Chapter B1

Elastomer selection considerations

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Individual chapters of the Kalsi Seals Handbook are periodically updated. To determine if a newer revision of this chapter exists, please visit www.kalsi.com/seal-handbook.htm.

1. Introduction[1]

Selecting an elastomer requires evaluation of many inter-dependent elastomer characteristics. These include resistance to temperature, abrasion, extrusion, compression set and the environment. Evaluation of these characteristics is an exercise in compromise. Perfect all-round elastomers simply do not exist. All elastomers have tradeoffs that achieve certain desirable characteristics at the expense of others. Material selection is further complicated by the fact that standard test data is not necessarily indicative of field performance. Such data should only be used to compare and rank elastomers, rather than to predict results in a given application. Service life in new applications is difficult to predict due to the number of variables. New applications should be considered experimental until validated by field results. Kalsi Engineering can provide application-specific elastomer testing and in-house rotary seal testing on a consulting basis, and can also recommend qualified third-party elastomer testing labs. In the final analysis, elastomer selection is the customer's responsibility.

Kalsi Engineering offers elastomer variations that cover a wide range of potential service conditions. Kalsi Seals are used extensively in oilfield drilling and production tools, and in severe service applications in other industries. Typically, HNBR –10[2] (80 ±5 Shore A) and –11 (85-90 Shore A) compounds are stocked due to their general applicability. If you require another elastomer, please begin procurement at least 4 to 6 weeks in advance.

Please inform our staff if you prefer a material that is not presently offered. If appropriate, Kalsi Engineering can obtain specific materials and coordinate custom molding.

2. Media resistance

Exposure to virtually any environment has some type of long-term effect on elastomers. No single elastomer is suitable for all environments. For example, EPDM has useful resistance to fire resistant hydraulic fluids and poor resistance to petroleum based fluids, while NBR is just the opposite.

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1 Much of this information was compiled from various third-party sources. It is provided as a general elastomer introduction for the convenience of our customers, and should not be used to predict performance for specific applications. Because each application involves many design factors and may require design compromises, elastomer selection is ultimately the customer's responsibility. Kalsi Seal suitability, including elastomer choice, should be confirmed by application-specific laboratory testing and thorough field testing.

2 We use the traditional dash numbering system to identify seal materials within seal part numbers. The part number includes the seal drawing number and the material dash number. At Kalsi Engineering, "-10" is spoken as "dash 10".

Media compatibility is often evaluated by volume change testing. Elastomers tend to absorb environmental fluids, causing permanent alteration of various characteristics. Absorption causes elastomers to swell until equilibrium is achieved. Excessive swelling alters an elastomer’s mechanical properties. The increased seal volume that can occur due to severe swelling can potentially result in the seal overfilling the gland. This over-fill condition will result in increasing contact pressure and shortening seal life. Moderate swelling could conceivably help to compensate for compression set and wear.

As a rule, media incompatibility problems usually increase as a function of increased temperature. For example, elastomers are much less resistant to concentrated low pH environments at elevated temperature. Swelling and gas permeation usually increase at elevated temperature.

Media related degradation can be evaluated by measuring tensile strength changes. Tensile strength is not necessarily a particularly important material characteristic in many rotary seal applications. Changes in hardness, specific gravity, tear strength, and ultimate elongation changes are also used to evaluate media compatibility. A variety of elastomer media compatibility charts are available in published literature, but many are based on moderate temperature tests. Ideally, media compatibility testing should be conducted at the actual service temperature.

Figure 1

Typical Elastomer Tensile Test Coupon

Shrinkage is another artifact of media incompatibility. It occurs when volatile fluids leech material, such as plasticizers, from the elastomer. Shrinkage, which is measured by volume change testing, has the same basic effect on rotary seal performance as compression set, and could cause sealing problems if compression drops below a functional level.

When testing for media compatibility, an immersion test (ASTM Test Method D 471-98$^{\varepsilon 1}$) is performed at a specified temperature and duration. When evaluating oil compatibility, several different petroleum based test oils are typically used, in order to span the aniline point range and swelling influence of commercial lubricants.

On a time-available consulting basis, Kalsi Engineering can coordinate immersion testing using customer-supplied immersion fluids and customer-specified temperatures, at pressures up to 1,900 psi. Changes in volume, hardness and tensile strength are typically measured, however the results are not directly predictive of seal performance. On a time-available consulting basis, Kalsi Engineering can also provide in-house rotary testing using customer-supplied fluids and customer-specified temperatures. Please contact us for quotations.

