Oxygen (O_2) and ozone (O_3) are very damaging to rubber products. Whenever possible, O-rings and other molded articles should be stored in *hermetic* (airtight) containers to protect them from circulating air. Oxygen (especially in combination with heat) causes rubber articles to form additional cross-links, leading to unwanted hardening of the seal. As with water and UV light, ozone is capable of causing chain scission. Rubber products should be kept away from ozone generators such as electric motors, mercury vapor lamps, and high voltage electrical equipment.

DEFORMATION

Rubber products should be stored in a relaxed condition, free from tension, compression, or other deformation which can lead to cracking or permanent shape change. Large O-rings and seals should not be stored on pegs.

Type	ASTM Desig.	Shelf Life
Nitrile (Buna N)	NBR	3 to 5 years
Styrene Butadiene (Buna S)	SBR	3 to 5 years
Polybutadiene	BR	3 to 5 years
Polyisoprene	NR, IR	3 to 5 years
Hypalon®	CSM	5 to 10 years
Ethylene Propylene	EPDM, EPM	5 to 10 years
Neoprene®	CR	5 to 10 years
Polyurethane (polyether)	EU	5 to 10 years
Epichlorohydrin	CO, ECO	5 to 10 years
Fluorocarbon (Viton®)	FKM	up to 20 years
Perfluoroelastomer	FFKM	up to 20 years
Silicone	Q	up to 20 years
Fluorosilicone	FVMQ	up to 20 years
Polyacrylate	ACM, ANM	up to 20 years
Polysulfide	T	up to 20 years

Table 35: Shelf Life of Common Elastomers

SHELF LIFE

In normal warehouse conditions, the shelf life of even relatively age-sensitive elastomers is considerable. This is largely due to advances in compounding. ***Table 35*** lists some of the generally recommended limitations of many compounds. Taken from Military Handbook 695, this table is quite conservative.

STORAGE AND CODING

All O-rings inventoried and shipped by R.L. Hudson & Company are stored in either zip lock or heat-sealed plastic bags. These bags feature bar-coded labels indicating both the contents' cure date and batch number.

Dimensions.

Having selected the most appropriate material for your O-ring seal, now is the time to consider a number of other factors that will undoubtedly impact your application. The dimensions of the O-ring itself always play a huge role in the success or failure of a seal. There are three main O-ring dimensions to consider: its initial size, the amount of stretch it undergoes, and the amount of squeeze necessary to complete the seal.

"The dimensions of the O-ring itself always play a huge role in the success or failure of a seal."

SIZE

O-ring size is typically specified according to AS 568A, the Aerospace Standard Uniform Dash Numbering System developed by the Society of Automotive Engineers (SAE). Per AS 568A, the size of each O-ring can be noted in terms of its inside diameter (I.D.) and width (W). (Width is also referred to as cross-section, or CS.) Each figure also includes a *tolerance*, or allowable deviation (plus and minus). Measurements are often given in both inches and millimeters.

Size listings may include two sets of figures: actual size and nominal size. The *actual size* is the exact size of the O-ring in decimal dimensions (inches or millimeters), including tolerances. The *nominal size* is the approximate size of the O-ring in fractional dimensions (inches, e.g. 1 1/8") and is generally included strictly for reference purposes. In addition to the inside diameter and width figures, a nominal listing may also include an outside diameter (O.D.) listing. Keep in mind that the width of an O-ring is one-half the difference between its O.D. and I.D. (see ***Figure 72***).

DEFINING THE SEAL

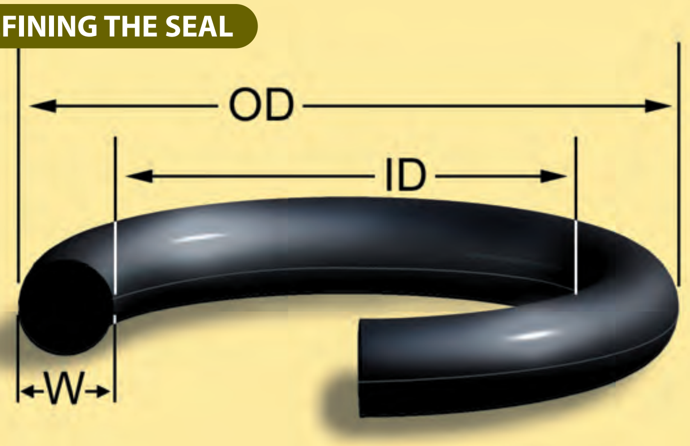


Figure 72: O-Ring Dimensions

The O-ring size that is best suited for a particular project depends on the needs of the seal. Keep in mind that cross-section determines sealability. Larger cross-sections typically provide more stability and allow more tolerance, but they also create more seal friction. Smaller sections generate less friction but are less stable and allow less tolerance. Regardless of the application, it is imperative that the cross-section be greater than the height of the gland into which it will be installed. Squeeze applied to the seal will compress the O-ring. The combination of compression and system pressure will cause the O-ring to block the diametral clearance gap and prevent leakage. The effects of variances in cross-section size are shown in ***Table 36***.

LARGER CROSS-SECTIONS	SMALLER CROSS-SECTIONS
Reciprocating Seals	
Increased friction	Decreased friction
Increased stability	Decreased stability
All Seals	
Less compression set*	More compression set*
(*esp. in fluorocarbons and nitriles; not in silicones and ethylene propylenes)	
Less swell in fluid	More swell in fluid
Less resistant to explosive decompression	More resistant to explosive decompression
Allows larger tolerances	Requires smaller tolerances
Less susceptible to dirt and damage	More susceptible to dirt and damage
Decreased physical properties**	Increased physical properties**
(**elongation in fluorocarbons; tensile and elongation in nitriles)	
Requires larger (heavier) design	Allows smaller (lighter) design

Table 36: Effects of Variances in Cross-Section Size

STRETCH

Measured as a percentage increase in the I.D. of an O-ring, stretch results in a reduction and flattening of the seal's cross-section (width). There are two "types" or "phases" of stretch: *installation stretch* (as the seal is being placed in the groove) and *assembled stretch* (once the seal is seated). Because installation stretch is temporary (or even momentary), an O-ring can generally undergo a high degree of it, sometimes as much as 100% or more if the installation is particularly tricky. An O-ring may have to be stretched in unusual ways or at odd angles in order to safely navigate an intricate design.

Assembled stretch, on the other hand, is permanent and must therefore be minimized if the seal itself is to have a long life.

But though it should be kept to a minimum, assembled stretch should not be eliminated altogether. A small degree of assembled stretch ensures the seal will fit snugly against the piston (or rod) and not sag and buckle in the groove. Assembled stretch is possible when the I.D. of an O-ring is slightly smaller than the groove diameter. This difference between the diameters ensures the O-ring will be subjected to some degree of stretch during both installation and use.

For most situations, assembled stretch should be at least 1% but not more than 5%. Care must be taken to avoid an assembled stretch greater than 5% so as not to exacerbate stresses and reduce the seal's overall life expectancy. This is especially true when using a nitrile compound. Fluorocarbons, polyurethanes, chloroprene, and ethylene propylene typically last longer under a higher degree of assembled stretch.

Keep in mind that higher amounts of assembled stretch may need to be compensated for by use of a smaller gland, especially if the stretch exceeds 2% or 3%. Reducing the gland depth helps maintain the required amount of squeeze on the O-ring's reduced and flattened cross-section (see ***Table 37***).

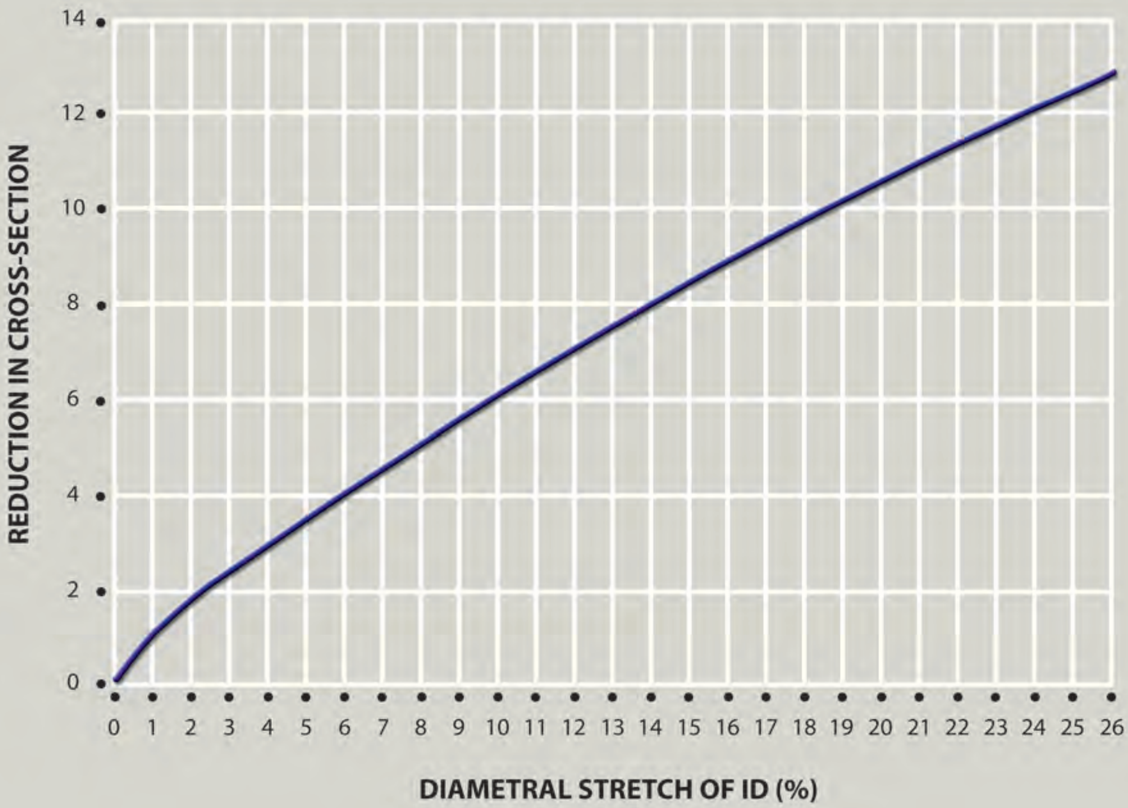


Table 37: Reduction of Cross-Section Due to Stretch

SQUEEZE

Expressed as both a decimal measurement (in inches and/or millimeters) and as a percentage of the original O-ring cross-section (width), squeeze is compression of the O-ring's cross-section between mating surfaces. For example, an O-ring with an original cross-section of .040″ (1.02 mm) that is squeezed .007″ (.18 mm) has been compressed approximately 16%. Likewise, a .275″ (7 mm) O-ring that is squeezed .035″ (.89 mm) has been compressed approximately 13%.

There are two main types of squeeze for static O-ring seals: *radial* and *axial*. Radial compression occurs on an O-ring's O.D. and I.D., as with cap and plug type configurations (see ***Figure 73***). Axial compression occurs on the top and bottom surfaces of the O-ring, as with face (flange) type designs (see ***Figure 74***).

Because of the nature of their installation and movement, dynamic seals (either reciprocating, rotary, or oscillating) almost always employ only radial squeeze, though there might be rare instances (as with a face seal involving rotary motion) in which axial squeeze is used.

RADIAL SQUEEZE

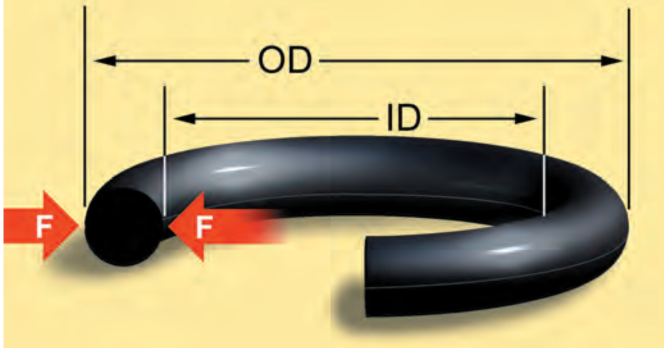


Figure 73: Applied to I.D. and O.D.

AXIAL SQUEEZE

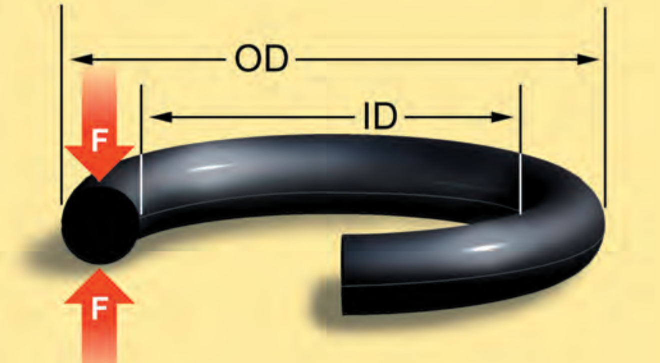


Figure 74: Applied to Top and Bottom

Squeeze depends on three variables: the amount of compressive force applied to a seal (as measured in pounds per linear inch, or pli), the hardness of the seal (its resistance to compression, as typified by a durometer reading), and the cross-section of the seal. As previously noted, the cross-section is reduced and flattened when the O-ring is stretched. A seal under a high degree of stretch will typically require a greater amount of squeeze (or, alternatively, a gland with less depth) in order to maintain the proper amount of contact between the seal and the mating surface.

As might be guessed, the proper amount of O-ring squeeze differs from application to application. Most static seals should never be squeezed more than 30%. Because of friction and wear considerations, the maximum recommended squeeze for most dynamic seals is only 16%. These percentages may vary, however, depending on factors such as the size of the O-ring and the temperatures to which the seal will be exposed. For example, a smaller O-ring or an O-ring that won't have to withstand higher temperatures can function effectively under greater squeeze. The necessary amount of O-ring squeeze can also fluctuate within a given application if O-rings made of differing compounds (with varying hardnesses) or having different inside diameters are used interchangeably. No matter what the size or amount of stretch, all O-rings must be squeezed at least 0.007" before the adequacy of the seal can be accurately determined.

Keep in mind that the amount of squeeze being employed affects a seal's susceptibility to gas permeation. As squeeze increases, permeability decreases. This is true for a couple of reasons. First, more squeeze translates to less groove depth, meaning less area available for gas to enter initially. Second, an O-ring under increased squeeze is wider, meaning gas must travel further (i.e. through a greater length of material) before reaching the low pressure side to escape.

Environment.

Another important design consideration is the environment in which any seals must function. The ability to withstand its environment is critical to a seal's success. Environmental issues include temperature, pressure, the possible use of anti-extrusion devices, friction, and the need for lubrication.

TEMPERATURE

Temperature extremes can lead to seal failure by changing an O-ring's size and consistency. Extreme heat can cause the seal to expand and harden, permanently deforming it. Very low temperatures may cause the shrinking seal to lose flexibility and become brittle. Knowing what range of temperatures a seal must withstand is essential to the design process. In some cases, designing a larger gland for high-temperature seals or a smaller gland for low-

"The ability to withstand its environment is critical to a seal's success."

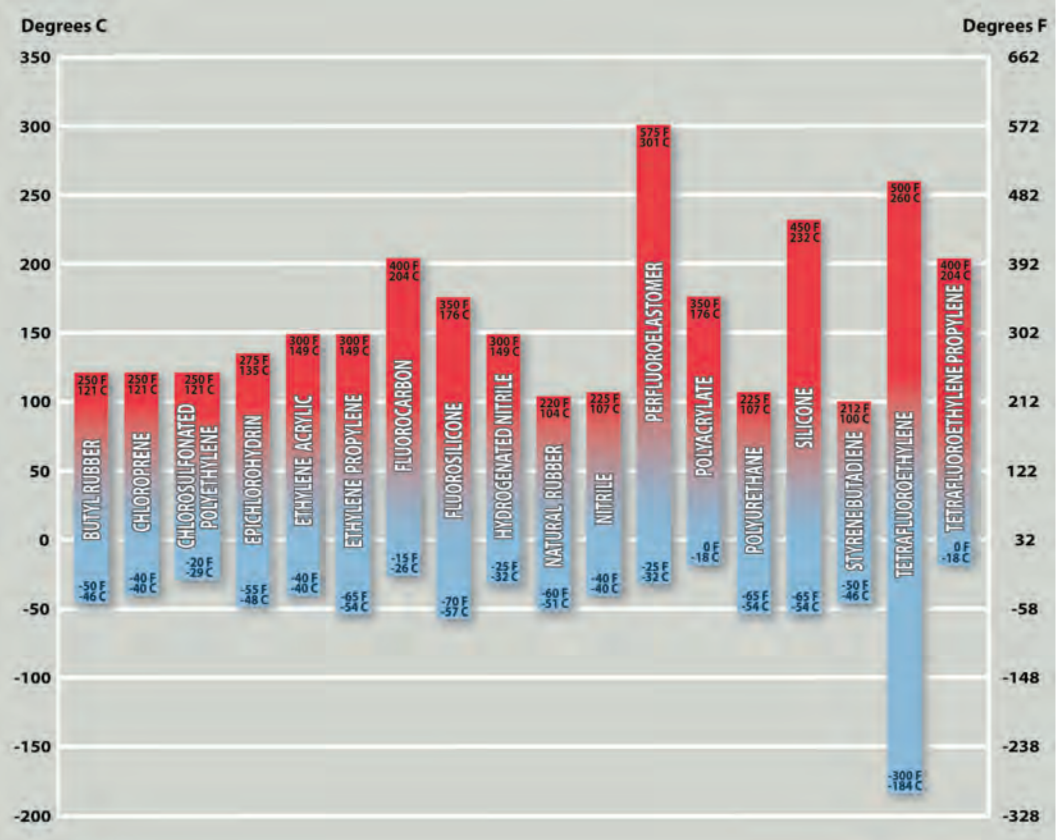


Table 38: Comparison of Material Temperature Ranges

temperature seals may help. ***Table 38*** shows the typical temperature ranges for the most common sealing materials.

PRESSURE & EXTRUSION

Pressure is a double-edged sword. In most O-ring sealing applications, a moderate amount of system pressure is desirable because it aids in effecting the seal. Since the rubbery O-ring is essentially a highly viscous fluid, moderate pressure forces this thick material firmly against the mating surfaces, and a positive seal is created. If an inadequate amount of squeeze is employed, or if the seal material has poor compressive modulus, low pressure (below 100 psi) may not be enough to help ensure adequate contact between the O-ring and the mating surfaces. A leak path may remain and failure can result.

High pressure can be even more problematic. Pressure increases may expand the mating components, often enlarging the clearance gap between parts. The larger the gap, the greater the likelihood that part of the O-ring will be forced (extruded) into it. Extrusion becomes most likely as pressure approaches or exceeds 1,500 psi. Constant high pressure will cause the surface of the extruded seal to rupture. Even if pressure occasionally drops (as during cycling or system fluctuations), the extruded portion of the seal is still vulnerable. The O-ring's elastic memory enables it to regain its original shape, but it may not recede out of the retracting gap quickly enough. A small chunk of its material may be torn (nibbled) away. Both extrusion and nibbling ultimately create a leak path, and seal failure inevitably results (see ***Figures 75 and 76***).

EFFECT OF HIGH PRESSURE

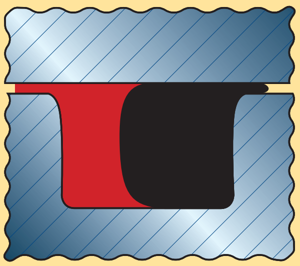


Figure 75: Extrusion

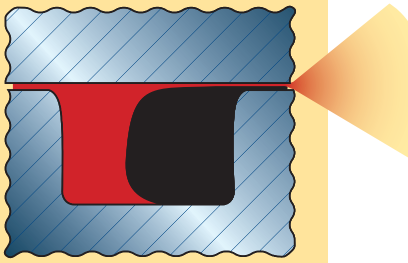


Figure 76: Failure

The amount of extrusion to be expected in a given application thus depends on three main factors: 1) the pressure imposed on the seal, 2) the amount of clearance between mating surfaces, and 3) the resistance of the seal material to deformation. The first two factors are not easy to adjust. The inherent needs of the application often dictate that system pressure cannot be lowered. Reducing the clearance gap is possible but can often be very expensive. Due to other variables (such as wear and misalignment of mating parts), a redesigned gap still may not adequately prevent extrusion. This leaves the third factor, resistance of the seal to deformation, as the most viable avenue for reducing extrusion concerns.

Hardness and Young's Modulus (modulus of elasticity, or stiffness) chiefly determine an O-ring's resistance to deformation. Materials with both high modulus and hardness tend to have fewer extrusion problems. Temperature-induced changes in modulus and stress relaxation behaviors (such as creep / cold flow) can, however, put even the most stalwart O-ring in danger. For more on extrusion, see also "Extrusion & Nibbling" on ***page 259***.

BACK-UP RINGS

Back-up rings are one way to protect the O-ring and prevent extrusion in both static and dynamic applications. A back-up ring is a relatively hard, high shear modulus material placed in a seal groove between the O-ring and the clearance gap (i.e. on the seal's low-pressure side). The back-up acts as a support or buttress for the O-ring even as it blocks the gap into which the pressurized seal might otherwise extrude. As an added bonus, the back-up ring also reduces friction and wear by trapping lubricant in the vicinity of the seal.

In some cases, 90-durometer O-rings are used to resist extrusion. Be aware, however, that sealability often suffers even as friction and wear increase with use of such a hard material. A resilient 70-durometer nitrile seal with a 90-durometer or harder back-up ring is preferable. Bi-directional pressure will necessitate back-ups on both sides of the O-ring. Use of two back-ups (even if pressure is acting from only one side) also eliminates the possibility of installing a single back-up on the wrong side of the O-ring. Performance differences for seals with and without a back-up ring are shown in ***Figure 77***. As you can see, use of a back-up ring has clear advantages.

A CLEAR ADVANTAGE

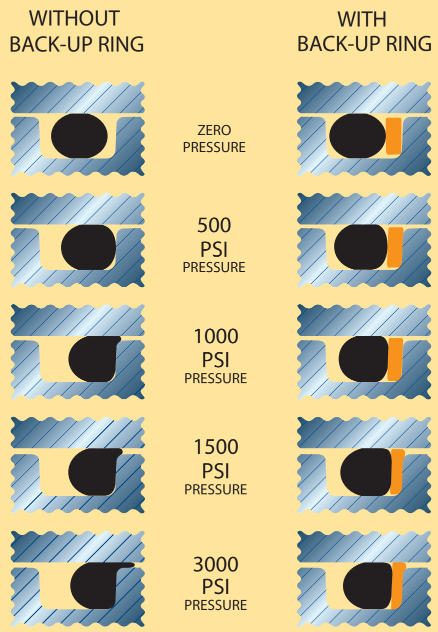


Figure 77: The Benefit of a Back-Up

Table 39 is included here as a general guide to help you determine if back-ups are necessary in a given application. Using the fluid pressure in your system (scaled

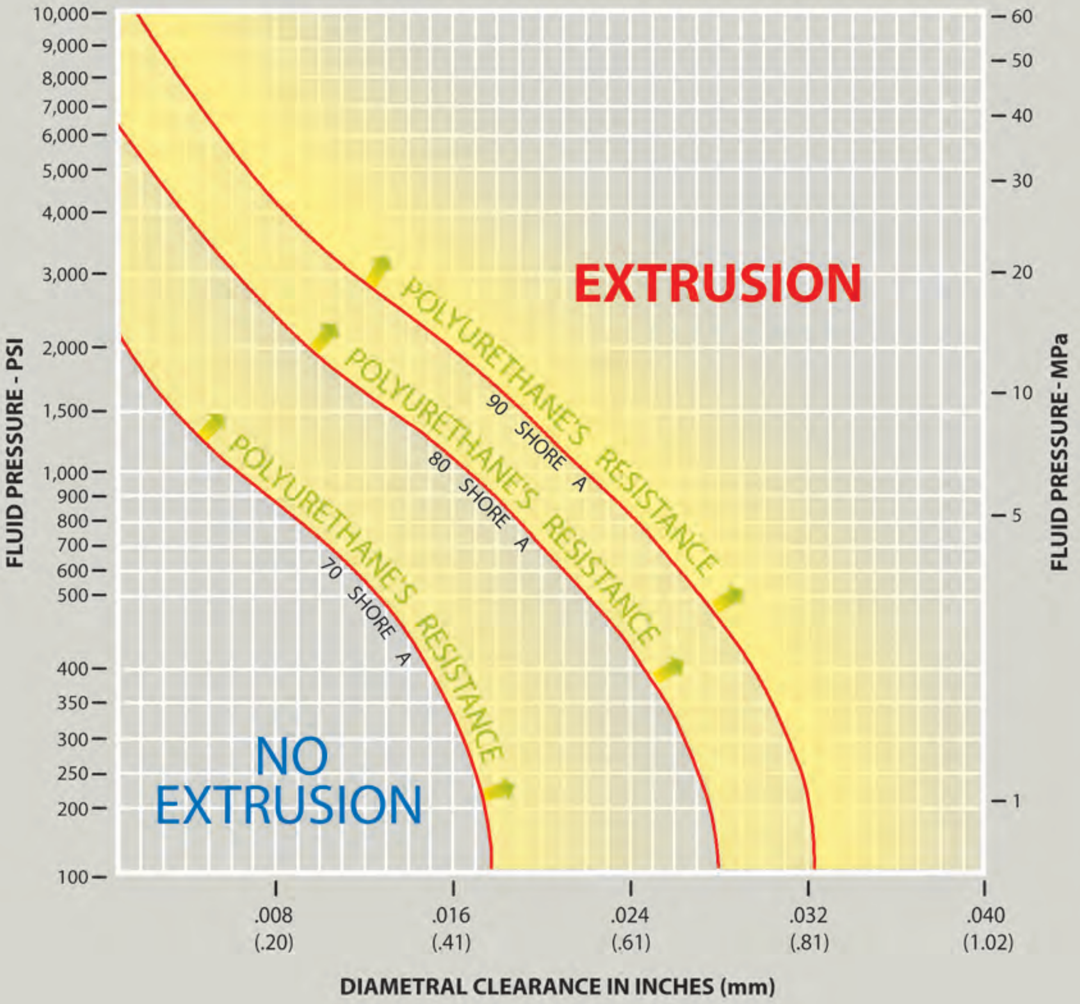


Table 39: Extrusion Curves

along the left of the graph in psi and along the right in MPa) and the diametral clearance of your design (scaled along the bottom in inches / millimeters), you can plot a point on the graph field. Using the line that corresponds to the durometer of your O-ring (e.g. 70 Shore A) as a reference point, you then note on which side of this durometer line the plotted point falls. If it falls to the left of the line, extrusion is not anticipated and no back-ups are necessary. If the point falls to the right, however, extrusion will likely be a problem and back-ups are recommended.

