Working, Design Considerations and Maintenance of O-rings

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The information contained in this booklet represents a significant collection of technical information about construction, working, size (dimensions) standards, design considerations, installation and maintenance (failure analysis) of O-rings. This information will help to achieve increased reliability at a decreased cost. Assemblage of this information will provide a single point of reference that might otherwise be time consuming to obtain. Most of information given in this booklet is mainly derived from literature on the subject from sources as per the reference list given at the end of this booklet. For more information, please refer them. All information contained in this booklet has been assembled with great care. However, the information is given for guidance purposes only. The ultimate responsibility for its use and any subsequent liability rests with the end user. Please view the disclaimer uploaded on http://www.practicalmaintenance.net.

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Content

Introduction

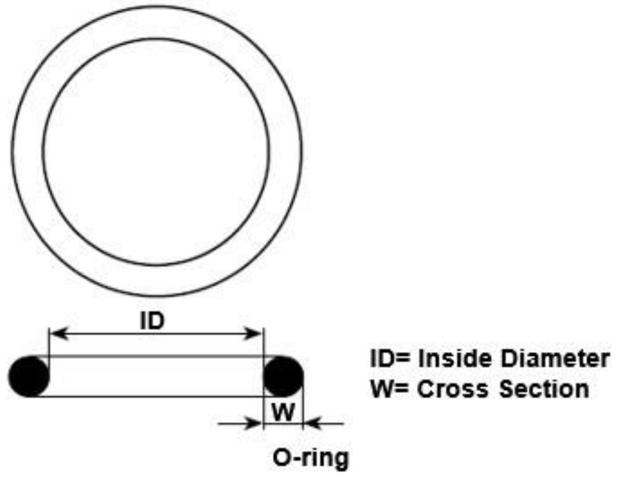
Any mechanical assembly containing fluids must be designed so that these substances flow only where intended and do not leak into other parts of the assembly (or out of the assembly entirely). Seals are incorporated into mechanical designs to prevent such leakage at the points where different parts of 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.

An O-ring seal is one of the most widely used seal to block the clearance gap in the industry today. It is also known as toroidal seal. O-ring seals are used in applications, ranging from garden hose couplings to aerospace or oil and gas duties due to the following advantages.

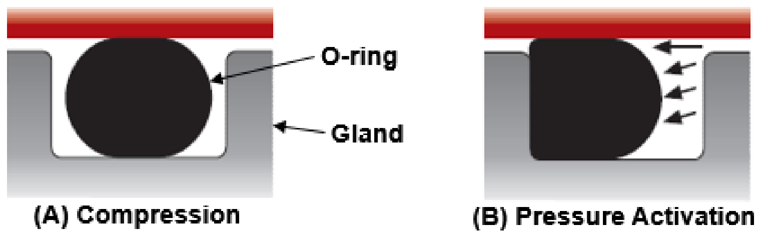
- Wide application range (pressures, tolerances, temperatures, media)
- No retightening required
- No critical torque
- Easy handling and assembly
- Simple, space saving and cost effective design

In view of above, information about construction, working, size (dimensions) standards, elastomer materials, design considerations, installation and maintenance (failure analysis) of O-rings is given in this booklet.

Construction and Working of O-rings



As shown in above figure, an O-ring is a one-piece molded elastomeric circular ring with a circular cross-section. O-rings are specified by the O-ring size (inside diameter and cross section, referred as width), the compound (material) and the hardness of the compound. As shown in the following figure, the gland, an enclosed space compresses and contains the O-ring. The combination of these elements, an O-ring and the gland, produce the O-ring seal.



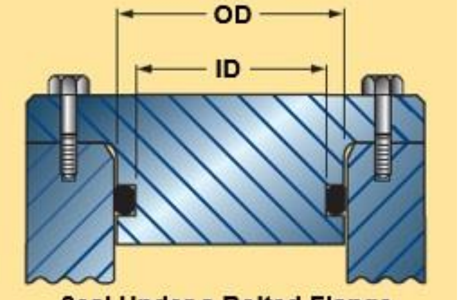
Working of O-ring

As shown at (A) in above figure, the compression (or more accurately the deformation) of the O-ring provides part of the sealing function. An additional sealing function is realized when the O-ring deforms into a D shape as shown at (B) in above figure due to its activation by the pressure of the gas or liquid that the O-ring serves to contain. The gland/groove (enclosed space) ensures that the sealing function is maintained by keeping the O-ring where it needs to be. The terms “gland”, “groove” and “housing” are interchangeable and their usage is a matter of local convenience.

O-rings are also called double-acting sealing elements because the initial compression (squeeze), which acts in a radial or axial direction depending on the installation, gives the O-ring its initial sealing capability. The initial sealing force is superimposed by the system pressure to create the total sealing force which increases as the system pressure increases. Under pressure, an O-ring behaves in a way similar to an incompressible, viscous fluid with very high surface tension. The applied pressure is transmitted uniformly in all directions.

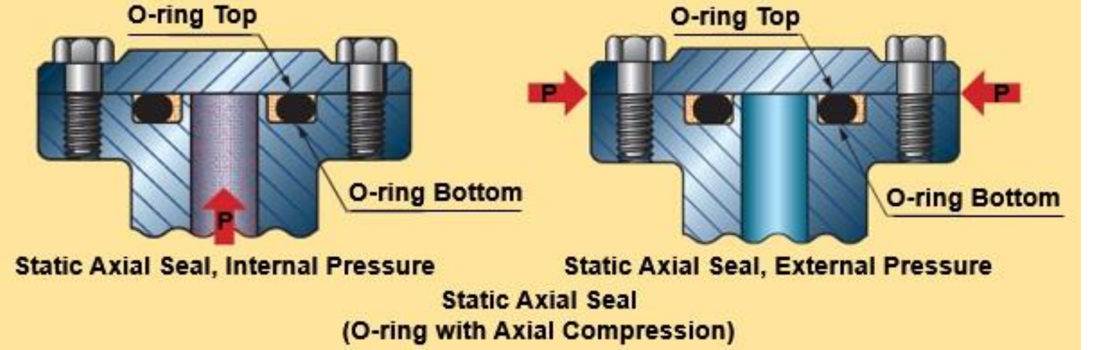
Generally, “Compression” is used as the more common terminology in the sealing industry to describe what happens to the O-ring. However, since elastomers are essentially incompressible, the technically correct term would be “deformation.”

Application (Installation) Types



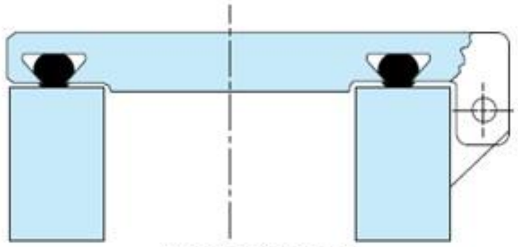
Seal Under a Bolted Flange
(Static Radial Seal, Male Gland)

A **static seal** is a seal in which adjacent surfaces (machine parts) do not move relative to each other (with the exception of small movements, called pulsation due to fluid cycle pressure). **Static radial seals** are formed when squeeze (compression) is applied to the inside diameter (ID) and outside diameter (OD) of the O-ring. As shown in above figure, a seal under a bolted flange is an example of a static radial seal (male gland).



Static Axial Seal
(O-ring with Axial Compression)

As shown in above figure, when an O-ring gets compressed/squeezed axially (similar to a flat gasket), the seal is called a **static axial seal** (also known as **static face seal**). As shown in above figure, there are two types of static axial seals, internal pressure and external pressure based on which side of the seal the pressure is acting.



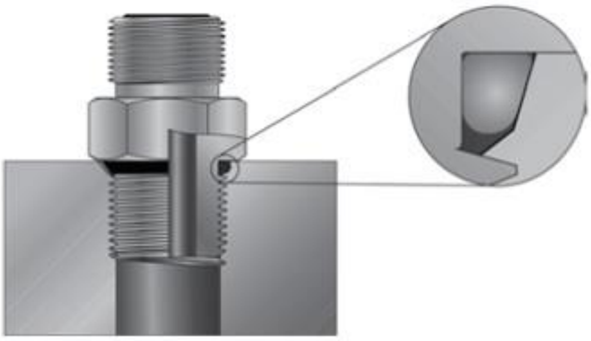
Dovetail Groove

As shown in above figure, an O-ring also gets compressed axially in a **dovetail groove**. The groove design allows the O-ring to be retained in the axial/face seal during assembly and maintenance. This is beneficial for special applications where the O-ring has to be fixed by the groove e.g. a lid which opens regularly.

Unlike tapered threads, parallel thread with an O-ring does not require sealing by the threads because the seal is obtained by the O-ring. When assembled properly, parallel thread with an O-ring provides the best leak-free connection.

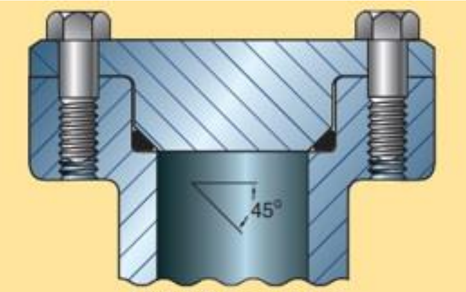
A **boss seal** is a seal in which an O-ring is used for sealing a straight-thread tube fitting on a boss or a port. A boss is a cylindrical projection on a casting or forging. The end of that projection is machined to provide a flat, smooth surface for sealing.

Tube fittings with parallel thread boss or port (ends) are made as per several standards. SAE J1926-1 is one of them.



O-ring Upon Assembly in Straight Threaded Boss

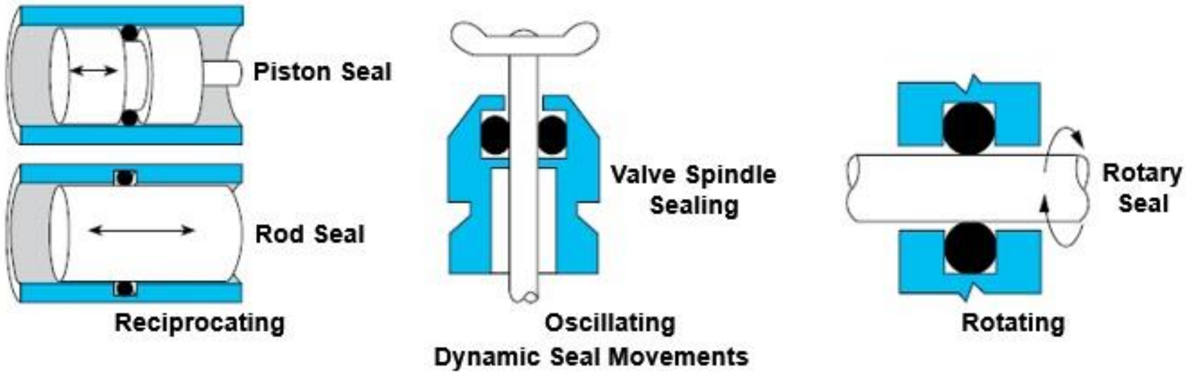
Above figure shows an O-ring upon assembly in a straight thread boss. The male end is fitted with an O-ring. On assembly, the O-ring is firmly sandwiched between the angular sealing surface of the female port and the male end. Sealing is thus made possible and maintained by the O-ring compression, which results from the sandwiching of the O-ring in the cavity. It may be noted that boss seal is a static seal.



Static Crush Seal

As shown in above figure, a 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.

In a **dynamic seal**, the parts to be sealed move relative to one another. As shown in the following figure, the different types of movement are reciprocating, oscillating or rotating.



Reciprocating seals refer to seals used in applications that slide back and forth (linear motion with a reversal of direction). Piston seal and rod seal are examples of a reciprocating application. Oscillating applications are those seeing slow rotation with a reversal of direction or seeing both slow rotation with a reversal of direction and reciprocating movement. A valve spindle is an example of an oscillating application. Rotary seals refer to seals used in applications that rotate.

It is recommended to use lip type shaft seals (oil 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 = 0.2618 × shaft diameter (inches) × rpm

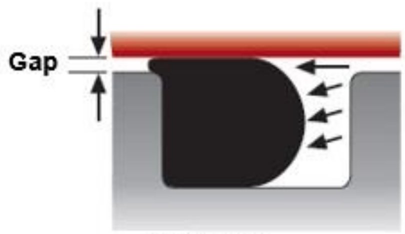
When a gland is cut in the outside machine part, it is called a **female gland seal**. It is also called **rod seal** or **inside sealing** (because sealing occurs at inside diameter of the O-ring).

When a gland is cut in the inside machine part, it is called a **male gland seal**. It is also called **piston seal** or **outside sealing** (because sealing occurs at outside diameter of the O-ring).

It may be noted that in a female gland seal and a male gland seal, the O-ring gets compressed radially.

Pressure and Extrusion

Extrusion is a concern for radial seals where there is a gap/clearance (commonly called extrusion gap) between the piston and the bore (cylinder) for a piston type seal or between the rod and the bore (gland) for a rod type seal. It is not typically a concern for static axial type seals where the metal parts to be sealed are in contact.



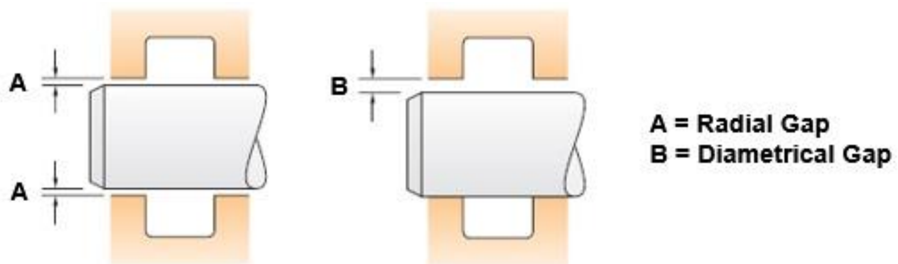
Extrusion

As shown in above figure, if the gap/clearance (called extrusion or clearance gap) between the mating surface and the gland (groove corners) is too large or if the pressure exceeds the deformation limits of the O-ring material (compound), the O-ring will extrude into the clearance gap reducing the effective life of the seal. Choosing a harder seal material or installing back-up rings to support the O-ring may alleviate this problem.

In most O-ring sealing applications, a moderate amount of system pressure is desirable because it aids in effecting the seal. However, high pressure can be 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 1500 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, resulting in seal failure.

The amount of extrusion to be expected in a given application thus depends on three main factors: the pressure imposed on the seal, the amount of clearance between mating surfaces and the resistance of the seal material to deformation.

