10.1. O-Ring Failure Modes

Like any device subject to judgment in design or to human error during installation, O-ring seals are susceptible to failure. The following brief summary of O-ring failure patterns is intended to give the designer/engineer a brief overview of the more common types of failure and a listing of recommended corrective actions. While there are a number of different types and causes of seal failure, we intend to cover only the types encountered most frequently. For a more complete listing of O-ring failure modes, Parker suggests the engineer obtain a copy of Publication AIR1707, Patterns of O-Ring Failure, available from:

SAE Inc.
400 Commonwealth Drive
Warrendale, PA 15095
www.sae.org

AIR1707, Patterns of O-Ring Failure, contains extensive material and some excellent photographs and will be most helpful for identifying the less common modes of O-ring failure not covered in this guide.

10.1.1 Why an O-Ring Fails Prematurely

The premature failure of an O-ring in service can usually be attributed to a combination of causes and not merely a single failure mode. It is important to maximize sealing life and reliability by reducing the probability of seal failure at the onset by the use of good design practices, proper compound selection, pre-production testing, and continued education and training of assembly personnel.

10.1.1.1 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 sealed 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. (See Section II, Basic O-Ring Elastomers, for an in-depth discussion of compression set and Section IV, Static O-Ring Sealing, for information on correct gland design.)

There are a number of factors that can contribute to compression set failure of an O-ring seal. They are listed below. Figure 10-1 provides an illustration of characteristic compression set. See Table 10-1 for a failure analysis and corrective action discussion.

Figure 10-1: Characteristic compression set — high deformation -seen as flattening on all contact surfaces.

Compression Set

Failure Analysis

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

1. Selection of O-ring material with inherently poor compression set properties.
2. Improper gland design.
3. Excessive temperature developed causing the O-ring to harden and lose its elastic properties. (High temperatures may be caused by system fluids, external environmental factors, or frictional heat build-up.)
4. Volume swell of the O-ring due to system fluid.
5. Excessive squeeze due to over tightening of adjustable glands.
6. Incomplete curing (vulcanization) of O-ring material during production.
7. Introduction of fluid incompatible with O-ring material.

Prevention/Correction

Suggested solutions to the causes of compression set are:

1. Use "Low-Set" O-ring material whenever possible.
2. Select O-ring material compatible with intended service conditions.
3. Reduce system operating temperature.
4. Check frictional heat build-up at seal interface and reduce if excessive.
5. Inspect incoming O-ring shipments for correct physical properties. (Requesting the Parker C.B.I. number will be of great assistance in this area. For a complete discussion of this exclusive Parker service, look later in this section.)

Identification of Compression Set Failure

A typical example of classic O-ring compression set in simplistic terms: the O-ring ceases to be "O" shaped and is permanently deformed into a flat sided oval, the flat sides of which were the original seal interface under compression before failure.

Table 10-1: Compression Set Failure Analysis

10.1.1.2 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 from time to time in static applications subject to high pressure pulsing which causes the clearance gap of the mating flanges to open and close, trapping the O-ring between the mating surfaces. See Table 10-2 for a failure analysis and corrective action discussion. Figure 10-2 shows an example of an extruded and "nibbled" O-ring.

Figure 10-2: Extruded O-Ring

Extrusion and Nibbling

Failure Analysis

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

1. Excessive clearances.
2. High pressure (in excess of system design or high pressure excursions).
3. O-ring material too soft.
4. Degradation (swelling, softening, shrinking, cracking, etc.) of O-ring material by system fluid.
5. Irregular clearance gaps caused by eccentricity.
6. Increase in clearance gaps due to excessive system pressure.
7. Improper machining of O-ring gland (sharp edges).
8. Improper size (too large) O-ring installed causing excessive filling of groove.

Prevention/Correction

Suggested solutions to the causes of Extrusion and Nibbling listed above are:

1. Decrease clearance by reducing machining tolerances.
2. Use back-up devices. (See Section VI, ParBack Back-Up Rings, for information on Parker Parbak anti-extrusion devices.)
3. Check O-ring material compatibility with system fluid.
4. Increase rigidity of metal components.
5. Replace current O-ring with a harder O-ring.
6. Break sharp edges of gland to a minimum radius 0.005 inches.
7. Insure installation of proper size O-rings.
8. Use alternative seal shape, for example, in some long stroke piston or rod applications, the Parker T-Seal, with its built-in back-up rings, may prevent extrusion and spiral failure.