Though the information in ***Table 39*** is useful, there are a number of things to keep in mind when consulting this data. First, these are general curves based on medium shear modulus hydrocarbons (such as nitrile and EPDM). Higher shear modulus materials (such as polyurethane) will offer increased extrusion resistance, thus shifting the curve upward (as indicated by the yellow shading).

For example, a 70-durometer polyurethane can withstand much higher pressures than a lower shear modulus 70-durometer nitrile. Also, these curves are not applicable for silicone, fluorosilicone, and other low shear modulus materials. Second, these curves assume a moderate system temperature (160° F). As temperature increases, the tendency of most elastomers is to soften and thus be more easily extruded. Third, these curves also assume that the total diametral gap is concentric. If eccentricity occurs (due to severe side-loading or misalignment), the gap on one side will become larger, making extrusion on that side more likely.

Again, it is always a good idea to use back-ups with O-rings (or other seals) in pressures exceeding 1,500 psi or in designs featuring large clearance gaps. The additional cost of back-ups is small in comparison with the cost of tighter machining tolerances, and back-ups easily pay for themselves by both improving seal performance and prolonging seal life.

R.L. Hudson & Company offers back-up rings in a wide array of materials, including contoured hard rubber (nitrile or fluorocarbon/ Viton®), polyurethane, Hytrel®, PTFE (Teflon®), and engineering plastics. Polyurethane's inherent toughness, ability to withstand high pressure, and resistance to extrusion make it an excellent material for back-ups. Hytrel® is a thermoplastic elastomer combining toughness, resilience, and chemical resistance.

As shown in ***Figures 78 through 80***, Teflon® back-up rings come in three basic types: *solid* (uncut), *single turn* (also known as scarf cut, or split), and *multi-turn* (spiral cut). In addition to PTFE, back-ups are also available in PEEK (another high performance plastic) and in nylon (an engineering plastic).

TEFLON® BACK-UPS

Figure 78: Solid (Uncut)

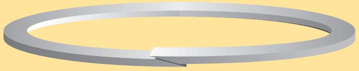


Figure 79: Single turn (Scarf Cut, or Split)

Figure 80: Multi-turn (Spiral Cut)

FRICTION

Simply defined, *friction* is the resistance to motion that develops when two objects are in contact. Friction must be minimized in order to reduce O-ring wear and prolong seal life. There are two main types of friction to be considered: break-out friction and running friction.

Also known as *static friction* or *stiction*, *break-out friction* is the static frictional force which must be overcome to initiate movement either at startup or after a period of inactivity. The amount or degree of break-out friction depends largely on how long the seal and the gland have been in contact. The longer the contact, the more of an opportunity the seal has had to flow into the gland's metallic micropores. A magnified view of what this interface between an O-ring and a mating surface might look like can be seen in ***Figure 81***. A combination of rubber-to-metal adhesion and the shearing force generated by the micropore irregularities must then be overcome before movement can begin.

POINT OF CONTACT

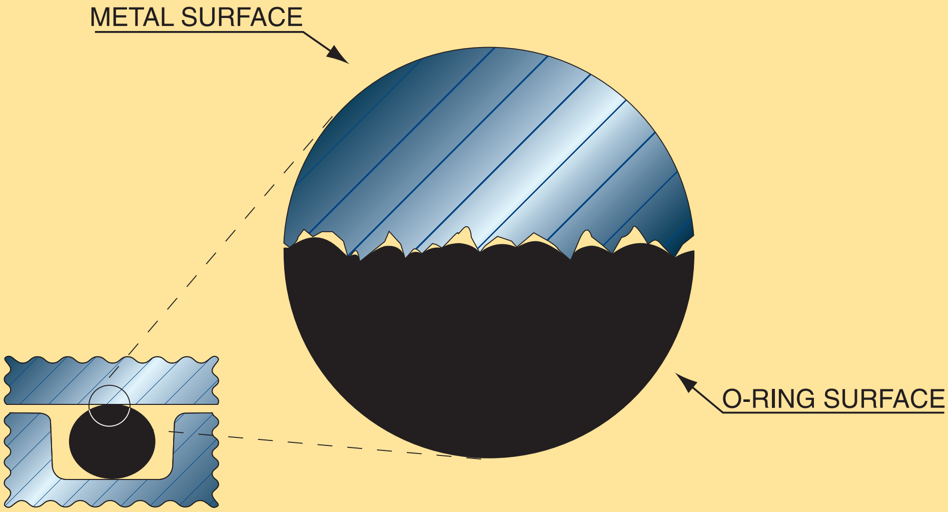


Figure 81: Interface Between O-Ring and Mating Surface

Running friction is the dynamic frictional force which must be overcome to maintain movement. Running friction is perhaps most problematic when soft metals (such as aluminum, copper, or brass) are in use. Other factors that affect both break-out and running friction include the hardness of the O-ring, the gland's surface finish, the amount of O-ring squeeze, the fluid temperature and pressure, and the amount and type of lubrication.

EXTERNAL LUBRICATION

One other environmental element that must always be addressed is the need for proper lubrication. As simple as it sounds, this really cannot be stressed enough. In almost any type of O-ring application, use of a proper lubricant — one that is chemically compatible with the seal, all system fluids, *and* all mating surfaces — is instrumental. This is true during both installation of the O-ring and its subsequent operation as a seal.

During installation, presence of a lubricant (such as oil or grease) simply helps ease the O-ring into place. You save both time and frustation. The chances of inadvertantly damaging the seal are also minimized. If you don't have to wrestle the O-ring into place, you're less likely to accidentally nick or cut the seal's surface. Lubrication helps seat static seals, and automated assembly would be impossible without the aid of some form of lubrication. But which form is best?

There are a variety of options. You can coat the outside of the O-ring with baked-on PTFE; this makes the seal super-slick. Or you can apply graphite, or even some molybdenum disulfide (MoS_2). But while such external treatments definitely help during installation, they don't last much beyond that point. "Moly" coatings rub off, and the baked-on PTFE soon flakes away.

Liquid lubricants are still another possibility. For example, International Products Corporation markets P-80, an emulsion formulated to provide temporary lubrication. Applied as a thin film on the surface of a rubber or plastic part, P-80 stays wet just long enough to allow the part to be installed.

But once the seal is successfully installed and the gland assembled, operational concerns take over. *Break-out* (startup) and *running* (dynamic) friction become the main concerns, especially in pneumatic equipment, plumbing devices, hydraulic valves and cylinders, or any application requiring manual operation. As during installation, surface treatments can help.

The most permanent surface treatment is *chlorination*, in which the O-ring elastomer (typically nitrile) is subjected to concentrated amounts of chlorine gas. This gas chemically attacks the seal's surface, simultaneously making it both harder (by a few durometer points) and more slippery.

Beneath the surface, the O-ring remains soft and resilient.

As a side effect of chlorination, the O-ring surface also develops numerous minute cracks. Because they are very small, however, these cracks will not impair the O-ring's sealability. These tiny cracks are actually advantageous in that they can act as reservoirs for secondary external lubricants, such as oils and greases.

While chlorination is particularly helpful in reducing running friction, the additional step of treating the seal's surface with oil or grease also facilitates installation and helps reduce break-out friction (otherwise known as static friction, or *stiction*). In addition, lubricants help protect the seal from oxygen and ozone damage. In vacuum applications, lubrication helps reduce the leak rate by filling in metal surface defects and O-ring micropores.

COMMON EXTERNAL LUBRICANTS

1. Hydrocarbon-based materials, such as petrolatum. As a clear to yellowish semisolid, petrolatum is better known as petroleum jelly (Vaseline®), but it is also available in liquid form. Petrolatum is typically suitable for use with nitrile (in hydraulic oils and fuels), chloroprene (in hydraulic oils and Freon®), polyurethane (in oils and fuels), silicone (general usage), fluorosilicone (in oils and fuels), and fluorocarbon (in hydraulic applications).

2. Silicone-based greases, such as Dow Corning DC-55, a general-purpose grease. Dow Corning offers a wide variety of silicone-based lubricants for use in vacuum and pneumatic applications, including DC-976, which is specially formulated for high vacuum applications.

3. Barium-based greases, which are intended for high temperature applications and/or applications requiring increased chemical compatibility. Barium greases are typically suitable for use with nitrile (in extreme conditions) and polyurethane (in heavy duty applications).

4. Other formulations, such as Celvacene® grease from Inland Vacuum Industries. Celvacene contains no silicone and is available in light, medium, and heavy viscosities. Specifically engineered for use in high vacuum pump applications, Celvacene is typically suitable for use with nitrile, chloroprene, and butyl.

INTERNAL LUBRICATION

Friction can also be reduced through use of internal lubricants. Internally-lubricated compounds have a friction-reducing agent homogeneously dispersed *directly into* their chemical structure. This dispersion of the lubricant is made at the time the elastomeric compound is initially mixed. Though the added lubricant does alter the compound, the elastomer's basic properties remain largely unchanged. An internally-lubricated nitrile is still nitrile; it is simply a special formulation of nitrile designed to minimize friction.

It may help you to think of internal lubrication as the end result of a planned incompatibility. By design, the added friction-reducing agent will *not* be chemically compatible with the base elastomer. This means that the agent will separate itself out and "bloom" up onto the O-ring's surface, as illustrated in ***Figure 82***. This continual blooming of the agent keeps the seal's exterior coated with lubricant, making the O-ring slippery and less inclined to stick during startup.

IN BLOOM

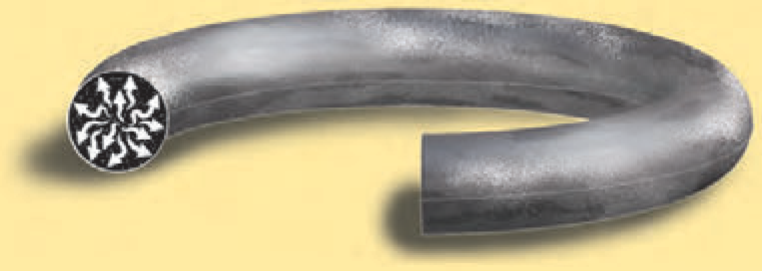


Figure 82: "Blooming" of the Internal Lubricant

It's also worth noting that lubrication can be either organic or inorganic. Widely used organic lubricants include amides (in both flake and pellet form), waxes, esters, powdered PTFE, and mineral oils. Inorganic agents include graphite (powdered and flake) and MoS_2. Whether organic or inorganic, the lubricant in use must be compatible with system fluids to avoid leaching (removal) of the agent, which can lead to dangerous degrees of seal shrinkage. The lubricant must also be compatible with all adjacent surfaces to avoid structural damage, such as graphite pitting of stainless steel.

Table 40 shows the results of abrasion and friction tests conducted on hydrogenated nitrile (HNBR) containing a number of widely used organic and inorganic lubricants. As shown, internal lubrication using organic oleamides offers

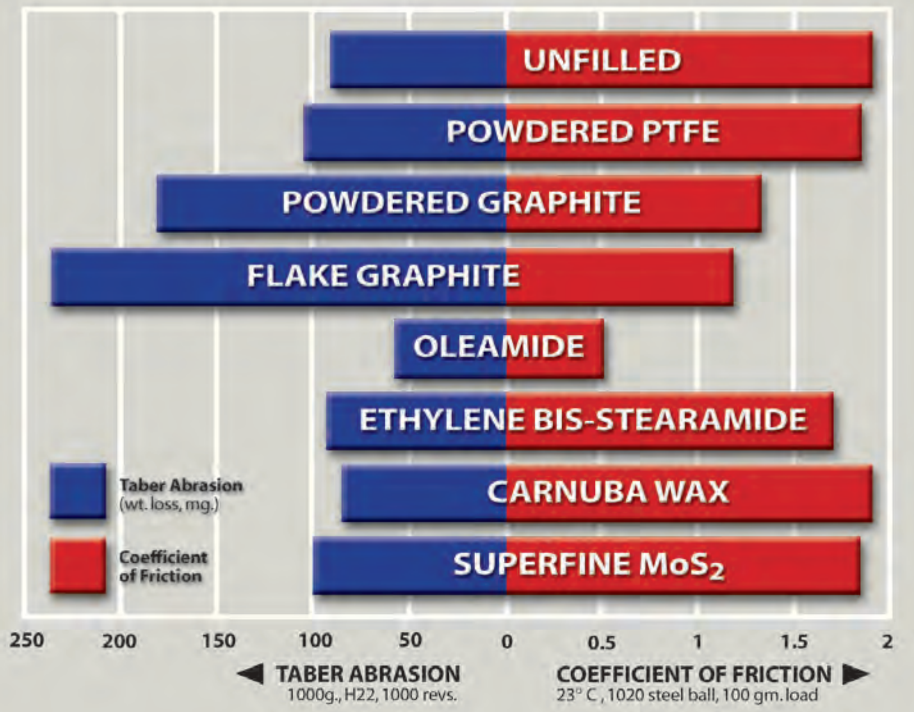


Table 40: Abrasion & Friction Testing Results for Lubricated HNBR

an outstanding blend of abrasion and friction properties. R.L. Hudson & Company is pleased to offer a series of internally-lubricated compounds utilizing oleamides (as well as compounds featuring MoS_2, graphite, waxes, and powdered PTFE). These compounds are available in a wide variety of products, including O-rings, U-cups, piston seals, and valve seats.

Once all the major environmental factors have been taken into consideration, due attention must still be paid to the actual physical space in which the O-ring will reside. With that in mind, let's take a closer look at the importance of proper gland construction next.

Construction.

Any seal design project must give due attention to the space in which the O-ring will reside, and here's where an important distinction should be made. Though sometimes used interchangeably when speaking of seal design, the terms "groove" and "gland" are not synonymous (see Figure 83). "Groove" refers specifically to the machined recess within a gland into which an O-ring is fitted. "Gland" is a more general term for the machined cavity which includes both the groove and the mating surface to be sealed. That said, choices as to the metal, surface finish, and shape of the gland and its groove must be made. It is also important to maintain cleanliness within the gland and not to damage the O-ring during installation or assembly.

> "Any seal design project must give due attention to the space in which the O-ring will reside."

METAL

The metal(s) in use must be hard enough to hold up under service conditions, especially in dynamic seals. Bronze, aluminum, brass, and other soft metals are not well suited for glandular use. Steel and cast iron are much better choices. Hard chrome plate, burnished, or honed surfaces are best. Though circumferential (crosswise) scratches on a cylinder or bore may not be problematic, surfaces must not have longitudinal (lengthwise) scratches.

"GROOVE" VS. "GLAND"

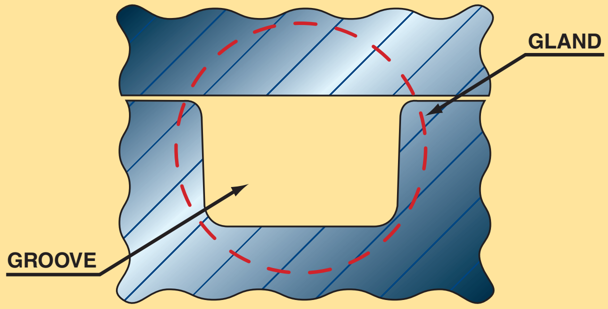


Figure 83: A "groove" is a machined recess within the "gland" cavity.

SURFACE FINISH

More than a singular concept, surface finish is really a function of four distinct factors. The most important factor is *roughness*, or the closely-spaced surface irregularities that result from manufacturing and/or cutting (as by tools or abrasive materials, see ***Figure 84***). These irregularities are typically measured in microinches (millionths of an inch) or micrometers (millionths of a meter). To make a topographic analogy, roughness is akin to a plowed field where the churned dirt forms countless small pockets in the topsoil.

The second factor is *lay*, or the direction of the primary roughness pattern (again, see ***Figure 84***). In other words, the way in which the surface irregularities are oriented. In terms of our analogy, lay would denote the particular pattern left in the dirt after it has been churned.

The third factor is *waviness*, or surface irregularities with considerably longer wavelengths than those referenced as roughness (see ***Figure 85***). Waviness irregularities can be caused by, among other things, machinery vibrations or material warping. If roughness is analogous to a plowed field, waviness can be thought of as a slowly rolling hill.

Flaws are the fourth factor that should be considered. Flaws are surface imperfections that occur only infrequently, i.e. not in a pattern (see ***Figure 86***). Flaws may be caused by inconsistencies within the metal itself, or through impact or abrasion after processing, as with scratches, cracks, etc. Depending on the severity, a single flaw may be enough to compromise the functionality of the surface. A flaw is like an isolated sinkhole or fissure in an otherwise unmarred plain.

THE FINISH LINE

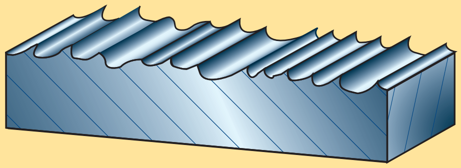


Figure 84: Roughness & Lay

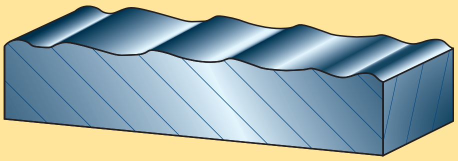


Figure 85: Waviness

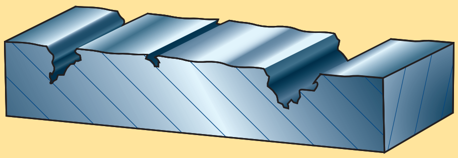


Figure 86: Flaws

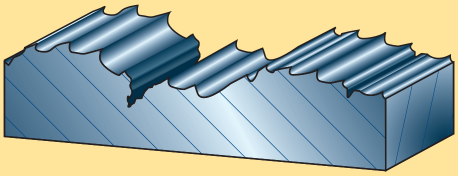


Figure 87: All Four Factors

The superimposition of these four factors onto one another determines the characteristics of a given surface (see ***Figure 87***). Roughness, lay, waviness, and flaws must all be measured to get a complete picture of the surface. The question then becomes: how best to reflect these measurements?

For many years, surface finish has been noted in terms of RMS, or Root Mean Square. As a mathematical concept, RMS is the square root of the sum of the squares of the individual surface irregularity readings taken over a given sampling distance. More simply, RMS reflects the average depth of the irregularities a seal may encounter across a gland surface. That is, the higher the RMS number, the greater the depth of these irregularities and the greater the likelihood that they will impede or damage the seal.

For example, *break-out friction* (also known as *static friction* or *stiction*) results when seal material flows into these tiny metallic irregularities during a period of no relative motion. The more time that the seal and the gland are in contact, the greater the interface between them, and the greater the break-out friction. A time-lapse look at the seal's progressive flow into the irregularities can be seen in ***Figure 88***. A combination of rubber-to-metal adhesion and the shearing force generated by the irregularities must be overcome before movement can begin. Smaller surface irregularities (as denoted by a lower RMS number) will allow for less interface with the seal material and thus decrease break-out friction, running friction, and wear.

GOING WITH THE FLOW

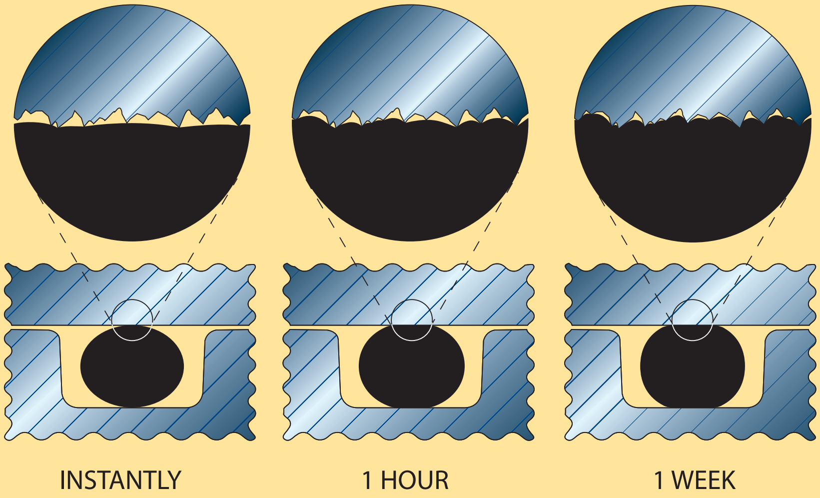


Figure 88: Progressive Flow of Seal into Surface Irregularities

A word of caution is in order here, however: RMS measurements are good as far as they go, but be aware that they deal solely in depth, ignoring both shape and direction. It is entirely possible to have a number of different types of surface irregularities that would all result in the same RMS measurement but would affect seal material in vastly different ways. Some examples of this can be seen in ***Figure 89***.

With this in mind, the optimal surface finish still depends on the application. Because they undergo no motion, most static seal surfaces need not be finished better than 32 microinches RMS. Some projects (e.g. low-pressure applications) may allow for surfaces as rough as 64 or even

128 microinches RMS. Due to increased friction and wear concerns, dynamic seals should have much smoother surfaces. Finishes of 8 to 16 microinches RMS are common for dynamic seals. As you might expect, smoother surfaces take longer to machine (and are more expensive) than rougher surfaces.

Keep in mind that there is not a fixed relationship between RMS measurements. In other words, a surface finish of 80 microinches is definitely rougher than a finish of 40 microinches, though not necessarily twice as rough. You should also be aware that, contrary to popular opinion, it is possible to have too much of a good thing; gland surfaces can be too smooth. The surface irregularities that contribute to frictional build-up are the same irregularities that entrap lubricating fluids. A finish of less than five microinches will essentially eliminate these metallic micropores, making the metal too smooth to hold on to lubrication. Friction will increase and the entire process will be for naught.

Experience has shown that traditional RMS measurements are not completely indicative of surface irregularities, so many manufacturers now use profilometers geared to generate "Ra" (roughness average) measurements. Ra is the sum of the absolute values of the peaks (above a median surface baseline) and the absolute values of the valleys (below this baseline) divided by the length of the sample (see ***Figure 90***). For example, let's say the peaks have a total absolute value of 23 microinches; the valleys have a total absolute value of 27 microinches. The sum of these values (50 microinches) divided by the sample length (we'll say two inches) yields an Ra value of 25 microinches. Since Ra measurements take into account both the peaks and the valleys in a given sample, many designers consider Ra results to be more indicative of surface irregularities than simple RMS figures.

ON THE SURFACE

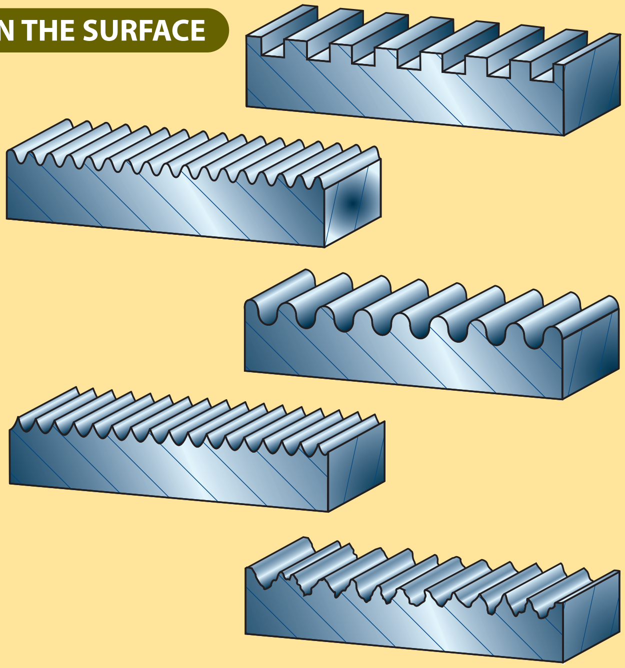


Figure 89: Differences in Surface Irregularities

"Ra" MEASUREMENT

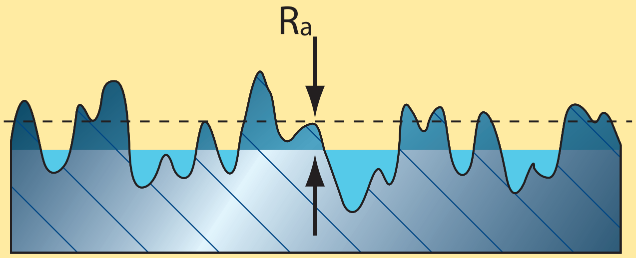


Figure 90: Roughness Average

SHAPE

The shape of the gland may be modified to suit the project's requirements, but typical rectangular grooves with straight sides help prevent O-ring extrusion and nibbling. Provided the seal pressure will not exceed 1,500 psi, a five-degree slope may be added to the sides of the groove to facilitate the machining process. *Radiusing* (rounding off) the internal recesses and top corners of the groove will eliminate sharp edges and further reduce the chances of damaging the O-ring during installation of the seal, assembly of the gland, or actual service (see ***Figure 91***).

Bear in mind that the O-ring will likely undergo changes (such as swell) during the course of its service life. For this reason, the minimum volume of the groove should exceed the maximum expected volume of the O-ring by at least 10%. This builds in a safety factor so the O-ring doesn't ever overfill the groove.

GETTING IN SHAPE

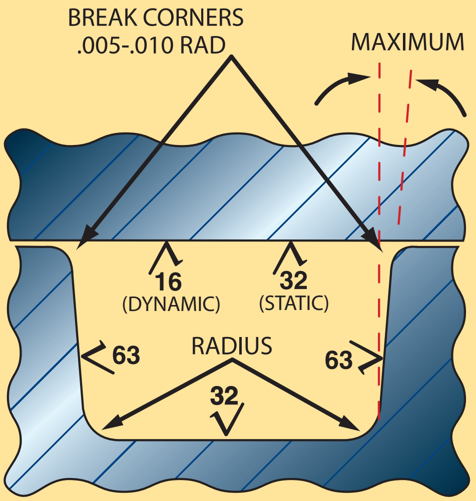


Figure 91: Surface Finish & Shape Suggestions

CLEANLINESS

Because any foreign bodies within a gland can potentially damage the O-ring or otherwise hamper the effectiveness of the seal, it is extremely important that you clean each of the elements before attempting assembly. Metal shavings, stray fibers, wire, dirt, grit, sand, dust, or other particulate matter must be completely removed from the groove and all other surfaces within the gland before the O-ring is installed. Use of a cleaning agent (which is, of course, chemically compatible with all of the seal elements) may prove helpful. Failure to thoroughly clean the seal environment prior to O-ring installation can quickly negate all the time and energy put into design and construction.