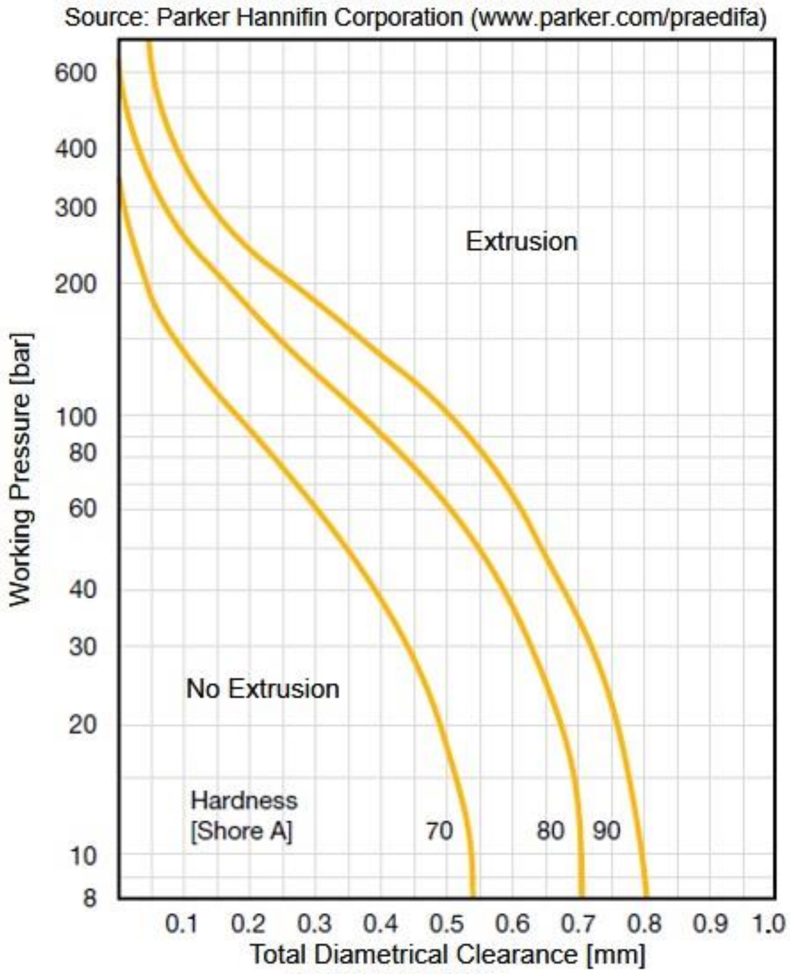
The inherent needs of the application often dictate that system pressure cannot be lowered. Reducing the clearance gap is possible but can often be very expensive. This leaves the third factor, resistance of the seal to deformation, as the most viable avenue for reducing extrusion concerns.



Extrusion Gap

As shown in above figure, the extrusion gap/clearance between the piston and the bore for a piston type seal or between the rod and the bore for a rod type seal is generally specified diametrically (maximum possible extrusion gap); that is, the total difference between the two metal parts. In service this condition can easily be attained when the rod or piston sits directly on the bore leaving all clearance on one side.

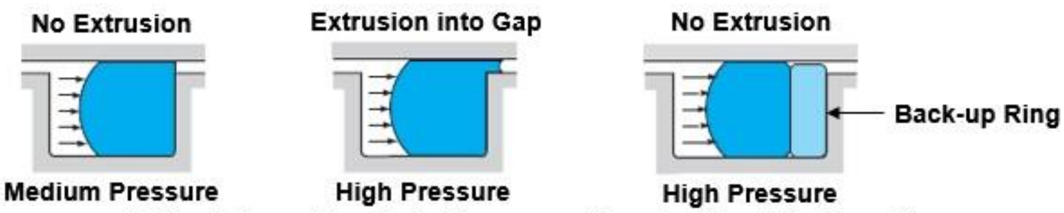
The following figure indicates conditions where O-ring seals may be used, depending on the fluid pressure and the O-ring hardness. If the conditions of use fall to the right of the curve, extrusion of the O-ring into the surrounding clearance gap will occur, greatly reducing the life of the ring. If conditions fall to the left of the curve, no extrusion of the O-ring will occur, and the O-ring may be used under these conditions. For example, in an O-ring application with a 0.3 mm diametral clearance and 100 bar pressure, extrusion will occur with a 70 durometer O-ring but not with 80 durometer O-ring. As the graph indicates, high pressure applications require lower clearances and harder O-rings for effective sealing.



Extrusion Limits

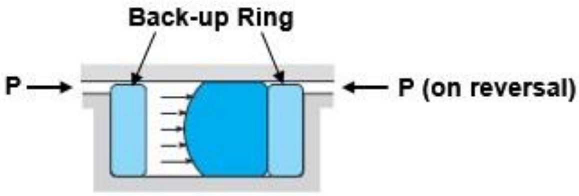
Notes (for above figure):

- The diagram is based on 100000 pressure cycles at 60 cycles / min.
- The allowable gap for silicone, fluorosilicone and other low shear modulus materials is half the normal recommended gap.
- The diagram is valid for temperatures up to 70°C.
- Cylinder expansions under pressure have not been considered.



O-ring Deformation Under Pressure with and without Back-up Ring

Back-up rings is the another way to protect the O-ring and prevent its extrusion in both static and dynamic applications. As shown in above figure, a back-up ring is a relatively hard, high shear modulus material placed in the gland (seal groove) between the O-ring and the clearance gap (i.e. on the seal's low-pressure side). The back-up ring acts as a support for the O-ring even as it blocks the gap into which the pressurized seal might otherwise extrude.



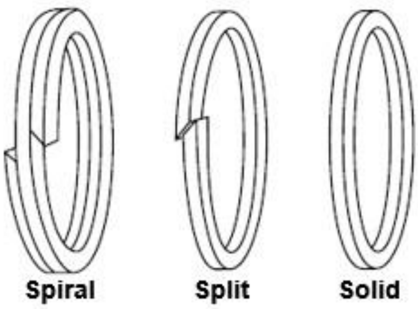
Back-up Rings on Both Sides of O-Ring

As shown in above figure, bi-directional pressure will necessitate back-up rings on both sides of the O-ring. Use of two back-up rings (even if pressure is acting from only one side) also eliminates the possibility of installing a single back-up ring on the wrong side of the O-ring.

In some cases, 90 Shore A hardness O-rings are used to resist extrusion. However, it may be noted that sealability often suffers because friction and wear increase with use of such a hard material. A resilient 70 Shore A hardness nitrile O-ring with a 90 Shore A hard or harder backup ring is preferable.

It is always a good idea to use back-up rings with O-rings (or other seals) in pressures exceeding 1500 psi or in designs featuring large clearance gaps. The additional cost of back-up rings is small in comparison with the cost of tighter machining tolerances, and back-up rings pay for themselves by both improving seal performance and prolonging seal life.

Back-up rings are made from a wide array of materials with better extrusion resistance than most elastomers including 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-up rings. Hytrel® is a thermoplastic elastomer combining toughness, resilience and chemical resistance.



Types of Teflon® Back-up Rings

As shown in above figures, Teflon® back-up rings come in three basic types: spiral cut (multi-turn) split cut (scarf cut, bias cut or single turn) and solid (uncut or endless ring). The width of the back-up ring is equal to the groove depth plus the clearance gap.

Spiral and split PTFE back-up rings are a common choice due to the ease of installation of these designs. The solid PTFE back-up ring is recommended for applications with higher system pressures; however, this design can only be installed in two piece applications. In addition to PTFE, back-up rings are also available in PEEK (another high performance plastic) and in nylon (an engineering plastic).

It is recommended to use back-up rings of spiral design with a pressure between 10 MPa and 20 MPa (1 MPa = 10 bar = 145 psi). If the operating temperature exceeds 100°C, use the spiral design with a pressure of less than 10 MPa. Back-up rings of split cut design excel at protecting O-rings at pressures ranging from 15 MPa to 20 MPa and above. Back-up rings of solid design are suited to use with pressures exceeding 25 MPa and temperatures exceeding 135°C.

Contoured Back-up Ring

Contoured nitrile back-up rings are recommended at higher system pressures where the ability to stretch the back-up ring in installation is required.

For more information on back-up rings, please see ISO 3601 Part 4: Anti-extrusion rings (back-up rings).

O-Rings are used predominantly for static sealing applications as a radial static seal (e.g. for bushings, pipes, etc.) and an axial static seal (e.g. for flanges, caps, etc.). However, for dynamic applications, they are recommended only for moderate service conditions. For dynamic applications, they are limited by the speed (rotary speeds below 600 feet per minute) and the pressure against which they have to seal. They are used for low duty sealing of reciprocating pistons, rods, plungers, etc. and for sealing of slowly pivoting or rotating movements on shafts, spindles, etc.

Physical Properties of Elastomeric Compounds

There are number of physical properties one should consider when choosing an elastomeric compound for an O-ring application. These include hardness, tensile strength, modulus, elongation, tear resistance, abrasion resistance, compression set resistance, resilience and volume change. 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. Brief information on them is given in this chapter.

Hardness

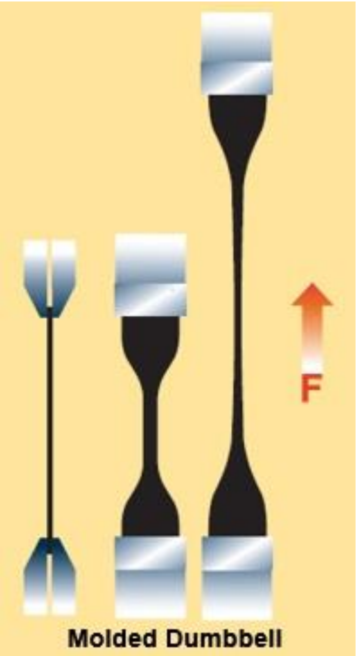
Hardness is defined as resistance to indentation. There are currently two hardness tests that predominate in the rubber industry: Shore durometer and International Rubber Hardness Degrees (IRHD).

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. Shore Instruments (now a division of Instron Corporation), offers a wide range of durometer scales conforming to the ASTM D 2240 standard. Rubber hardness is most often measured via a Shore type A or type D durometer.

Most elastomers are measured on the Shore A scale. Shore A durometer is a portable device which uses a frustum (truncated) cone indentor point and a calibrated steel spring to gauge the resistance of rubber to indentation. Shore A hardness of 35 is soft, 90 is hard. Shore D gauges are recommended where the Shore A rating is greater than 90 (e.g. some polyurethanes and plastics).

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. As per ASTM D 412, a compound's tensile strength is generally tested using a molded dumbbell. The dumbbell is placed in the grips (jaws) of a tensile tester. To convert from MPa to psi, multiply the MPa figure by 145.

Modulus

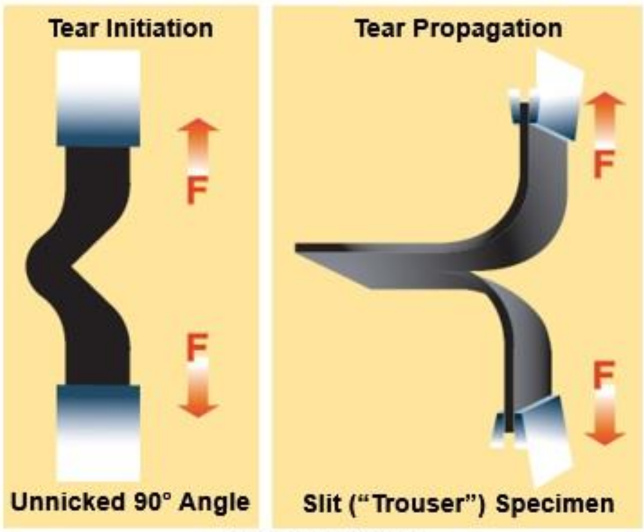
Modulus is the force (stress) in pounds per square inch (psi) required to produce a certain elongation (strain). This elongation might be 50%, 100%, or even 300%, though 100% is the most widely used figure for testing and comparison purposes. Industry literature typically refers to 100% elongation as "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.

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.

Ultimate elongation is the elongation at the moment the specimen breaks.

Tear Resistance



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.

As described in ASTM D 624, different specimen types can be used to measure both tear initiation (resistance to the start of a tear) and tear propagation (resistance to the spread of a tear). 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.

Abrasion Resistance

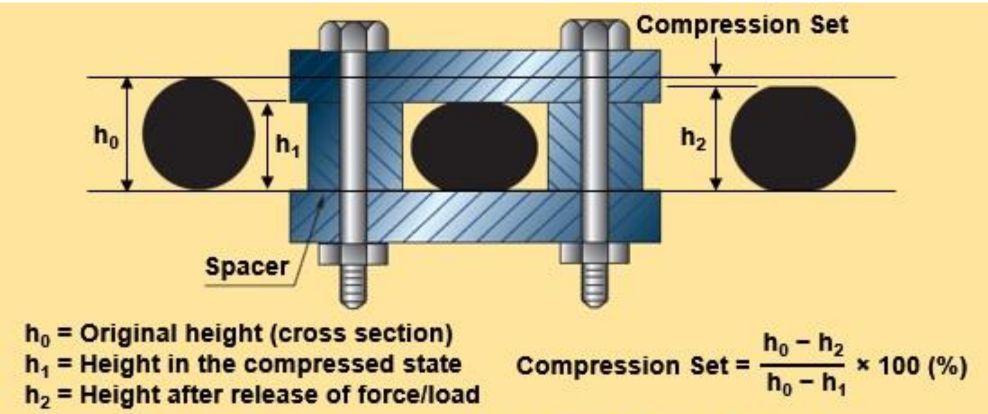
Abrasion resistance is the resistance of a rubber compound to wearing away by contact with a moving abrasive surface. It is measured as a loss percentage based on original weight. Testing typically involves the uniform application of an abrasive material (such as sandpaper) to the surface of a sample.

ASTM standards describe three different abraders: D 1630 relies on a National Bureau of Standards (NBS) abrader, D 2228 uses a Pico abrader and D 3389 (also known as Taber Abrasion) employs a double-head abrader and a rotary platform.

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.

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. Compression set can be calculated as either a percentage of original specimen thickness or as a percentage of original deflection.



Effects of Compression Set on O-ring's Cross Section

Compression set is generally determined in air and measured as a percentage of original deflection. As shown in above figure, compression set is the percentage of original deflection that the elastomer fails to recover after a fixed period of time (e.g. 22 hours) under a specific squeeze (normally 25% of original height/thickness) and temperature (e.g. 100°C). Compression set (permanent plastic deformation) is a very important sealing factor, because it is a measure of the expected loss of resiliency or "memory" of a compound.

ASTM D 395 and ISO 815 details compression set testing for rubber.

As a general rule, the better the compression set, i.e. the lower the permanent deformation (in percent related to the deformation of the sample or the cross section), the higher the evaluation of quality.

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 it. Seals are most likely to fail when there is both high compression set and shrinkage.

Resilience

As detailed in ASTM D 2632, resilience (also known as 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). 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 (cause) a 70% rebound value, but values in the range of 40 to 50% are more typical for the majority of elastomers tested. As a general rule, resilience is most critical in dynamic seals.

Volume Change

Volume change is the increase or decrease of the volume of an elastomer after it has been in contact with a medium. Volume change is typically noted as a percentage of the original volume. Increase by swell or decrease by shrinkage in volume is almost always accompanied by a change in hardness. An elastomeric seal typically becomes softer as a result of swell, whereas shrinkage generally hardens the seal.

Volume swell is caused by absorption of gaseous or liquid medium by the O-ring. A limited amount of swell may even compensate for other variables, such as compression set. In static applications, even extreme volume swell can sometimes be tolerated. In dynamic applications, volume swell up to 15 or 20 percent is usually acceptable, but higher values are likely to increase friction and reduce toughness and abrasion resistance to the point that use of a particular compound is no longer feasible.

Volume shrinkage is often caused by fluids which extract the soluble components (such as plasticizers) from the compound. Decrease in volume is usually accompanied by an increase in hardness. Volume shrinkage will intensify the compression set effect, causing the O-ring to pull away from sealing surfaces - providing a leakage path. It is apparent then, that shrinkage is far more critical than swell. More than 3 or 4% shrinkage can be a serious problem for dynamic O-ring seals.