Identification of Extrusion Failure
A typical example of O-ring extrusion is when edges of the ring on the low pressure or downstream side of the gland exhibit a "chewed" or "chipped" appearance. In an O-ring that has failed due to nibbling, it may have the appearance that many small pieces have been removed from the low pressure side. In some forms of extrusion, more than 50% of the O-ring may be destroyed before catastrophic leakage is observed.

Table 10-2: Extrusion and Nibbling Failure Analysis

10.1.1.3 Spiral Failure

Spiral failure of an O-ring is often found on long stroke hydraulic piston seals and to a lesser degree on rod seals. This type of O-ring failure is caused when the seal becomes "hung-up" at one point on its diameter (against the cylinder wall) and slides and rolls at the same time. The resultant twisting of the O-ring as the sealed device is cycled finally causes the seal to develop a series of deep spiral cuts (usually at a 45° angle) on the surface of the seal. (For more complete discussion on spiral failure, see Section IV, Static O-Ring Sealing).

Table 10-3 provides a discussion of spiral failure analysis. Figure 10-3 illustrates spiral failures.

Spiral Failure

Failure Analysis

As stated above, spiral failure is generally caused by an O-ring both sliding and rolling at the same time. Conditions which may cause this to occur are:

1. Eccentric components.
2. Wide clearance combined with side loads.
3. Uneven surface finishes.
4. Inadequate or improper lubrication.
5. O-ring too soft.
6. Stroke speed (usually too slow).
7. Improper installation (O-ring pinched or rolled).

Prevention/Correction

Suggested solutions to the causes of spiral failure are as follows:

1. Improve surface finish of sealed assembly at dynamic interface (Cylinder Bore, Piston Rod).
2. Check for out-of-round components (Cylinder Bores especially).
3. Provide proper lubrication. Consider the use of internally lubed O-rings.
4. Replace with a harder O-ring.
5. Consider use of alternate seal shapes. for example, the Parker T-seal is specifically designed to prevent spiral failure and its use will allow for increased tolerances because of built-in anti-extrusion back-up rings. Parker T-Seals are available to fit a number of standard AS568 O-ring grooves and may directly interchange with O-rings in most cases.

Identification of Spiral Failure
You will see the typical cuts that gave this type of O-ring failure its name.

Table 10-3: Spiral Analysis

Figure 10-3: Twisted O-ring with spiral marking, or with spiral cuts in surface

10.1.1.4 Explosive Decompression

As system pressures increase we are seeing this type of O-ring failure with more frequency. It might be termed O-ring embolism, in that after a period of service under high pressure gas, when the pressure is reduced too rapidly, the gas trapped within the internal structure of the O-ring expands rapidly, causing small ruptures or embolisms on the O-ring surface.

Table 10-4 provides a failure analysis discussion. Figure 10-4 illustrates an O-ring damaged by explosive decompression.

Figure 10-4: O-Ring Damaged by Explosive Decompression

Explosive Decompression

Failure Analysis

Explosive decompression or gas expansion rupture is caused by high pressure gas trapped within the internal structure of the elastomeric seal element. Rapid decrease in system pressure causes the trapped gas to expand to match the external pressure and this expansion causes blisters and ruptures on the seal surface. If the volume of trapped gas is small, the blisters may recede as the pressure is equalized with little effect on seal integrity. Excessive trapped gas may cause total destruction of the seal. (Refer to Section III, O-Ring Applications, for more information on this problem.)

Prevention/Correction

Suggested solutions to explosive decompression are:

1. Increase decompression time to allow trapped gas to work out of seal material.
2. Choose a seal material with good resistance to explosive decompression.
3. If problem persists and pressures are very high, consider use of Parker Metal Seals.

Identification of Explosive Decompression Failure

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.

Table 10-4 Explosive Decompression Failure Analysis

10.1.1.5 Abrasion

Another rather common type of O-ring failure is abrasion. This usually is found only in dynamic seals subject either to reciprocating, oscillating, or rotary motion. Possible causes of O-ring abrasion are listed in Table 10-5. Figure 10-5 shows wear on an O-ring.

Abrasion

Failure Analysis

In general, abrasion of O-ring seals is caused by one or more of the following:

1. 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.
2. Improper lubrication provided by system fluid.
3. Excessive temperatures.
4. Contamination of system fluid by abrasive particles.