In actual service, Kalsi Seals are not completely immersed in the environmental media. As will be discussed in detail, only the small portion of the seal between the housing and rotating shaft is exposed to the environment media. Most of the seal surface is exposed to the lubricant. This means that media related problems can be minimized by employing a lubricant that is compatible with the seal material. Media effects can be further reduced by keeping the lubricant pressure higher than the pressure of the environmental media, and/or by spring loading the seals axially. The spring force and/or differential pressure forces the seal against the environment side groove wall so that the only place that the seal is completely exposed to the media is at the relatively small extrusion gap between the shaft and the housing (see the Engineering section for portrayals of the extrusion gap).

The volume change effect of a petroleum-based fluid can be characterized by its aniline point, which is a measure of aromatic content. A low aniline point is typically associated with high elastomer swell while a high aniline point is typically associated with low elastomer swell or shrinkage. Low aniline point fluids are undesirable for use with most elastomers. The aniline point of a lubricant can generally be obtained by contacting the manufacturer or supplier. NBR and FKM elastomers have excellent resistance to petroleum based fluids, while EPDM has very poor resistance with such fluids, and should be used exclusively with synthetic lubricants.

Media Resistance Guidelines

General media compatibility information is provided in Table 4-1. It is impractical to include comprehensive information on elastomer media compatibility in this seal handbook. Instead, we refer our customers to the voluminous book, **Chemical Resistance Guide for Elastomers III** by Kenneth M. Pruett (Compass Publications, La Mesa, CA USA: 2005) and to the many other handbooks and industry literature that specialize in the subject of elastomer compatibility.

	HNBR	NBR	FKM	EPDM
Acid, dilute	R		R	
Acid, concentrated	NC	NC	R	
Aliphatic hydrocarbons (propane, butane, petroleum, oil, mineral oil, grease, diesel fuel, fuel oils)		R	R	
Amine (corrosion inhibitors)			NC	
Animal fats	R	R	R	
Aromatic hydrocarbons (methane, CH4 or benzene)			R	NC
ASTM oils No. 1 through No. 3			R	
Brake fluids				R
Brine (salt solutions)	R	R		
Bromides			R (-30)	
Carbon dioxide (CO2)		R		
Caustics				
Crude oil			R	
Esters	NC	NC		
Ethers				
Formate brines	R		NC	
Glycols (general)		R	R	R
Halohydrocarbons (carbon tet and trichlorethylene)	NC		R	
Hydraulic fluids			R	R
Hydrogen sulfide (H2S)	R (≤7%)			
Ketones (solvents: MEK and acetone)	NC	NC	NC	R
Mineral oils		R	R	NC
Oils	R			
Ozone		NC	R	R
Petroleum based fluids		R	R	
Phosphate esters (Chevron Hyjet, MIL-H-19457)	NC	NC	R (alkyl)	R
Silicone (grease and oil)		R	R	R
Skydrol 500 and 7000	NC	NC		R
Soda (ash, baking, caustic &niter)				R
Steam	R		NC	R
Vegetable oil		R	R	
Water	R	R		R
Weathering			R	R

R-Resistant
NC-Not compatible

Table 1
Media Compatibility

This chart was compiled from various published sources, and is intended only as a general guide. No warranty of performance is implied. Elastomer deterioration is a function of temperature and many other variables, therefore Kalsi Engineering encourages its customers to perform immersion and rotary testing under anticipated service conditions to establish material suitability for specific applications.

3. High temperature resistance

Although Kalsi Seals run much cooler than non-hydrodynamic rotary shaft seals, temperature resistance is still a critical consideration. The location of highest temperature is at the dynamic sealing interface due to lubricant shear. The interfacial running temperature is difficult to measure or predict. It is a function of hardware geometry and materials, as well as environmental conditions such as temperature and flow rates. For methods to manage interfacial seal temperature, see the Engineering section, and review your application with Kalsi Engineering.