The O-ring itself should also be free from any and all contaminants. The "better safe than sorry" rule applies here. You should always avoid using seals that have fallen on a dirty surface (such as the floor or a countertop) or been in contact with unclean articles (such as used shop rags or dusty storage bins). In addition, the system fluid(s) should be filtered prior to use if you suspect any possible contamination. Continuous careful monitoring of the seal and all aspects of its environment will pay dividends by preventing unexpected shutdowns and costly delays.

Cleanliness is perhaps most important when using a seal material (such as silicone or Teflon®) that has inherently poor tear resistance. An undetected piece of metal or wire can nick or cut the O-ring surface during installation. For materials lacking in tear resistance, relatively minor surface damage can quickly become a major tear during service.

O-RING INSTALLATION & GLAND ASSEMBLY

Even if the edges of the groove have been radiused and the gland thoroughly cleaned, other dangers still exist. The O-ring may have to move across threads, slots, burrs, or other hazards while being installed. In such cases you should place a sleeve, piece of tape, or other buffer between the O-ring and the abrasive surface(s). Beveled-edge chamfers built into the gland design can also assist O-ring placement.

If installation tools are used, care must be taken to avoid damaging the O-ring and prematurely dooming the seal. As a rule, hard and/or sharp instruments should not be used, as they are much more likely to nick or puncture the seal. A common type of damage is "skiving," or slicing of a seal's surface (see ***Figure 92***). This can be done by either tools or gland edges and may not become apparent until operation begins. (For more on installation damage, see ***page 262***.) Don't forget that lubrication is also an essential installation "tool." Lubrication may be added separately or built into the seal, either as an external treatment or an internal lubricant. Any lubrication must be compatible with all other seal elements.

SEAL "SKIVING"

Figure 92: Installation Damage

As a general rule, the O-ring's I.D. should not be stretched more than 100% during installation. If smaller seals require more than 100% stretch, they should be allowed time to regain their normal size before the gland is shut. Twisting or folding the O-ring may also contribute to spiral failure and should be kept to a minimum. Recall that final resting (service) I.D. stretch should not exceed 5% so as not to compromise the seal's longevity. The gland itself should be closed with a simple longitudinal motion, without any unnecessary oscillation or rotation that could roll or pinch the seal. You must also exercise due caution during post-use O-ring extraction if the seal is to be reused.

Static Seals.

After considering the factors that generally affect all O-ring seals, you must also think about your specific type of application. O-ring seals fall into two main application categories: static and dynamic. Static seals exist where there is no relative motion between the mating surfaces being sealed. Both static and dynamic seals engender their own unique concerns. Relatively-speaking, however, static seals are easier to design because they can handle wider tolerances, rougher surface finishes, and higher pressure limits. There are four major types of static seals:

> **"Static seals exist where there is no relative motion between the mating surfaces being sealed."**

STATIC RADIAL SEALS

Static radial seals are formed when squeeze (compression) is applied to the inside diameter (I.D.) and outside diameter (O.D.) of the O-ring. Cap and plug type configurations commonly utilize radial seals. An example of a static radial O-ring seal for a male gland is shown in ***Figure 93***. A static radial O-ring seal for a female gland is shown in ***Figure 94***.

RADIAL

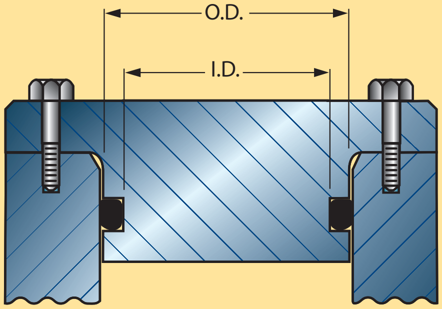


Figure 93: Static radial seal, male gland.

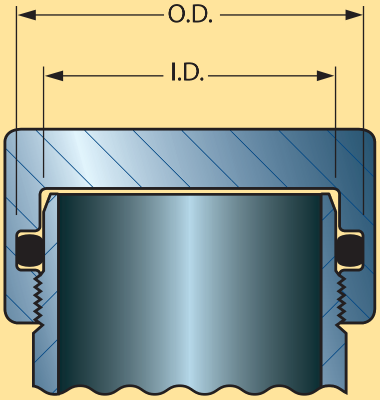


Figure 94: Static radial seal, female gland.

STATIC AXIAL (FACE) SEALS

Static axial seals (also known as face seals) are formed when squeeze is applied to the top and bottom surfaces of the O-ring. Axial seals are most often used in face (flange) type designs where an O-ring seats against the groove's low-pressure side. A static axial O-ring seal (internal pressure) is shown in ***Figure 95***. A static axial O-ring seal (external pressure) is shown in ***Figure 96***.

AXIAL

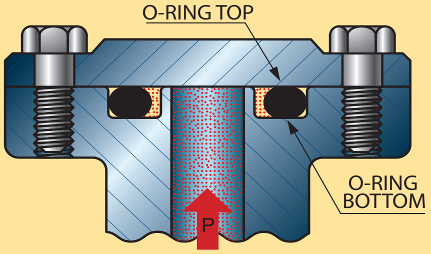


Figure 95: Static axial seal, internal pressure.

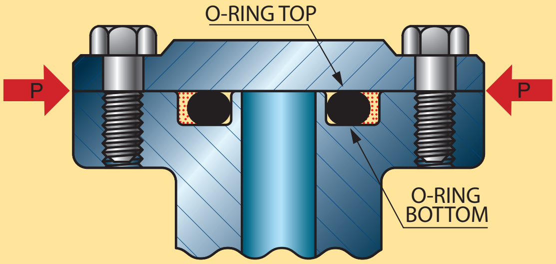


Figure 96: Static axial seal, external pressure.

STATIC SEALS WITH "DOVETAIL" GROOVES

Dovetails are face type designs that have been customized to form static seals by structurally immobilizing the O-ring within the gland. Dovetails are more expensive and difficult to design and install than the other types of static seals. A dovetail seal is shown in ***Figure 97***.

DOVETAIL

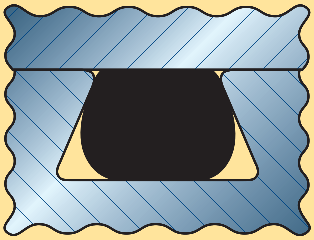


Figure 97: Dovetail Seal

STATIC CRUSH SEALS

Static crush seals use a male cover with a machined 45° angle to "crush" an O-ring into the corner of a triangular gland. Because the resulting distortion to the O-ring is permanent, it cannot be reused later. An example of a static crush seal is shown in ***Figure 98***.

CRUSH

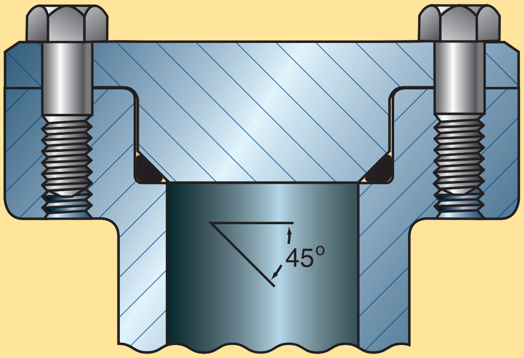


Figure 98: Static Crush Seal

Dynamic Seals.

In contrast to static seals, dynamic seals exist where there *is* relative motion between the mating surfaces being sealed. In most instances, the dimensional variations inherent in dynamic seals make them more difficult to design and more expensive to construct than static seals. Nevertheless, dynamic O-ring seals are indispensable to a wide variety of applications. Here's a closer look at the major types of dynamic seals:

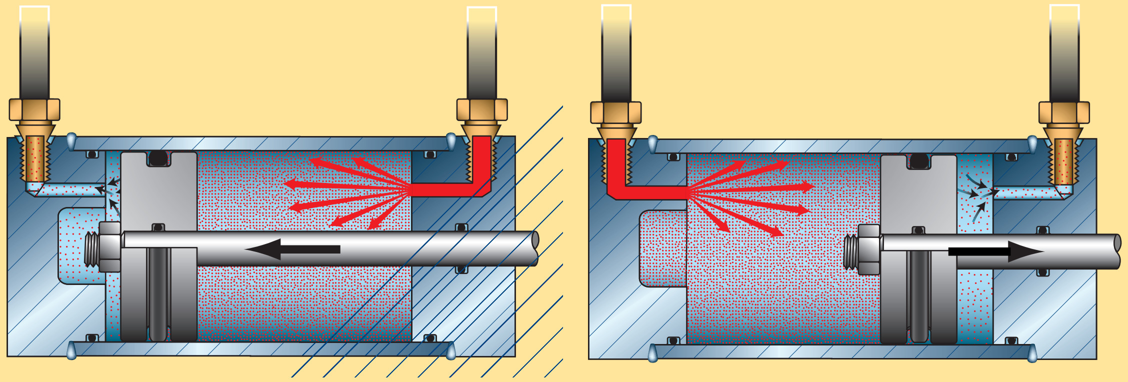
"Dynamic seals exist where there is relative motion between the mating surfaces being sealed."

RECIPROCATING SEALS

Reciprocating seals involve relative reciprocating motion along the shaft axis between the inner and outer elements. In reciprocating seal applications, the O-ring slides or rocks back and forth within its gland with the reciprocating motion.

Reciprocating seals are most often seen in cylinders and linear actuators. Some examples of reciprocating O-ring seals are shown in ***Figures 113 and 114***.

RECIPROCATING



Figures 113 and 114: Reciprocating O-Ring Seals

FLOATING PNEUMATIC PISTON SEALS

Floating pneumatic piston seals are reciprocating in nature, but the way in which the seals are effected is unique. Normal reciprocating designs rely on the O-ring being stretched over a piston and then squeezed radially (on the inside diameter, or I.D., and the outside diameter, or O.D.).

In floating O-ring designs, however, there is no radial squeeze on the seal's cross-section. The O-ring's O.D. is larger than the cylinder bore diameter. Peripheral squeeze is applied to the O.D. as the O-ring is installed into the bore. Incoming air pressure forces the O-ring against the groove wall, and a seal is effected as shown in ***Figure 115***.

Floating designs offer a number of advantages, including greatly reduced breakout friction and longer seal life. Floating pneumatic piston seals are suited for applications in which the air pressure does not exceed 200 psi (or in hydraulic designs where a small amount of leakage is permissible). Floating O-rings are NOT suitable as rod seals. Please note that there is a separate design table (***Table 50***) and dimensional table (***Table 51***) for floating pneumatic applications.

FLOATING PNEUMATIC

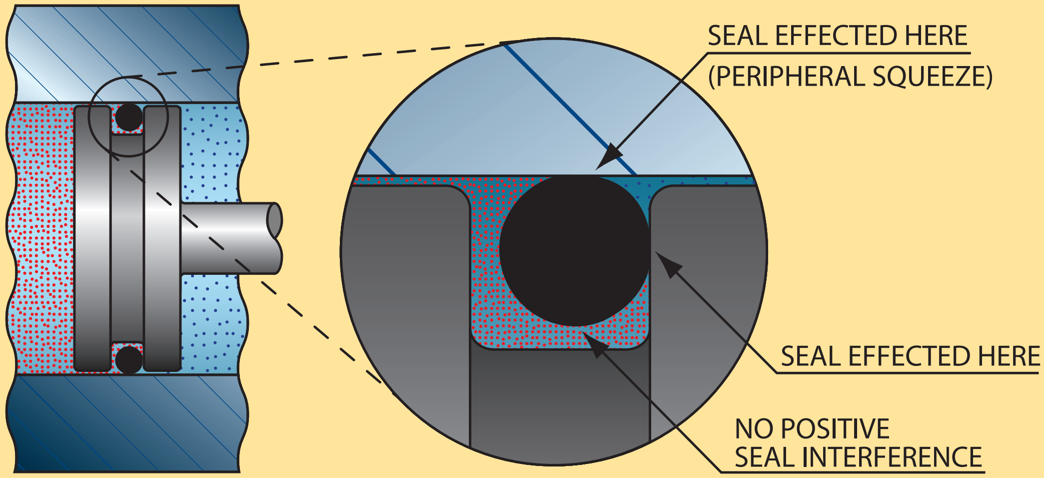


Figure 115: Floating Pneumatic Piston Seal

ROTARY SEALS

Rotary seals involve motion between a shaft and a housing. Typical rotary seals include motor shafts and wheels on a fixed axle. Installation of a rotary O-ring seal is shown in ***Figure 116***.

R.L. Hudson & Company recommends lip type shaft seals for most rotary applications. There are applications, however, where an O-ring will provide an effective rotary seal.

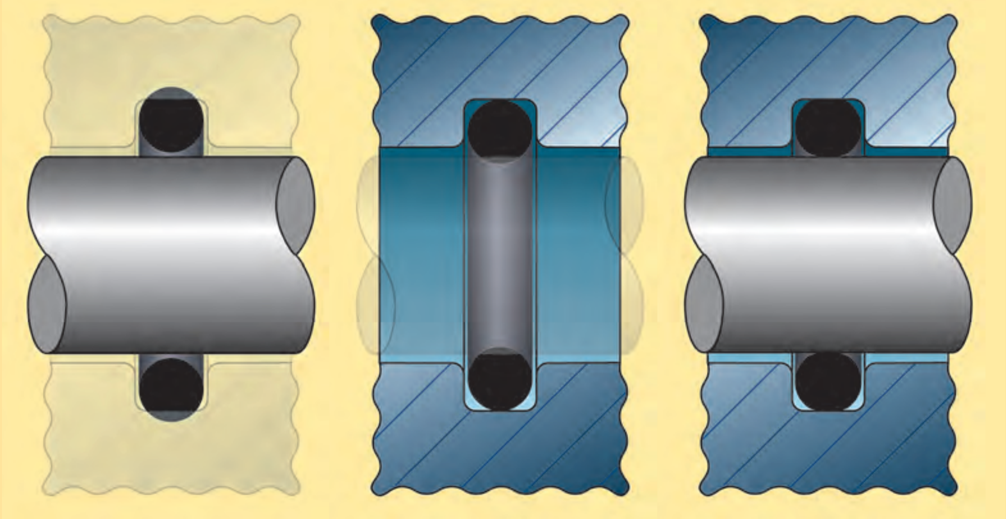
O-ring seals are NOT recommended for rotary applications under the following conditions:

- Pressures exceeding 800 psi.
- Temperatures lower than -40° C (-40° F) or higher than 107° C (225° F).
- Surface speeds exceeding 600 feet per minute (fpm).

Note: Feet per minute = .2618 X shaft diameter (inches) X rpm

When an elastomer is stretched and heated, it will contract. This is called the Gough-Joule effect (see ***page 88***). This is an important design consideration in a rotary application because if an O-ring is installed in a stretched condition, frictional heat will cause the O-ring to contract onto the shaft. This may cause the O-ring to seize the rotating shaft so that the dynamic interface becomes the O-ring O.D. and the groove I.D. The contraction will also cause more frictional heat, further exacerbating the situation and causing premature failure of the O-ring.

ROTARY



O-ring in free state relative to shaft & housing.

O-ring installed in housing without shaft installed.

O-ring installed in housing with shaft installed.

Figure 116: Installation of a Rotary Seal

We designed our rotary O-ring seals so that the free O-ring I.D. is larger than the shaft onto which it fits. The gland I.D. is smaller than the free O-ring O.D. so that when it is placed into the gland, the O-ring is peripherally squeezed, and the I.D. is reduced so that a positive interference exists between the O-ring I.D. and the shaft. Because the O-ring is not in a stretched condition, it will not build up heat, seize the shaft, and rotate in the groove.

Rotary seals (such as the one shown in ***Figure 117***) do not dissipate heat as well as reciprocating seals do, so provisions must be made to keep heat build-up to a minimum.

- The housing I.D. should not be used as a bearing surface.
- Bearings should be provided to ensure that the shaft runout does not exceed .002" T.I.R.
- The O-ring groove should be located away from the bearing and close to the lubricating fluid.
- The housing length should be 8 to 10 times the O-ring cross-section to provide for better heat transfer.

To prevent extrusion of the O-ring, we recommend the clearance gap (extrusion gap) to be no more than .005" per side. If pressures greater than 800 psi are encountered, it is recommended that an 80 durometer O-ring be used.

The minimum hardness for the section of shaft that comes into contact with the O-rings is Rockwell C30. To prevent excessive wear, scratches, nicks, and handling damage, a hardness of Rockwell C45 is recommended. A shaft finish of 10-20 micro-inches is recommended, and plunge grinding with no machine lead is the preferred finishing method. The shaft ends should be chamfered with a 15/30° chamfer to prevent installation damage.

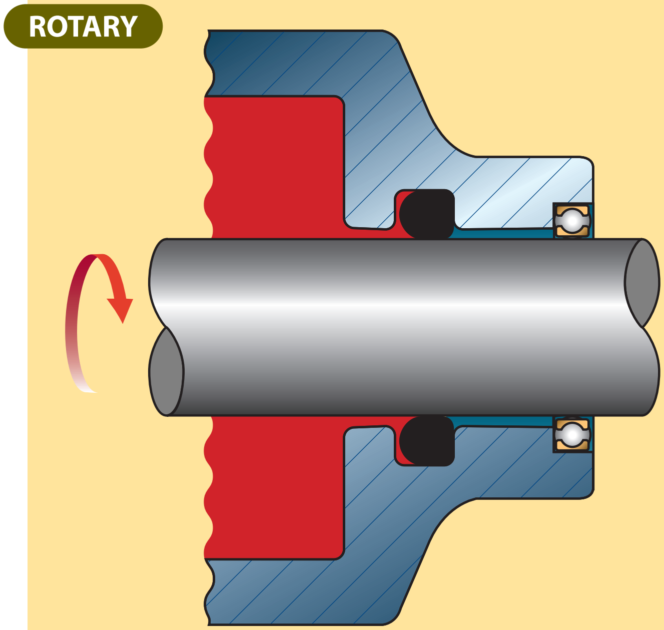


Figure 117: Rotary O-Ring Seal

OSCILLATING SEALS

Oscillating seals are commonly used in faucet valves. In oscillating applications, the shaft or housing rotates back and forth through a limited number of turns around the axis of the shaft. An oscillating O-ring seal is shown in ***Figure 118***.

Because the surface speed in oscillating seals is so slow, reciprocating design charts are used.

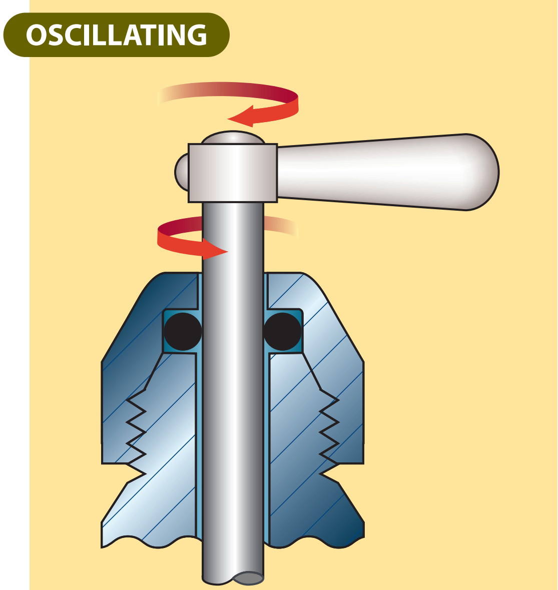


Figure 118: Oscillating O-Ring Seal

Common Causes.

As should be clear by now, designing a seal and selecting a material that will function well in its environment are far from simple tasks. Even experienced seal engineers are often met with unusual service requirements that test both their ingenuity and the capabilities of the seal. Whether your sealing needs are simple or complex, the factors to be considered are numerous enough to guarantee that not every seal will be successful in every application.

When O-rings do fail, the cause can generally be traced back to a handful of usual suspects. These include use of an incorrect O-ring size, non-compatibility between the seal and its environment, installation error, and lack of proper lubrication. All of these dangers were discussed in previous sections of this design guide.

A fifth common culprit is improper gland design. Since the correct amount of O-ring squeeze is vital to a seal's longevity, a design that allows for either not enough compression or too much compression is problematic. A gland that does not provide enough room for the seal to undergo normal expansion is equally troublesome. Since the various elements of any seal design each carry their own tolerances, these potential deviations must be incorporated into the design calculations.

An improper design can often be spotted by calculating the *tolerance stack-up* (also known as tolerance build-up, see ***Table 54***). Let's say, for example, that an O-ring cross-section has a tolerance of ± 0.003". This means that the cross-section may actually be either 0.003" larger or 0.003" smaller than the stated measurement, thus creating a 0.006" tolerance range. In the same design, the groove diameter has its own tolerance of ± 0.001" (a 0.002" range), and the bore diameter also has a tolerance of ± 0.001" (again, a 0.002" range). The sum total of these three tolerance ranges (in this case, 0.006" plus 0.002" plus 0.002", or 0.010") is the total tolerance stack-up for this particular seal.

> **"Whether your sealing needs are simple or complex, the factors to be considered are numerous enough to guarantee that not every seal will be successful in every application."**

Keep in mind that there is no "magic number" when it comes to tolerance stack-up. While 0.010" might be an acceptable stack-up tolerance for one application, this same total in a different design may result in either too little or too much O-ring compression, and, ultimately, seal failure. It is also important to realize that as the overall size of a seal decreases, the importance of even the slightest tolerances increases. In other words, the smaller the space in question, the less "elbow room" you have.

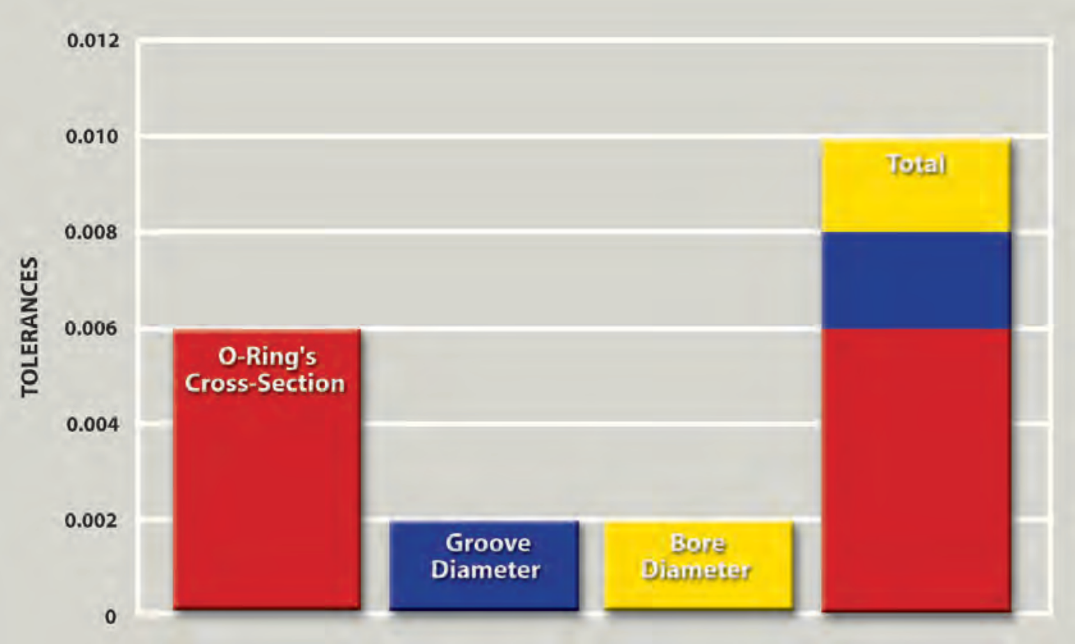


Table 54: Tolerance Stack-Up

Many times there is not just a single cause for seal failure. Rather, a combination of factors often act in unison to damage the O-ring and doom the seal. These causes should be looked at individually, however, before any interaction among factors can be fully understood. With that in mind, what follows are separate discussions of the most common causes of O-ring failure.

Abrasion.

Failure due to abrasion is most likely to occur in dynamic seals. The surface of the O-ring in dynamic contact with the mating part gradually becomes worn and flattened. Wear lines parallel to the direction of movement are often visible within this flattened area. While flattening on one side of an O-ring's cross-section is indicative of abrasion failure, flattening on both sides is an indication of compression set. For more information on compression set, see page 256.

Directly or indirectly, improperly finished metal surfaces usually contribute to abrasion failure. Surfaces that are too rough (generally greater than 32 microinches RMS for static seals or 16 microinches RMS for dynamic seals) directly abrade the seal material. Surfaces that are too smooth (less than 5 microinches RMS) lack the necessary pockets or cavities that act as reservoirs for lubrication. Either way, the O-ring suffers. ***Figure 128*** is an illustration of O-ring failure due to abrasion.

Even if the surface finish is correct, failure to keep the seal properly lubricated will lead to abrasion problems. Lubrication concerns can often be alleviated through the use of either internally lubricated or surface-treated O-rings. For more information on O-ring lubrication, see ***page 188***.

Also keep in mind that abrasive contaminants in the system fluid(s) can damage seals and should be excluded and/or filtered out. Polyurethane, carboxylated nitrile, and hydrogenated nitrile all offer increased abrasion resistance.

"The surface of the O-ring in dynamic contact with the mating part gradually becomes worn and flattened."

ABRASION

Figure 128: Failure Due to Abrasion

Compression Set.

Failure due to compression set occurs in both static and dynamic seals. Compression set failure looks similar to abrasion failure, in which there is a flattening on one side of the O-ring's cross-section. With compression set, this permanent flattening of the cross-section can be seen on both sides of the O-ring at the original points of compression. The seal usually hardens and assumes the shape of the gland. In some instances, surface cracks may also be visible.

> **"This permanent flattening of the cross-section can be seen on both sides of the O-ring at the original points of compression."**

At the most basic level, use of an elastomer with inherently poor compression set properties or a compound that has not been properly cured can doom a seal. Even if materials are initially acceptable, the aforementioned O-ring hardening (and an accompanying loss of elasticity) can be caused by temperature increases during service. These thermal increases can be frictional (i.e. as a result of the buildup of friction-generated heat), environmental (as a result of external elements), and/or systemic (as a result of system fluids).

A limited degree of fluid-induced volume swell may help offset the effects of compression set. On the other hand, some fluids may cause excessive swell, which can exacerbate compression set. The excessive squeeze generated by improperly designed glands or adjustable glands that are overtightened can also be problematic. ***Figure 129*** is an illustration of O-ring failure due to compression set.