Prevention/Correction

Suggested solutions to problems caused by abrasion are:

1. Use proper surface finish (see surface finish in Dynamic Seals section).
2. Provide adequate lubrication by use of proper system fluid.
3. Consider use of internally lubricated O-rings to reduce friction and wear.
4. Check for contamination of fluid and eliminate source. Install filters if necessary.
5. Consider changing to an O-ring material with improved abrasion resistance.

Table 10-5: Abrasion Failure Analysis

Figure 10-5: Wear is Seen as Flattening of O-ring on One Side

10.1.1.6 Installation Damage

Many O-ring failures can be directly attributed to improper installation. In spite of its simple appearance, the O-ring is a precision device requiring care during installation. Some of the more frequent causes of O-ring failure due to careless handling are listed in Table 10-6.

Installation Damage

Failure Analysis

Damage to an O-ring during installation can occur when:

1. There are sharp corners on mating metal components such as the O-ring gland or threads over which the O-ring must pass during assembly.
2. Insufficient lead-in chamfer.
3. Blind grooves in multi-port valves.
4. Oversize O-ring on piston seal application.
5. Undersize O-ring on rod application.
6. O-ring twisted/pinched during installation.
7. O-ring not properly lubricated before installation.
8. O-ring dirty upon installation.
9. O-ring gland and/or other surfaces over which O-ring must pass during assembly contaminated with metal particles.
10. General Carelessness.

Prevention/Correction

Probably the best way to prevent damage to O-rings during installation is the use of good old-fashioned “Common Sense.” There are some specific solutions which are listed below:

1. Break all sharp edges on metal components.
2. Provide a 20° lead-in chamfer.
3. Check all components for cleanliness before installation.
4. Tape all threads over which the O-ring will pass.
5. Use an O-ring lubricant such as Parker O-Lube or Parker Super O-Lube if its use will not contaminate system.
6. Double check O-ring to ensure correct size and material.
7. Be CAREFUL.

Table 10-6: Installation Damage Failure Analysis

10.1.1.7 Other Causes of O-Ring Failure

Damages to O-rings can be caused by compounding of the causes described in paragraphs 10.1.2.1 through 10.1.2.6. Upon failure of an O-ring check all causes mentioned above.

Although not illustrated here, there are several other possible causes of O-ring failure. They are:

1. Weather and ozone degradation
2. Heat aging and oxidation
3. Loss of plasticizer(s)

If you encounter an unusual type of O-ring failure or are unable to identify a particular failure mode, please feel free to contact the O-Ring Division Applications Engineering Department for assistance. In most cases these experienced engineers will be able to offer both an identification of the problem and a number of possible solutions.

10.1.2 Assembly Hints

Leak-free seals are achieved only when a proper sealing material is selected in the right size and sufficiently deformed. Correct deformation depends on observance of machine element tolerances and surface finishes. In practical terms all factors influencing the seal must be considered. Inadequate or improper assembly will lead to high servicing costs and subsequent downtime.

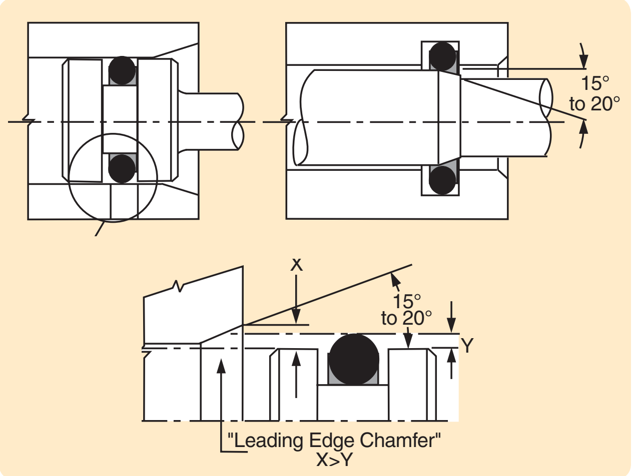


Figure 10-6: Chamfers

10.1.2.1 Chamfers

To prevent damaging of seals during assembly, chamfers are necessary on all leading edges. All edges must be free from burrs and sharp edges bevelled.

Figure 10-6 shows the leading edge chamfer and an O-ring before deformation. The dimension X should be greater than dimension Y to ensure a trouble-free assembly operation.