ASTM D 471 details volume change testing for rubber.

Thermal Properties of Elastomeric Compounds

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. Information about high and low temperature effects, coefficient of thermal expansion, and the Gough-Joule effect is given in this chapter.

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.

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.

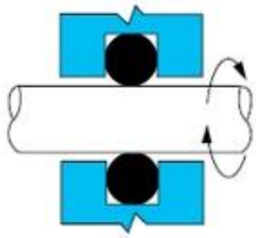
Coefficient of Thermal Expansion

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.

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.

Gough-Joule Effect

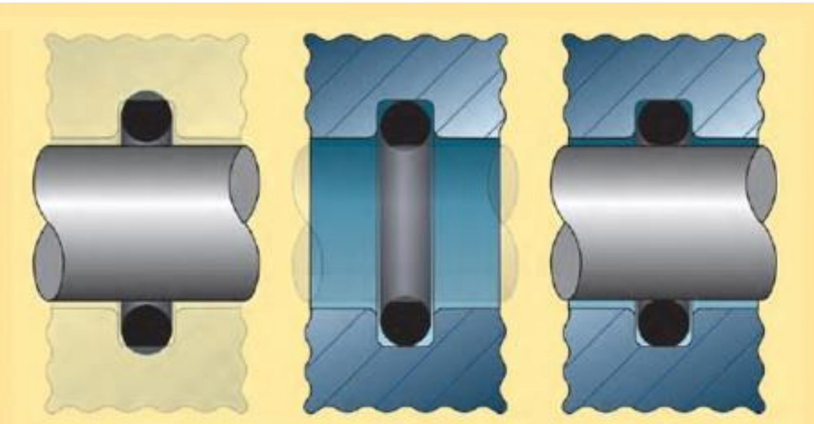
An unloaded rubber strip when heated expands to the coefficient of expansion for that rubber. However, as shown in above figure, if a freely suspended rubber strip is loaded with a weight and subsequently heated, the strip will contract and lift the load. This happens because the rubber's stressed macromolecular chains are trying to regain a less stressful state. This phenomenon of contraction is referred to as Gough-Joule effect and occurs only when a previously stretched rubber object is heated.



Rotary Seal

The Gough-Joule effect is perhaps most important in rotary seal designs, where excessive installed stretch in conjunction with system / friction heat can cause an O-ring to retract, seizing the rapidly rotating shaft and dooming the design.

When using O-rings with an inner diameter smaller than the shaft diameter, the O-ring is stressed. If the O-ring heats up due to system / friction heat, it contracts. This leads to even higher friction and a rise in temperature, ultimately leading to seizing.



Installation of a Rotary Seal

To overcome the seizing problem, as shown in above figure, it is recommended that larger O-ring with controllable compression and an inner diameter exceeding the shaft diameter by 1 to 3 % should be used, with the gland compressing the O-ring. Because the O-ring is not in a stretched condition, it will not build up heat, seize the shaft, and rotate in the groove.

Since rotary seals do not dissipate heat as well as reciprocating seals do, so provisions must be made to keep heat build-up to a minimum. It is recommended that the housing length should be 8 to 10 times the O-ring cross-section to provide for better heat transfer. The O-ring groove should be located away from the bearing and close to the lubricating fluid.

O-ring Compounds

When choosing an O-ring compound, many factors must be taken into account, the main ones being pressure and temperature ranges and the medium to be sealed (compatibility of the compound with the fluid media to be sealed). As explained in the previous chapter, the hardness required for the compound depends on the fluid pressure and maximum extrusion gap/clearance.

In view of above, brief information on general properties, compatibility with medium to be sealed and application temperature range for commonly used O-ring compounds is given in this chapter.

Polymers

Polymers are long molecular chains formed by polymerization, polyaddition or polycondensation of small molecular units (monomers). The name, Polymers is derived from the Greek “poly” (many) and “meros” (parts).

When a monomer (e.g. ethylene gas) is polymerized the resultant product is called a homopolymer (e.g. the plastic material polyethylene). If two or more monomers are involved in the composition of the polymer (e.g. ethylene and propylene gas) the polymerization results in copolymers (e.g. ethylene propylene rubber). Many times polymers made up of two types of monomer are called dipolymers, while those made from three types of monomer are called terpolymers. Both plastics and elastomers are polymers.

One classification method of polymeric materials is according to physical properties at elevated temperatures. **Thermoset** polymers become permanently “set” in the presence of heat and do not soften in the presence of subsequent heating. Conversely, a **thermoplastic** material will soften when heated (and eventually liquefy) and harden when cooled. This process is reversible and repeatable, as opposed to thermoset polymers where the process is irreversible. However, thermoset polymers possess superior mechanical, thermal, and chemical properties as well as better dimensional stability than thermoplastic elastomers.

Elastomeric Compounds

Polymers which have the property of elasticity are called elastomers (rubber). Elasticity and resilience are the most important properties of an elastomer. Elastomers are thermoset polymers.

Elasticity is the ability of a material to return to its original shape and size after being stretched, compressed, twisted or bent. Elastic deformation (change of shape) lasts only as long as a deforming force is applied and disappears once the force is removed.

Resilience as applied to elastomers is essentially their ability to return quickly to their original shape after temporary deflection. In other words, it indicates the speed of recovery.

According to the definition of the American Society for Testing and Materials (ASTM) for the term “elastomer” it is essential that:

- An elastomer part must not break when stretched approximately 100%.
- After being stretched 100%, held for 5 minutes and then released, it must retract to within 10% of its original length within 5 minutes after release.

“Rubber” refers to elastomeric compound that is heat cured (vulcanized). The basic material of rubber compounds or elastomers is unvulcanized rubber, which is produced either as natural rubber on plantations or manufactured by the chemical industry.

Elastomeric compounds consist of 50 to 60 % unvulcanized rubber based on their weight. The remainder is made up of fillers, vulcanizing agents, accelerators, ageing retardants and other additives that support and modify the properties of the raw material so as to meet the particular requirements of a specific application. Following is the information on most commonly used elastomeric compounds for O-rings.

Nitrile or Buna N (NBR)

Nitrile rubber is a copolymer of butadiene and acrylonitrile (ACN). Depending on the application, the content of acrylonitrile can vary between 18% and 50%. Low ACN content improves cold flexibility at the expense of the resistance to oil and fuel. High ACN content improves the resistance to oil and fuel while reducing the cold flexibility and increasing compression set. To obtain balanced properties, a standard general purpose nitrile compound usually contains 34% ACN. Nitrile rubber is also known as Buna N. The name Buna N is derived from **bu**tadiene and **na**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. The reasons for this are good mechanical properties, high abrasion resistance, low gas permeability and the high resistance to mineral oil based lubricating oils and greases.

Standard grades of NBR are typically resistant to (performs well in) mineral oil based fuels, lubricants and greases; oil based hydraulic fluids; silicone oils and greases; fats, animal and vegetable oils; dilute acids and water to about 80°C.

NBR is generally not resistant to (does not perform well in) aromatic hydrocarbons (benzene, toluene, xylene); chlorinated hydrocarbons or halogen derivatives (carbon tetrachloride, trichloroethylene); fuels with a high aromatic content; polar solvents (ketone, acetone, acetic acid, ethylene-ester); glycol-based automotive brake fluids; phosphate ester hydraulic fluids (Skydrol®, Pydraul®). NBR also has low resistance to ozone, sunlight and ageing, but in many applications this has no negative effect.

Hydrogenated Nitrile or Highly Saturated Nitrile (HNBR)

HNBR is obtained by partially or fully hydrogenation of NBR. Hydrogenation is the process of adding hydrogen atoms to the butadiene. HNBR exhibits distinctly better resistance to high temperatures, ozone and ageing as well as improved mechanical properties as compared to NBR, and can be used in more severe conditions with much longer service life. This compound is extensively used in air conditioning systems where R134a refrigerant gas has replaced the chlorofluorocarbon (CFC) containing R12 refrigerant.

Chloroprene (CR, Neoprene®)

Chemically known as polychloroprene, chloroprene is 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. Chloroprene has excellent resistance to ozone, aging and weathering and good mechanical properties. Because Nitrile is economically competitive with Neoprene, and generally has superior performance characteristics in most situations, it has largely replaced Neoprene in the O-rings of today.

Chloroprene is resistant to ammonia, carbon dioxide, Freon® (R12, R13, R21, R22, R113, R114, R115, R134A), silicone oils, water at moderate temperature, ozone, vegetable oils and alcohols. However, CR has average resistance to mineral oils. CR has got FDA approval for use in the food and beverage industries.

Chloroprene is not resistant to aromatic hydrocarbons (benzene), chlorinated hydrocarbons (trichloroethylene), polar solvents (ketones, esters, ethers, acetone) and phosphate ester fluids.

Ethylene Propylene (EPM, EPDM)

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). It has good resistance to ozone, weathering and ageing.

EPDM has good resistance to hot water & steam, detergents, caustic potash solutions, sodium hydroxide solutions, silicone oils and greases, many polar solvents (ketones, acetone, alcohols) and many diluted acids & chemicals. Special formulations are excellent for use with glycol based brake fluids.

EPDM materials are totally unsuitable for use with all mineral oil products - greases, oils and fuels.

Polyacrylate Rubber (ACM)

Polyacrylate rubber is a copolymer (ethyl acrylate) which offers good resistance to petroleum fuels and oils. ACM is used mainly by the automotive industry, as it is resistant to most engine oils and transmission fluids, even at high temperatures. ACM also resists damage from oxygen, sunlight and ozone.

ACM has good resistance to mineral oil-based engine, gear and ATF oils.

ACM is not resistant to glycol based brake fluids; aromatic and chlorinated hydrocarbons; hot water, steam; alcohol; acids and bases.

Silicone and Fluorosilicone Rubber (VMQ and FVMQ)

Silicones are a group of elastomeric materials made from silicone, oxygen, hydrogen, and carbon. Extreme temperature range and low temperature flexibility are characteristics of silicone compounds. As a group, silicones have poor tensile strength, tear resistance, and abrasion resistance. Due to the weak mechanical properties, silicone O-rings are preferably used in static applications.

Silicones are resistant to hot air, ozone, UV radiation, animal & vegetable fats & oils and brake fluids. Generally, silicone materials are physiologically harmless so they are commonly used by the food and drug industries. They do not impart odor or taste.

Silicones are generally not resistant to fuels, mineral oils, silicone oils & greases, acids and alkalis.

Although fluorosilicone elastomers have the same mechanical properties as silicones, they have substantially better resistance to mineral oils and fuels than normal silicones.

Fluorocarbon (FKM, Viton®)

Fluorocarbon is also referred to as fluoroelastomer. FKM materials are noted for their very high resistance to heat and a wide variety of chemicals. FKM materials usually have good compression set resistance. Other key benefits include excellent resistance to aging, ozone and sunlight, very low gas permeability (suitable for high vacuum applications) and the fact that the materials are self-extinguishing.

Standard FKM materials have excellent resistance to mineral oils and greases; vegetable and animal oils and fats; aliphatic hydrocarbons (fuel, butane, propane, natural gas); aromatic hydrocarbons (benzene, toluene); chlorinated hydrocarbons (trichloroethylene and carbon tetrachloride); silicone oils and greases; non-flammable hydraulic fluids (of the HFD group) and many organic solvents & chemicals.

In addition to the standard FKM materials, a number of specialty materials with different monomer compositions and fluorine content (65% to 71%) are available that offer improved chemical or temperature resistance and/or better low temperature performance.

FKM materials are generally not resistant to hot water, steam, polar solvents (acetone, methyl ether, ketone, ethyl acetate), glycol-based brake fluids, Ammonia gas, amine, alkalis and low molecular weight organic acids (formic acid, acetic acid).

It may be noted that **TFE/P** (**Aflas®**), is a copolymer of tetrafluoroethylene and propylene. In some respects, it exhibits media compatibility properties similar to fluorocarbon.

Perfluoroelastomer (FFKM, Kalrez®)

FFKM materials are elastomers with the highest chemical and heat resistance. Some FFKM types can be exposed to temperatures a little above 300°C. The resistance to chemicals is nearly universal and compares to that of PTFE. The advantage of FFKM is the combination of the chemical and thermal stability of PTFE with the elastic properties of an elastomer material.

These special purpose elastomers are used wherever safety requirements and high maintenance input justify the high price of these materials and where standard elastomers cannot be used.

FFKM is not resistant to chemical compounds containing fluorine (e. g. Freon 11, 12, 13, 113, 114)

Polyurethane (AU, EU)

Thermoplastic elastomers are rubber-elastic at service temperatures but are suitable for thermoplastic processing at higher temperatures. Polyurethane is a thermoplastic elastomer.

Polyurethane is the toughest, most extrusion resistant, and most abrasion resistant of all elastomeric sealing materials. Polyurethane O-rings can withstand pressures up to 5000 psi with a 0.010” extrusion gap. Polyurethane is also very resistant to explosive decompression and has excellent properties over a wide temperature range. Polyurethane O-rings are used for applications requiring extreme abrasion or extrusion resistance.

Polyurethanes are generally resistant to aging and ozone; mineral oils and greases; silicone oils and greases; non-flammable hydraulic fluids (HFA & HFB); water up to 50°C and aliphatic hydrocarbons.

Polyurethanes quickly deteriorate when exposed to acids, ketones, glycol-based brake fluids and chlorinated hydrocarbons. Certain types of polyester-urethanes (AU) are also sensitive to water and humidity. Polyether-urethanes (EU) offer better resistance to water and humidity. Unless specially compounded, at elevated temperatures Polyurethane begins to soften, losing its physical strength.

The following table gives the temperature range for commonly used O-ring compounds.

Elastomer	Temperature Range*, °F (°C)
Nitrile, Hydrogenated Nitrile (NBR, HNBR)	-70°F (-57°C) to +250°F (+120°C)
Chloroprene (CR, Neoprene®)	-65°F (-55°C) to +250°F (+120°C)
Ethylene Propylene (EPM, EPDM)	-70°F (-57°C) to +300°F (+150°C)
Silicone, Fluorosilicone (VMQ, FVMQ)	-150°F (-101°C) to +500°F (+260°C)
Fluorocarbon (FKM, Viton®)	-40°F (-40°C) to +500°F (+260°C)
Perfluoroelastomer (FFKM, Kalrez®)	-20°F (-29°C) to +620°F (+327°C)
Urethane, Polyurethane (AU, EU)	-40°F (-40°C) to +200°F (+93°C)
Polyacrylate Rubber (ACM)	-5°F (-20°C) to +350°F (+177°C)

*Maximum possible range with special compounds (standard grades will withstand lower range).

Polytetrafluoroethylene (PTFE, FEP, Teflon®)

Polymers which are soft and moldable during their production are called plastics. The Greek word plasticós means "to mold". Polytetrafluoroethylene (PTFE) is a plastic.

Poly**t**etra**f**luoro**e**thylene (PTFE) is a completely fluorinated polymer produced when the monomer tetrafluoroethylene (TFE) undergoes free radical vinyl polymerization.

PTFE is 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. 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.

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.

Other important properties include resistance to both weathering and water absorption.

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. However, with too much creep, the seal is compromised. Compounding fillers are used to control unwanted creep, as well as to improve wear, friction, and other properties.