COMPRESSION SET

Figure 129: Failure Due to Compression Set

Materials offering improved compression set properties include peroxide-cured nitrile, peroxide-cured EPDM, hydrogenated nitrile, ethylene acrylic (Vamac®), fluorocarbon (Viton®), fluorosilicone, silicone, and natural rubber.

Dieseling.

Failure due to dieseling can occur in hydraulic systems. Dieseling occurs when air becomes trapped in the hydraulic fluid. Problems arise during high pressure situations when the gas becomes compressed, with a resulting increase in temperature.

If the hydraulic fluid (or lubricating fluid) is flammable, the increasing temperature can reach the combustion point, setting off a series of miniature explosions. As a result of these explosions, the seal is burned, leaving it with a black, charred appearance and burned surface pits. ***Figure 130*** is an illustration of O-ring failure due to dieseling.

"The seal is burned, leaving it with a black, charred appearance."

DIESELING

Figure 130: Failure Due to Dieseling

Explosive Decompression.

Also known as gas expansion rupture or O-ring embolism, explosive decompression is a major risk for any seal operating in a high-pressure gas environment. Gas can get trapped inside the seal's micropores. If the seal faces an equilibrium shift (as with rapid decompression), this trapped gas rapidly expands in an effort to match external pressure.

"Explosive decompression is a major risk for any seal operating in a high-pressure gas environment."

The amount of structural damage done to the O-ring as a result of this internal expansion depends on the volume of the trapped gas and the hardness of the seal. Smaller volumes (especially in soft compounds) may only cause surface blisters which can disappear as pressure equalizes. Larger volumes (particularly in hard compounds) can cause deep cross-section ruptures or even total O-ring disintegration. Higher temperatures further aggravate this phenomenon. ***Figure 131*** is an example of O-ring failure due to explosive decompression.

One way to prevent explosive decompression is to allow for longer decompression periods. Trapped gas can exit the elastomer more slowly, minimizing the chances for damage. Use of seal materials in excess of 80 Shore A may also be helpful. Harder, high shear modulus seals have the strength to dissipate fracture energy as it propagates through the O-ring. Smaller cross-sections offer less space in which gas can become trapped.

EXPLOSIVE DECOMPRESSION

Figure 131: Failure Due to Explosive Decompression

Generally speaking, carbon dioxide (CO_2) is more likely to cause elastomer swell and rupture than nitrogen. For CO_2 contact, as in air guns, polyurethane is by far the best choice. For seals facing nitrogen and other pressurized gases, high-ACN content nitrile may be a solution. In some cases, you might consider soaking the seal in specific oils (such as MIL-H-5606) prior to use. The oil fills the spaces that might otherwise be filled by gas.

Extrusion & Nibbling.

Elevated system pressure can sometimes forcibly extend, or extrude, part of an O-ring into the gland's diametral clearance gap. The extruded portion of the seal is susceptible to being chewed away to the point of failure. Even if permanent extrusion is avoided, small bits may still be "nibbled" away from the low-pressure side of the seal.

This nibbling is the result of pressure fluctuations within the system. Increasing pressure expands metal components, often enlarging the clearance gap. The larger the gap, the easier it is for the O-ring to flow into it. When pressure later returns to normal, the O-ring's memory allows it to regain its original shape, but it does not evacuate the retracting gap before a small chunk is torn away. Repeated instances of this nibbling can lead to seal failure. Though extrusion and nibbling are most often seen in dynamic rod or piston seals, static seals facing high pressure pulsations may also suffer. ***Figure 132*** is an example of O-ring failure due to extrusion and nibbling.

No matter what the application, excessive system pressure will obviously increase the likelihood of seal extrusion, especially if no back-up rings or other anti-extrusion devices are employed. Even if they don't increase under pressure, clearance gaps that are inherently too large or irregularly shaped are dangerous. O-rings that are too soft or too large for the gland (either initially or after swelling in system fluid) are to be avoided. Temperature increases can also soften O-rings and make them more susceptible to extrusion. Sharp edges within the gland will be problematic and should be radiused to .001" to .002". Use of polyurethane O-rings and/or back-up rings is suggested to avoid both extrusion and nibbling.

"The extruded portion of the seal is susceptible to being chewed away to the point of failure."

EXTRUSION & NIBBLING

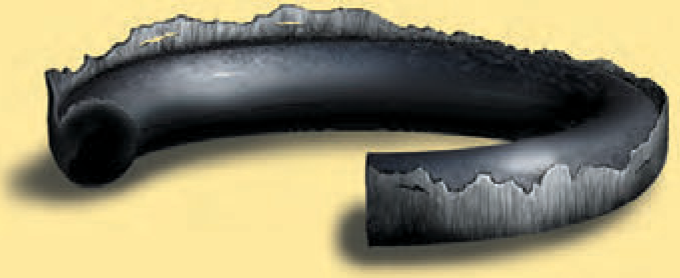


Figure 132: Failure Due to Extrusion & Nibbling

Hardening & Embrittlement.

Occurring in both static and dynamic seals, O-ring hardening is chiefly caused by exposure to high temperatures. Hardening results when exposure extends for a period sufficient to 1) cause additional cross-linking among the material's macromolecular chains, 2) evaporate plasticizers in the compound, and 3) promote oxidation. Hardening of an O-ring in service dramatically reduces its resilience, and, as a result, severely limits its ability to act as an effective seal.

Unwanted cross-linking of the rubber can also be caused by chemical attack. For example, sulfur-containing compounds can cause nitrile rubber to cross-link. Amine exposure will lead to cross-linking and hardening in fluorocarbon elastomers.

Progressive hardening of the seal has two phases: surface cracking and/or pitting, followed by hardening of the entire cross-section. Compressed seals will also undergo high degrees of compression set as they harden. ***Figure 133*** is an example of O-ring failure due to hardening.

Lowering the system's operating temperature will help avoid or correct this problem. Use of materials that can withstand higher temperatures and that are resistant to chemical attack will also be beneficial.

"Hardening of an O-ring in service dramatically reduces its resilience, and, as a result, severely limits its ability to act as an effective seal."

HARDENING

Figure 133: Failure Due to Hardening

Hole Crossing Damage.

A problem seen in dynamic seals, hole crossing damage is a clipping, or shearing away, of part of the pressurized O-ring's exterior where it crosses a hole or pressure port in a mating surface. It can be caused when the edges of the hole are sharp and / or when differential pressure has unseated the O-ring from its groove, allowing the edge of the hole to clip the O-ring as it crosses. Regardless of the cause, the shearing of the seal compromises the O-ring and leads to immediate failure.

Ideally, the design should be such that the pressurized seal does not have to pass over a groove, port, or hole during service. Barring that, hole crossing damage can generally be avoided by chamfering the edges of the hole in advance. Use of chamfering and correct radiusing will help ensure the O-ring is correctly guided back into its normal squeeze mode as it finishes crossing the hole.

Tough, cut-resistant polyurethane seals should be considered for applications where hole crossing damage may occur. Reducing or eliminating differential pressure will also help lessen hole crossing damage. Concave back-up rings can help restrain the O-ring in its groove to prevent hole crossing damage. Composite rubber-bonded-to-metal seals also prevent the rubber from flowing into the hole as the seal passes by. ***Figure 134*** is an example of O-ring failure due to hole crossing damage.

"The shearing of the seal compromises the O-ring and leads to immediate failure."

HOLE CROSSING DAMAGE

Figure 134: Failure Due to Hole Crossing Damage

Installation Damage.

As should be clear, care must be taken during the installation of each and every O-ring in order to avoid damaging the seal and limiting its effectiveness. All of the care taken in selecting the most effective O-ring material or designing the most efficient seal can be negated by careless installation practices.

Admittedly, however, some environments are more inherently hostile to O-rings than others. Situations most conducive to installation damage include either static or dynamic seals in which the squeeze is between the O-ring's inside diameter (I.D.) and outside diameter (O.D.), as well as seals in which the O-ring must fit over tube ends or threads.

Installation damage can be seen in the form of surface "skiving," clean cuts made by metal components. Damage may also involve twisting or puncturing the seal. ***Figure 135*** is an example of O-ring failure due to installation damage.

Though it sounds simplistic, consistently careful use of correctly-sized and adequately-lubricated O-rings can eliminate many installation errors. Beyond that, all sharp gland edges should be radiused prior to installation. Threads should be covered with tape or other buffer elements during installation. A 15° to 20° lead-in chamfer is also advisable. Cleanliness of the installation area will reduce the chances of particulate damage. Proper use of any necessary installation tool(s) will save both time and money.

> **"All of the care taken in selecting the most effective O-ring material or designing the most efficient seal can be negated by careless installation practices."**

INSTALLATION DAMAGE

Figure 135: Failure Due to Installation Damage

Plasticizer Extraction (Shrinkage).

Plasticizer extraction can affect all seals, especially those used in fuel systems. Plasticizer is initially added to an O-ring compound in order to augment its flexibility and resilience. If plasticizer is extracted (chemically removed) by system fluids, the seal's flexibility and resilience both suffer. The O-ring hardens, small cracks start to appear in the stressed area of the cross-section, and the seal's overall volume decreases.

This loss of volume (shrinkage), coupled with the aforementioned hardening, is typically accompanied by a loss in retained sealing force, i.e. the seal will leak. The best available solution is to use a seal material that is still compatible with all elements of the system but that contains little or no extractable plasticizer. ***Figure 136*** is an example of O-ring failure due to plasticizer extraction.

> **"If plasticizer is extracted (chemically removed) by system fluids, the seal's flexibility and resilience both suffer."**

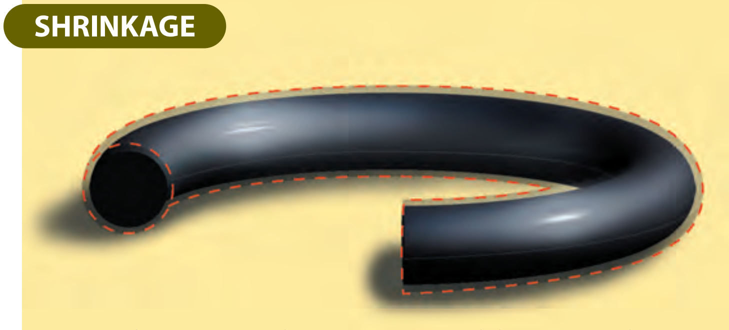


Figure 136: Failure Due to Plasticizer Extraction

Spiral Failure.

As the name implies, spiral failure results when the O-ring develops spiral surface cuts. These cuts typically recur at regular intervals along the seal's exterior. At its most basic level, spiral failure results from instability of the seal, which is unable to adequately hold its intended position within the gland. Generally seen in long-stroke hydraulic or pneumatic (piston and rod) seals, spiral failure is most likely to occur in O-rings with a large inside diameter (I.D.) to cross-section (W) ratio.

This is because the O-ring doesn't have enough strength to resist the twisting forces that naturally develop during dynamic movement. Part of the O-ring rolls as part of it slides, and this spiraling motion causes the cross-section to be twisted and cuts to develop on the seal's surface.

Other factors that may also contribute to spiral failure include uneven surface finishes, lack of proper lubrication, and installation error. ***Figure 137*** is an example of O-ring failure due to spiraling.

Possible solutions to spiral failure include using 1) as large a seal cross-section as possible, 2) harder compounds, 3) smoother surface finishes, and 4) lubrication. In some cases, it may be preferable to use an alternate seal cross-section that will be more stable within the gland. For more information on O-ring alternatives, see "Exploring Other Options" beginning on ***page 267***.

"Spiral failure results from instability of the seal, which is unable to adequately hold its intended position within the gland."

SPIRAL FAILURE

Figure 137: Failure Due to Spiraling

Weather & Ozone Cracking.

Exposure to ozone (O_3) and other atmospheric contaminants can cause tiny cracks to form on the O-ring's surface. Running perpendicular to the direction of stress, these cracks are visible evidence of the fact that ozone weakens the O-ring compound by attacking unsaturated (double) bonds and breaking apart the polymer chains. This breakage is known as *chain scission*.

Cracking (also known as *crazing*) may be prevented (or at least limited) by using materials with fully-saturated bonds that are less susceptible to chemical attack. Weather- and ozone-resistant elastomers such as silicone, fluorocarbon (Viton®), EPDM, polyurethane, polyacrylate, fluorosilicone, ethylene acrylic, and epichlorohydrin are all good choices. In some instances, an elastomer whose ozone resistance is inherently poor can be supplemented with antiozonant additives.

Keep in mind that stretching an O-ring more than 5% increases its exposure to chemical attack. Storage around ozone-generating equipment (such as electric motors), especially in a stretched (installed) condition, will lead to rapid deterioration of the elastomeric compound, often in as little as a few days. ***Figure 138*** is an example of O-ring failure due to weather and ozone cracking.

"Ozone weakens the O-ring compound by attacking unsaturated (double) bonds and breaking apart the polymer chains."

WEATHER & OZONE CRACKING

Figure 138: Failure Due to Weather & Ozone Cracking

Exploring Other Options.

The savvy seal designer recognizes both the possible uses and inherent limitations of a given product. Though O-rings are ideal for a wide variety of applications, they are not the best solution to every design problem. Since trying to force an O-ring to perform beyond its capabilities can only lead to failure, you will probably be faced from time to time with difficult or unusual situations that require you to consider other seal cross-sections.

What follows is information on a handful of alternate seals that can retrofit directly into standard O-ring glands without the need for either redesign or remachining. Of course, each cross-section has both advantages and disadvantages, so the specific needs of your application will always dictate which one is best for you. Familiarity with your options, however, should make the choice somewhat easier.

> **"Though O-rings are ideal for a wide variety of applications, they are not the best solution to every design problem."**

LOBED SEALS

Also known as X-rings or Quad-Ring® seals, four-lobed seals double the number of sealing surfaces found on traditional O-rings. Used primarily in dynamic applications, lobed seals require less squeeze than O-rings and thus generate less friction.

Thanks to their unique design, lobed seals also provide improved sealability and are more resistant to the twisting stresses that can lead to spiral failure. Be aware, however, that lobed seals are more expensive than O-rings. ***Figure 139*** illustrates the cross-section of a four-lobed seal.

FOUR-LOBED SEAL

Figure 139: More sealing surfaces than an O-ring.

SQUARE RINGS

Also known as Tetraseals® or lathe-cut rings, square rings are circular sealing devices that utilize square rather than round cross-sections. Available in many elastomeric compounds, square rings are used primarily in static applications. In larger diameters (above 2”), square rings often cost less than O-rings. Keep in mind, however, that O-rings generally provide a more positive seal because the circular cross-sections allow for more concentrated unit loading. ***Figure 140*** illustrates the cross-section of a square ring.

SQUARE RING

Figure 140: Square cross-section for static uses.

U-CUPS

U-cups (usually made of rubber or polyurethane) are used in dynamic applications. Because they are pressure-actuated lip type seals (rather than squeeze seals), they operate with lower break-out and running friction. They can also maintain smoother, steadier movement. U-cups are unidirectional, however, so two seals will be required for bidirectional sealing. U-cups are more expensive than O-rings. ***Figure 141*** illustrates the cross-section of a U-cup.

U-CUP

Figure 141: Creates less friction than squeeze seals.

PTFE CAPPED SEALS

Made of polytetrafluoroethylene (PTFE, better known as Teflon®), capped seals (also called slipper seals) are used in combination with standard O-rings. Because the PTFE cap drastically reduces break-out friction, capped seals are often used in applications where machinery undergoes prolonged idle periods. As added benefits, PTFE capped seals have outstanding chemical resistance and can operate across a wide temperature range (-300° to +450° F). Capped seals are available in two configurations: one which seals on the I.D. (the "kin" configuration) and one which seals on the O.D. (the "kex" configuration, see ***Figure 142***).

PTFE CAPPED SEAL

Figure 142: "Kex" - sealing on the OD.

T-SEALS

Also known as T-rings, T-seals (see ***Figure 143***) are used with pressure-energized backup rings (typically made of nylon or PTFE) on both sides, making them ideal for dynamic sealing. Harder (higher shear modulus) back-ups can be used than with O-rings, and the forcing of these back-ups into the clearance gap makes T-seals very extrusion-resistant. The T-shaped cross-section adds stability, so T-seals are more resistant to spiral failure than O-rings. Chief downsides: T-seals require installation of three parts (the seal and two backups), and they cost much more than O-rings.

T-SEAL

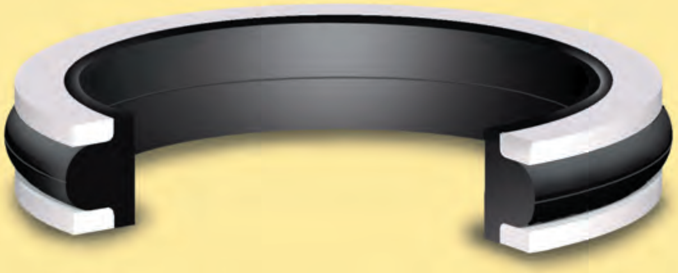


Figure 143: The T-shape means added stability.

CROWN SEALS ™

Typically made of Hytrel® or polyurethane, crown seals (see ***Figure 144***) are dynamic seals energized by an O-ring. The tough outer "crown" imparts wear and anti-extrusion properties even as the resilient inner O-ring enables the seal to handle low temperature and low pressure applications. The narrowness of the contact line and the shape of the cross-section also help crown seals resist spiral failure. Though rod configurations are available, crown seals are mainly used in piston designs. Crown seals cost much more than O-rings.

CROWN SEAL

Figure 144: Great wear in combination with good resilience.

FLUOROPLASTIC-ENCAPSULATED O-RINGS

Unlike the other options highlighted in this section, fluoroplastic-encapsulated O-rings retain the same circular cross-section as standard O-rings (see ***Figure 145***). They feature a fluoroplastic jacket around a core material (such as Viton® or silicone). These expensive alternatives to elastomeric O-rings are used as static seals in environments featuring harsh chemicals and high temperatures.

FLUOROPLASTIC-ENCAPSULATED O-RING

Figure 145: Fluoroplastic jacket around a silicone core.

SPRING-ENERGIZED PTFE SEALS

Offering the highest performance among O-ring alternatives, spring-energized seals feature a PTFE (Teflon®) jacket uniformly energized by a spring made of stainless steel or Elgiloy®, as shown in ***Figure 146***. In addition to being chemically inert (making it resistant to harsh environments), the PTFE jacket minimizes both break-out and running friction. The jacket's high shear modulus resists extrusion, and the stable cross-section resists spiraling. PTFE seals can also function across a wide temperature range. Spring-energized PTFE seals are the most expensive of the alternatives outlined in this section.

SPRING-ENERGIZED PTFE SEAL

Figure 146: PTFE jacket around a spring.

Ordering Made Easy.

O-rings are amazingly simple devices. Shouldn't ordering them be just as simple? We've made ordering O-rings as easy as specifying two characteristics: the size of the seal, and the seal material (or compound). Here's how it works:

SIZE

Standard imperial (inch) sizes are specified using the three-digit "dash numbers" defined in Aerospace Standard (AS) 568A (see ***page 274***). Published by the Society of Automotive Engineers (SAE), AS 568A supersedes and cancels both AS 568 and Aerospace Recommended Practice (ARP) 568. When ordering standard sizes, all you need to specify is an AS 568A dash number (for example, AS 568A-011). Or, if you prefer, simply request an OR-011 seal. The "OR" is our designation for an O-ring.

For **non-standard** imperial sizes, please specify both the inside diameter (ID) and cross-section (W) in the following format: OR-ID x W. For example, OR-1.250 x .125 for a seal with a 1.250" ID and a .125" W.

For **metric** sizes, please specify using the following format: OR-IDmm x Wmm. For example, OR-25mm x 3mm.

COMPOUND

Compound information includes both the base polymer and the hardness. You may specify these in any of three ways:

1) Simply identify the compound using either its full name or its ASTM D 1418 designation (for example, nitrile or NBR) and the desired hardness (for example, 70 Shore A). NBR-70 is a 70 (Shore A) durometer nitrile.

2) Give us a compound number (if known) which notes both polymer and hardness. For example, N470 is a standard 70 (Shore A) durometer nitrile.

3) Provide an ASTM D 2000 / SAE J200 line call-out for the compound (see ***page 146***).

Other than the quantity you want, that's all we need!

"We've made ordering O-rings as easy as specifying two characteristics: the size of the seal, and the seal material (or compound)."

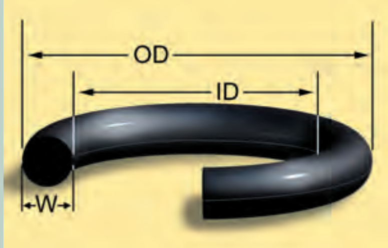


Figure 147: O-Ring Dimensions

Questions? Please feel free to call us at 1-800-722-6766 for more information.

O-Ring Size Tables.

AS568A	Nominal Reference			Actual Dimensions (inches)				Actual Dimensions (mm)			
No.	I.D.	O.D.	Width	I.D.	Tol	Width	Tol	I.D.	Tol	Width	Tol
-001	1/32	3/32	1/32	.029	±.004	.040	±.003	0.74	±.10	1.02	±.08
-001 1/2	1/16	1/8	1/32	.070	±.004	.040	±.003	1.78	±.10	1.02	±.08
-002	3/64	9/64	3/64	.042	±.004	.050	±.003	1.07	±.10	1.27	±.08
-003	1/16	3/16	1/16	.056	±.004	.060	±.003	1.42	±.10	1.52	±.08
-004	5/64	13/64	1/16	.070	±.005	.070	±.003	1.78	±.13	1.78	±.08
-005	3/32	7/32	1/16	.101	±.005	.070	±.003	2.57	±.13	1.78	±.08
-006	1/8	1/4	1/16	.114	±.005	.070	±.003	2.90	±.13	1.78	±.08
-007	5/32	9/32	1/16	.145	±.005	.070	±.003	3.68	±.13	1.78	±.08
-008	3/16	9/16	1/16	.176	±.005	.070	±.003	4.47	±.13	1.78	±.08
-009	7/32	11/32	1/16	.208	±.005	.070	±.003	5.28	±.13	1.78	±.08
-010	1/4	3/8	1/16	.239	±.005	.070	±.003	6.07	±.13	1.78	±.08
-011	5/16	3/16	1/16	.301	±.005	.070	±.003	7.65	±.13	1.78	±.08
-012	3/8	1/2	1/16	.364	±.005	.070	±.003	9.25	±.13	1.78	±.08
-013	7/16	9/16	1/16	.426	±.005	.070	±.003	10.82	±.13	1.78	±.08
-014	1/2	3/8	1/16	.489	±.005	.070	±.003	12.42	±.13	1.78	±.08
-015	9/16	11/16	1/16	.551	±.007	.070	±.003	14.00	±.18	1.78	±.08
-016	5/8	3/4	1/16	.614	±.009	.070	±.003	15.60	±.23	1.78	±.08
-017	11/16	13/16	1/16	.676	±.009	.070	±.003	17.17	±.23	1.78	±.08
-018	3/4	7/8	1/16	.739	±.009	.070	±.003	18.77	±.23	1.78	±.08
-019	13/16	15/16	1/16	.801	±.009	.070	±.003	20.35	±.23	1.78	±.08
-020	7/8	1	1/16	.864	±.009	.070	±.003	21.95	±.23	1.78	±.08
-021	15/16	1 1/16	1/16	.926	±.009	.070	±.003	23.52	±.23	1.78	±.08
-022	1	1 1/8	1/16	.989	±.010	.070	±.003	25.12	±.25	1.78	±.08
-023	1 1/16	1 3/16	1/16	1.051	±.010	.070	±.003	26.70	±.25	1.78	±.08
-024	1 1/8	1 1/4	1/16	1.114	±.010	.070	±.003	28.30	±.25	1.78	±.08
-025	1 3/16	1 5/16	1/16	1.176	±.011	.070	±.003	29.87	±.28	1.78	±.08
-026	1 1/4	1 3/8	1/16	1.239	±.011	.070	±.003	31.47	±.28	1.78	±.08
-027	1 5/16	1 7/16	1/16	1.301	±.011	.070	±.003	33.05	±.28	1.78	±.08
-028	1 3/8	1 1/2	1/16	1.364	±.013	.070	±.003	34.65	±.33	1.78	±.08
-029	1 1/2	1 5/8	1/16	1.489	±.013	.070	±.003	37.82	±.33	1.78	±.08
-030	1 5/8	1 3/4	1/16	1.614	±.013	.070	±.003	41.00	±.33	1.78	±.08
-031	1 3/4	1 7/8	1/16	1.739	±.015	.070	±.003	44.17	±.38	1.78	±.08
-032	1 7/8	2	1/16	1.864	±.015	.070	±.003	47.35	±.38	1.78	±.08
-033	2	2 1/8	1/16	1.989	±.018	.070	±.003	50.52	±.46	1.78	±.08
-034	2 1/8	2 1/4	1/16	2.114	±.018	.070	±.003	53.70	±.46	1.78	±.08
-035	2 1/4	2 3/8	1/16	2.239	±.018	.070	±.003	56.87	±.46	1.78	±.08
-036	2 3/8	2 1/2	1/16	2.364	±.018	.070	±.003	60.05	±.46	1.78	±.08
-037	2 1/2	2 5/8	1/16	2.489	±.018	.070	±.003	63.22	±.46	1.78	±.08
-038	2 5/8	2 3/4	1/16	2.614	±.020	.070	±.003	66.40	±.51	1.78	±.08
-039	2 3/4	2 7/8	1/16	2.739	±.020	.070	±.003	69.57	±.51	1.78	±.08
-040	2 7/8	3	1/16	2.864	±.020	.070	±.003	72.75	±.51	1.78	±.08
-041	3	3 1/8	1/16	2.989	±.024	.070	±.003	75.92	±.61	1.78	±.08
-042	3 1/4	3 3/8	1/16	3.329	±.024	.070	±.003	82.27	±.61	1.78	±.08
-043	3 1/2	3 5/8	1/16	3.489	±.024	.070	±.003	88.62	±.61	1.78	±.08
-044	3 3/4	3 7/8	1/16	3.739	±.027	.070	±.003	94.97	±.69	1.78	±.08
-045	4	4 1/8	1/16	3.989	±.027	.070	±.003	101.32	±.69	1.78	±.08
-046	4 1/4	4 3/8	1/16	4.239	±.030	.070	±.003	107.67	±.76	1.78	±.08
-047	4 1/2	4 5/8	1/16	4.489	±.030	.070	±.003	114.02	±.76	1.78	±.08
-048	4 3/4	4 7/8	1/16	4.739	±.030	.070	±.003	120.37	±.76	1.78	±.08
-049	5	5 1/8	1/16	4.989	±.037	.070	±.003	126.72	±.94	1.78	±.08
-050	5 1/4	5 3/8	1/16	5.239	±.037	.070	±.003	133.07	±.94	1.78	±.08