10.1.2.2 Traversing of Cross-Drilled Ports

An O-ring can be sheared when a spool or rod 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 is 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.

Optimal solution is the relief of the bore on complete circumference which allows the O-ring to return to a round cross-section before being compressed again. See Figure 10-7.

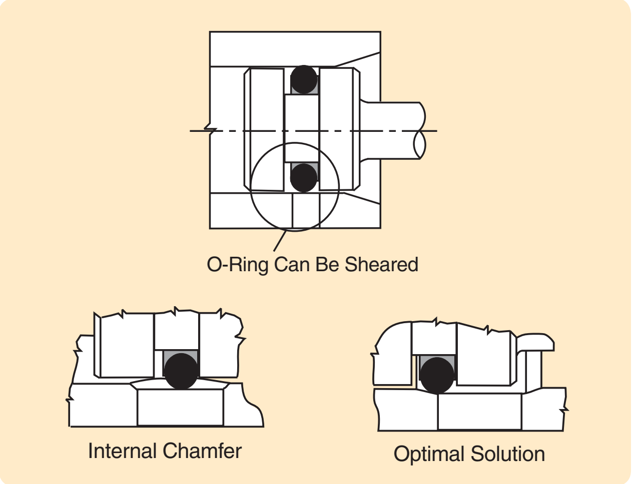


Figure 10-7: Drilled Port Assembly

10.1.2.3 Cleanliness and Cleaning Materials

Lack of cleanliness of O-ring glands leads to leakage. To ensure protection from foreign particles of sealing faces during working life it is necessary to use filters or to plan maintenance cycles.

Cleaning material must also be a medium which is compatible with the elastomer. Also grease used to ease assembly must be compatible.

10.1.2.4 Stretching for Assembly

O-rings or back-up rings can be stretched during assembly by 50% of their inner diameters. With small inner diameters the percentage can be significantly greater eventually becoming critical.

It therefore is important to ensure that the stretch remains less than elongation at break given in compound data sheets. If an O-ring is stretched to near its elastic limit it will still return to its original size after a short delay.

10.1.2.5 Rolling

O-rings of large inner diameters and small cross-sections tend to roll during assembly. An O-ring rolled during fitting can be prone to spiral failure (cf. paragraph 10.1.2.3) or tend to leak. See Figure 10-8.

10.1.2.6 Sharp Edges

O-rings should not be forced over sharp edges, threads, slits, bores, glands, splines, etc. Such sharp edges must be removed or covered. Fitting aids assist assembly and thus avoid sharp edges. See Figures 10-9 and 10-10.

10.1.3 Failure Mode and Effects Analysis for Customers

Parker Seal has a wide network of people who are trained to analyze your requirements and assist in suggesting intelligent solutions to specific problems during all stages…design…prototype…testing…qualification…specification writing…and purchasing. All these services can be supplied by a trained Parker Territory Sales Manager or Parker Distributor.