Generally encapsulated O-rings are used instead of PTFE O-rings because solid PTFE O-rings do not offer sufficient elasticity for reliable, long-term fluid sealing. However solid PTFE O-rings are used where high levels of chemical resistance or hygiene are needed - typically in petrochemical, chemical, food or pharmaceutical plant.

General temperature range for PTFE is −184°C (−300°F) to +260°C (+500°F).

Because it does not possess a good elastic memory at or below normal temperatures, PTFE may need to be heated to facilitate installation. Heating PTFE in boiling water, or in a controlled oven, to 200°F is said to enable an O-ring stretch of 10 to 20% to be achieved, thereby assisting installation. PTFE has poor cut resistance, so extra care must be taken not to damage seals during installation.

Encapsulated O-rings

Encapsulated O-rings are having a core of elastomer that is completely covered with a seamless sheath of fluorinated ethylene propylene (FEP). The core is normally fluorocarbon (FKM, Viton®), ethylene-propylene (EPDM) or silicone (VMQ).

Encapsulated O-rings are generally used when a standard elastomeric O-ring has inadequate chemical resistance for a specific application. The high resistance of the envelope protects the elastic core material against the influence of the utilized medium.

FEP is a thermoplastic copolymer of tetrafluoroethylene (TFE) and hexafluoropropylene (HFP) with properties very similar to those of PTFE. This material is being used for seamless coatings of O-rings.

With its energizing core, in addition to providing chemical inertness of PTFE, an encapsulated O-ring returns to its original form. However, due to the FEP sheath, encapsulated O-rings are less flexible than elastomeric O-rings and have limited stretch. This presents problems in O-ring installation, requiring extra care to be taken in control over O-ring I.D. stretch. Heating an O-ring in boiling water, or in a controlled oven, to 200°F is said to enable a stretch of 10 to 20% to be achieved, thereby assisting installation.

Choosing O-ring Compound

Wherever possible it is recommended to use compound having 70 Shore A hardness as it offers the best combination of properties for most O-ring applications. Softer compounds stretch easier and seal better on rough surfaces. Harder compounds offer greater abrasion resistance and resistance to extrusion.

Since no one elastomer is rated “excellent” for all properties, compromises are sometimes necessary when selecting an elastomer for a specific O-ring application. It is recommended to start with the most critical properties to narrow your choices.

For more information on compatibility of a compound with the fluid media to be sealed (Chemical Compatibility Guide), you may see the following:

- O-ring Handbook by Dichtomatik Americas (www.dichtomatik.us)
- O-rings by Daemar® Inc. (www.daemar.com)
- O-Ring Handbook by Parker Hannifin GmbH (www.parker.com/praedifa)

For general information on elastomers and plastics, please see articles on elastomers and plastics uploaded in Materials Category on www.practicalmaintenance.net.

Design Considerations

Information on design considerations/recommendations for an O-ring and a gland is given in this chapter to insure satisfactory performance from an O-ring seal.

For an O-ring design there are three things to be considered: its initial cross section size, the amount of ID stretch or OD interference it undergoes and the amount of squeeze (compression) necessary to complete the seal.

Selecting Cross Section

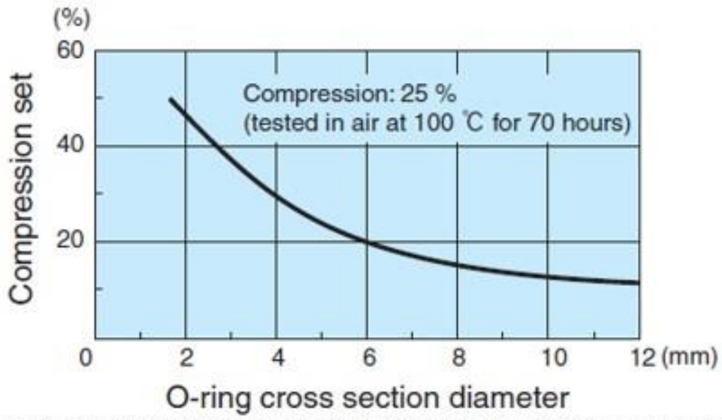
Whereas the ID (Inside Diameter) or OD (Outside Diameter) of the O-ring for a design is significantly influenced by the diameter of the mating components (piston/rod and bore), the cross section (also referred as width) of the O-ring is usually fairly arbitrary. The following describes some of the advantages when opting for a small cross section or a large cross section.

Advantages of Small Cross Section

- More compact and lighter weight
- Less expensive; especially for higher cost elastomers like FKM or fluorosilicone
- Less machining required for machined grooves since grooves are smaller
- More resistant to explosive decompression

Advantages of Large Cross Section

- Less prone to compression set.
- Allows for larger tolerance while still maintaining acceptable compression squeeze (or compression ratio).
- Less likely to twist during service in dynamic sealing applications or during installation.



Relation between O-ring Cross Section Diameter and Compression Set

Larger cross section diameter offers more stable sealing performance. As shown in above figure, when the O- ring compression rate is constant (25 % in the figure), the larger is the cross section diameter, smaller is the compression set.

However, larger cross section diameter creates more seal friction.

Following table shows recommended O-ring cross sections for piston and rod applications as per ISO 3601-2.

O-ring Cross Sections for Piston and Rod Applications as per ISO 3601-2 (Dimensions in Millimetres)		
Nominal O-ring Cross Section	Bore Diameter (Piston Applications)	Rod Diameter
1.78	4 to 12	2 to 8
2.62	> 12 to 24	> 8 to 18
3.53	> 24 to 46	> 18 to 38
5.33	> 46 to 124	> 38 to 112
6.99	> 124 to 500	> 112 to 400

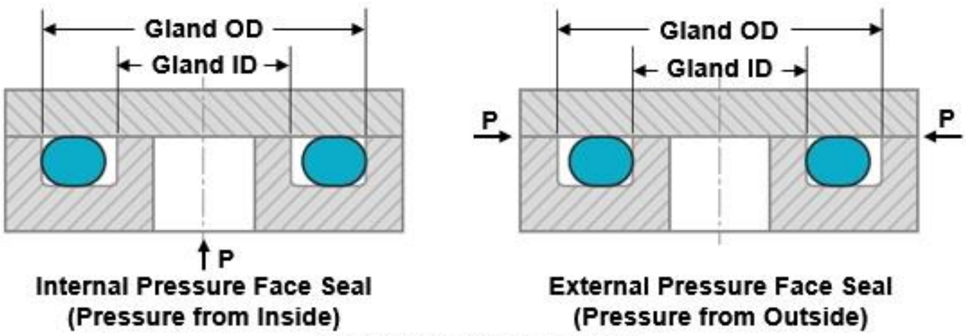
For a piston application, the bore of the cylinder is established and H8 tolerance is applied to the bore dimension. Tolerance f7 is applied to the piston. For a rod application, the diameter of the rod is normally identified and f7 tolerance is applied to it. Tolerance H8 is applied to the bore diameter.

ID Stretch or OD Interference

The ID or OD of the O-ring should be chosen to minimize the potential for installation damage and to minimize wear during use. This can be accomplished by adhering to the following guidelines.

For male gland seals the ID of the O-ring should be smaller than the gland diameter so that when installed, O-ring is always slightly stretched. Measured as a percentage increase in the ID of an O-ring, for most situations, assembled stretch should be at least 1% but not more than 5%. Since elastomers are essentially incompressible materials, if the ID of the O-ring is stretched (as a result of ID interference), the cross section (width) of the O-ring will decrease. The new cross-section should be used for all squeeze (compression) and gland fill calculations.

For female gland seals the OD of the O-ring should be slightly larger than the gland diameter so that there is always some interference resulting in its compression. The amount of compression should be between 1% to 3%. The impact of OD interference on the O-ring cross section change does not require design considerations.



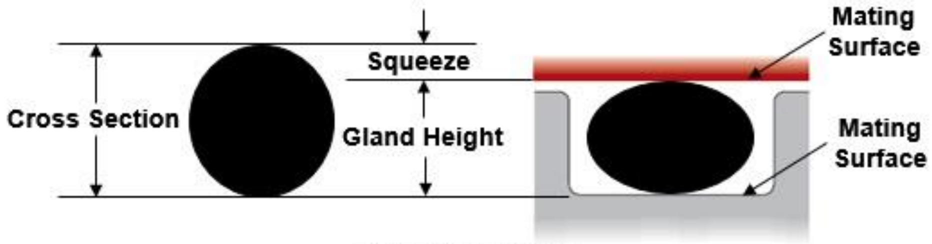
O-ring Size for Face Seals

For internal pressure face/axial seals the OD of the O-ring should be slightly larger than the gland outer diameter (Gland OD) so that when the pressure is applied, the O-ring is already where it would be as a result of the pressure.

For external pressure face/axial seals the ID of the O-ring should be slightly smaller than the gland inner diameter (Gland ID) so that when the pressure is applied, the O-ring is already where it would be as a result of the pressure.

Amount of Squeeze (Compression)

The squeeze, also referred as compression is a major consideration in O-ring seal design.



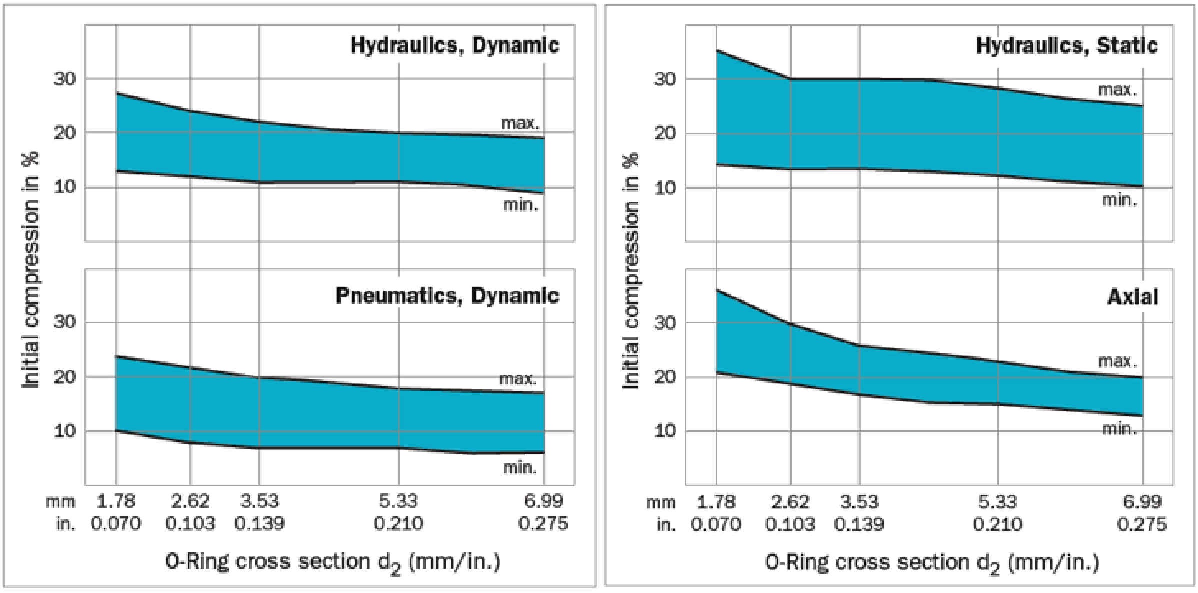
O-ring's Squeeze

As shown in the above figure, squeeze is the difference between the O-ring's original cross section (width of O-ring) and the gland height, height between mating (also called sealing) surfaces [i.e. difference between O-ring's cross sectional height before and after installation]. The squeeze should be determined carefully because an O-rings may become permanently deformed if squeezed excessively, thus deteriorating sealing performance. Squeeze is generally expressed as a percentage of the O-ring's original cross section (width).

In static applications the recommended squeeze is usually between 15 to 30%. Generally, it is 20%. O-rings with smaller cross sections are squeezed by a higher percentage to overcome the relatively higher groove dimension tolerances. In some cases, the very small cross sections can even be squeezed up to 30%.

In vacuum applications the squeeze can even be higher.

In dynamic applications the recommended squeeze is between 6 to 16% due to friction and wear considerations. However, smaller cross sections may be squeezed as much as 20%.



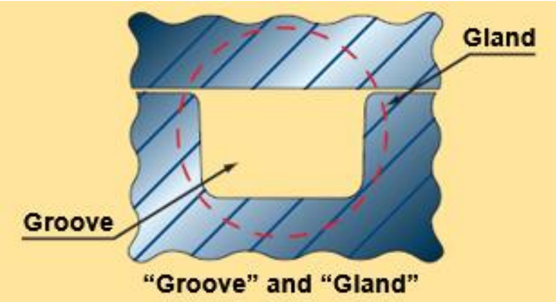
Permissible Range of Initial Compression as a Function of Cross Section for Various Seals

Above figure shows permissible range (max. and min. amount) of initial compression i.e. squeeze as a function of O-ring cross section for radial dynamic, radial static and axial seals.

It may be noted that the amount of squeeze being employed affects a seal's susceptibility to gas permeation. As squeeze increases, permeability decreases.

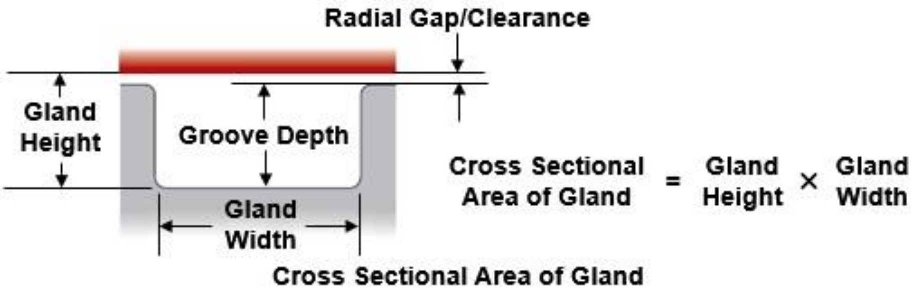
For a gland design, things to be considered are: gland fill, housing dimensions, extrusion gap, use of back-up rings (information about extrusion gap and use of back-up rings is already covered in earlier chapter), groove side angle, transition radii, surface roughness and installation (lead-in) chamfer.

“Groove” and “Gland”



Though sometimes used interchangeably when speaking of seal design, the terms “groove” and “gland” are not synonymous. As shown in above figure, “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.