Table 55: Standard O-Ring Sizes

AS568A	Nominal Reference			Actual Dimensions (inches)				Actual Dimensions (mm)			
No.	I.D.	O.D.	Width	I.D.	Tol	Width	Tol	I.D.	Tol	Width	Tol
-102	1/16	1/4	3/32	.049	±.005	.103	±.003	1.24	±.13	2.62	±.08
-103	3/32	9/32	3/32	.081	±.005	.103	±.003	2.06	±.13	2.62	±.08
-104	1/8	5/16	3/32	.112	±.005	.103	±.003	2.84	±.13	2.62	±.08
-105	5/32	11/32	3/32	.143	±.005	.103	±.003	3.63	±.13	2.62	±.08
-106	3/16	3/8	3/32	.174	±.005	.103	±.003	4.42	±.13	2.62	±.08
-107	7/32	13/32	3/32	.206	±.005	.103	±.003	5.23	±.13	2.62	±.08
-108	1/4	7/16	3/32	.237	±.005	.103	±.003	6.02	±.13	2.62	±.08
-109	5/16	1/2	3/32	.299	±.005	.103	±.003	7.59	±.13	2.62	±.08
-110	3/8	9/16	3/32	.362	±.005	.103	±.003	9.19	±.13	2.62	±.08
-111	7/16	5/8	3/32	.424	±.005	.103	±.003	10.77	±.13	2.62	±.08
-112	1/2	11/16	3/32	.487	±.005	.103	±.003	12.37	±.13	2.62	±.08
-113	9/16	3/4	3/32	.549	±.005	.103	±.003	13.94	±.18	2.62	±.08
-114	5/8	13/16	3/32	.612	±.009	.103	±.003	15.54	±.23	2.62	±.08
-115	11/16	7/8	3/32	.674	±.009	.103	±.003	17.12	±.23	2.62	±.08
-116	3/4	15/16	3/32	.737	±.009	.103	±.003	18.72	±.23	2.62	±.08
-117	13/16	1	3/32	.799	±.010	.103	±.003	20.30	±.25	2.62	±.08
-118	7/8	1 1/16	3/32	.862	±.010	.103	±.003	21.89	±.25	2.62	±.08
-119	15/16	1 1/8	3/32	.924	±.010	.103	±.003	23.47	±.25	2.62	±.08
-120	1	1 3/16	3/32	.987	±.010	.103	±.003	25.07	±.25	2.62	±.08
-121	1 1/16	1 1/4	3/32	1.049	±.010	.103	±.003	26.64	±.25	2.62	±.08
-122	1 1/8	1 5/16	3/32	1.112	±.010	.103	±.003	28.24	±.25	2.62	±.08
-123	1 3/16	1 3/8	3/32	1.174	±.012	.103	±.003	29.82	±.30	2.62	±.08
-124	1 1/4	1 7/16	3/32	1.237	±.012	.103	±.003	31.42	±.30	2.62	±.08
-125	1 5/16	1 1/2	3/32	1.299	±.012	.103	±.003	32.99	±.30	2.62	±.08
-126	1 3/8	1 9/16	3/32	1.362	±.012	.103	±.003	34.59	±.30	2.62	±.08
-127	1 7/16	1 5/8	3/32	1.424	±.012	.103	±.003	36.17	±.30	2.62	±.08
-128	1 1/2	1 11/16	3/32	1.487	±.012	.103	±.003	37.77	±.30	2.62	±.08
-129	1 9/16	1 3/4	3/32	1.549	±.015	.103	±.003	39.34	±.38	2.62	±.08
-130	1 5/8	1 13/16	3/32	1.612	±.015	.103	±.003	40.94	±.38	2.62	±.08
-131	1 11/16	1 7/8	3/32	1.674	±.015	.103	±.003	42.52	±.38	2.62	±.08
-132	1 3/4	1 15/16	3/32	1.737	±.015	.103	±.003	44.12	±.38	2.62	±.08
-133	1 13/16	2	3/32	1.799	±.015	.103	±.003	45.69	±.38	2.62	±.08
-134	1 7/8	2 1/16	3/32	1.862	±.015	.103	±.003	47.29	±.38	2.62	±.08
-135	1 15/16	2 1/8	3/32	1.925	±.017	.103	±.003	48.90	±.43	2.62	±.08
-136	2	2 3/16	3/32	1.987	±.017	.103	±.003	50.47	±.43	2.62	±.08
-137	2 1/16	2 1/4	3/32	2.050	±.017	.103	±.003	52.07	±.43	2.62	±.08
-138	2 1/8	2 5/16	3/32	2.112	±.017	.103	±.003	53.64	±.43	2.62	±.08
-139	2 3/16	2 3/8	3/32	2.175	±.017	.103	±.003	55.25	±.43	2.62	±.08
-140	2 1/4	2 7/16	3/32	2.237	±.017	.103	±.003	56.82	±.43	2.62	±.08
-141	2 5/16	2 1/2	3/32	2.300	±.020	.103	±.003	58.42	±.51	2.62	±.08
-142	2 3/8	2 9/16	3/32	2.362	±.020	.103	±.003	59.99	±.51	2.62	±.08
-143	2 7/16	2 5/8	3/32	2.425	±.020	.103	±.003	61.60	±.51	2.62	±.08
-144	2 1/2	2 11/16	3/32	2.487	±.020	.103	±.003	63.17	±.51	2.62	±.08
-145	2 9/16	2 3/4	3/32	2.550	±.020	.103	±.003	64.77	±.51	2.62	±.08
-146	2 5/8	2 13/16	3/32	2.612	±.020	.103	±.003	66.34	±.51	2.62	±.08
-147	2 11/16	2 7/8	3/32	2.675	±.022	.103	±.003	67.95	±.56	2.62	±.08
-148	2 3/4	2 15/16	3/32	2.737	±.022	.103	±.003	69.52	±.56	2.62	±.08
-149	2 15/16	3	3/32	2.800	±.022	.103	±.003	71.12	±.56	2.62	±.08
-150	2 7/8	3 1/16	3/32	2.862	±.022	.103	±.003	72.69	±.56	2.62	±.08
-151	3	3 3/16	3/32	2.987	±.024	.103	±.003	75.87	±.61	2.62	±.08
-152	3 1/4	3 7/16	3/32	3.237	±.024	.103	±.003	82.22	±.61	2.62	±.08
-153	3 1/2	3 11/16	3/32	3.487	±.024	.103	±.003	88.57	±.61	2.62	±.08
-154	3 3/4	3 15/16	3/32	3.737	±.028	.103	±.003	94.92	±.71	2.62	±.08
-155	4	4 3/16	3/32	3.987	±.028	.103	±.003	101.27	±.71	2.62	±.08
-156	4 1/4	4 7/16	3/32	4.237	±.030	.103	±.003	107.62	±.76	2.62	±.08
-157	4 1/2	4 11/16	3/32	4.487	±.030	.103	±.003	113.97	±.76	2.62	±.08
-158	4 3/4	4 15/16	3/32	4.737	±.030	.103	±.003	120.32	±.76	2.62	±.08
-159	5	5 3/16	3/32	4.987	±.035	.103	±.003	126.67	±.89	2.62	±.08
-160	5 1/4	5 7/16	3/32	5.237	±.035	.103	±.003	133.02	±.89	2.62	±.08
-161	5 1/2	5 11/16	3/32	5.487	±.035	.103	±.003	139.37	±.89	2.62	±.08

Table 55: Standard O-Ring Sizes

AS568A	Nominal Reference			Actual Dimensions (inches)				Actual Dimensions (mm)			
No.	I.D.	O.D.	Width	I.D.	Tol	Width	Tol	I.D.	Tol	Width	Tol
-162	5 3/4	5 15/16	3/32	5.737	±.035	.103	±.003	145.72	±.89	2.62	±.08
-163	6	6 3/16	3/32	5.987	±.035	.103	±.003	152.07	±.89	2.62	±.08
-164	6 1/4	6 7/16	3/32	6.237	±.040	.103	±.003	158.42	±1.02	2.62	±.08
-165	6 1/2	6 11/16	3/32	6.487	±.040	.103	±.003	164.77	±1.02	2.62	±.08
-166	6 3/4	6 15/16	3/32	6.737	±.040	.103	±.003	171.12	±1.02	2.62	±.08
-167	7	7 3/16	3/32	6.987	±.040	.103	±.003	177.47	±1.02	2.62	±.08
-168	7 1/4	7 7/16	3/32	7.237	±.045	.103	±.003	183.82	±1.14	2.62	±.08
-169	7 1/2	7 11/16	3/32	7.487	±.045	.103	±.003	190.17	±1.14	2.62	±.08
-170	7 3/4	7 15/16	3/32	7.737	±.045	.103	±.003	196.52	±1.14	2.62	±.08
-171	8	8 3/16	3/32	7.987	±.045	.103	±.003	202.87	±1.14	2.62	±.08
-172	8 1/4	8 7/16	3/32	8.237	±.050	.103	±.003	209.22	±1.27	2.62	±.08
-173	8 1/2	8 11/16	3/32	8.487	±.050	.103	±.003	215.57	±1.27	2.62	±.08
-174	8 3/4	8 15/16	3/32	8.737	±.050	.103	±.003	221.92	±1.27	2.62	±.08
-175	9	9 3/16	3/32	8.987	±.050	.103	±.003	228.27	±1.27	2.62	±.08
-176	9 1/4	9 7/16	3/32	9.237	±.055	.103	±.003	234.62	±1.40	2.62	±.08
-177	9 1/2	9 11/16	3/32	9.487	±.055	.103	±.003	240.97	±1.40	2.62	±.08
-178	9 3/4	9 15/16	3/32	9.737	±.055	.103	±.003	247.32	±1.40	2.62	±.08
-201	3/16	7/16	1/8	.171	±.005	.139	±.004	4.34	±.13	3.53	±.10
-202	1/4	1/2	1/8	.234	±.005	.139	±.004	5.94	±.13	3.53	±.10
-203	5/16	9/16	1/8	.296	±.005	.139	±.004	7.52	±.13	3.53	±.10
-204	3/8	5/8	1/8	.359	±.005	.139	±.004	9.12	±.13	3.53	±.10
-205	7/16	11/16	1/8	.421	±.005	.139	±.004	10.69	±.13	3.53	±.10
-206	1/2	3/4	1/8	.484	±.005	.139	±.004	12.29	±.13	3.53	±.10
-207	9/16	13/16	1/8	.546	±.007	.139	±.004	13.87	±.18	3.53	±.10
-208	5/8	7/8	1/8	.609	±.009	.139	±.004	15.47	±.23	3.53	±.10
-209	11/16	15/16	1/8	.671	±.009	.139	±.004	17.04	±.23	3.53	±.10
-210	3/4	1	1/8	.734	±.010	.139	±.004	18.64	±.25	3.53	±.10
-211	13/16	1 1/16	1/8	.796	±.010	.139	±.004	20.22	±.25	3.53	±.10
-212	7/8	1 1/8	1/8	.859	±.010	.139	±.004	21.82	±.25	3.53	±.10
-213	15/16	1 1/16	1/8	.921	±.010	.139	±.004	23.39	±.25	3.53	±.10
-214	1	1 1/4	1/8	.984	±.010	.139	±.004	24.99	±.25	3.53	±.10
-215	1 1/16	1 5/16	1/8	1.046	±.010	.139	±.004	26.57	±.25	3.53	±.10
-216	1 1/8	1 3/8	1/8	1.109	±.012	.139	±.004	28.17	±.30	3.53	±.10
-217	1 3/16	1 7/16	1/8	1.171	±.012	.139	±.004	29.74	±.30	3.53	±.10
-218	1 1/4	1 1/2	1/8	1.234	±.012	.139	±.004	31.34	±.30	3.53	±.10
-219	1 5/16	1 9/16	1/8	1.296	±.012	.139	±.004	32.92	±.30	3.53	±.10
-220	1 3/8	1 5/8	1/8	1.359	±.012	.139	±.004	34.52	±.30	3.53	±.10
-221	1 7/16	1 11/16	1/8	1.421	±.012	.139	±.004	36.09	±.30	3.53	±.10
-222	1 1/2	1 3/4	1/8	1.484	±.015	.139	±.004	37.69	±.38	3.53	±.10
-223	1 5/8	1 7/8	1/8	1.609	±.015	.139	±.004	40.87	±.38	3.53	±.10
-224	1 3/4	2	1/8	1.734	±.015	.139	±.004	44.04	±.38	3.53	±.10
-225	1 7/8	2 1/8	1/8	1.859	±.018	.139	±.004	47.22	±.46	3.53	±.10
-226	2	2 1/4	1/8	1.984	±.018	.139	±.004	50.39	±.46	3.53	±.10
-227	2 1/8	2 3/8	1/8	2.109	±.018	.139	±.004	53.57	±.46	3.53	±.10
-228	2 1/4	2 1/2	1/8	2.234	±.020	.139	±.004	56.74	±.51	3.53	±.10
-229	2 3/8	2 5/8	1/8	2.359	±.020	.139	±.004	59.92	±.51	3.53	±.10
-230	2 1/2	2 3/4	1/8	2.484	±.020	.139	±.004	63.09	±.51	3.53	±.10
-231	2 5/8	2 7/8	1/8	2.609	±.020	.139	±.004	66.27	±.51	3.53	±.10
-232	2 3/4	3	1/8	2.734	±.024	.139	±.004	69.44	±.61	3.53	±.10
-233	2 7/8	3 1/8	1/8	2.859	±.024	.139	±.004	72.62	±.61	3.53	±.10
-234	3	3 1/4	1/8	2.984	±.024	.139	±.004	75.79	±.61	3.53	±.10
-235	3 1/8	3 3/8	1/8	3.109	±.024	.139	±.004	78.97	±.61	3.53	±.10
-236	3 1/4	3 1/2	1/8	3.234	±.024	.139	±.004	82.14	±.61	3.53	±.10
-237	3 3/8	3 5/8	1/8	3.359	±.024	.139	±.004	85.32	±.61	3.53	±.10
-238	3 1/2	3 3/4	1/8	3.484	±.024	.139	±.004	88.49	±.61	3.53	±.10
-239	3 5/8	3 7/8	1/8	3.609	±.028	.139	±.004	91.67	±.71	3.53	±.10
-240	3 3/4	4	1/8	3.734	±.028	.139	±.004	94.84	±.71	3.53	±.10
-241	3 7/8	4 1/8	1/8	3.859	±.028	.139	±.004	98.02	±.71	3.53	±.10
-242	4	4 1/4	1/8	3.984	±.028	.139	±.004	101.19	±.71	3.53	±.10
-243	4 1/8	4 3/8	1/8	4.109	±.028	.139	±.004	104.37	±.71	3.53	±.10

Table 55: Standard O-Ring Sizes

AS568A	Nominal Reference			Actual Dimensions (inches)				Actual Dimensions (mm)			
No.	I.D.	O.D.	Width	I.D.	Tol	Width	Tol	I.D.	Tol	Width	Tol
-244	4 1/4	4 1/2	1/8	4.234	±.030	.139	±.004	107.54	±.76	3.53	±.10
-245	4 3/8	4 5/8	1/8	4.359	±.030	.139	±.004	110.72	±.76	3.53	±.10
-246	4 1/2	4 3/4	1/8	4.484	±.030	.139	±.004	113.89	±.76	3.53	±.10
-247	4 5/8	4 7/8	1/8	4.609	±.030	.139	±.004	117.07	±.76	3.53	±.10
-248	4 3/4	5	1/8	4.734	±.030	.139	±.004	120.24	±.76	3.53	±.10
-249	4 7/8	5 1/8	1/8	4.859	±.035	.139	±.004	123.42	±.89	3.53	±.10
-250	5	5 1/4	1/8	4.984	±.035	.139	±.004	126.59	±.89	3.53	±.10
-251	5 1/8	5 3/8	1/8	5.109	±.035	.139	±.004	129.77	±.89	3.53	±.10
-252	5 1/4	5 1/2	1/8	5.234	±.035	.139	±.004	132.94	±.89	3.53	±.10
-253	5 3/8	5 5/8	1/8	5.359	±.035	.139	±.004	136.12	±.89	3.53	±.10
-254	5 1/2	5 3/4	1/8	5.484	±.035	.139	±.004	139.29	±.89	3.53	±.10
-255	5 5/8	5 7/8	1/8	5.609	±.035	.139	±.004	142.47	±.89	3.53	±.10
-256	5 3/4	6	1/8	5.734	±.035	.139	±.004	145.64	±.89	3.53	±.10
-257	5 7/8	6 1/8	1/8	5.859	±.035	.139	±.004	148.82	±.89	3.53	±.10
-258	6	6 1/4	1/8	5.984	±.035	.139	±.004	151.99	±.89	3.53	±.10
-259	6 1/4	6 1/2	1/8	6.234	±.040	.139	±.004	158.34	±1.02	3.53	±.10
-260	6 1/2	6 3/4	1/8	6.484	±.040	.139	±.004	164.69	±1.02	3.53	±.10
-261	6 3/4	7	1/8	6.734	±.040	.139	±.004	171.04	±1.02	3.53	±.10
-262	7	7 1/4	1/8	6.984	±.040	.139	±.004	177.39	±1.02	3.53	±.10
-263	7 1/4	7 1/2	1/8	7.234	±.045	.139	±.004	183.74	±1.14	3.53	±.10
-264	7 1/2	7 3/4	1/8	7.484	±.045	.139	±.004	190.09	±1.14	3.53	±.10
-265	7 3/4	8	1/8	7.734	±.045	.139	±.004	196.44	±1.14	3.53	±.10
-266	8	8 1/4	1/8	7.984	±.045	.139	±.004	202.79	±1.14	3.53	±.10
-267	8 1/4	8 1/2	1/8	8.234	±.050	.139	±.004	209.14	±1.27	3.53	±.10
-268	8 1/2	8 3/4	1/8	8.484	±.050	.139	±.004	215.49	±1.27	3.53	±.10
-269	8 3/4	9	1/8	8.734	±.050	.139	±.004	221.84	±1.27	3.53	±.10
-270	9	9 1/4	1/8	8.984	±.050	.139	±.004	228.19	±1.27	3.53	±.10
-271	9 1/4	9 1/2	1/8	9.234	±.055	.139	±.004	234.54	±1.40	3.53	±.10
-272	9 1/2	9 3/4	1/8	9.484	±.055	.139	±.004	240.89	±1.40	3.53	±.10
-273	9 3/4	10	1/8	9.734	±.055	.139	±.004	247.24	±1.40	3.53	±.10
-274	10	10 1/4	1/8	9.984	±.055	.139	±.004	253.59	±1.40	3.53	±.10
-275	10 1/2	10 3/4	1/8	10.484	±.055	.139	±.004	266.29	±1.40	3.53	±.10
-276	11	11 1/4	1/8	10.984	±.065	.139	±.004	278.99	±1.65	3.53	±.10
-277	11 1/2	11 3/4	1/8	11.484	±.065	.139	±.004	291.69	±1.65	3.53	±.10
-278	12	12 1/4	1/8	11.984	±.065	.139	±.004	304.39	±1.65	3.53	±.10
-279	13	13 1/4	1/8	12.984	±.065	.139	±.004	329.79	±1.65	3.53	±.10
-280	14	14 1/4	1/8	13.984	±.065	.139	±.004	355.19	±1.65	3.53	±.10
-281	15	15 1/4	1/8	14.984	±.065	.139	±.004	380.59	±1.65	3.53	±.10
-282	16	16 1/4	1/8	15.955	±.075	.139	±.004	405.26	±1.91	3.53	±.10
-283	17	17 1/4	1/8	16.955	±.080	.139	±.004	430.66	±2.03	3.53	±.10
-284	18	18 1/4	1/8	17.955	±.085	.139	±.004	456.06	±2.16	3.53	±.10
-309	7/16	13/16	3/16	.412	±.005	.210	±.005	10.46	±.13	5.33	±.13
-310	1/2	7/8	3/16	.475	±.005	.210	±.005	12.07	±.13	5.33	±.13
-311	9/16	15/16	3/16	.537	±.007	.210	±.005	13.64	±.18	5.33	±.13
-312	3/8	1	3/16	.600	±.009	.210	±.005	15.24	±.23	5.33	±.13
-313	11/16	1 1/16	3/16	.662	±.009	.210	±.005	16.81	±.23	5.33	±.13
-314	3/4	1 1/8	3/16	.725	±.010	.210	±.005	18.42	±.25	5.33	±.13
-315	13/16	1 3/16	3/16	.787	±.010	.210	±.005	19.99	±.25	5.33	±.13
-316	7/8	1 1/4	3/16	.850	±.010	.210	±.005	21.59	±.25	5.33	±.13
-317	15/16	1 5/16	3/16	.912	±.010	.210	±.005	23.16	±.25	5.33	±.13
-318	1	1 3/8	3/16	.975	±.010	.210	±.005	24.77	±.25	5.33	±.13
-319	1 1/16	1 7/16	3/16	1.037	±.010	.210	±.005	26.34	±.25	5.33	±.13
-320	1 1/8	1 1/2	3/16	1.100	±.012	.210	±.005	27.94	±.30	5.33	±.13
-321	1 3/16	1 9/16	3/16	1.162	±.012	.210	±.005	29.51	±.30	5.33	±.13
-322	1 1/4	1 5/8	3/16	1.225	±.012	.210	±.005	31.12	±.30	5.33	±.13
-323	1 5/16	1 11/16	3/16	1.287	±.012	.210	±.005	32.69	±.30	5.33	±.13
-324	1 3/8	1 3/4	3/16	1.350	±.012	.210	±.005	34.29	±.30	5.33	±.13
-325	1 1/2	1 7/8	3/16	1.475	±.015	.210	±.005	37.47	±.38	5.33	±.13
-326	1 5/8	2	3/16	1.600	±.015	.210	±.005	40.64	±.38	5.33	±.13
-327	1 3/4	2 1/8	3/16	1.725	±.015	.210	±.005	43.82	±.38	5.33	±.13

Table 55: Standard O-Ring Sizes

AS568A	Nominal Reference			Actual Dimensions (inches)				Actual Dimensions (mm)			
No.	I.D.	O.D.	Width	I.D.	Tol	Width	Tol	I.D.	Tol	Width	Tol
-328	1 7/8	2 1/4	3/16	1.850	±.015	.210	±.005	46.99	±.38	5.33	±.13
-329	2	2 3/8	3/16	1.975	±.018	.210	±.005	50.17	±.46	5.33	±.13
-330	2 1/8	2 1/2	3/16	2.100	±.018	.210	±.005	53.34	±.46	5.33	±.13
-331	2 1/4	2 5/8	3/16	2.225	±.018	.210	±.005	56.52	±.46	5.33	±.13
-332	2 3/8	2 3/4	3/16	2.350	±.018	.210	±.005	59.69	±.46	5.33	±.13
-333	2 1/2	2 7/8	3/16	2.475	±.020	.210	±.005	62.87	±.51	5.33	±.13
-334	2 5/8	3	3/16	2.600	±.020	.210	±.005	66.04	±.51	5.33	±.13
-335	2 3/4	3 1/8	3/16	2.725	±.020	.210	±.005	69.22	±.51	5.33	±.13
-336	2 7/8	3 1/4	3/16	2.850	±.020	.210	±.005	72.39	±.51	5.33	±.13
-337	3	3 3/8	3/16	2.975	±.024	.210	±.005	75.57	±.61	5.33	±.13
-338	3 1/8	3 1/2	3/16	3.100	±.024	.210	±.005	78.74	±.61	5.33	±.13
-339	3 1/4	3 5/8	3/16	3.225	±.024	.210	±.005	81.92	±.61	5.33	±.13
-340	3 3/8	3 3/4	3/16	3.350	±.024	.210	±.005	85.09	±.61	5.33	±.13
-341	3 1/2	3 7/8	3/16	3.475	±.024	.210	±.005	88.27	±.61	5.33	±.13
-342	3 5/8	4	3/16	3.600	±.028	.210	±.005	91.44	±.71	5.33	±.13
-343	3 3/4	4 1/8	3/16	3.725	±.028	.210	±.005	94.62	±.71	5.33	±.13
-344	3 7/8	4 1/4	3/16	3.850	±.028	.210	±.005	97.79	±.71	5.33	±.13
-345	4	4 3/8	3/16	3.975	±.028	.210	±.005	100.97	±.71	5.33	±.13
-346	4 1/8	4 1/2	3/16	4.100	±.028	.210	±.005	104.14	±.71	5.33	±.13
-347	4 1/4	4 5/8	3/16	4.225	±.030	.210	±.005	107.32	±.76	5.33	±.13
-348	4 3/8	4 3/4	3/16	4.350	±.030	.210	±.005	110.49	±.76	5.33	±.13
-349	4 1/2	4 7/8	3/16	4.475	±.030	.210	±.005	113.67	±.76	5.33	±.13
-350	4 5/8	5	3/16	4.600	±.030	.210	±.005	116.84	±.76	5.33	±.13
-351	4 3/4	5 1/8	3/16	4.725	±.030	.210	±.005	120.02	±.76	5.33	±.13
-352	4 7/8	5 1/4	3/16	4.850	±.030	.210	±.005	123.19	±.76	5.33	±.13
-353	5	5 3/8	3/16	4.975	±.037	.210	±.005	126.37	±.94	5.33	±.13
-354	5 1/8	5 1/2	3/16	5.100	±.037	.210	±.005	129.54	±.94	5.33	±.13
-355	5 1/4	5 5/8	3/16	5.225	±.037	.210	±.005	132.72	±.94	5.33	±.13
-356	5 3/8	5 3/4	3/16	5.350	±.037	.210	±.005	135.89	±.94	5.33	±.13
-357	5 1/2	5 7/8	3/16	5.475	±.037	.210	±.005	139.07	±.94	5.33	±.13
-358	5 5/8	6	3/16	5.600	±.037	.210	±.005	142.24	±.94	5.33	±.13
-359	5 3/4	6 1/8	3/16	5.725	±.037	.210	±.005	145.42	±.94	5.33	±.13
-360	5 7/8	6 1/4	3/16	5.850	±.037	.210	±.005	148.59	±.94	5.33	±.13
-361	6	6 3/8	3/16	5.975	±.037	.210	±.005	151.77	±.94	5.33	±.13
-362	6 1/4	6 5/8	3/16	6.225	±.040	.210	±.005	158.12	±1.02	5.33	±.13
-363	6 1/2	6 7/8	3/16	6.475	±.040	.210	±.005	164.47	±1.02	5.33	±.13
-364	6 3/4	7 1/8	3/16	6.725	±.040	.210	±.005	170.82	±1.02	5.33	±.13
-365	7	7 3/8	3/16	6.975	±.040	.210	±.005	177.17	±1.02	5.33	±.13
-366	7 1/4	7 5/8	3/16	7.225	±.045	.210	±.005	183.52	±1.14	5.33	±.13
-367	7 1/2	7 7/8	3/16	7.475	±.045	.210	±.005	189.87	±1.14	5.33	±.13
-368	7 3/4	8 1/8	3/16	7.725	±.045	.210	±.005	196.22	±1.14	5.33	±.13
-369	8	8 3/8	3/16	7.975	±.045	.210	±.005	202.57	±1.14	5.33	±.13
-370	8 1/4	8 5/8	3/16	8.225	±.050	.210	±.005	208.92	±1.27	5.33	±.13
-371	8 1/2	8 7/8	3/16	8.475	±.050	.210	±.005	215.27	±1.27	5.33	±.13
-372	8 3/4	9 1/8	3/16	8.725	±.050	.210	±.005	221.62	±1.27	5.33	±.13
-373	9	9 3/8	3/16	8.975	±.050	.210	±.005	227.97	±1.27	5.33	±.13
-374	9 1/4	9 5/8	3/16	9.225	±.055	.210	±.005	234.32	±1.40	5.33	±.13
-375	9 1/2	9 7/8	3/16	9.475	±.055	.210	±.005	240.67	±1.40	5.33	±.13
-376	9 3/4	10 1/8	3/16	9.725	±.055	.210	±.005	247.02	±1.40	5.33	±.13
-377	10	10 3/8	3/16	9.975	±.055	.210	±.005	253.37	±1.40	5.33	±.13
-378	10 1/2	10 7/8	3/16	10.475	±.060	.210	±.005	266.07	±1.52	5.33	±.13
-379	11	11 3/8	3/16	10.975	±.060	.210	±.005	278.77	±1.52	5.33	±.13
-380	11 1/2	11 7/8	3/16	11.475	±.065	.210	±.005	291.47	±1.65	5.33	±.13
-381	12	12 3/8	3/16	11.975	±.065	.210	±.005	304.17	±1.65	5.33	±.13
-382	13	13 3/8	3/16	12.975	±.065	.210	±.005	329.57	±1.65	5.33	±.13
-383	14	14 3/8	3/16	13.975	±.070	.210	±.005	354.97	±1.78	5.33	±.13
-384	15	15 3/8	3/16	14.975	±.070	.210	±.005	380.37	±1.78	5.33	±.13
-385	16	16 3/8	3/16	15.955	±.075	.210	±.005	405.26	±1.91	5.33	±.13
-386	17	17 3/8	3/16	16.955	±.080	.210	±.005	430.66	±2.03	5.33	±.13
-387	18	18 3/8	3/16	17.955	±.085	.210	±.005	456.06	±2.16	5.33	±.13