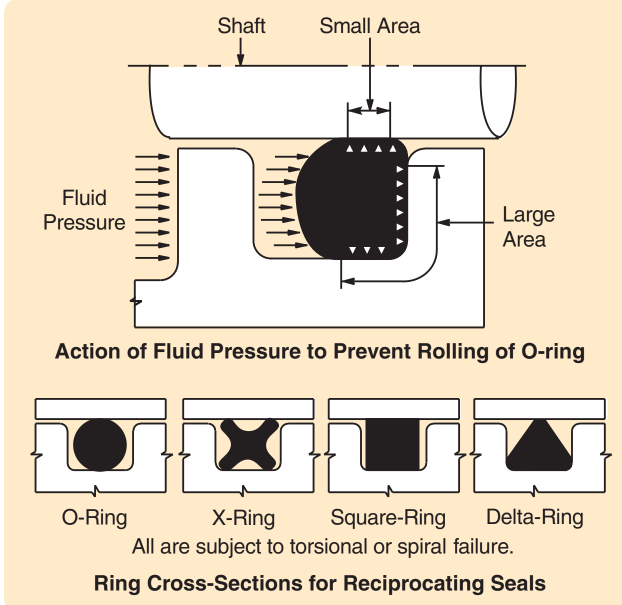


Figure 10-8: Rolling of O-ring

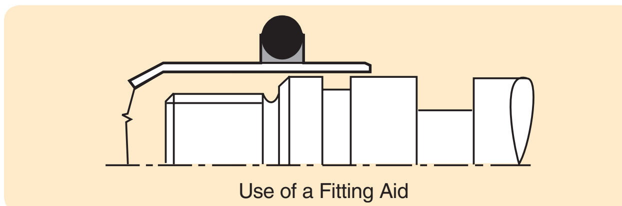


Figure 10-9: Use of a Fitting Aid

Parker Territory Sales Managers serving customers in the field are trained to recognize undesirable or uneconomical proposed applications in favor of those that are logical and cost efficient. You can count on your Parker Territory Sales Manager and your Parker Distributor to give you good counsel. They can help you in many ways — preparation of preliminary sketches, submission of working samples for test and evaluation, and even during qualification of a component or entire assembly.

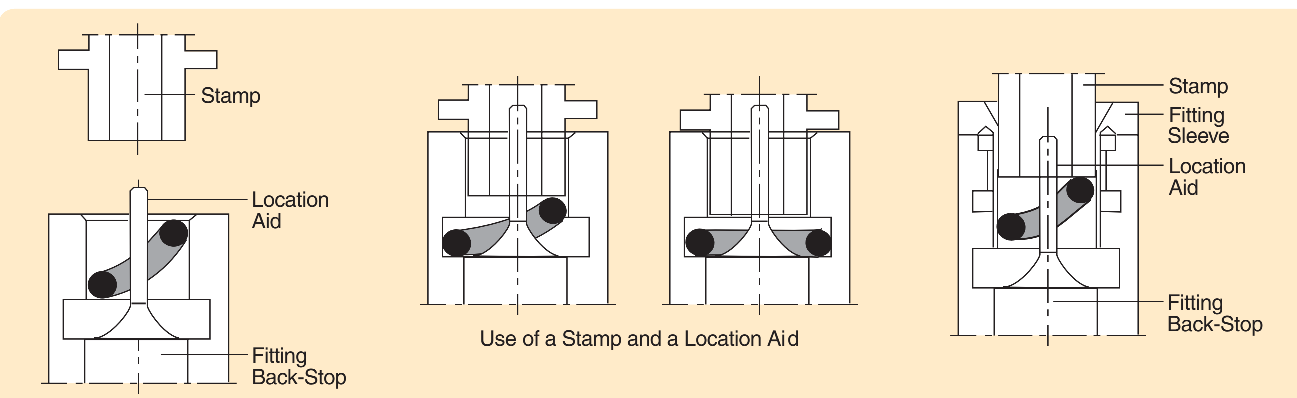


Figure 10-10: Use of a Stamp and a Location Aid

Parker Seal also has the capability to analyze seals and their behavior in proposed applications through Finite Element Analysis (FEA). FEA is a powerful tool which allows the designer and the engineer to design complex parts and then verify with FEA mathematical models whether the design will perform under actual conditions. If the proposed design shows shortcomings under this modeling analysis, changes can easily be made in the design until acceptable performance is predicted by the model. All this can be done in a matter of days without investment in tooling, prototype parts, or physical testing. Parker engineers are available to help you with your sealing questions and all are fully qualified to recommend solutions to your sealing problems and how these problems can be corrected to prevent future failure. At Parker Seal, customer satisfaction is our goal. Our internal and field personnel are ready to help you with all your sealing needs, and your Authorized Parker Seal Distributor is a sealing expert who can assure you fast service and the kind of reliable seals you need, when you need them.

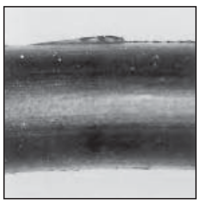
10.2 Molded Elastomeric O-Ring Quality Pass/Fail Limits

This section is intended to provide visual references regarding the standard published visual defect tolerances, which are dependant upon the actual cross section size of the subject O-ring. This information is based upon the industry standard MIL-STD-413C, which has subsequently been cancelled but is still in common use.

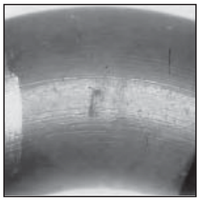
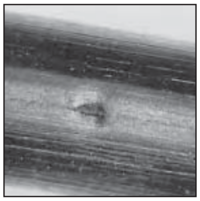
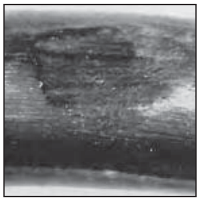
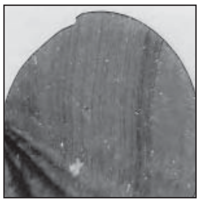
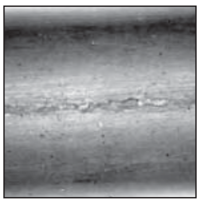
The pictures displayed do not necessarily represent an acceptable or defective product. They are intended to display examples of how a given defect may appear. Several of the noted defects may vary in actual physical representation as it relates to size and shape.