Gland/Groove/Housing Fill



As shown in above figure, Gland’s Cross Sectional Area = Gland Height × Gland Width

It may be noted that Gland Height (or Gland Depth) = Groove Depth + Radial Gap

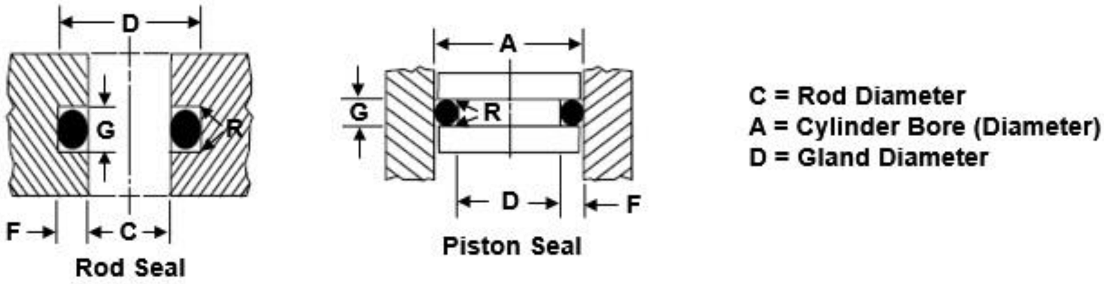
Gland fill is the percentage of the gland that is occupied by the O-ring. It is calculated by dividing the cross sectional area of the O-ring by the cross sectional area of the gland.

i.e. Gland Fill (%) = (O-ring’s Cross Sectional Area / Gland’s Cross Sectional Area) × 100

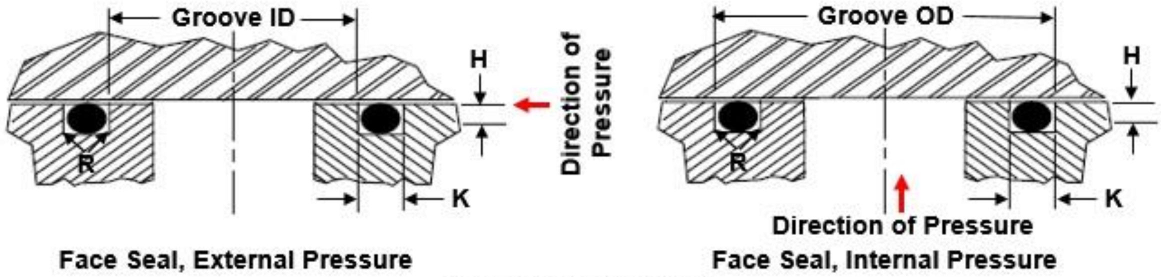
It is recommended that the gland fill of the installed O-ring should not be more than 85 % to allow for possible O-ring thermal expansion, volume swell due to fluid exposure and effects of tolerances.

Housing Dimensions

The right gland/groove depth in O-ring applications is very important because it strongly influences the squeeze of the O-ring cross section. In view of this, housing dimensions (groove depth, groove width, groove radius, surface roughness, lead-in chamfer, etc.) should be selected based on appropriate standard (for example ISO 3601-2) or as per O-ring manufacturer's recommendation. For O-rings as per AS 568, Daemar® Inc. (http://www.daemar.com) recommends housing dimensions (inch sizes) to be as per the following figure and table. Their recommendation is similar to recommendation by many reputed O-ring manufacturers.



Note: Gland Depth (F) = Machined Groove Depth + Radial Gap/Clearance



Housing Dimensions

Housing Dimensions (All dimensions are in inch)												
AS 568 Dash Numbers	Actual Cross Section Diameter	Gland Depth F		Groove Width G +/− .003			Flange Groove		Dia. Clearance		Housing Radius R
		Dynamic +.000 −.001	Static +.000 −.004	No Backup Ring	One Backup Ring	Two Backup Ring	Depth H	Width K min	500 psi	1500 psi	
-001	.004	.033	.031	.056	-	-	.028/.032	.068	.005	.0025	.010
-002	.005	.042	.039	.070	-	-	.037/.041	.078	.006	.003	.010
-003	.006	.051	.048	.084	-	-	.045/.050	.091	.007	.0035	.016
-004 thru -050	.070	.056	.051	.098	.140	.207	.051/.061	.095	.008	.004	.016
-102 thru -178	.103	.090	.082	.144	.173	.240	.081/.091	.140	.009	.004	.016
-201 thru -284	.139	.121	.114	.195	.210	.277	.110/.120	.190	.010	.006	.031
-309 thru -395	.210	.184	.173	.294	.313	.412	.170/.180	.280	.011	.007	.031
-425 thru -475	.275	.241	.227	.385	.410	.540	.231/.241	.370	.012	.008	.047

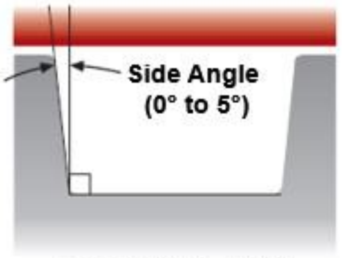
Note 1: Clearances shown are based on 70 durometer materials. The clearances must be held to an absolute minimum consistent with design requirements for temperature variations and should not exceed the values shown.

Note 2: The following sizes are not normally recommended for dynamic service (due to the possibility of spiral failure occurring in these larger diameter sizes of the smaller cross section O-rings), although special applications may permit their use.

-001 thru -003, -013 thru -050, -117 thru -178, -223 thru -284, -350 thru -395 and -461 thru -475

Groove Side Angle

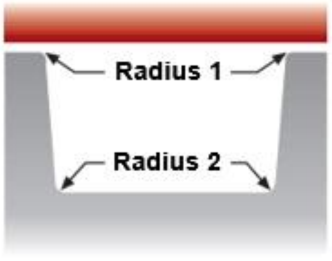
Typical rectangular grooves with straight sides (also called walls or flanks) help prevent O-ring extrusion and nibbling. Provided the seal pressure will not exceed 1500 psi, as shown in the following figure, a slope between 0° and 5° may be added to the sides of the groove to facilitate the machining process.



Groove Side Angle

However, if back-up rings are used, straight groove sides are necessary.

Transition Radii



Transition Radii

As shown in above figure, radius provided at top corners of the groove (Radius 1) and at groove bottom (Radius 2) are called transition (transition/change between surfaces) radii. Radius 2 is generally called housing radius.

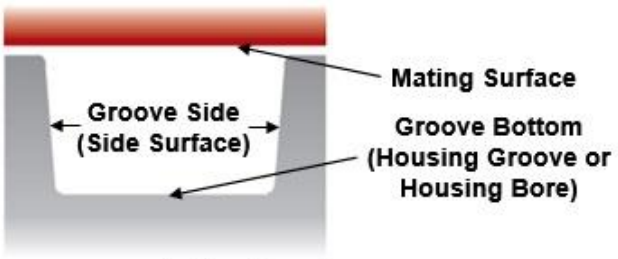
Rounding off of the top corners and providing housing radius eliminates sharp edges and reduce the chances of damage to the O-ring during its installation and in actual service.

It is recommended to provide radius of 0.1 to 0.3 mm at the top corners. To reduce risk of extrusion the radius at top corners ideally should not exceed the maximum permissible radial gap/clearance.

The housing radius depends on the cross section of the housing (cross section of O-ring). The recommended housing radius is given in the table for housing dimensions (see the table given on previous page).

Surface Roughness

The surface roughness of the O-ring housing and any mating part has a significant impact on the life and sealing performance of the O-ring.



Surface Roughness

It is recommended that surface roughness values (in micrometers/microns) of groove sides, groove bottom and the mating surface should as per the following table.

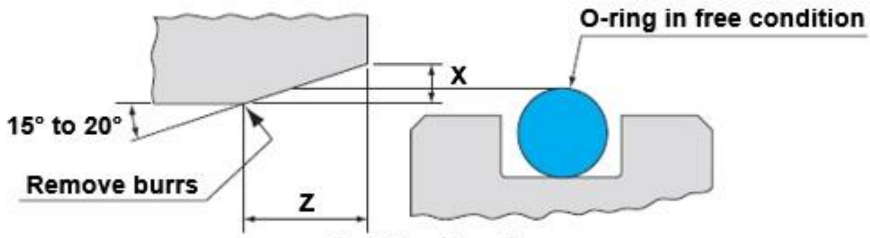
Location	Purpose	Type of Pressure		Surface Roughness	
				µm Ra	µm Rz
Groove Side (Side Surface) and Groove Bottom (Housing Groove)	Static Sealing	Constant	Flat Surface (Axial Seal)	3.2	12.5
			Cylindrical Surface	1.6	6.3
		Pulsating		1.6	6.3
	Dynamic Sealing	With Back-up Rings		1.6	6.3
		Without Back-up Ring		0.8	3.2
Mating Surface	Static Sealing	Constant		1.6	6.3
		Pulsating		0.8	3.2
	Dynamic Sealing	-		0.4	1.6

Note: 1 micro meter ≈ 40 micro inch

Though circumferential (crosswise) scratches on a cylinder or bore may not be problematic, surfaces must not have longitudinal (lengthwise) scratches. However, visual surface imperfections are not allowed on mating surface and groove bottom surface.

Lead-in Chamfer

A perfectly designed O-ring seal is of little use if the O-ring is damaged during installation. To prevent damage for male gland and female gland seals, a 15° to 20° lead-in chamfer on the bore or rod is recommended. The chamfer must be long enough to ensure that the O-ring sees only the chamfer when it is installed. Face seals do not require lead-in chamfers.

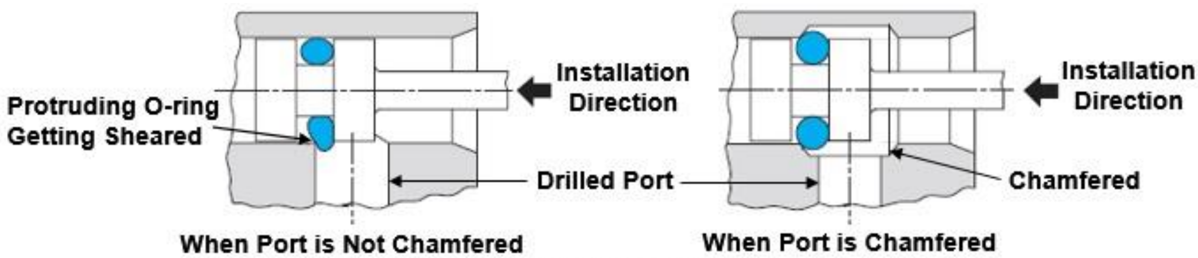


Lead-in Chamfer

Following table shows recommended values of Z (chamfer length) and X (chamfer height) for 15° and 20° chamfer in mm. All edges must be free from burrs and sharp edges beveled.

O-ring Cross Section Diameter (mm)		**X**	**Z** (mm)	
Over	Up to	(mm, minimum)	At 15°	20°
-	2.4	0.9	3.4	2.5
2.4	3.5	1.1	4.1	3.0
3.5	5.7	1.3	4.9	3.6
5.7	8.4	1.5	5.6	4.1

Note: Dimension Z is shown when dimension X is minimum



Traversing of Cross Drilled Ports

As shown in above figure, while traversing of cross drilled ports, an O-ring can be sheared when a spool or piston moves in a bore broken by cross drilled ports. The deformed O-ring returns to its original round cross section as it enters the port and gets sheared as it leaves the drilled area. To avoid this, connection holes should be repositioned. If repositioning is not possible, an internal chamfer is recommended.

It is recommended that surface roughness on the lead-in chamfer (also called installation chamfer) should be 1.6 μm Ra (6.3 μm Rz).

Lubrication

As friction leads to O-ring wear, for all dynamic applications, proper lubrication is essential for long seal life. A lubricant should be selected on the basis of system fluid and the material of which the O-ring is made (chemically compatible). Lubrication can be carried out either externally and/or internally.

External Lubrication

In external lubrication, outside of the O-ring is coated with a lubricant. External lubricant helps during installation, but it doesn't last much beyond that point. Following are the common external lubricants.

Hydrocarbon-based materials, such as petrolatum, better known as petroleum jelly (Vaseline®). 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).

Silicone based greases, such as Dow Corning DC-55, a general purpose grease. It is generally used in vacuum and pneumatic applications.

Barium based greases. They 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).

Internal Lubrication

Friction can also be reduced through use of internal lubricant, use of an internally lubricated elastomer. Internal lubrication is typically accomplished in one of following two ways.

A lubricant (typically an oil or wax) that is somewhat incompatible with the elastomer is added to the elastomer during compounding. The incompatibility causes the lubricant to separate itself out and "bloom" up onto the O-ring's surface over time. This continual blooming of the lubricant keeps the seal's exterior coated with lubricant, thus providing longer term lubrication.

A non-blooming lubricant, such as molybdenum disulfide or PTFE, is added during compounding to provide even longer term lubrication.

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. However, 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.

Note

It is recommended not to use lubricants that are composed of the same material as the O-ring (For example - a silicone lubricant on a silicone O-ring).

Materials

The preferred bore materials are steel and cast iron, and pistons should be softer than the bore to avoid scratching them. The bore sections should be thick enough to resist expansion and contraction under pressure so that the radial clearance gap remains constant, reducing the chance of damage to the O-ring by extrusion and nibbling.

Applications using stainless steel glands and bores should not use graphite loaded O-ring materials. Graphite has a tendency to "pit" stainless steel.

The best quality surfaces are honed, burnished or hard chromium plated.

Cord Rings

In addition to the traditional O-rings produced by endless molding, cord rings of butt-glued (using cyanoacrylate) or butt-vulcanized extruded round cords are available. Butt-vulcanized cord rings are made by vulcanizing the ends of an extruded round cord together in a mold tool. There is no upper limit to diameter of a cord ring. The main benefits of cord rings are huge cost saving as molds are not required and short lead times. However, the drawbacks of cord rings include the distinctly higher cord thickness (cross section diameter) tolerances and the lower stress bearing capacity of the glued / vulcanized joint.

Joint by Scarfing at 45°

As shown in above figure, to achieve high tensile strength, it is recommended to make the joint/splice by scarfing at 45°. This is very important in achieving high tensile strengths as the area of the vulcanizing surface is greatly increased due to scarfing at 45°.

Mold and mold-joined method is used when the nonstandard O-ring must have a cross section diameter to very close tolerances and a mold-join is acceptable. It is often used for sizes above 2.0 m diameter, when two or more smaller rings are manufactured (by endless molding), then cut and mold joined.

As the joint/splice always has poorer mechanical properties than the basic material, cord rings should be used with caution for dynamic applications, gaseous media or vacuum conditions.

O-Ring Calculator Tool

For saving time calculating and designing O-ring grooves and verify the O-ring sealing performance, you may use O-Ring Calculator Tool (https://oringcalculator.eriksgroup.com) by ERIKS.

O-ring Size Standards

Shortly after O-rings first came into common use, it became obvious that standards for O-ring sizes, tolerances, and groove design would be beneficial. In view of this, various government and engineering organizations have produced a multitude of O-ring standards.

Information on O-ring size standards by the most common global O-ring size standards is given in this chapter.

In general, two dimensions describe the size of an O-ring: its inside diameter (ID) and its cross-sectional diameter (CS). Information on global O-ring size standards follows.

Aerospace Standard (AS) 568D

SAE Aerospace Standard (AS) 568D, titled Aerospace Size Standard for O-rings is published by the SAE (Society of Automotive Engineers) International. This Standard specifies the inside diameters, cross sections, tolerances and size identification codes (dash numbers) for O-rings used in sealing applications and for straight thread tube fitting boss gaskets. AS568D is the most commonly used standard in the USA for aerospace, automotive and general industrial applications.

There are two tables for O-ring sizes in the standard: Table 1 is for O-rings used for sealing applications and Table 2 is for straight thread tube fitting boss gaskets.