Table 55: Standard O-Ring Sizes

AS568A	Nominal Reference			Actual Dimensions (inches)				Actual Dimensions (mm)			
No.	I.D.	O.D.	Width	I.D.	Tol	Width	Tol	I.D.	Tol	Width	Tol
-388	19	19 3/8	3/16	18.955	±.090	.210	±.005	481.41	±2.29	5.33	±.13
-389	20	20 3/8	3/16	19.955	±.095	.210	±.005	506.81	±2.41	5.33	±.13
-390	21	21 3/8	3/16	20.955	±.095	.210	±.005	532.21	±2.41	5.33	±.13
-391	22	22 3/8	3/16	21.955	±.100	.210	±.005	557.61	±2.54	5.33	±.13
-392	23	23 3/8	3/16	22.940	±.105	.210	±.005	582.68	±2.67	5.33	±.13
-393	24	24 3/8	3/16	23.940	±.110	.210	±.005	608.08	±2.79	5.33	±.13
-394	25	25 3/8	3/16	24.940	±.115	.210	±.005	633.48	±2.92	5.33	±.13
-395	26	26 3/8	3/16	25.940	±.120	.210	±.005	658.88	±3.05	5.33	±.13
-425	4 1/2	5	1/4	4.475	±.033	.275	±.006	113.67	±.84	6.99	±.15
-426	4 5/8	5 1/8	1/4	4.600	±.033	.275	±.006	116.84	±.84	6.99	±.15
-427	4 3/4	5 1/4	1/4	4.725	±.033	.275	±.006	120.02	±.84	6.99	±.15
-428	4 7/8	5 3/8	1/4	4.850	±.033	.275	±.006	123.19	±.84	6.99	±.15
-429	5	5 1/2	1/4	4.975	±.037	.275	±.006	126.37	±.94	6.99	±.15
-430	5 1/8	5 5/8	1/4	5.100	±.037	.275	±.006	129.54	±.94	6.99	±.15
-431	5 1/4	5 3/4	1/4	5.225	±.037	.275	±.006	132.72	±.94	6.99	±.15
-432	5 3/8	5 7/8	1/4	5.350	±.037	.275	±.006	135.89	±.94	6.99	±.15
-433	5 1/2	6	1/4	5.475	±.037	.275	±.006	139.07	±.94	6.99	±.15
-434	5 5/8	6 1/8	1/4	5.600	±.037	.275	±.006	142.24	±.94	6.99	±.15
-435	5 3/4	6 1/4	1/4	5.725	±.037	.275	±.006	145.42	±.94	6.99	±.15
-436	5 7/8	6 3/8	1/4	5.850	±.037	.275	±.006	148.59	±.94	6.99	±.15
-437	6	6 1/2	1/4	5.975	±.037	.275	±.006	151.77	±.94	6.99	±.15
-438	6 1/4	6 3/4	1/4	6.225	±.040	.275	±.006	158.12	±1.02	6.99	±.15
-439	6 1/2	7	1/4	6.475	±.040	.275	±.006	164.47	±1.02	6.99	±.15
-440	6 3/4	7 1/4	1/4	6.725	±.040	.275	±.006	170.82	±1.02	6.99	±.15
-441	7	7 1/2	1/4	6.975	±.040	.275	±.006	177.17	±1.02	6.99	±.15
-442	7 1/4	7 3/4	1/4	7.225	±.045	.275	±.006	183.52	±1.14	6.99	±.15
-443	7 1/2	8	1/4	7.475	±.045	.275	±.006	189.87	±1.14	6.99	±.15
-444	7 3/4	8 1/4	1/4	7.725	±.045	.275	±.006	196.22	±1.14	6.99	±.15
-445	8	8 1/2	1/4	7.975	±.045	.275	±.006	202.57	±1.14	6.99	±.15
-446	8 1/2	9	1/4	8.475	±.055	.275	±.006	215.27	±1.40	6.99	±.15
-447	9	9 1/2	1/4	8.975	±.055	.275	±.006	227.97	±1.40	6.99	±.15
-448	9 1/2	10	1/4	9.475	±.055	.275	±.006	240.67	±1.40	6.99	±.15
-449	10	10 1/2	1/4	9.975	±.055	.275	±.006	253.37	±1.40	6.99	±.15
-450	10 1/2	11	1/4	10.475	±.060	.275	±.006	266.07	±1.52	6.99	±.15
-451	11	11 1/2	1/4	10.975	±.060	.275	±.006	278.77	±1.52	6.99	±.15
-452	11 1/2	12	1/4	11.475	±.060	.275	±.006	291.47	±1.52	6.99	±.15
-453	12	12 1/2	1/4	11.975	±.060	.275	±.006	304.17	±1.52	6.99	±.15
-454	12 1/2	13	1/4	12.475	±.060	.275	±.006	316.87	±1.52	6.99	±.15
-455	13	13 1/2	1/4	12.975	±.060	.275	±.006	329.57	±1.52	6.99	±.15
-456	13 1/2	14	1/4	13.475	±.070	.275	±.006	342.27	±1.78	6.99	±.15
-457	14	14 1/2	1/4	13.975	±.070	.275	±.006	354.97	±1.78	6.99	±.15
-458	14 1/2	15	1/4	14.475	±.070	.275	±.006	367.67	±1.78	6.99	±.15
-459	15	15 1/2	1/4	14.975	±.070	.275	±.006	380.37	±1.78	6.99	±.15
-460	15 1/2	16	1/4	15.475	±.070	.275	±.006	393.07	±1.78	6.99	±.15
-461	16	16 1/2	1/4	15.955	±.075	.275	±.006	405.26	±1.91	6.99	±.15
-462	16 1/2	17	1/4	16.455	±.075	.275	±.006	417.96	±1.91	6.99	±.15
-463	17	17 1/2	1/4	16.955	±.080	.275	±.006	430.66	±2.03	6.99	±.15
-464	17 1/2	18	1/4	17.455	±.085	.275	±.006	443.36	±2.16	6.99	±.15
-465	18	18 1/2	1/4	17.955	±.085	.275	±.006	456.06	±2.16	6.99	±.15
-466	18 1/2	19	1/4	18.455	±.085	.275	±.006	468.76	±2.16	6.99	±.15
-467	19	19 1/2	1/4	18.955	±.090	.275	±.006	481.46	±2.29	6.99	±.15
-468	19 1/2	20	1/4	19.455	±.090	.275	±.006	494.16	±2.29	6.99	±.15
-469	20	20 1/2	1/4	19.955	±.090	.275	±.006	506.86	±2.41	6.99	±.15
-470	21	21 1/2	1/4	20.955	±.090	.275	±.006	532.26	±2.41	6.99	±.15
-471	22	22 1/2	1/4	21.955	±.100	.275	±.006	557.66	±2.54	6.99	±.15
-472	23	23 1/2	1/4	22.940	±.105	.275	±.006	582.68	±2.67	6.99	±.15
-473	24	24 1/2	1/4	23.940	±.110	.275	±.006	608.08	±2.79	6.99	±.15
-474	25	25 1/2	1/4	24.940	±.115	.275	±.006	633.48	±2.92	6.99	±.15
-475	26	26 1/2	1/4	25.940	±.120	.275	±.006	658.88	±3.05	6.99	±.15

Table 55: Standard O-Ring Sizes

Note: The following sizes are intended for use with internal straight thread fluid connection bosses and tube fittings.

AS568A	Tube O.D.	Actual Dimensions (inches)				Actual Dimensions (mm)			
No.	(Reference)	I.D.	Tol	Width	Tol	I.D.	Tol	Width	Tol
-901	3/32	.185	±.005	.056	±.003	4.70	±.13	1.42	±.08
-902	1/8	.239	±.005	.064	±.003	6.07	±.13	1.63	±.08
-903	3/16	.301	±.005	.064	±.003	7.65	±.13	1.63	±.08
-904	1/4	.351	±.005	.072	±.003	8.92	±.13	1.83	±.08
-905	5/16	.414	±.005	.072	±.003	10.52	±.13	1.83	±.08
-906	3/8	.468	±.005	.078	±.003	11.89	±.13	1.98	±.08
-907	7/16	.530	±.007	.082	±.003	13.46	±.18	2.08	±.08
-908	1/2	.644	±.009	.087	±.003	16.36	±.23	2.21	±.08
-909	9/16	.706	±.009	.097	±.003	17.93	±.23	2.46	±.08
-910	5/8	.755	±.009	.097	±.003	19.18	±.23	2.46	±.08
-911	11/16	.863	±.009	.116	±.004	21.92	±.23	2.95	±.10
-912	3/4	.924	±.009	.116	±.004	23.47	±.23	2.95	±.10
-913	13/16	.986	±.010	.116	±.004	25.04	±.26	2.95	±.10
-914	7/8	1.047	±.010	.116	±.004	26.59	±.26	2.95	±.10
-916	1	1.171	±.010	.116	±.004	29.74	±.26	2.95	±.10
-918	1 1/8	1.355	±.012	.116	±.004	34.42	±.30	2.95	±.10
-920	1 1/4	1.475	±.014	.118	±.004	37.47	±.36	3.00	±.10
-924	1 1/2	1.720	±.014	.118	±.004	43.69	±.36	3.00	±.10
-928	1 3/4	2.090	±.018	.118	±.004	53.09	±.46	3.00	±.10
-932	2	2.337	±.018	.118	±.004	59.36	±.46	3.00	±.10

Table 55: Standard O-Ring Sizes

Glossary.

A

ABRASION - progressive wearing away of a surface in service by mechanical action such as scraping, rubbing, or erosion.

ABRASION RESISTANCE - resistance of a rubber compound to wearing away when in dynamic contact with an abrasive surface.

ABSORPTION - physical mechanism by which one substance attracts and takes up another substance (liquid, gas, or vapor) into its interior.

ACCELERATED LIFE TEST - any set of test conditions designed to reproduce in a short time the deterioration obtained under normal service conditions.

ACCELERATED SERVICE TEST - bench or service test in which a particular service condition, such as speed, temperature, or continuity of operation, is exaggerated so as to obtain a more rapid result.

ACCELERATOR - chemical which speeds the vulcanization of an elastomer, so that it takes place in a shorter time or at a lower temperature. Picking up where an activator leaves off, an accelerator is often used in conjunction with a catalyst, hardener, or curing agent.

ACID RESISTANT - able to withstand the degrading effects of acids.

ACTIVATOR - chemical which initiates the vulcanization of an elastomer.

ACTUAL SIZE - exact size of an O-ring or seal in decimal dimensions (inches or millimeters), including tolerances.

ADDITIVE - material added to an elastomeric compound to alter its properties, e.g. a reinforcing agent to improve strength or a plasticizer to aid flexibility and processibility.

ADHERE - (a) to cling or stick together; or (b) to cause two surfaces to stick together.

"This glossary contains a wide variety of terms frequently used within the sealing industry. Familiarity with these terms will be beneficial as you design O-ring seals."

ADHESION - tendency of rubber or other material to stick to a contact surface; may result from chemical or physical interlocking.

ADHESIVE - substance used to hold materials together.

ADSORPTION - physical mechanism by which one substance attracts another substance (either solid, liquid, gas, or vapor) to its surface.

AERATION - air (or gas) bubbles built up within a liquid.

AFTER CURE - uncontrolled continuation of vulcanization after the desired cure has been effected and the heat source removed; not the same as post cure.

AGING - change in rubber characteristics over time brought about by environmental factors such as heat and light.

AIR CHECKS / TRAPS - surface marks or depressions on a molded rubber product resulting from air getting trapped between the material being cured and the mold surface.

AIR CURING - vulcanization of rubber in air as opposed to steam or press vulcanization.

ALCOHOLS - organic compounds containing the hydroxyl (-OH) group; used as starting points in the production of synthetic resins, synthetic rubbers, and plasticizers.

ALIPHATIC HYDROCARBONS - organic compounds recognizable by their straight chains of carbon atoms. Three subgroups comprise aliphatic hydrocarbons: paraffins (alkanes), olefins (alkenes), and acetylenes (alkynes).

AMBIENT TEMPERATURE - temperature of the environment surrounding a component; not necessarily the same as atmospheric temperature.

AMINE - chemical used as a curing agent for fluoroelastomers; also a film-forming inhibitor used to prevent corrosion in oil-field tubular goods.

AMORPHOUS - non-crystalline in structure; may be used in reference to polymers whose molecular chains are irregular and that therefore do not fit closely together.

ANILINE POINT - lowest temperature at which equal volumes of aniline and a petroleum fluid will completely dissolve in one another. The aniline point of oil is a measure of the aromatic content or the amount of unsaturated hydrocarbons present. The lower the aniline point, the higher the level of unsaturants, and the higher the potential for swelling certain rubber compounds.

ANTI-DEGRADANT - chemical added to an elastomeric compound to shield against the degrading effects of environmental elements like oxygen or ozone.

ANTI-EXTRUSION RING (DEVICE) - relatively hard, high modulus ring (or similar device) placed in the gland between the O-ring and the groove side walls, to prevent extrusion of the seal into the clearance gap; also known as a back-up ring.

ANTIOXIDANT - chemical added to a rubber compound to resist oxidation.

ANTIOZONANT - chemical added to a rubber compound to resist ozone (O_3) degradation.

AROMATIC HYDROCARBONS - organic compounds recognizable by their rings of carbon atoms. Benzene, for example, is a six carbon ring with three double bonds. Other aromatic hydrocarbons include toluene and xylene (see ***Figure 148***).

AS 568A - Aerospace Standard Uniform Dash Numbering System; specifies O-ring sizes based on their inside diameter (I.D.) and cross-section (W); supersedes and cancels AS 568 and ARP 568.

ATMOSPHERIC CRACKING - cracking and degradation of the physical properties of a rubber product exposed to atmospheric conditions; also known as weathering.

ATOM - smallest unit of an element that (a) still retains all the properties of that element; and (b) is capable of entering into a chemical reaction.

AROMATIC HYDROCARBON

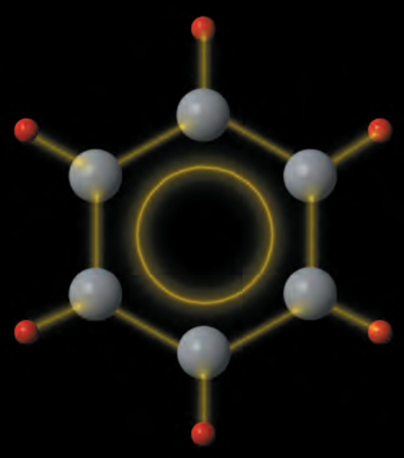


Figure 148: Benzene Ring

ATOMIC NUMBER - the number of protons within the nucleus of an atom. For example, carbon has six protons and its atomic number is 6. Elements are listed in order of their increasing atomic numbers in the Periodic Table.

ATOMIC WEIGHT - sum of the masses of the protons and neutrons within the nucleus of a given atom. Because their weight is negligible, electrons are not included in this total; also known as atomic mass.

AXIAL SEAL - an O-ring that seals on a plane perpendicular to its axis instead of on its outside diameter (O.D.) or inside diameter (I.D.); also known as a face seal.

B

BACKRIND - ragged indentation at the parting line of a finished rubber product resulting from molding stresses.

BACK-UP RING - relatively hard, high modulus ring placed in the gland between the O-ring and the groove side walls, to prevent extrusion of the seal into the clearance gap; also known as an anti-extrusion ring or device.

BANBURY MIXER - specific type of internal mixer in which rubber compounds are blended.

BI-DIRECTIONAL SEAL - seal which provides fluid sealing on both sides (see ***Figure 149***).

BI-DIRECTIONAL SEAL

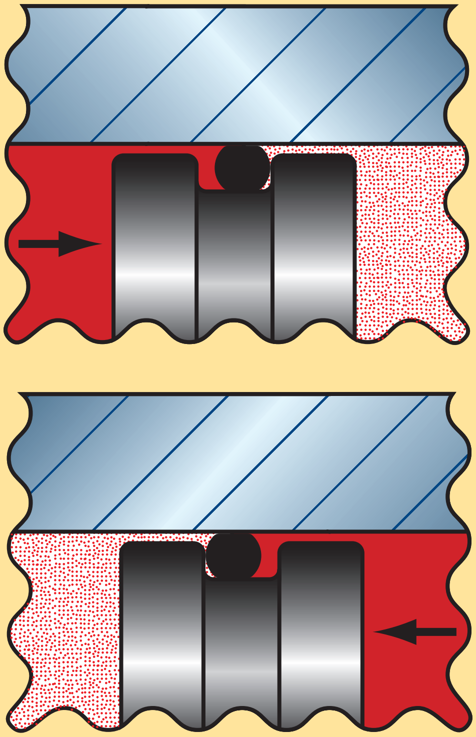


Figure 149: Sealing on both sides.

BLEEDING - migration of plasticizers, waxes, or other compound ingredients to the surface of a molded rubber product; also known as blooming.

BLEMISH - mark or deformity on the surface of a molded product.

BLISTER - raised area on the surface of a molded product caused by the pressure of internal gases.

BLOOM - creamy or dusty deposit appearing on the surface of a molded rubber product; caused by the migration of certain compound ingredients to the rubber's surface after molding and storage.

BLOOMING - migration of plasticizers, waxes, or other compound ingredients to the surface of a molded rubber product; also known as bleeding.

BOND - (a) to unite two materials; or (b) the mechanical, chemical, or adhesive force which binds an elastomer to another object. Mechanical bonds use interlocking design characteristics to ensure continued physical contact. Chemical bonds are based on internal cross-linking. Adhesive bonds rely on cements or other external adhesives.

BREAK-OUT FRICTION - static frictional force which must be overcome to initiate movement; also known as static friction or stiction.

BRITTLENESS - tendency to crack upon deformation.

BRITTLE POINT - temperature at which an elastomer becomes brittle.

BUNA N - copolymer of butadiene and acrylonitrile; also known as NBR or nitrile rubber.

BUNA S - copolymer of butadiene and styrene; also known as SBR or styrene butadiene rubber.

BUTT JOINT - joining two seal ends such that the junction is perpendicular to the mold parting line.

BUTYL - copolymer of isobutylene and isoprene.

C

C (° C) - degrees Centigrade (Celsius).

CATALYST - chemical that causes or accelerates the cure of a rubber compound, but that does not usually become a chemical component of the end product.

CAVITY - hollow space within the mold in which uncured rubber is shaped and vulcanized; also known as mold cavity.

CHAIN EXTENDER - chemical combined with a polyurethane pre-polymer; acts much like a cross-linking or vulcanizing agent used to cure rubber.

CHAIN SCISSION - breaking of molecular bonds within the backbone of a polymer due to chemical or thermal attack that divides the polymer chains into smaller segments, with a resulting loss in physical properties; also known simply as scission.

CHAMFER - beveled edge in a component to facilitate assembly of a seal onto a rod or shaft, or into a cylinder or housing; also known as a lead-in chamfer.

CHECKING - cracking or crazing of an elastomer's surface due to the action of sunlight; also known as sun checking.

CHLORINATED HYDROCARBONS - organic compounds having chlorine and hydrogen atoms in their chemical structure. Examples include trichloroethylene, methylene chloride, and methyl chloroform.

CHLORINATION - surface treatment using chlorine gas that reduces break-out and running friction in molded rubber seals.

CLEARANCE - the gap between two mating surfaces.

CLEAVAGE - breaking of any chemical bond; most commonly refers to the breaking of crosslink bonds between polymer chains or sidegroups that are pendent to the polymer backbone.

COEFFICIENT OF THERMAL EXPANSION - may be linear or volumetric: (a) the coefficient of linear thermal expansion is the change in length per unit of length for a one degree rise in temperature; and (b) the coefficient of volumetric thermal expansion is the change in volume divided by the product of the original volume and the change in temperature. The coefficient of volumetric thermal expansion is three times the coefficient of linear thermal expansion for a solid material.

COLD FLEXIBILITY - ability of an elastomeric product to resist cracking or breaking when flexed or bent at low temperatures; also known as low temperature flexibility.

COLD FLOW - increasing deformation of a rubber material under a constant compressive load; also known as creep.

COLD RESISTANT - able to function in low temperature applications.

COMMERCIALLY SMOOTH - surface smoothness that is acceptable for use.

COMPOSITE SEAL - seal composed of two (or more) separate materials, such as rubber and metal, generally bonded together.

COMPOUND - (a) molecules made up of differing atoms; and (b) a mixture of polymers and other ingredients to produce an elastomeric material.

COMPRESSION MODULUS - ratio of compression stress (force in psi) to resulting compression strain (noted as a percentage of the original specimen thickness).

COMPRESSION MOLDING - thermoset molding technique (see ***Figure 150***) in which the uncured rubber compound is put in a heated, open mold cavity and the mold is closed under pressure (often in a hydraulic press). The material flows to completely fill the cavity. Pressure is maintained until curing is complete.

COMPRESSION MOLDING

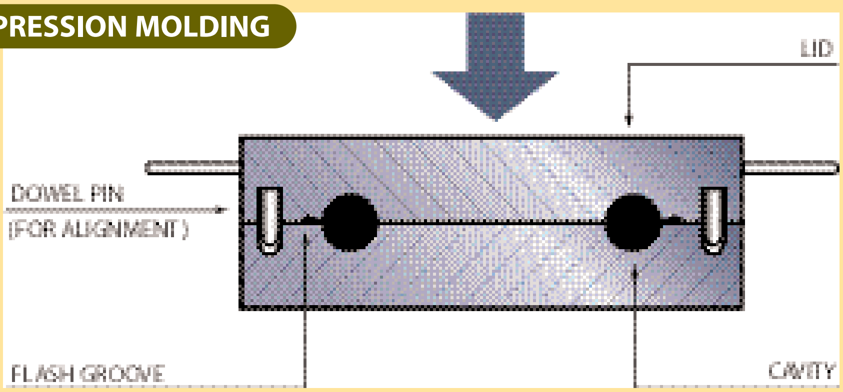


Figure 150: Compression molding relies on pressure and material flow.

COMPRESSION SEAL - seal effected by compressing a rubbery material between mating surfaces.

COMPRESSION SET - the amount, expressed as a percentage of deflection, by which a rubber specimen does not return to its original thickness following release of a compressive load.

CONDUCTIVE RUBBER - rubber material that is capable of conducting electricity, usually static electricity. To be classified as conductive, an elastomer must have a direct current resistivity of less than 105 ohm/cm.

COPOLYMER - polymer composed of two different monomers, chemically combined. For example, Buna N is a copolymer of butadiene and acrylonitrile.

CORROSION - progressive wearing away of a surface in service by chemical action.

CORROSIVE - material property that promotes corrosion of a mating sealing surface.

COVALENT BOND - bond between atoms consisting of a pair of shared electrons.

CRACKING - sharp breaks or fissures in a rubber surface caused by excessive strain and/or exposure to detrimental environmental conditions, such as ozone, weather, or ultraviolet (UV) light; also known as crazing.

CREEP - increasing deformation of a rubber material under a constant compressive load; also known as cold flow.

CRITICAL TEMPERATURE (T_C) - (a) regarding gases, the temperature above which a gas cannot be liquefied, regardless of the amount of pressure applied to it; and (b) regarding rubber compounds, the temperature above which a rubber can no longer strain crystallize.

CROSS-SECTION - (a) view of a seal, cut at right angles to the mold parting line, exposing the seal's internal structure; and (b) one-half the difference between the outside diameter (O.D.) and inside diameter (I.D.) of a seal; also known as width (W).