The use of other defect tolerance documents may apply if requested by the customer, and agreed upon at the time of quote. Unless requested otherwise, the requirements of MIL-STD-413C are utilized during the processing and inspection of Parker Seals O-Rings.

O-Ring Defect Description: MIL-STD-413C

Description	Definition	Cause	Tolerances for:
Excess Flash or Parting Line Projection 	Parting Line Projection: A continuous ridge of material on the parting line at the ID and/or OD. Flash: A film-like material which extends from the parting line on the ID, and/or OD, and may be super-imposed on the parting line projection	Parting Line Projection: Enlarged corner radii due to mold wear (triangular formation). Excessive Flash: Mold plate separation or inadequate trim and deflash	Flash and/or Projection: Cross Section / Depth .070 / .003 .103 / .003 .139 / .004 .210 / .005 .275 / .006
Flow Marks (Flow Lines) 	A thread-like recess, usually curved, of very slight depth with normal surface texture and radial edge.	Incomplete flow and knit of the material.	Flow Marks: Cross Section / Depth / Length .070 / .002 / .060 .103 / .002 / .060 .139 / .002 / .180 .210 / .002 / .180 .275 / .002 / .180
Foreign Material 	Any extraneous, imbedded matter, or depression formed by its removal.	Dirt, contamination, undispersed pigment, etc.	Foreign Material: No "protruding" foreign material is acceptable on any cross section. For depression formed by foreign material removal revert to Mold Deposit. Width is measured at widest direction. Cross section / Depth / Width .070 / None / None .103 / .003 / .005 .139 / .004 / .007 .210 / .005 / .010 .275 / .006 / .015

O-Ring Defect Description: MIL-STD-413C (Continued)

Description	Definition	Cause	Tolerances for:
Mold Deposit (Dirty Mold) 	Surface indentations, irregular in shape, with a rough surface texture.	A build-up of hardened deposits adhering to the mold cavity.	Mold Deposit (Dirty Mold): Cross section / Depth / Width .070 / .003 / .010 .103 / .003 / .015 .139 / .004 / .020 .210 / .004 / .025 .275 / .005 / .030
Nicks or Parting Line Indentation 	A shallow, saucer-like recess, sometimes triangular in shape, located on the parting line at the ID or OD, and usually divided by the parting line. The edges are smoothly flared into the O-ring surface and have similar texture.	A deformity in the \mold cavity edge at the parting line.	Nicks or Parting Line Indentations: Cross Section / Depth / Width .070 / .003 / .010 .103 / .003 / .015 .139 / .004 / .020 .210 / .005 / .025 .275 / .006 / .030
Non- Fill or Void 	A randomly spaced, irregularly shaped, surface indentation having a coarser texture than the normal O-ring surface. It may have molded edges which may or may not join.	Mold cavities not being completely filled with material.	Non-Fills or Voids: Cross Section / Depth / Width .070 / None allowed / None allowed .103 / .002 / .010 .139 / .003 / .015 .210 / .003 / .025 .275 / .003 / .040
Off-Register and Mismatch 	Off-Register: Misaligned O-ring halves. Mismatch: Cross section of each half are different sizes.	Off-Register: Relative lateral shift of mold plates. Mismatch: Dimensional differences in the mold halves	Off-Register and/or Mismatch: Cross Section / Maximum Allowed .070 / .003 .103 / .004 .139 / .005 .210 / .006 .275 / .006
Backrind 	A longitudinal recess of wide angle “U-like” or “W-like” cross sections orientated circumferentially and located only at parting lines.	Thermal expansion over a sharp mold edge or by premature cure.	Backrind: Edges, though smoothly faired into ring surface are irregular and can be present on full circumference on OD and/or ID within the following limits Cross Section / Depth / Width .070 / None / None .103 / .003 / .005 .139 / .004 / .006 .210 / .004 / .006 .275 / .005 / .010