Table 1 - Aerospace Size Standards for O-rings

Dash Number	ID Inches min	ID Inches max	ID mm min	ID mm max	W Inches min	W Inches max	W mm min	W mm max	Volume (Ref) Cubic Inches	Volume (Ref) Cubic cm
-001	0.025	0.033	0.64	0.84	0.037	0.043	0.94	1.09	0.0003	0.005
-002	0.038	0.046	0.97	1.17	0.047	0.053	1.19	1.35	0.0006	0.010
-003	0.052	0.060	1.32	1.52	0.057	0.063	1.45	1.60	0.0010	0.016
-004	0.065	0.075	1.65	1.91	0.067	0.073	1.70	1.85	0.0017	0.028
-005	0.096	0.106	2.44	2.69	0.067	0.073	1.70	1.85	0.0021	0.034
-006	0.109	0.119	2.77	3.02	0.067	0.073	1.70	1.85	0.0022	0.036
-007	0.140	0.150	3.56	3.81	0.067	0.073	1.70	1.85	0.0026	0.043
-008	0.171	0.181	4.34	4.60	0.067	0.073	1.70	1.85	0.0030	0.049
-009	0.203	0.213	5.16	5.41	0.067	0.073	1.70	1.85	0.0034	0.056
-010	0.234	0.244	5.94	6.20	0.067	0.073	1.70	1.85	0.0037	0.061
-011	For information on Dash Numbers beyond -011, please see the standard.									

Above table shows a small part of the Table 1 for illustration purpose. It may be noted that each ID and W combination is identified by a three digit "dash (-) number". It may be also noted that the O-ring sizes are defined by maximum and minimum ID (inside diameter) and maximum and minimum W (width) dimensions in both inches and millimeters. Width (W) is commonly referred to as cross section (CS). Though the sizes in the standard are defined by maximum and minimum ID and W dimensions, most listings (by O-ring manufacturers), show them as a midpoint value (average value) and a ± tolerance.

In Table 1, the dash numbers are divided into groups (series) of one hundred. Within each group, the dash numbers are sequential with increasing ID and are non-significant. Each hundred group, however, identifies the cross section size of the O-rings within the group. For example, all 0.070 inch (1.78 mm) and smaller O-ring cross sections fall into the group of -001 thru -099. The 0.103 inch (2.62 mm) cross section rings fall into the group of -100 thru -199, and so on. Following table shows the cross sections for the 5 groups covered in the table.

Groups	Cross Section (W)					
	Inches			mm		
	min	max	**midpoint**	min	max	**midpoint**
-001 thru -099	0.067*	0.073*	**0.070***	1.70*	1.85*	**1.78***
-100 thru -199	0.100	0.106	**0.103**	2.54	2.69	**2.62**
-200 thru -299	0.135	0.143	**0.139**	3.43	3.63	**3.53**
-300 thru -399	0.205	0.215	**0.210**	5.21	5.46	**5.33**
-400 thru -475	0.269	0.281	**0.275**	6.83	7.14	**6.99**

* Except for sizes -001, -002 and -003.

It may be noted that first of the three digits (Group/series 0, 1, 2, 3 or 4) of the dash numbers (-001 to -475) represents cross section of the O-ring (for example, midpoint size in mm to be: 1.78, 2.62, 3.53, 5.33 and 6.99 resp.). In Table 1, there are 349 standard size of O-rings.

Table 2 - Aerospace Size Standards for Straight Thread Tube Fitting Boss Gaskets												
Dash Number	**Tube Size (Nom) Inches**	**Tube Size (Nom) mm**	**ID Inches min**	**ID Inches max**	**ID mm min**	**ID mm max**	**W Inches min**	**W Inches max**	**W mm min**	**W mm max**	**Volume (Ref) Cubic Inches**	**Volume (Ref) Cubic cm**
-901	0.094	2.38	0.180	0.190	4.57	4.83	0.053	0.059	1.35	1.50	0.0019	0.031
-902	0.125	3.18	0.234	0.244	5.94	6.20	0.061	0.067	1.55	1.70	0.0031	0.051
-903	0.188	4.76	0.296	0.306	7.52	7.77	0.061	0.067	1.55	1.70	0.0037	0.061
-904	0.250	6.35	0.346	0.356	8.79	9.04	0.069	0.075	1.75	1.91	0.0054	0.088
-905	0.313	7.94	0.409	0.419	10.39	10.64	0.069	0.075	1.75	1.91	0.0062	0.102
-906	For information on Dash Numbers beyond -905, please see the standard.											

Above table shows a small part of the Table 2 for illustration purpose.

The Table 2, using the 900 series dash numbers, lists all of the presently standardized straight thread tube fitting boss gaskets (O-rings). This series has traditionally utilized the significant dash numbering system, wherein second and third digit of the dash number designates the tube size in 16th's of an inch (examples: 02 of -902 designates that it is a boss gasket for 02/16 = 0.125 inch nominal OD (outside diameter) tube; 05 of -905 designates that it is a boss gasket for 05/16 = 0.313 inch nominal OD tube and so on) with the exception of the -901, which is intended for a 0.0938 inch (2.38 mm) nominal OD tube because the 0.0625 inch (1.59 mm) OD tube is not in common aircraft use. There are 20 sizes for boss gaskets/seals in Table 2.

AS568D thus gives size for total 369 (349 in table 1 and 20 in Table 2) standard O-rings.

ISO 3601-1

ISO 3601 is published by the International Organization for Standardization.

ISO 3601 consists of the following parts, under the general title Fluid power systems - O-rings:

Part 1: Inside diameters, cross-sections, tolerances and designation codes
Part 2: Housing dimensions for general applications
Part 3: Quality acceptance criteria
Part 4: Anti-extrusion rings (back-up rings)
Part 5: Suitability of elastomeric materials for industrial applications

Information on Part 1 (ISO 3601-1) is given in this section.

ISO 3601-1 specifies the inside diameters, cross-sections, tolerances and designation codes for O-rings used in fluid power systems for two applications: general industrial and aerospace.

The following symbols are used in ISO 3601-1
d_1 = O-ring inside diameter
d_2 = O-ring cross-section diameter

O-rings for General Industrial Application

For general industrial applications, two classes of inside diameter tolerances, class A and class B, are specified. Class A O-rings have tighter inside diameter tolerances than class B O-rings and are suitable for industrial or aerospace applications when the application or the housing require tighter tolerances. Class B O-rings have dimensions and tolerances suitable for general purpose applications.

For general industrial application O-rings, there are six tables (Tables 1 through 6) giving information on size code, size, inside diameter, inside diameter tolerances (class A and class B) and cross-section diameter.

O-rings for general industrial applications that conform to ISO 3601-1 shall be designated as follows:

a) the word "O-ring" followed by a hyphen;
b) "ISO3601-1" followed by a hyphen;
c) the **size code** from the relevant table (see **Tables 1 through 6**) and "A" or "B" for the inside diameter tolerance class, followed by a hyphen;
d) the nominal inside diameter and cross-section dimensions, separated by an "×" and followed by a hyphen;
e) the grade letter (N, S or CS), in accordance with ISO 3601-3.

Example 1: O-ring-ISO3601-1-012A-9,25 × 1,78-S
Example 2: O-ring-ISO3601-1-130B-40,94 × 2,62-N

Like group/series in AS568D, the first of the three digits of a size code (0, 1, 2, 3 or 4) except for size codes 001, 002 and 003 represents cross section of the O-ring.

Table 1 - Size code, size, inside diameter and inside diameter tolerances of class A and class B O-rings for general industrial applications - Cross-section diameter, d_2, of 1,02 mm, 1,27 mm and 1,52 mm

Size code	Size	Inside diameter						Cross-section diameter				Volume ref.	
		d_1 nom. mm	Tolerance mm Class A	Tolerance mm Class B	d_1 nom. in	Tolerance in Class A	Tolerance in Class B	d_2 nom. mm	Tol.	d_2 nom. in	Tol.	cm^3	in^3
001	0,74 × 1,02	0,74	±0,10	±0,12	0,029	±0,004	±0,005	1,02	±0,08	0,040	±0,003	0,005	0,0003
002	1,07 × 1,27	1,07			0,042			1,27		0,050		0,010	0,0006
003	1,42 × 1,52	1,42			0,056			1,52		0,060		0,016	0,0010

It may be noted that in ISO standards, a comma (,) is used as the decimal marker (.).

Above table is Table 1 of ISO 3601-1. It may be noted that each size code (001, 002 and 003) has different cross-section diameter. This is the main difference between Table 1 and Tables 2 to Table 6 in the standard. Each of the table from Table 2 to Table 6 are having same cross-section for all the size codes in them. Table 2 contains all size codes starting with 0 (0XX) except for size codes 001, 002 and 003 which are forming Table 1. Table 3 contains all size codes starting with 1 (1XX) and so on. Thus Table 6 contains all size codes starting with 4 (4XX).

Like Table 1, Table 2 to Table 6 gives information on size code, size, inside diameter, and inside diameter tolerances of class A and class B. It also gives cross-section diameter d_2, and tolerances for it.

Following table shows cross-section diameter of O-rings in Table 2 to Table 6.

ISO 3601-1 Table	Size Codes	Cross-section Diameter d_2	
		mm	in
Table 2	0XX (except size codes 001, 002 and 003)	1,78	0,070
Table 3	1XX	2,62	0,103
Table 4	2XX	3,53	0,139
Table 5	3XX	5,33	0,210
Table 6	4XX	6,99	0,275

O-rings for Aerospace Applications

O-rings for aerospace applications shall be designated as follows:

a) the word “O-ring” followed by a hyphen;
b) “ISO3601-1” followed by the letter “A” (to designate an aerospace application), followed by a hyphen;
c) the size code from the relevant table (Tables 7 through 11), followed by a hyphen;
d) the nominal inside diameter and cross-section dimensions, separated by an “×” and followed by a hyphen;
e) the grade letter (N, S or CS), in accordance with ISO 3601-3.

Example 1: O-ring-ISO3601-1A-C0515-51,5 × 3,55-S
Example 2: O-ring-ISO3601-1A-D1450-145 × 5,3-CS

For aerospace application O-rings, there are five tables (Tables 7 through 11) giving information on size code, size, inside diameter, inside diameter tolerances and cross-section diameter.

The first digit of the size code indicates the cross-section group (A to E), while the last four digits indicate the O-ring’s inside diameter rounded to one-tenth of millimeter. The following table gives information on various cross-section groups.

Cross-section Group (Size Code Starting with)	ISO 3601-1 Table	Cross-section Diameter d_2	
		mm	in
A	Table 7	1,80	0,071
B	Table 8	2,65	0,104
C	Table 9	3,55	0,140
D	Table 10	5,30	0,209
E	Table 11	7,00	0,276

For more information on size code, size, inside diameter and cross-section for O-rings in each table, please see ISO 3601-1.

DIN 3771

DIN 3771 is published by the German Institute for Standardization (Deutsches Institut für Normung e.V.). The title of the part (Part 1) that defines standard sizes is Fluid Systems; O-rings; Dimensions.

The O-ring sizes in the DIN standard are very similar to the ISO 3601 sizes (cross-section diameters in mm are: 1.80, 2.65, 3.55, 5.30 and 7.00). The most significant difference between the standards is that the DIN standard uses quality grade (to DIN 3771-4) rather than an application type to differentiate between standard/normal and precision/special O-rings. Two quality grade/levels specified are: N - Normal Quality (1.0 AQL) and S - Special Quality (0.65 AQL).

O-ring sizes are designated/identified by the internal/inside diameter (ID) in mm x cross-section in mm, followed by a letter indicating the quality grade/level, and a code indicating the rubber polymer (to DIN 3771-3) and IRHD hardness.

Example:
Designation of an O-ring with an internal diameter, d_1, of 13,2 mm, a section diameter, d_2, of 1,8 mm, quality grade N, made of material NBR with 70 IRHD (NBR 70) is:
O-ring DIN 3771 - 13,2 x 1,8 - N - NBR 70

The current DIN standard for O-rings is DIN ISO 3601-1 (DIN ISO 3601-1 supersedes DIN 3771-1) titled Fluid Power Systems - O-rings - Part 1: Inside Diameters, Cross-sections, Tolerances and Designation Codes. This standard is identical to ISO 3601-1.

BS 4518

BS 4518 is published by the British Standards Institution. The full title of the standard is Specification for Metric dimensions of toroidal sealing rings ('O'-rings) and their housings. As indicated in the title, the standard includes both the standard O-ring dimensions and the dimensions of the glands to house the O-rings in a variety of configurations.

The size code for these O-rings is a four-digit number indicating the O-ring ID in tenths of millimeters followed by a hyphen and two digits indicating the O-ring cross section (1.6, 2.4, 3.0, 5.7 or 8.4), also in tenths of a millimeter (Example: BS 4518 0371 - 16).

BS 1806

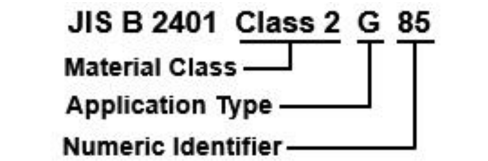
BS 1806 is also published by the British Standards Institution. The full title of this standard is British Standard Specification for Dimensions of toroidal sealing rings ('O'-rings) and their housings (inch series). As with BS 4518, the standard offers both standard O-ring and gland dimensions. The sizes are almost identical to the sizes available in SAE AS568.

It may be noted that BS ISO 3601-1:2008 is the UK implementation of ISO 3601-1:2008. Together with BS ISO 3601-2:2008 it supersedes BS 1806:1989 which is withdrawn.

JIS B 2401

JIS B 2401 is published by the Japanese Standards Association. Its official title is O-Rings. The standard specifies O-rings used for general machinery applications, more specifically, O-rings for dynamic applications (P), O-rings for static applications (G) and O-rings for vacuum flanges applications (V). JIS B 2401 is unique in that it specifies standard O-ring dimensions and standard materials.

The O-rings are identified/designated as:



O-rings Identification as per JIS B 2401

JIS B 2401 calls out 6 material classes/codes: 1A, 1B, 2, 3, 4C and 4D as under.

Material Class	Symbol	Remarks	Typical Material
Class 1A	None / 1A	Mineral oil resistance.	NBR 70
Class 1B	1B	Mineral oil resistance but more hard for pressure resistance.	NBR 90
Class 2	2	Gasoline (kerosene and other light fuel oils) resistance.	NBR 70
Class 3	3	Animal oil and vegetable oil resistance.	EPDM 70
Class 4C	4C	For high temperature application.	VMQ 70
Class 4D	4D	For high temperature and chemical resistance application.	FKM 70

The three application types are: dynamic applications (P), static applications (G) and vacuum flanges applications (V)

Numeric identifiers are ascending numbers for size (dimensional) code. Size code gives information on inside diameter and cross-section diameter.

The cross-section diameters used by various applications are as under.

Application Type	Cross-section Diameters in mm
Dynamic Applications (P), also used for static applications	1.9, 2.4, 3.5, 5.7 and 8.4
Static Applications (G)	3.1 and 5.7
Vacuum Flanges Applications (V)	4, 6 and 10
Static Applications, Slim Series (S) - not covered by JIS B 2401	1.5 and 2.0

In addition to the sizes included in the JIS B 2401, the standard has also made provision for using the JIS B 2401 material types with the O-ring sizes as per ISO 3601-1. For this, O-rings are identified/designated by using ISO size code instead of application type and numeric identifier - JIS B 2401 Material Class ISO 3601-1 Size Code

For information on standard O-ring sizes (inside diameter, cross-section dimension and tolerances) as per various standards, you may see O-ring Handbook by Dichtomatik Americas (www.dichtomatik.us).

One of the problems people experience is accurately measuring O-ring's cross section (CS) dimension. This task can be made easier by ascertaining the origin of the machine to which it belongs. As each country works to a specific set of standard cross sections, the information can be used to eliminate many potential selections.