CRYOGENIC - pertaining to very low temperatures. Some molded articles are deflashed in cryogenic chambers.

CRYSTALLINE - containing crystals; may be used in reference to polymers whose molecular chains are very regular and that therefore fit closely together into a rigid pattern.

CURE - heat-induced process whereby the long chains of the rubber molecules become crosslinked by a vulcanizing agent to form three-dimensional elastic structures. This reaction transforms soft, weak, non-cross-linked materials into strong elastic products; also known as vulcanization.

CURE DATE - the quarter and year indicating the molding date of a rubber part. For example, "1Q00" denotes a cure date in the first quarter (January, February, or March) of 2000.

CURING TEMPERATURE - temperature at which a rubber product is vulcanized.

CYCLE TIME - the time that elapses between a given point in one molding cycle and the same point in the next cycle (for example, loading of raw stock, through molding and unloading of finished parts, then back to reloading again). Generally speaking, the longer the cycle time, the more the process costs and the more expensive the finished part will be.

CYLINDER - chamber in which a piston, ram, rod, or shaft operates.

D

DAMPER - device capable of minimizing motion or dissipating energy, such as a shock absorber. Because an elastomer has a viscous phase, it can be thought of as a damper, i.e. the elastomer resists motion (deformation), making it an effective seal material.

DASH NUMBER - three-digit number preceded by a dash as specified by SAE Aerospace Standard 568A to indicate the O-ring size based on its inside diameter (I.D.) and cross-section (W); also known as size number.

DEFLASH - process of removing excess material (flash) from the parting line of a molded rubber product.

DEFLECTION - change in the shape of a seal as a result of compression; also known as deformation.

DEGASSING - the intentional, controlled evaporation of volatile substances out of a rubber material.

DEGRADATION - breakdown in chemical structure and/or loss of physical properties after exposure to harmful agents (such as heat, sunlight, oxygen, ozone, or weather).

DIAMETRAL CLEARANCE GAP - the difference in diameters between two mating surfaces to be sealed.

DIENE RUBBER - rubber containing a double bond in the main chain; such double bonds are vulnerable to attack (such as by oxygen, ozone, and UV light).

DIFFERENTIAL PRESSURE - difference in the amount of force being exerted on the high-pressure side of a seal (the side facing system pressure) relative to the low-pressure side (the side facing away from system pressure). Differential pressure is responsible for forcing a seal toward the low pressure side of a gland (see ***Figure 151***).

DIFFERENTIAL PRESSURE

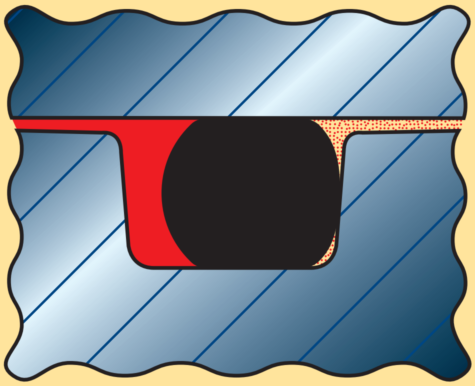


Figure 151: The two sides of a seal.

DIISOCYANATE - hard segment in the polyurethane backbone; imparts toughness and heat resistance.

DOUBLE-ACTING SEAL - dynamic reciprocating seal capable of sealing in both directions of movement.

DOUBLE BOND - covalent bond consisting of two pairs of shared electrons. A double bond occurring between two carbon atoms (such as is found in the butadiene segment of nitrile rubber) is inherently more chemically reactive and is a site for both crosslinking and chemical attack (see ***Figure 152***).

DOUBLE BOND

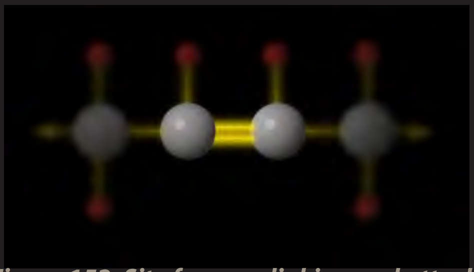


Figure 152: Site for crosslinking and attack.

DRY RUNNING - absence of liquid or lubrication in a dynamic sealing application.

DUROMETER - (a) an instrument that measures the hardness of rubber by its resistance to surface penetration of an indentor point; and (b) the numerical scale indicating the hardness of rubber. See also "Shore A Durometer" and "Shore D Durometer."

DYNAMIC - describes an application in which the mating surfaces to be sealed are in relative motion to each other.

DYNAMIC FRICTION - friction resulting from relative motion between two contacting surfaces.

DYNAMIC SEAL - seal functioning in an environment in which there is relative motion (e.g. reciprocating, rotary, or oscillating) between the mating surfaces being sealed.

E

ELASTICITY - an elastomer's inherent ability to readily regain its original size and shape after being released from a deforming load.

ELASTOMER - any natural or synthetic material meeting the following requirements: (a) it must not break when stretched 100%; and (b) after being held at 100% stretch for five minutes then released, it must return to within 10% of its original length within five minutes.

ELECTRON - small, negatively-charged particle orbiting the nucleus of an atom; for electrically-neutral atoms, the number of electrons equals the number of positively-charged protons within the nucleus.

ELEMENT - term referring to a single type of atom making up a substance.

ELONGATION - percentage increase in original length (strain) of a specimen produced by a tensile force (stress) applied to the specimen. "Ultimate elongation" is the elongation at the moment the specimen breaks.

ENCAPSULATION - enclosure or jacket surrounding another material; for example, a Teflon® encapsulation over an O-ring core molded from a different material.

ENDOTHERMIC - absorbing heat.

EVAPORATION - direct conversion of a fluid from liquid to vapor.

EXOTHERMIC - giving off heat, as during a chemical reaction.

EXPLOSIVE DECOMPRESSION - phenomenon occurring in rubber seals after exposure to high-pressure gas. This gas permeates into the elastomer through flaw sites present in all molded rubber products. During an equilibrium shift (lowered pressure), the gas then expands within the seal, causing internal ruptures in high shear modulus (hard) materials and surface blisters in low shear modulus (soft) materials. Explosive decompression can be likened to "getting the bends."

EXTEND - add fillers or other low-cost materials to an elastomeric mixture in an effort to reduce costs and to increase the amount of compound that is available for use, i.e. "extend" its usage.

EXTENDER - relatively inexpensive and inert material added to an elastomeric compound to reinforce or modify properties (e.g. physical, mechanical, electrical, thermal), impart certain processing properties, or reduce costs; also known as a filler.

EXTRACTION - removal from a material, as when fuel or other system fluids chemically remove a compound's plasticizer, leading to seal shrinkage.

EXTRUSION - pressure-induced distortion or extension of part of a seal into the clearance gap between mating seal surfaces.

F

F (° F) - degrees Fahrenheit.

FACE - front surface of a seal; in an O-ring, the two surfaces that are perpendicular to its axis.

FACE SEAL - an O-ring that seals on a plane perpendicular to its axis instead of on its outside diameter (O.D.) or inside diameter (I.D.); also known as an axial seal.

FATIGUE RESISTANCE - capable of withstanding fatigue caused by repeated bending, extension, or compression; also known as flex resistance.

FILLER - relatively inexpensive and inert material added to an elastomer to reinforce or modify properties (e.g. physical, mechanical, electrical, thermal), impart certain processing properties, or reduce cost; also known as an extender.

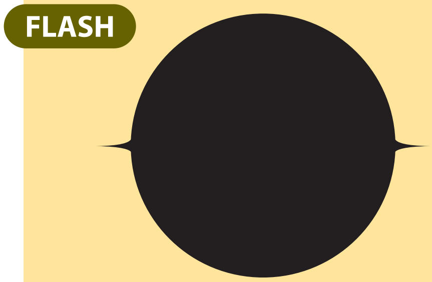


Figure 153: Excess rubber on the OD and ID.

FLASH - excess rubber remaining on the parting line of a molded rubber product (see ***Figure 153***).

FLAWS - surface imperfections that occur infrequently (i.e. not in a pattern), as with an isolated scratch or crack in the metal of a gland.

FLEX CRACKING - surface cracks caused by repeated flexural cycling.

FLEX RESISTANCE - capable of withstanding fatigue caused by repeated bending, extension, or compression; also known as fatigue resistance.

FLOW LINES - imperfections in a molded rubber product caused by imperfect flow of the material during molding; also known as flow cracks.

FLUID - a liquid or a gas.

FLUOROCARBON - carbon backbone, organic compound having fluorine atoms in its chemical structure. Presence of the fluorine provides increased chemical and high temperature resistance.

FRICTION - motion resistance resulting from contact between mating surfaces, usually accompanied by liberation of heat energy.

FRICTION (BREAK-OUT) - static frictional force which must be overcome to initiate movement; also known as static friction or stiction.

FRICTION (RUNNING) - dynamic frictional force which must be overcome to maintain movement.

FUEL (AROMATIC) - fuel containing aromatic (ringed) hydrocarbons (such as benzene, toluene, and xylene). Aromatic fuels cause high swell of rubber.

FUEL (NON-AROMATIC) - fuel containing aliphatic (straight chain) hydrocarbons (such as octane). Non-aromatic fuels cause less rubber swell than aromatic fuels.

G

GASKET - static seal effected when a deformable material is sandwiched and compressed between two mating surfaces.

GATE MARK - raised spot or small depression seen on an injection or transfer molded product; caused when the finished molded part is removed from the injection nozzle (gate or sprue) through which the material is injected into the mold cavity; also known as a sprue mark.

GLAND - machined cavity into which an O-ring or other seal is fitted; includes the groove and the mating surface to be sealed.

GLASS TRANSITION (T_g) - temperature at which a viscous polymer loses all ability to flow or store energy, becoming hard and brittle (like glass).

GOUGH-JOULE EFFECT - tendency of a stretched rubber specimen to retract when heated.

GROOVE - machined recess within a gland into which an O-ring or other seal is fitted.

H

HARDNESS - measure of rubber's relative resistance to an indentor point on a testing device. Shore A durometers gauge soft to medium-hard rubber. Shore D durometers are more accurate on samples harder than 90 Shore A.

HEAT AGING - loss of physical properties as a result of exposure to heat.

HEAT BUILD-UP - temperature rise in a molded rubber product due to hysteresis during repeated deformations.

HEAT RESISTANCE - rubber compound's capacity to undergo exposure to some specified level of elevated temperature and retain a high level of its original properties.

HERMETIC SEAL - an airtight seal.

HETEROPOLYMER - polymer composed of differing monomers.

HOMOGENEOUS - used to describe a rubber material of uniform composition, with no fabric or metal reinforcement.

HOMOPOLYMER - polymer composed of identical monomers.

HYDROCARBONS - organic compounds with both hydrogen and carbon in their chemistry. Many organic compounds are hydrocarbons. Aliphatic hydrocarbons, such as butane, have a straight-chain structure. Aromatic hydrocarbons, such as benzene, are ringed structures.

HYDROGENATION - addition of hydrogen atoms to an organic compound to reduce the number of carbon-to-carbon double bonds that would otherwise be weak links in the polymer chain. For example, the hydrogenation of nitrile produces a great compound (HNBR) with both high strength and superior oxidation resistance.

HYDROGEN BOND - an electrostatic attraction between a hydrogen atom in one molecule and a small electronegative atom (like fluorine, oxygen, or nitrogen) in an adjoining molecule. Though not nearly as strong as covalent bonds, hydrogen bonds are present in such numbers in hydrocarbon polymers that they are an important source of polymer strength.

HYDROLYSIS - chemical decomposition as a result of contact with water.

HYGROSCOPIC - capable of absorbing moisture, especially from the air.

HYSTERESIS - percent of energy lost per cycle of deformation, or 100% minus the resilience percentage. Hysteresis is the result of internal friction and is evident by the conversion of mechanical energy into heat.

I

I.D. - inside diameter of a seal or component.

IDENTIFICATION - colored stripes or dots on seals to differentiate among rubber compounds.

IMMERSION - putting an article into a fluid so that it is totally covered.

IMMISCIBLE - not capable of being mixed. With elastomers, “immiscible” is generally analogous to “insoluble” and refers to a substance (such as a seal) that cannot be dissolved in a fluid (such as the fluid being sealed). In order to have long seal life, it is important to maximize immiscibility.

IMPACT - forceful contact between two bodies, at least one of which is in motion.

INERT - inactive or non-reactive; often used to describe a material (like Teflon®) that is impervious to many chemicals.

INHIBITOR - chemical added to an elastomeric compound to ensure vulcanization does not proceed too quickly.

INJECTION MOLDING - process in which preheated rubber is injected under pressure from the heating chamber through a series of runners and sprues and into a closed, heated mold cavity, then vulcanized. Injection molding is ideal for high-volume production of molded rubber parts (see ***Figure 154***).

INJECTION MOLDING

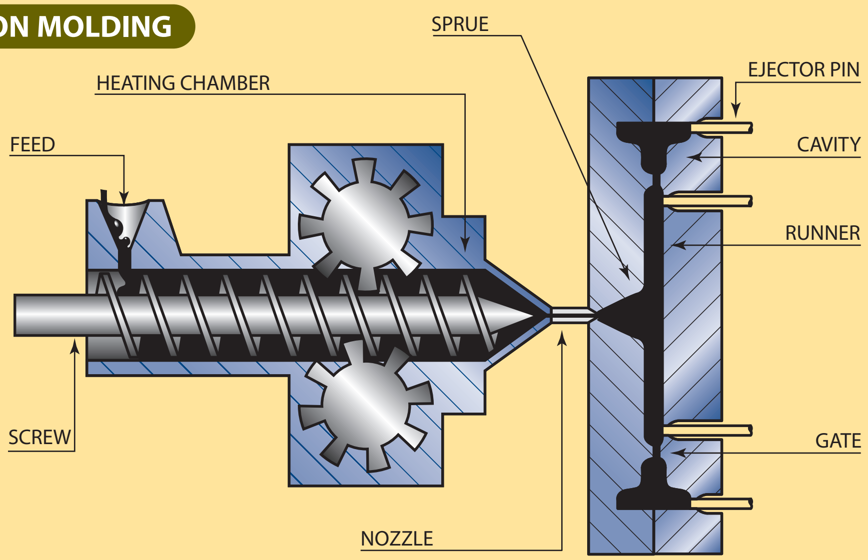


Figure 154: Injection molding forces rubber into a closed mold.

INORGANIC - containing chemical structures not based on the carbon atom.

INSOLUBLE - not susceptible to being dissolved in a fluid.

ION - atom with an electrical charge (either positive or negative) due to unequal numbers of protons and electrons. An ion with more protons than electrons will have a positive charge, whereas an ion with more electrons than protons will have a negative charge.

IONIC BOND - strong electrical attraction between oppositely charged atoms (ions).

ISO - International Organization for Standardization, a non-governmental organization whose primary aim is to develop guidelines on what constitutes an effective quality management system.

ISOTOPE - one of two or more distinct forms of a given element. Isotopes have the same atomic number (due to identical numbers of protons) but different atomic masses (due to unlike numbers of neutrons).

K

K (° K) - degrees Kelvin. 0° K (also known as Absolute Zero) is equal to -273° C.

L

LAY - direction of the primary roughness pattern on a gland surface.

LEACHING - removal of soluble components, as when system fluids remove a compound's plasticizer, leading to seal shrinkage.

LEAD-IN

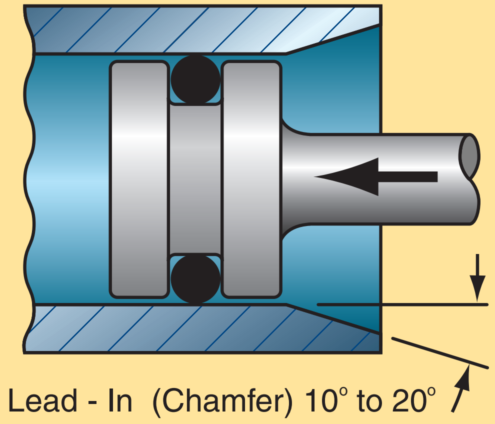


Figure 155: Beveled edge smooths assembly.

LEAD-IN (CHAMFER) - beveled edge in a component to facilitate assembly of a seal onto a rod or shaft, or into a cylinder or housing (see ***Figure 155***).

LEAK RATE - rate at which a fluid (liquid or gas) passes a seal or barrier.

LIFE TEST - laboratory test used to determine the length of a product's life in a defined set of service conditions.

LOAD - actual pressure at a sealing face; normally the sum of the interference load and the fluid pressure at work on the seal.

LOGY - term used to describe a material with poor visco-elastic properties.

LOW TEMPERATURE FLEXIBILITY - ability of an elastomeric product to resist cracking or breaking when flexed or bent at low temperatures.

M

MACROMOLECULE - large chainlike molecule, formed during a process called "polymerization," in which small molecules (monomers) form chemical bonds between one another; also known as a polymer.

MAXIMUM TEMPERATURE - highest temperature a rubber compound can withstand prior to undergoing a physical or chemical change.

MEMORY - an elastomer's ability to regain its original size and shape following deformation.

MICROPORES - very tiny pores on the surfaces of a gland. The presence of micropores, even on finely-machined metal surfaces, contributes to break-out friction. However, these pores also help hold lubricants, so their total elimination is not advantageous.

MINIMUM TEMPERATURE - lowest temperature a rubber compound can withstand prior to losing rubbery properties.

MISCIBLE - capable of being mixed. In the case of elastomers, "miscible" is generally analogous to "soluble" and refers to a substance (such as an elastomeric seal) that can be dissolved in a fluid (such as the fluid being sealed). In order to have long seal life, it is important to minimize miscibility.

MISMATCH - asymmetrical seal cross section caused by dimensional or mating differences in mold sections.

MODULUS - the force in psi (stress) required to produce a certain elongation (strain), usually 100%; a good indication of toughness and resistance to extrusion; also known as tensile modulus or tensile stress.

MODULUS OF ELASTICITY - ratio of the stress (force in psi) to the strain (percent increase in original length) as measured on a rubber specimen; also known as Young's modulus (E); not the same as tensile modulus.

MOISTURE RESISTANCE - able to resist absorbing moisture from the air or during water immersion.

MOLD - (a) to shape or process a material into a usable form; and (b) metal tools, usually steel or aluminum, machined and assembled so as to create openable cavities for the purpose of shaping and vulcanizing rubber.

MOLD CAVITY - hollow space within the mold in which uncured rubber is shaped and vulcanized; also known simply as a cavity.

MOLD FINISH - surface finish of the mold; determines the surface finish of any product taken from that mold.

MOLD LUBRICANT - coating used in the mold cavity to prevent a molded rubber product from sticking to the cavity during removal; also known as mold release.

MOLD MARKS - imperfections in a molded rubber product replicating surface defects on the mold itself.

MOLD REGISTER - accuracy of alignment of mold plates and cavities. An improperly aligned mold is said to be off-register and will produce mismatched parts.

MOLD RELEASE - coating used in the mold cavity to prevent a molded rubber product from sticking to the cavity during removal; also known as mold lubricant.

MOLD SHRINKAGE - dimensional loss in a molded rubber product that occurs during cooling after it has been removed from the mold.

MOLD STORAGE

Figure 156: Individual mold plates are organized for easy retrieval.

MOLD STORAGE - holding area in which removable mold plates are stored when not in use (see ***Figure 156***).

MOLECULE - an electrically neutral aggregate of chemically bonded atoms.

MOLECULAR WEIGHT - sum of the atomic masses of the elements forming a molecule.

MONOMER - small molecule capable of reacting with other molecules to form large chainlike molecules (macromolecules) called polymers.

MOONEY VISCOMETER - shearing disk device used to gauge the viscosity of a rubber sample under heat and pressure. Named for developer Melvin Mooney, this was once the standard tool for determining processing characteristics but has now largely been replaced by the rheometer.

MULTIPLE CAVITY MOLD - mold in which more than one article can be made at a time.

N

NEUTRON - non-charged particle within the nucleus of an atom; hydrogen is the only atom which contains no neutrons.

NIBBLING - progressive mode of seal failure that occurs when excessive pressure forces a portion of an O-ring or other rubber seal into a clearance gap. Expansion and contraction of the gap (breathing) caused by pressure cycling traps extruded portions of the seal in the gap, resulting in bite-like portions (nibbles) being removed from the seal (see ***Figure 157***).

NIBBLING

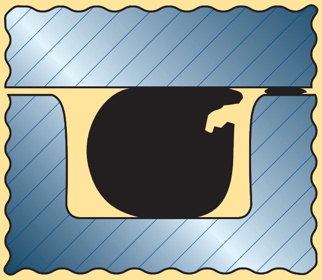


Figure 157: Small bits of the seal are torn off.

NITRILE (BUNA-N) - copolymer of butadiene and acrylonitrile widely used in O-rings and other seals.

NOMINAL SIZE - approximate size of an O-ring or seal in fractional dimensions (inches); typically given solely for reference purposes; also known as nominal dimension.

NON-FILL - defect in a finished molded part caused by the rubber failing to completely fill the mold cavity.

O

OCCLUSION - (a) mechanical process by which vapors, gases, liquids, or solids are entrapped within the folds of a given substance during working or solidification; and (b) the materials entrapped by this process.

O.D. - outside diameter of a seal or component.

OFF-REGISTER - mismatched O-ring cross-section caused by misalignment of mold cavities.

OIL RESISTANT - ability of vulcanized rubber to resist swelling and deterioration due to oil exposure.

OIL SWELL - increase in volume of a rubber product as a result of oil absorption.

OPTIMUM CURE - vulcanization state yielding the most desirable properties.

ORGANIC - containing chemical structures based on the carbon atom.

O-RING - solid elastomer ring seal of circular cross-section; technically, a torus.

OSCILLATING SEAL - rotary seal with limited, reversing travel; as in an on/off valve.

OUTGASSING - phenomenon occurring in vacuums where the volatile materials in a rubber compound are vaporized and released into the environment.

OVER CURE - longer than optimum vulcanization causing some properties to be degraded. Over-cure can be of two types. In the first type, the material continues to harden, the modulus rises, and both tensile strength and elongation fall. In the second type, the rubber begins to break down. The material softens, and the modulus, tensile strength, and elongation all decrease.

OXIDATION - reaction of oxygen with a rubber compound, usually resulting in surface cracking and/or changes in the physical properties of the material.

OZONE (O_3) - unstable form of oxygen (usually generated by electricity) that can cause surface cracking in some elastomers.

OZONE RESISTANCE - ability of a rubber material to withstand exposure to ozone without cracking or otherwise deteriorating.

P

PACKING - generic name for a compression-type dynamic seal housed within a gland.

PERIPHERAL SQUEEZE - compression applied to the

O.D. of a seal when installed in a bore that is smaller than the O.D. of the seal.

PERMANENT SET - amount of deformation in a rubber part after a distorting load has been removed.

PERMEABILITY - measure of the ease with which a liquid or gas can pass through a rubber material (see ***Figure 158***).

PIT OR POCK MARK - small surface void in a molded rubber product caused by mechanical erosion (wear) or chemical action.

PLASTICIZER - chemical substance added to a rubber compound to soften the elastomer, provide flexibility at low temperatures, and improve processing; also known as a softener.

POISSON'S RATIO - ratio of the change in width per unit of width to the change in length per unit of length. For most rubber materials, Poisson's ratio is essentially equal to 0.5.

POLARITY - imbalance in electrical charge (dipole moment) caused by covalent bonds occurring between two dissimilar atoms. The difference in electrical charges of each atom creates a slight negative charge on one atom and a slight positive charge on the other atom. Since hydrocarbon oils are usually non-polar, they are repelled by polymers that have polarity, resulting in increased oil resistance and other properties not found in elastomers containing only carbon and hydrogen atoms.

PERMEABILITY

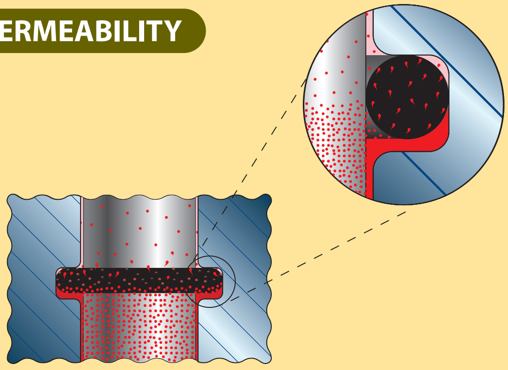


Figure 158: Just passing through.

POLYMER - large chainlike molecules (macromolecules) made up of small repeating units (monomers). When two different monomers are chemically combined, the resulting product is called a copolymer. When three different monomers are involved, the result is a terpolymer.

POLYMERIZE - to chemically unite two or more monomers or polymers to form a molecule with a higher molecular weight.

POLYOL - soft segment in the polyurethane backbone; imparts rubber-like softness and flexibility.

POROSITY - quality or state of having pores or holes in a material.

POST CURE - controlled continuation of vulcanization, usually in an oven, to complete the curing process, drive off residual byproducts, and provide stabilization of parts; not the same as after cure.

POTABLE - (a) drinkable; and (b) a liquid that is safe or suitable for drinking.

PRE-POLYMER - polyurethane polyol and diisocyanate mixture prior to combination with a chain extender.

PROFILOMETER - an instrument used to gauge surface roughness, i.e. to determine the "profile" of a given surface.

PROTON - positively-charged particle within the nucleus of an atom; for electrically-neutral atoms, the number of protons exactly equals the number of negatively-charged electrons orbiting the nucleus. The number of protons in an atom is also said to be that element's atomic number, e.g. carbon has six protons, so its atomic number is 6.

Q

QUAD RING - solid elastomeric ring seal with a four-lobed cross-section.

QPL - Military Qualified Products List; listing of commercial products shown in pretesting to meet the demands of a specification, particularly a federal specification.

QS 9000 - Quality System developed by the automotive industry to supplement the ISO 9000 standard.

R

RADIAL SEAL - O-ring or seal having compression applied to its outside diameter (O.D.) and inside diameter (I.D.).

RADIUS - (a) the distance from the center of a circle to the edge, or one-half the diameter; and (b) to round off a sharp corner, as in the "radiusing" of a gland's top edges to prevent them from nicking or cutting an O-ring during installation.

RECIPROCATING SEAL - dynamic seal used to seal pistons or rods that are in linear motion.

REINFORCING AGENT - material added to an elastomer to improve physical properties such as tensile strength, tensile modulus, and compression modulus.

RELATIVE HUMIDITY - ratio of the amount of water vapor present in the air to the greatest amount that could be present at a given temperature; expressed as a percentage.