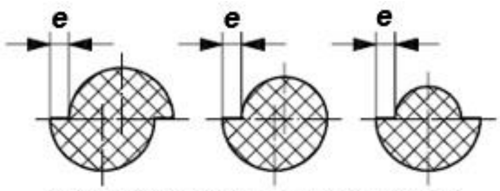
Quality Acceptance Criteria

Quality is the condition of a product or service which makes it suitable for its purpose and complying with existing requirements. The surface quality of an O-ring has a significant impact on its sealing performance. Several industry standards exist that define surface quality defect types and set maximum acceptable sizes for each defect type. To give an idea about different types of surface imperfections and maximum acceptable limits of imperfections, information on them based on ISO 3601-3:2005 is given in this chapter.

Types of Surface Imperfection

Following are the most common types of surface imperfections/defects. Limiting dimensions (also called measurements) for each type of imperfection are also shown in the figures.

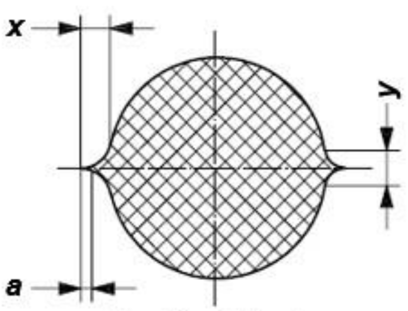
Off-register and Mismatch (Offset)



Off-register and Mismatch (Offset)

As shown in above figure, an off-register condition is caused when the top and bottom halves of the mould are not aligned but are shifted laterally with respect to one another. A mismatch condition is caused when the top half and the bottom half of the O-ring are of different sizes. Off-register and/or mismatch of O-ring halves is called offset. The off-register or mismatch is measured by dimension "*e*".

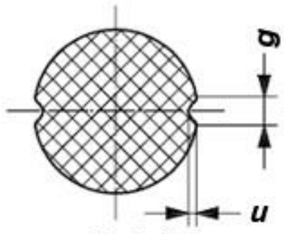
Combined Flash



Combined Flash

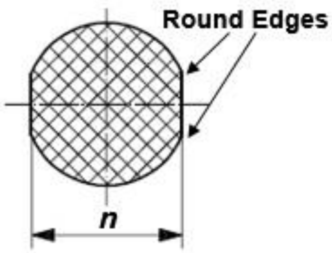
Combined flash is a combination of offset, flash and parting line projection. Flash is the film-like material that extends from the parting line projection or inner and/or outer diameters, caused by mould separation or present due to inadequate trimming. Parting line projection is a continuous ridge of material situated at the parting line of inner and/or outer diameters caused by worn or excessively rounded edges of the mould cavity. Combined flash is measured by dimensions *a*, *x* and *y*.

Backrind



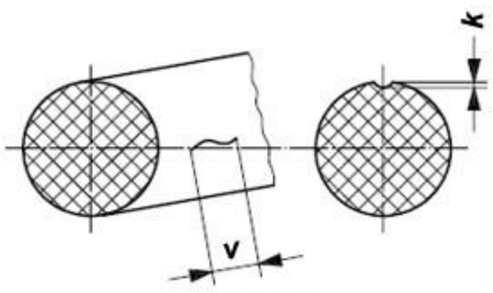
Backrind is a longitudinal recess in which the rubber adjacent to the parting line shrinks below the level of the moulding and has a “U”-like or “W”-like cross section on the seal’s OD and/or ID. This recess may sometimes exist on the entire circumference of the O-ring. Backrind is usually caused by thermal expansion of the elastomer material over a sharp mould edge. It can also be caused by premature curing of the elastomer material. Backrind is measured by dimensions *g* and *u*.

Excessive Trimming



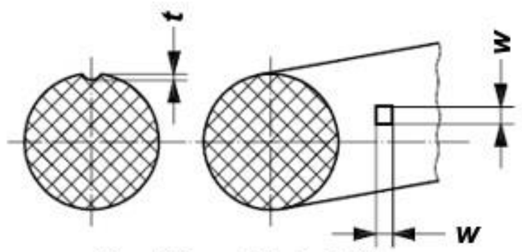
Excessive trimming (buffing) is the flattened and often roughened area around the ID and/or OD of an O-ring caused by the trimming process. Excessive trimming is caused by improper removal of flash. It may be noted that radial tool marks are not allowed. Excessive trimming is measured by dimension *n* and then the measured value (*n*) is compared with minimum cross-section diameter (d_2) to decide its acceptance or rejection.

Flow Marks



Flow marks are shallow, thread-like recess, in the surface of the seal. They are usually curved and have rounded edges. They are caused by incomplete flow of the material. They can also be caused by premature curing of the material in the mold. Flow marks are measured by dimensions *v* and *k*. The radial orientation of flow marks is not permissible.

Non-fills and Indentations



Non-fills and Indentations

Non-fills are random and irregular shaped surface indentation with a coarser texture than the unaffected portions of the O-ring surface. They are caused by incomplete filling of the mould cavity. They are also caused by trapping of air in the mould cavity.

Indentation are depression, usually irregular in form, caused by the removal of inclusions (foreign material such as contamination, dirt, etc.) from the surface or the build-up of hardened deposits on the surface of the mould cavity. The indentations are also caused by deformation of the mould edge at the parting line called parting line indentations. The parting line indentation are shallow saucer-like recess sometimes triangular in shape, located on the parting line at the ID and/or OD. Non-fills and indentations are measured by dimensions *t* and *w*.

Grades

Quality requirement, acceptance criteria (permissible limits) for imperfections is specified by a grade. There are three grades based on an application's requirement.

Grade N (General Purpose)

Grade N (general purpose) specifies acceptance criteria for O-rings intended for general use.

Grade S (Special)

Grade S (special) specifies acceptance criteria for O-rings intended for applications requiring a higher level of quality and/or precision with respect to dimensional tolerances of surface imperfections. For example, aerospace or critical industrial or automotive applications.

Grade CS (Critical Service)

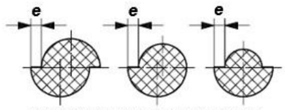
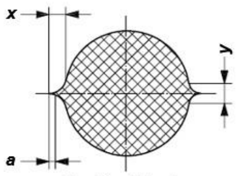
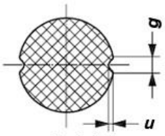
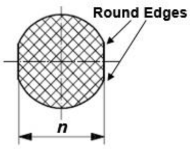
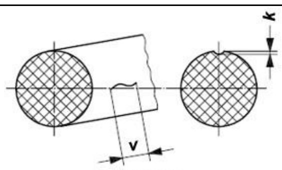
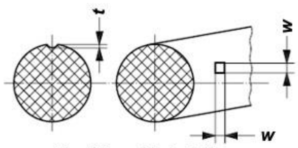
Grade CS specifies acceptance criteria for O-rings intended for applications requiring a much higher level of quality and/or precision with respect to dimensional tolerances of surface imperfections. For example, critical service aerospace or medical applications where the surface of the O-ring must be near-perfect to perform in a satisfactory manner.

The user should specify the grade at the time of purchase based on the application's requirement. Grade N will be assumed if no grade is specified by the user.

Note:
Inspection for quality checking should be carried out on an unstretched O-ring by viewing it under a ×2 magnifier viewer with adequate illumination. Other methods should be agreed between the manufacturer and the user. No foreign material embedded in the surface shall be visible under the viewing conditions.

Limits of Size for Surface Imperfections

Following table shows limits of size for surface imperfections for Grade N O-rings.
All dimensions are in millimetres.

Surface Imperfection Type	Diagrammatic Representation	Limiting Dimensions	Maximum Limits of Imperfections Grade N O-rings Cross-section, d_2				
			> 0,8[b] ≤ 2,25	> 2,25 ≤ 3,15	> 3,15 ≤ 4,50	> 4,50 ≤ 6,30	> 6,30 ≤ 8,40[b]
Off-register, mismatch (offset)	 Off-register and Mismatch (Offset)	*e*	0,08	0,10	0,13	0,15	0,15
Combined flash (combination of offset, flash and parting line projection)	 Combined Flash	*x*	0,10	0,12	0,14	0,16	0,18
		y	0,10	0,12	0,14	0,16	0,18
		a	When the flash can be differentiated, it shall not exceed 0,07 mm.				
Backrind	 Backrind	*g*	0,18	0,27	0,36	0,53	0,70
		u	0,08	0,08	0,10	0,10	0,13
Excessive trimming	 Excessive Trimming	*n*	Trimming is allowed provided the dimension *n* is not reduced below the minimum diameter d_2 for the O-ring.				
Flow marks	 Flow Marks	*v*	1,50[a]	1,50[a]	6,50[a]	6,50[a]	6,50[a]
		k	0,08	0,08	0,08	0,08	0,08
Non-fills and indentations (including parting line indentations)	 Non-fills and Indentations	*w*	0,60	0,80	1,00	1,30	1,70
		t	0,08	0,08	0,10	0,10	0,13

a - Or 0,05 times the O-ring's inside diameter (d_1), whichever is greater.
b - Limits of imperfections for cross sections < 0,8 mm or > 8,40 mm shall be agreed upon between manufacturer and customer.

For limits of size for surface imperfections for Grade S and CS O-rings, please see ISO 3601-3.

Note:
Flow marks, non-fills and indentations within the limits of the tables (showing limits of size for surface imperfections) shall not be allowed if

a) there are more than three in any 25 mm length of circumference for Grades N and S or there is more than one in any 25 mm length of circumference for Grade CS;
b) they interconnect;
c) there are more than three that are separated from each other by a distance that is less than the maximum limiting dimensions of such imperfection for Grades N and S, or there are more than two that are separated from each other by a distance that is less than the maximum limiting dimensions of such imperfection and only one per 25 mm length of circumference for Grade CS.

Installation Guidelines

The reliable function of an O-ring depends on the correct installation. The O-ring must not be damaged during installation. The following general guidelines should be observed for installation of O-ring to avoid damage.

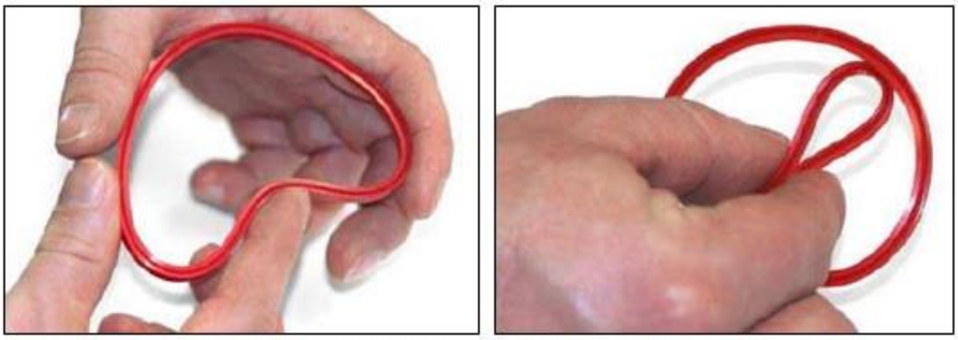
Avoid reuse of used O-ring.

The O-ring must not be stretched beyond its elongation limit. Heating to approximately 80°C in oil or water facilitates expansion and recovery of the O-ring.

Ensure that the edges of the groove have been radiused and chamfers are provided on all leading edges.

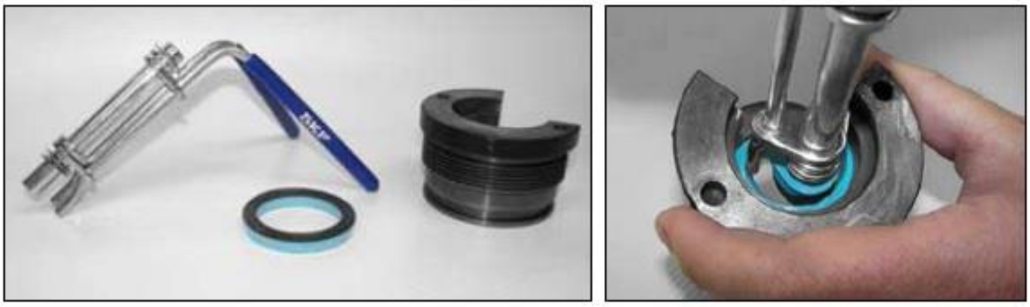
Because any foreign bodies within a gland can potentially damage the O-ring, it is extremely important to clean each of the elements before assembly. Metal chips, stray fibers, dirt, sand, dust, or other particulate matter must be completely removed from the groove and all other surfaces within the gland before installation of the O-ring. Use of a cleaning agent (chemically compatible with O-ring material) may prove helpful.

The O-ring may have to move across threads, splines, keyways or other hazards while being installed. In such cases place a sleeve, piece of tape, or other buffer between the O-ring and the abrasive surface(s).



Bending O-ring to Kidney Shape

As shown in above figure, O-ring can often be installed into closed grooves through carefully bending it similar to a kidney shape and then inserting it into the groove. It is very important to avoid sharp bending. Thin and flexible profiles can be installed by hand.



Installation Tool to Install Profiles of Greater Section Thickness

As shown in above figure, an installation tool helps to install profiles of greater section thickness.

Hard and/or sharp instruments/tools should not be used as they are more likely to nick or puncture the seal.

lubrication is an essential installation “tool.” A suitable lubricant (check lubricant for compatibility with the seal material) should be applied to the assembly surfaces and/or the O-ring. Sealing medium can be applied for lubrication. However, one should not use lubricants that are composed of the same material as the O-ring. For example - Do not use silicone grease or oil on seals made from silicone (VMQ) compounds.

The O-ring should not be rolled over assembly surfaces.

Ensure that the O-ring is not twisted during installation into the groove.

Storage of O-rings

During storage, the properties of elastomer products can be damaged either by chemical reactions or by physical processes. Chemical reactions are basically caused by the influence of heat, light, oxygen, ozone or contamination by chemicals. The physical processes, which are called physical ageing, are either due to the influence of external stresses leading to cracks and permanent deformation, or due to the migration of plasticizers, which makes the material more brittle and can lead to deformation of the parts.

Therefore, elastomer products only maintain their characteristics for several years without major changes, if they are properly stored. The ageing behavior of elastomer products and their reaction on storage conditions depend considerably on their chemical structure. Unsaturated elastomers (e.g. nitrile rubber) age more quickly under improper storage conditions than saturated elastomers (e.g. fluorocarbon rubber).

Storage of Elastomer Products

In view of above, elastomer products (O-rings) should be stored in accordance with the following recommendations, indicating the most suitable conditions for storing them. They are in line with the recommendations provided in ISO 2230 or DIN 7716.

Humidity

Products should be stored in a cool and dry room. The relative humidity should be < 65%. The relative humidity should be such that, given the variations of temperature in storage, condensation does not occur.

Temperature

Storage temperature should be around 15°C (60°F) and not exceed 25°C (75°F). If the storage temperature is below 15°C (60°F), care should be taken during handling of stored products because they may have stiffened. They should be warmed up slowly at ambient temperature.

To avoid direct heat radiation, the products should be stored at least 1m away from direct sources of heat such as boilers, radiators and direct sunlight.

Light

Protection from direct sunlight and strong artificial light with a high ultraviolet content is important. It is advisable to light the storage rooms with conventional bulbs. Unless packed in opaque containers, it is advisable to cover windows with red or orange screens or coatings.

Oxygen and Ozone

Products should be protected from circulating air wherever possible. As ozone is particularly harmful to rubber, storage rooms should be free from high-voltage electrical equipment giving rise to electric sparks or electrical discharges. Products should be stored in airtight containers or other suitable means to limit exposure to these gases. The container’s material must not contain plasticizers. Polyethylene is the most suitable material for containers.