RELAXATION - decrease in the force exerted against a mating part by a rubber component that has been under a constant load for a period of time.

REPEATABILITY - consistency of test results taken within a single lab. For example, the similarity (or lack thereof) of multiple durometer readings taken on a single sample with the same tester.

REPRODUCIBILITY - consistency of test results taken among several different labs. For example, the similarity (or lack thereof) of multiple durometer readings taken on a single sample with a series of different testers.

RESILIENT - able to rapidly regain original size and shape following deformation.

REVERSION - condition in an elastomer caused by thermal or chemical attack whereby chemical bonds are broken with a resulting loss in physical properties.

RHEOMETER - cure meter which determines and plots a cure curve illustrating the state of cure for a given time and temperature; typically either an Oscillating Disk Rheometer (ODR) or a Moving Die Rheometer (MDR).

RMS - Root Mean Square, or the square root of the sum of the squares of deviation from true flat; a measure of surface roughness (as with glands or shafts) generally noted in microinches.

ROTARY SEAL - seal capable of sealing between a rotating shaft and an outer surface, such as a groove or housing bore.

ROUGHNESS - closely-spaced irregularities on a gland's surface that are the result of manufacturing and/or cutting (as by tools or abrasive materials, see ***Figure 159***).

RUBBER - natural or synthetic elastomeric substance.

RUNNING FRICTION - dynamic frictional force which must be overcome in order to maintain movement. Running friction generally necessitates the use of some form of lubrication.

RUNOUT (SHAFT) - phenomenon which occurs when the shaft's axis and the axis of rotation are different, causing the shaft to wobble or gyrate; expressed in inches followed by the abbreviation "TIR" (Total Indicator Reading).

ROUGHNESS

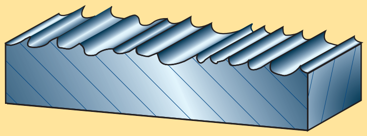


Figure 159: Surface irregularities.

S

SATURATED BONDS - single bonds between carbon atoms and other atoms (such as hydrogen) that are less reactive and less prone to chemical attack than carbon-to-carbon double or triple bonds. The carbon atoms in the backbone of an organic polymer are each capable of forming four individual and separate single covalent bonds.

SATURATION - (a) addition of atoms to a compound to occupy the otherwise "open" or unbonded sites on a polymer chain; results in a more stable, less reactive compound. For example, a highly-saturated organic compound has almost every carbon atom already bonded to a hydrogen atom and therefore has a dramatically reduced ability to interact with other compounds and an increased resistance to chemical attack. Saturation using hydrogen atoms is also known as hydrogenation; and (b) state in which most of the carbon atoms in an organic polymer's backbone have formed four individual and separate covalent bonds, resulting in increased chemical resistance as there are fewer double bonds that are susceptible to chemical attack (see ***Figure 160***).

SATURATION

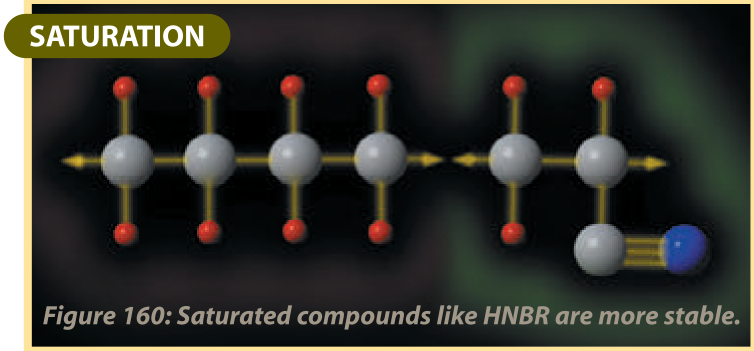


Figure 160: Saturated compounds like HNBR are more stable.

SCISSION - breaking of molecular bonds within the backbone of a polymer due to chemical or thermal attack that divides the polymer chains into smaller segments, with a resulting loss in physical properties; also known as chain scission.

SCORCHING - premature curing of rubber during storage or processing, usually caused by excessive heat.

SEAL - device that prevents fluid flow.

SEAL WIDTH (W) - axial dimension of a seal. In an O-ring, this is the same as the cross-section.

SERVICE - operating conditions, such as temperature, pressure, chemical environment, and surface speeds, under which a seal must perform.

SERVICE TEMPERATURE - range of temperatures to which a rubber compound will be subjected in a given application.

SHAFT - rotating or reciprocating component that operates within a cylinder or housing.

SHEAR MODULUS (G) - measure of stiffness or resistance to deformation taken in shear rather than in tension; technically, the ratio of a shearing stress (force in psi) to shearing strain (amount of linear deflection divided by the specimen thickness). In rubber materials, shear modulus is one-third of Young's modulus (E); not the same as tensile modulus.

SHELF-AGING - degradation of a rubber material's properties that occurs in storage over time.

SHELF LIFE - length of time a molded rubber compound can be stored without suffering significant loss of physical properties.

SHORE A DUROMETER - instrument used to gauge soft to medium hard rubber based on resistance to a frustum (truncated) cone indentor point; most accurate for materials below 90 Shore A.

SHORE D DUROMETER - instrument used to gauge hard rubber based on resistance to a sharp, 30° angle indentor point; most accurate for materials at or above 90 Shore A.

SHRINKAGE - (a) after vulcanization, dimensional loss in a molded rubber product that occurs after it has been removed from the mold and allowed to cool; and (b) in seal service, a decrease in seal volume due to extraction of soluble components from the rubber compound by environmental fluids.

SILICONE RUBBER - silicon-oxygen backbone elastomer with excellent high temperature and low temperature properties.

SINGLE-ACTING SEAL - dynamic reciprocating seal capable of sealing in only one direction of movement.

SIZE - actual size refers to the actual dimensions of an O-ring or seal, including tolerances. Nominal size refers to the approximate size in fractional dimensions.

SIZE NUMBER - three-digit number preceded by a dash as specified by SAE Aerospace Standard 568A to indicate the O-ring size based on its inside diameter (I.D.) and cross-section (W); also known as dash number.

SKIVING - slicing of a seal's surface, as by gland edges during installation.

SOLUBLE - susceptible to being dissolved in a fluid.

SOLVENT - any substance, typically a liquid, capable of dissolving other substances.

SOUR CRUDE - petroleum oil contaminated with hydrogen sulfide (H_2S).

SOUR GAS - natural gas contaminated with hydrogen sulfide (H_2S).

SPECIFIC GRAVITY - ratio of the weight of a given substance to the weight of an equal volume of water at a specified temperature. Specific gravity is often used to identify rubber compounds.

SPIRAL FAILURE - type of O-ring failure occurring when one portion of the ring tends to roll while another portion slides in the gland, causing twisting and seal failure.

SPRUE MARK - raised spot or small depression seen on an injection or transfer molded product; caused when the finished molded part is removed from the injection nozzle (sprue or gate) through which the material is injected into the mold cavity; also known as a gate mark.

SQUEEZE - compression of an O-ring's cross-section between mating surfaces; noted as both a decimal measurement (in inches and/or millimeters) and as a percentage of the original cross-section (width). Radial compression occurs on the outside diameter (O.D.) and inside diameter (I.D.). Axial compression occurs on the top and bottom surfaces.

STATIC FRICTION

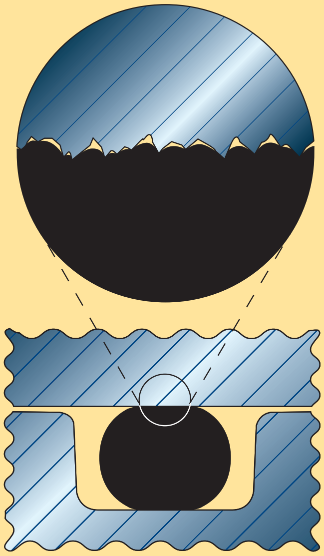


Figure 161: Flow of the seal into surface pores.

STATIC - describes an application in which there is no relative motion between the mating surfaces to be sealed.

STATIC FRICTION - initial frictional force which must be overcome to initiate movement; also known as break-out friction or stiction (see ***Figure 161***).

STATIC SEAL - seal functioning in an environment in which there is no relative motion between the mating surfaces being sealed.

STICK-SLIP - irregular or jerky seal motion caused by varying amounts of static and dynamic friction.

STICTION - initial frictional force which must be overcome to initiate movement; also known as static friction or break-out friction (see ***Figure 161***).

STOICHIOMETRY, PERCENT - level of curative (chain extender) used on a given pre-polymer. Percentages used have varying effects on the physical properties of the finished elastomer.

STRAIN - amount of deflection, expressed as a percentage of original length, due to an applied force (stress).

STRAIN CRYSTALLIZATION - partial crystallization of an elastomer that temporarily results when a stretching force causes the tangled macromolecular chains to untangle and align to form crystals; the chains revert to their normal state of entanglement when the force is removed. Most elastomers do not strain crystallize, but natural rubber, chloroprene (Neoprene®), and hydrogenated nitrile will.

STRESS - an applied force (in psi) resulting in material deflection (strain).

STRESS RELAXATION - steady decline in sealing force when an elastomer is compressed over a period of time. In terms of the life of a seal, stress relaxation is like dying, whereas compression set is like death.

STRETCH - measured as a percentage increase in the inside diameter (I.D.) of an O-ring, stretch results in a reduction and flattening of the seal's cross-section. There are two types of stretch: installation stretch (as the seal is being placed in the groove) and assembled stretch (once the seal is seated).

SUBLIMATION - direct conversion of a substance from a solid state to a vapor state, and from a vapor back to a solid. The substance does not become liquid during either transition.

SUN CHECKING - cracking or crazing of an elastomer's surface due to the action of sunlight; also known simply as checking.

SURFACE FINISH - average value of exterior roughness, often expressed in microinches RMS (Root Mean Square) or Ra (roughness average).

SWELL - volumetric increase of an elastomeric material when in contact with a fluid.

T

TEAR RESISTANCE - resistance to the growth of a nick or cut in a rubber specimen when tension is applied.

TEMPERATURE (MAXIMUM) - highest temperature a rubber compound can withstand prior to undergoing a physical or chemical change.

TEMPERATURE (MINIMUM) - lowest temperature a rubber compound can withstand prior to losing rubbery properties.

TEMPERATURE RANGE - minimum and maximum temperature limits within which a rubber material will effectively perform.

TEMPERATURE (SERVICE) - range of temperatures to which a rubber compound will be subjected in a given application.

TENSILE MODULUS - the force in psi (stress) required to produce a certain elongation (strain), usually 100%; a good indication of toughness and resistance to extrusion; also known as modulus or tensile stress.

TENSILE STRENGTH - force in pounds per square inch (psi) required to break a rubber specimen.

TENSILE STRESS - the force in psi (stress) required to produce a certain elongation (strain), usually 100%; a good indication of toughness and resistance to extrusion; also known as modulus or tensile modulus.

TENSION SET - increase in the length of an elastomeric specimen following initial stretching and release.

TERPOLYMER - polymer composed of three different monomers chemically combined (see ***Figure 162***).

TERPOLYMER

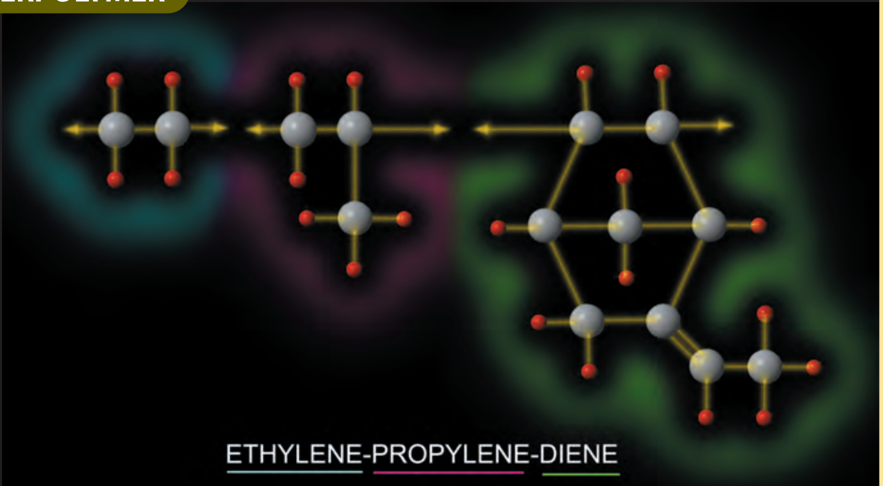


Figure 162: EPDM is a terpolymer.

TETRAPOLYMER - polymer composed of four different monomers chemically combined.

THERMAL EXPANSION - linear or volumetric expansion of a material due to a temperature increase.

THERMOPLASTIC - an ionically-bonded polymeric material capable of being softened and formed when heated and injected into a cool mold. Upon cooling in the mold, a thermoplastic material will harden (freeze) and regain its original properties. A thermoplastic material can be reprocessed many times.

THERMOSET - polymeric material that forms permanent covalent bonds in an irreversible chemical reaction known as crosslinking, curing, or vulcanizing. Although the cured part can later be softened by heat, it cannot be remelted or reprocessed without extensive chemical treatment.

TIR - Total Indicator Reading; a measurement of shaft eccentricity that results when the shaft centerline is different from its axis of rotation.

TOLERANCE - allowable deviation (plus and minus) from a specified dimension.

TOLERANCE BUILD-UP - sum of the tolerances of all of the elements in a sealing system (e.g. I.D., cross-section, gland dimension); also known as tolerance stack-up.

TOOL - alternative name for a mold.

TORQUE - turning or twisting force that produces, or tends to produce, rotation of a shaft.

TORSIONAL STRENGTH - ability of a material to resist twisting and its damaging effects.

TORUS - donut-shaped ring; another name for an O-ring.

TPE - thermoplastic elastomer with rubber-like properties that is processed by injection molding, blow molding, extrusion, etc.

TPU - thermoplastic polyurethane elastomer that is processed by injection molding, blow molding, or extrusion.

TRANSFER CHAMBER - area within a transfer mold in which the elastomeric compound is heated prior to being squeezed down through a sprue, a runner, and a gate leading into a closed mold cavity to be shaped and vulcanized; also known as a pot.

TRANSFER MOLDING - method of molding thermosetting materials (see ***Figure 163***). The elastomeric compound is placed in a transfer chamber (pot) which is part of the mold, heated, then squeezed down through a sprue, a runner, and a gate leading into a closed mold cavity to be shaped and vulcanized. The advantages of transfer molding are that vulcanization is faster, so the process is more efficient, and the part is formed with little or no flash.

TRANSFER MOLDING

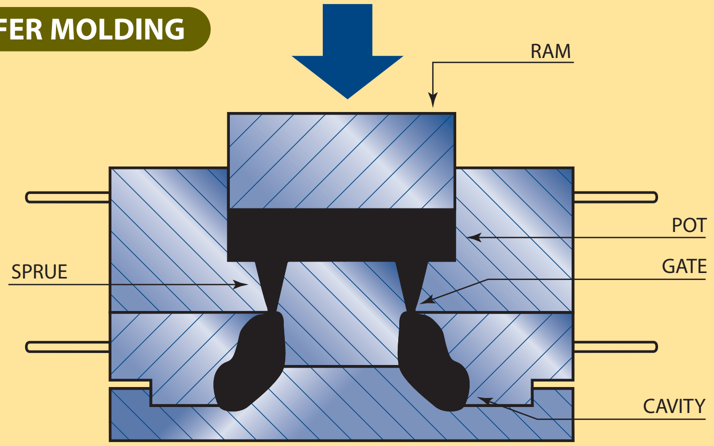


Figure 163: Transfer molding utilizes a closed mold accessed through a gate.

TRIM - removal of excess material from a molded rubber product.

TRIM CUT - damage done to a molded rubber product by excessive trimming.

U

ULTIMATE ELONGATION - amount, expressed as a percentage of original length, that a specimen has stretched at the time of breakage.

UNDER-CURE - degree of incomplete vulcanization resulting in undeveloped physical properties and tackiness.

UNI-DIRECTIONAL SEAL - seal which provides fluid sealing on only one side.

UNSATURATED BONDS - double or triple bonds between carbon atoms creating sites that can undergo numerous chemical reactions, including addition of hydrogen atoms (hydrogenation), crosslinking, or chemical deterioration such as oxidation.

V

VACUUM - condition in which the pressure in a chamber is less than atmospheric pressure.

VALENCE - ability of an atom to form one or more energy bonds with neighboring atoms.

VAN DER WAALS FORCES - weak electrostatic attractions between polymer chains that are adjacent but that have not yet been cross-linked. These intermolecular forces are at their peak when a material is cool. Heating the material weakens the forces and "loosens" the chains, thus increasing pliability and making molding possible.

VAPOR - a gas, whose temperature is below its critical temperature (t_C), that normally exists as a liquid under atmospheric conditions.

VAPOR PRESSURE - pressure exerted by a heated liquid or solid in a closed container.

VENT - (a) to give off excess air or pressure so as to avoid build-up and possible rupture; and (b) a shallow hole or channel designed into a mold to facilitate the escape of air as it is displaced by incoming materials to be molded.

VESTIGE - remnants of a runner system visible on the surface of a molded article.

VISCO-ELASTIC - describes rubber-like materials having both a viscous phase (like a damper) and an elastic phase (like a spring).

VISCOMETER - shearing disk device used to gauge the viscosity of a rubber sample under heat and pressure. Often referred to as the Mooney Viscometer, this device was once the most common tool for determining processing characteristics but has now largely been replaced by the rheometer.

VISCOSITY - resistance to flow; the thicker the substance (such as a liquid), the more viscous it is, i.e. the less it flows.

VOID - unintended empty space, such as a pit or air pocket.

VOLATILE - readily vaporizable at a relatively low temperature.

VOLUME CHANGE - increase (swell) or decrease (shrinkage) in the volume of a specimen which has been immersed in a fluid, noted as a percentage of original volume.

VOLUME SHRINKAGE - volumetric decrease of an elastomeric material when in contact with a fluid; also known simply as shrinkage.

VOLUME SWELL - volumetric increase of an elastomeric material when in contact with a fluid; also known simply as swell.

VULCANIZATE - cured rubber compound.

VULCANIZATION - heat-induced process whereby the long chains of the rubber molecules become cross-linked by a vulcanizing agent to form three-dimensional elastic structures. This reaction transforms soft, weak, non-cross-linked materials into strong elastic products; also known as cure.

VULCANIZING AGENT - material added to an uncured batch of rubber that causes the polymer chains to crosslink to one another (vulcanize), forming a three-dimensional elastic structure.

W

WAVINESS - irregularities on a gland's surface with considerably longer wavelengths than those referenced as roughness. Waviness may be caused by machinery vibrations or material warping.

WEATHERING - cracking and degradation of the physical properties of a rubber product exposed to atmospheric conditions; also known as atmospheric cracking.

WEEPAGE - seal leakage of less than one drop per minute; not necessarily an indication of seal failure.

WIDTH (W) - another term for the cross-section of an O-ring.

WIPER - flexible ring used to remove dirt, dust, mud, and other contaminants from a rod or a shaft in order to prevent them from entering a hydraulic, pneumatic, or mechanical system; also known as a wiper ring.

Y

YOUNG'S MODULUS (E) - a measure of material stiffness; defined as the ratio of the stress (force in psi) to the strain (percentage increase in original length) as measured on a rubber specimen; also known as modulus of elasticity; not the same as tensile modulus.

Abbreviations.

ACM - polyacrylate rubber

ACN - acrylonitrile; component in nitrile rubber

AEM - ethylene-acrylic rubber; copolymer of ethylene and methyl acrylate

AMS - Aerospace Material Specification

ANSI - American National Standards Institute

AQL - Acceptable Quality Level

ARP - Aerospace Recommended Practice

AS - Aerospace Standard

ASTM - American Society for Testing and Materials

AU - polyester-based polyurethane rubber

BR - polybutadiene rubber

CC - cubic centimeter

CO - homopolymer of epichlorohydrin

CR - polychloroprene rubber (Neoprene®)

CSM - chlorosulfonated polyethylene rubber (Hypalon®)

DIA - diameter

DIN - German standardization organization

ECO - copolymer of epichlorohydrin and ethylene oxide

EP, EPM, EPDM - ethylene-propylene rubber

EPA - Environmental Protection Agency

EU - polyether-based polyurethane rubber

FDA - Food and Drug Administration

FEPM - tetrafluoroethylene-propylene rubber

FFKM - perfluoroelastomer

FKM - fluorocarbon elastomers

FMQ - fluoromethyl silicone rubber (fluorosilicone)

FPM - feet per minute; fpm = [shaft dia (in) x rpm x 3.1416] divided by 12

FSA - Fluid Sealing Association

FVMQ - fluoro vinyl methyl silicone rubber (fluorosilicone)

> **“This list includes the abbreviations you will encounter most often in the sealing industry. Familiarity with them will save time as you design O-ring seals.”**

GRS - Government Rubber Styrene; now SBR

HNBR - hydrogenated nitrile rubber

HSN - highly saturated nitrile; alternative name for HNBR

IIR - butyl rubber; copolymer of isobutylene and isoprene

IN. - inch

IR - isoprene rubber

IRHD - International Rubber Hardness degrees

IRM - Industry Reference Material, as in IRM 903 oil

ISO - International Organization for Standardization

JIC - Joint Industrial Conference on Hydraulic Standards for Industrial Equipment

KN/M - kilonewton per meter; SI equivalent of pli; sometimes a unit of measure in ASTM D 2000 line call-outs

MAX - maximum

MIL - Military (specification)

MIL STD - Military Standard

MIN - minimum

MPA - megapascal; SI equivalent of psi; sometimes a unit of measure in ASTM D 2000 line call-outs

MQ - methyl silicone rubber

MS - Military Standard

NAS - National Aerospace Standard

NASA - National Aeronautics and Space Administration

NBR - nitrile butadiene rubber (Buna N); copolymer of acrylonitrile and butadiene

NBS - National Bureau of Standards

NR - natural rubber; polyisoprene

NSF - National Sanitation Foundation

OSHA - Occupational Safety and Health Administration

PLI - pounds per linear inch

PMQ - phenyl methyl silicone rubber

PSI - pounds per square inch

PVMQ - phenyl vinyl methyl silicone rubber

RMA - Rubber Manufacturers Association

RPM - revolutions per minute

SAE - Society of Automotive Engineers

SBR - styrene butadiene rubber (Buna S); copolymer of styrene and butadiene

SG - specific gravity

SI - denotes The International System of Units (the modern metric system); taken from the French, “Le Système International d’Unités”

SPEC - specification

T_C - critical temperature

TFE - tetrafluoroethylene; a fluoroplastic

T_g - glass transition

TIR - Total Indicator Reading

UL - Underwriters Laboratories

UV - ultraviolet light

VMQ - vinyl methyl silicone rubber

XNBR - carboxylated nitrile rubber

Temperature Scales.

"To convert Centigrade to Fahrenheit, multiply by 9/5 (1.8), then add 32."

"To convert Fahrenheit to Centigrade, subtract 32, then multiply by 5/9 (0.555)."

° CENTIGRADE (CELSIUS)	° FAHRENHEIT	
100	212	(Boiling Point of Water)
95	203	
90	194	
85	185	
80	176	
75	167	
70	158	
65	149	
60	140	
55	131	
50	122	
45	113	
40	104	
35	95	
30	86	
25	77	
20	68	
15	59	
10	50	
5	41	
0	32	(Freezing Point of Water)
-10	14	
-20	-4	
-30	-22	
-40	-40	
-50	-58	
-100	-148	
-150	-238	
-200	-328	
-250	-418	
-273.1	-459.6	(Absolute Zero*)

**Absolute zero is, in theory, the lowest possible temperature. It is considered to be the point at which all molecular motion stops.*

Table 56: Temperature Scales

Index.

"No book of this scope would be complete without a comprehensive index to help you quickly locate key terms and concepts."

TRADEMARK INFORMATION

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Aurum®…Mitsui Toatsu
Baypren®…Bayer Corp.
Baysilone®…Bayer Corp.
Buna EP®…Bayer Corp.
Celcon®…Hoechst Celanese
Celvacene®…Inland Vacuum Industries
Chemraz®…Greene, Tweed & Company
Crown Seal™…Macrotech/Polyseal
Cycolac T®…General Electric Company
DAI-EL®…Daikin Industries
Deep-Z Seal™…Macrotech/Polyseal
Delrin®…DuPont
Dyneon®…Dyneon
Ekonol®…Norton Performance Plastics
Elgiloy®…Elgiloy Limited Partnership
Estane®…B.F. Goodrich
Exxon Butyl®…Exxon Chemicals
FE®…Shincor Silicones
Freon®…DuPont
FSE®…General Electric
Fyrquel®…Akzo Nobel
Hydrin®…Zeon Chemicals, L.P.
Hypalon®…DuPont Dow Elastomers
Hytemp®…Zeon Chemicals, L.P.
Hytrel®…DuPont
Kalrez®…DuPont Dow Elastomers
KE®…Shincor Silicones
Keltan®…DSM Copolymer, Inc.
Krynac®…Polysar International, USA
Lexan®…GE Plastics
Millthane®…TSE Industries
Morthane®…Morton International, Inc.
Neoprene®…DuPont Dow Elastomers
Nipol®…Zeon Chemicals, L.P.
Nordel®…DuPont Dow Elastomers
Noryl®…GE Plastics
Nysyn®…Copolymer Rubber & Chemical Corp.
Paracril®…Uniroyal, Inc.
Pellethane®…Dow Chemical
Polyflon®…Daikin Industries, Ltd.
Polysar®…Bayer Corp.
Pydraul®…Monsanto
Quad-Ring®…Minnesota Rubber
Royalene®…Uniroyal, Inc.
Ryton®…Chevron Phillips Chemical Company, L.P.
Silastic®…Dow Corning Corp.
Silplus®…General Electric
Skydrol®…Solutia Inc.
Tecnoflon®…Ausimont USA, Inc.
Teflon®…DuPont
Tetraseal®…Parker Hannifin Corp.
Texin®…Bayer Corp., Plastics Division
Therban®…Bayer Corp.
Thiokol®…Cordant Technologies Inc.
Torlon®…Amoco Performance Products
Tufel®…General Electric
Type B Poly Seal™…Macrotech/Polyseal
Ultem®…GE Plastics
Vamac®…DuPont Dow Elastomers
Vaseline®…Chesebrough-Ponds, Inc.
Vespel®…DuPont
Vibrathane®…Uniroyal, Inc.
Vistalon®…Exxon Chemicals
Viton®…DuPont Dow Elastomers
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