Deformation

Where possible, Products should be stored in a relaxed position, free from tension or compression. Laying them flat and avoiding suspension or crushing keeps it free from strain and minimizes deformation. Products must not be hung on nails or tightly folded or rolled for reasons of space. It is advisable that O-rings of large internal diameter are formed into three equal loops so as to avoid creasing or twisting. It may be noted that it is not possible to achieve this condition (avoid creasing or twisting) by forming just two loops.

Contact between Different Products

Contact between products made from rubbers of different compositions should be avoided. This includes products of the same type but differing in color.

Contact with Liquid and Semi-Solid Material

Contact with liquids and semi-solid materials, particularly solvents, such as petrol, oils, greases or cleaning fluids should be avoided unless so packed by the manufacturer.

Contact with Metals

Certain metals and their alloys (in particular, copper and manganese) are known to have harmful effects on some rubbers. Rubber should not be stored in contact with such metals. They should be protected by wrapping in, or by separation with, a suitable material, e.g. paper or polyethylene. The metal part of bonded elastomeric seals shall not come in contact with the elastomeric element of another seal. The bonded seal shall be individually packaged.

Contact with Dusting Powder

Dusting powders should only be used for the packaging of rubber items in order to prevent adhesion. In such cases, the minimum quantity of powder to prevent adhesion should be used. Any powder used should be free from any constituent that would have a harmful effect on the rubber or the subsequent application of the rubber.

Assembly

These are products or components containing more than one element, one or more of which is made of rubber. Generally, it is not recommended to store elastomeric products in an assembled condition. If it is necessary to do so, the units should be checked more often. The inspection interval depends on the design and geometry of the components.

Stock Rotation

Elastomers should be stored for as short a period as possible. In general, stock of rubber end products should be issued based on their shelf life expiration date. Use of a first-in, first-out (FIFO) principle based on cure date may aid in this process.

Cleaning

Rubber products should be cleaned using a clean cloth and moderately warm (lukewarm) water. Organic solvents such as trichloroethylene, carbon tetrachloride and petroleum (petrol, benzene, turpentine, etc.) are the most harmful agents. Soap and water and methylated spirits are the least harmful. All rubber products should be dried at room temperature before use. Drying rubber products near radiators/heaters is not recommended.

Sharp-edged or pointed objects, such as wire brushes, grinding paper, etc. must not be used on the products.

Shelf Life

As per Military Handbook MIL-HDBK-695E, shelf life is the maximum period of time between the cure (vulcanization) date and the date the elastomeric product is first removed or unpackaged for installation or fabrication into a component part of a subassembly, assembly, or system. During the shelf life time, the stored elastomeric product is expected to retain its characteristics as originally specified, if it is stored under proper storage conditions.

As MIL-HDBK-695E applies to any and all rubber goods - but does not satisfy the needs of the seal industry. ARP5316 was written to provide a foundation upon which seal manufacturers, distributors, and users could generate realistic shelf life criteria.

ARP5316, “Storage of Aerospace Elastomeric Seals and Seal Assemblies Which Include an Elastomer Element Prior to Hardware Assembly” is controlled and issued by the Society of Aerospace Engineers. ARP5316 is a “Recommended Practice” and is offered as a guideline for those companies that deal with elastomer (rubber) seals.

The following table summarizes the recommended shelf life (as per ARP5316 or MIL-HDBK-695 if items are not covered by ARP5316) for the most common elastomers.

ASTM Designation	Chemical Name	Common or Trade Names	Recommended Shelf Life
AU	Polyester Urethane	Urethane	5 Years
EU	Polyether Urethane	Urethane	5 Years
CR	Chloroprene	Neoprene®	15 Years
EPDM	Ethylene Propylene	EPDM	Unlimited
FEPM	Tetrafluoroethylene Propylene	Aflas®	Unlimited
FFKM	Perfluorocarbon	Kalrez®	Unlimited
FKM	Fluorocarbon	Viton®, Fluorel®	Unlimited
FVMQ	Fluoro Methyl Vinyl Silicone	Fluorosilicone	Unlimited
IIR	Isobutylene Isoprene	Butyl	15 Years
NBR	Butadiene Acrylonitrile	Buna N, Nitrile	15 Years
VMQ	Methyl Vinyl Silicone	Silicone	Unlimited
ACM	Polyacrylate	Acrylic	20 Years
HNBR	Hydrogenated Nitrile	Highly Saturated Nitrile	15 Years
SBR	Styrene Butadiene	Buna S	5 Years

Inspection Before Installation

As a general rule, all elastomer products should be checked to confirm that they are in proper condition prior to installation. Negative changes caused by inappropriate storage can usually be detected by visual inspection. The inspection involves checking for mechanical damage, permanent distortion, cracking, hardening, softening, stickiness and discoloration.

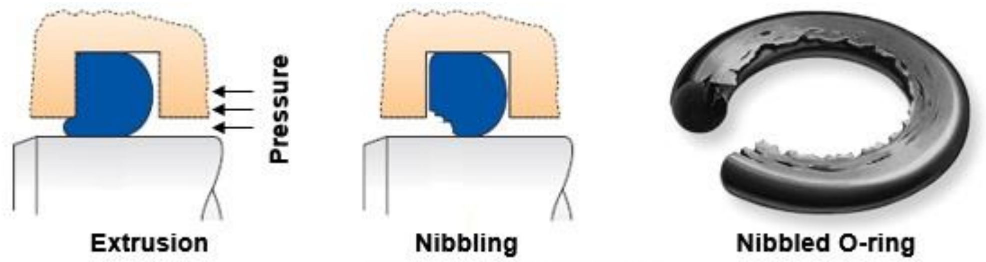
Failure Analysis

Successful seal performance requires careful consideration of process conditions (pressure, temperature, environment, etc.), elastomer properties and seal design. A deficiency in any one of these areas will result in a reduction of seal service life. If a seal failure does occur, a systematic approach should be taken to determine the root cause of the failure.

Usually, defects / failures are evident directly on the O-ring. The following information about O-ring failure patterns/modes is intended to give an engineer a brief overview of the most common types of O-ring failures and corrective action to be taken to prevent their reoccurrence. For a complete listing of O-ring failure modes please see AIR1707, Patterns of O-ring Failure published by SAE INC.

Extrusion and Nibbling

Extrusion and nibbling of the O-ring is a primary cause of seal failure in dynamic applications such as hydraulic rod and piston seals. This form of failure may also be found in static applications also which is subjected to high pressure pulsing which causes the clearance (gap) between the mating faces to open and close, trapping the O-ring between the mating surfaces.



Extrusion and Nibbling

The 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.

As shown in above figure, O-ring failure due to extrusion and nibbling will have edges of the O-ring on the low pressure (downstream) side of the gland with a "chewed" or "chipped" appearance (many small pieces removed).

In general, extrusion and nibbling are caused by one or more of the following conditions.

- Excessive clearances.
- High pressure (in excess of system design).
- O-ring material too soft.
- Degradation (swelling, softening, shrinking, cracking, etc.) of O-ring material by system fluid.
- Irregular clearance gaps caused by eccentricity.
- Improper machining of O-ring gland (sharp edges).
- Improper size (too large) O-ring installed causing excessive filling of groove.

Suggested corrective solutions for extrusion and nibbling are as under.

- Decrease clearance by reducing machining tolerances.
- Use back-up rings.
- Check elastomer compatibility with system fluid.
- Replace current O-ring with a harder O-ring.
- Improve concentricity.
- Break sharp edges of the gland.
- Install proper size O-ring.

Compression Set

Probably the most common cause of O-ring failure is compression set. An effective O-ring seal requires a continuous “seal line” between the mating surfaces. The establishment of this “seal line” is a function of gland design and seal cross-section which determines the correct amount of squeeze (compression) on the O-ring to maintain seal integrity without excessive deformation of the seal element.

Compression Set

Compression set is common to both static and dynamic seals. As shown in above figure, compression set failure produces flat surfaces on both sides of the O-ring cross section in the areas being squeezed. Compression set may also develop circumferential splits within the flattened surfaces.

In general, compression set is caused by one or more of the following conditions:

- Selection of O-ring material with inherently poor compression set properties.
- Improper gland design (too much squeeze to achieve seal).
- Excessive temperature developed causing the O-ring to harden and lose its elastic properties.
- System pressure is too high
- Volume swell of the O-ring due to system fluid.
- Incomplete curing (vulcanization) of O-ring material during production.

Suggested corrective solutions for compression set are as under.

- If possible, use low compression set elastomer.
- If possible, reduce O-ring squeeze.
- Select elastomer which is compatible with intended service conditions.
- Reduce system operating temperature.
- Check frictional heat build-up at seal interface and reduce if excessive.

Abrasion

Another rather common type of O-ring failure is abrasion. Failure due to abrasion is most likely to occur in dynamic seals.

Abrasion

As shown in above figure, the O-ring that has failed due to abrasion usually exhibits a flat area on the side of the seal which was in contact with the dynamic surface. Frequently there will be wear lines on this flat surface parallel to the direction of motion. Abrasion failure may be differentiated from compression set failure in that with abrasion, only one side of the O-ring will be flat or worn while with compression set failure, both sides of the O-ring are equally deformed.

In general, abrasion is caused by one or more of the following conditions:

- Improper finish of the surface in dynamic contact with the O-ring. This surface finish may be too rough, acting as an abrasive, or too smooth, causing inadequate lubrication due to inability of surface to hold lubricant.
- Improper lubrication provided by system fluid.
- Contamination of system fluid by abrasive particles.

Suggested corrective solutions for abrasion are as under.

- Use proper surface finish.
- Consider use of internally lubricated O-rings to reduce friction and wear.
- Check for contamination of fluid and eliminate source. Install filters if necessary.
- Consider changing to an O-ring material with improved abrasion resistance.

Explosive Decompression

Explosive Decompression

Explosive decompression is a major risk for any seal operating in a high-pressure gas environment. In a high-pressure gas environment, gas can get trapped inside the seal's micro pores. If the seal faces an equilibrium shift (as with rapid decompression - when the system pressure is reduced too rapidly), this trapped gas rapidly expands in an effort to match external pressure causing surface blisters and ruptures as they escape. 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.

As shown in above figure, the seal subjected to explosive decompression will often exhibit small pits or blisters on its surface. In severe cases, examination of the internal structure of the O-ring will reveal other splits and fissures.

Suggested corrective solutions for explosive decompression are as under.

- Increase decompression time to allow trapped gas to work out of seal material.
- Increase material hardness to 80 - 90 shore A.
- Choose a seal material with good resistance to explosive decompression.
- Reduce O-ring cross sectional size as smaller cross-sections offer less space in which gas can become trapped.

Spiral Failure

Spiral failure results from instability of the seal, which is unable to adequately hold its intended position within the gland. It is generally found in long-stroke hydraulic or pneumatic (piston and rod) seals with low pressure differential.

Spiral Failure

An O-ring doesn't have enough strength to resist the twisting forces that naturally develop during dynamic movement and part of the O-ring rolls while part of it slides. This spiraling motion causes the cross-section to be twisted and spiral (45° angle) cuts to develop on the seal's surface as shown in above figure. Spiral failure is most likely to occur in O-rings with a large inside diameter (ID) to cross-section (W) ratio.

In general, spiral failure is caused by one or more of the following conditions:

- Eccentric components.
- Wide clearance combined with side loads.
- Uneven surface finishes.
- Inadequate or improper lubrication.
- O-ring too soft.
- Stroke speed (usually too slow).
- Improper installation (O-ring rolled).

Suggested corrective solutions for spiral failure are as under.

- Use as large a seal cross-section as possible.
- Check for out-of-round components (especially cylinder bores).

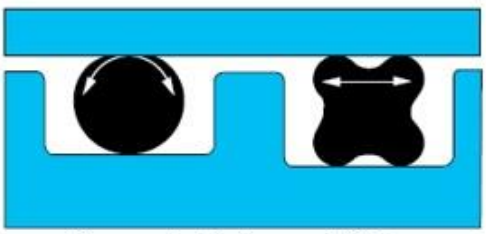
- Improve surface finish of sealed assembly at dynamic interface (cylinder bore, piston rod).
- Improve lubrication or use internally lubricated O-rings.
- Replace with a harder O-ring.
- Consider use of alternate seal cross-sections (shapes) that will be more stable within the gland (e.g. X-Rings/Quad-Rings®)

X-rings or Quad-Ring® Seals

X-ring Seal

X-rings or Quad-rings® can be used as an alternative to O-rings in dynamic applications because of their reduced friction and their resistance to spiral failure. As shown in the above figure, a X-ring is a four lipped/lobed seal.

The sealing principle of the X-Ring is nearly the same as the O-ring sealing. The initial sealing is achieved by the diametrical squeeze in a right angled groove. The system pressure itself creates a positive sealing force.



Groove for X-ring and O-ring

AS shown in above figure, with X-rings, the standard grooves are deeper in comparison with O-ring glands. So the diametrical squeeze is lower in X-rings than with O-rings. This makes dynamic sealing possible with reduced friction. In the situation that an O-ring rolls in the groove and creates torsion, a X-ring slides with no negative results.

The four lips of the X-ring create more sealing capacity and at the same time a groove for lubrication, which is very favorable for dynamic sealing.

It is recommended, especially for dynamic seals, to use the X-ring with the largest possible cross section or thickness because thicker rings can withstand more tolerance variance.

It is recommended not to install X-ring in a groove in the shaft because the X-ring may rotate with the shaft.

For rotating application, it is recommended to use X-rings in 80 or 90 Shore A.

The surface finish of the groove always has to be rougher than the surface finish of the shaft to avoid spinning.

It may be noted that since X-ring glands have deeper grooves than O-rings, standard O-ring back-up rings cannot be used. The actual groove dimensions are needed to procure the correct sized machined back-up ring.

Hardening and 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.

Failure Due to Hardening

Above figure shows O-ring failure due to hardening. 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.

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.

Weather and Ozone Cracking

Weather and Ozone Cracking

As shown in above figure, 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.

Weather and ozone cracking (also known as crazing) may be prevented (or at least limited) by using elastomers with fully-saturated bonds that are less susceptible to ozone and chemical attack.

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.

The best available solution is to use a seal material that is compatible with all elements of the system but that contains little or no extractable plasticizer.

Installation Damage

Many O-ring failures can be directly attributed to improper installation. One of the more common failure modes due to improper installation is the "Skiving'' of the O-ring surface due to cutting by metal components. Those cuts are usually very clean as if made with a very sharp knife. Another indication of bad installation will be small cuts or notches on the O-ring.

To prevent O-ring failures due to improper installation, follow the installation guidelines.

References

O-ring Design & Materials Guide by R.L. Hudson & Company (www.rlhudson.com)

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O-Ring Handbook by Parker Hannifin GmbH (www.parker.com/praedifa)

‘O’ Ring Guide by James Walker UK Ltd (www.jameswalker.biz)

O-Rings and Back-up Rings by Trelleborg (www.Tss.trelleborg.com)

Sealing Elements, Technical Handbook O-rings by ERIKS (www.eriks.info)

Hydraulic Seals by SKF (www.skf.com)

Oil Seals & O-rings by KOYO Sealing Techno Co., Ltd.; Sales by JTEKT CORPORATION (www.jtekt.co.jp)

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