Table 2

Typically Published Maximum Elastomer Continuous Use Operating Temperatures

(Actual values depend on specific compounding)

Elastomer	Maximum Continuous Operating Temperature
HNBR	300 to 320°F (149 to 160°C)
NBR	250°F (121°C)
FKM	400°F (204°C)
EPDM	300°F (149°C)

All elastomers are affected, to one degree or another, by elevated temperatures and time. Seal life (time) decreases as temperature increases. Published maximum operating temperatures for elastomers are typically based on retention of useful properties for an arbitrary time period in the presence of select compatible environments. Especially when high differential pressure is involved, such data cannot be expected to be accurate for every environment, or to correlate directly with rotary seal performance. The published temperature limits are based on measurement of gradual physical changes such as hardness, tensile strength, and compression set. Typically quoted maximum continuous use operating temperatures are shown in Table 2.

The typical signs of unacceptably high temperature are severe compression set, blisters, a melted appearance, longitudinal cracking of the heat affected interfacial zone, charring, hardening and brittleness. In high pressure applications, excessive extrusion damage may also occur due to temperature-related reduction of the modulus of the elastomer.

4. Low temperature resistance

Low temperature affects elastomers in several ways including making the elastomer shrink. Thermal expansion/contraction coefficients for elastomers are ~10 times greater than that of steel. Accordingly, rotary seal compression decreases as temperature decreases, which directly reduces rotary seal compression. Elastomers also get harder, stiffer and less responsive as temperature decreases and eventually become brittle. This temperature is referred to as the glass transition point. At this temperature, the elastomer is brittle to the point that it will break when struck. This temperature varies from elastomer family to elastomer family and even compound formulation to compound formulation within a given elastomer family. Startup can potentially damage seals if the temperature approaches the elastomer brittle point, due to various operating effects such as breakout torque and dynamic runout. The low temperature effects are usually temporary, and original properties are typically restored upon warm-up. Low temperature affects the dynamic response of the elastomer. At low seal operating temperature, significant runout or severe vibration may cause significantly increased leakage. In reduced compression implementations, thermal contraction can cause leakage, even though the seal may still be flexible. Typical Kalsi Seal performance will be realized once the seals temperature increases and typical elastomer properties are restored.

Standardized low temperature elastomer testing

The ASTM Test Method D 746-98 for establishing brittle (glass transition) point is an impact test. The brittle point is the temperature where half of the specimens fail under a specified impact induced bending force. The brittle point is not a measure of useful working temperature; rather it is a reference point for elastomer comparisons. Typical published brittle points for various elastomers are shown in Table 3. Actual values vary as a function of specific compounding, and can be established on a case-by-case basis.

Low temperature comparisons can also be done with low temperature temporary compression set testing (ASTM Test Method D 1229-87(1997)[1]) and temperature-retraction testing (ASTM Test Method D 1329-88(1998)). The temperature retraction test involves stretching a specimen, exposing it to low temperature, and then releasing it. The retraction of the specimen is measured as it is warmed at a uniform rate. The rate of retraction is used to evaluate low temperature resiliency and crystallization tendencies.

Table 3

Typically Published Brittle Point Temperatures of Various Elastomers

(Actual values depend on specific compounding)

Material	Brittle Point / Glass Transition Point	Dynamic minimum temperature	Static minimum temperature
HNBR			-40°F (-40°C)
XNBR			-20°F (-29°C)
FEPM	-45°F (-43°C)		-35°F (-37°C)
NBR	-40 to –85°F (-40 to –65°C)	-30°F (-34°C)	-40 to –65°F (-40 to –54°C)
FKM	-60°F (-51°C)	-5°F (-21°C)	-20 to –40°F (-29 to –40°C)
EPDM	-90°F (-68°C)	-60°F (-51°C)	-50 to –80°F (-46 to –62°C)

Rotary seal selection for low temperature service

While Kalsi Engineering does not have extensive low temperature sealing experience at present, limited experience in arctic conditions has shown the –10 (80 ±5 Shore A HNBR) material is more resistant in low temperature arctic operation than the –11 material, although abrasive service life may be somewhat reduced. Experience also suggests that the additional compression associated with Wide Footprint Kalsi Seals may be beneficial in arctic conditions, compared to Standard Kalsi Seals.

Reviewing the case history, 0.335” (8.51 mm) cross-section Standard Kalsi Seals in -11 material were used to retain pressurized hydraulic fluid in a fleet of vehicles. When temperatures of –18 to –31°F (-28 to –35°C) were encountered, the atmosphere-exposed seals leaked statically even though they were in new condition, and also leaked during rotation until warmed up by self-generated heat. A number of alternative low temperature compounds were tested in the lab, but none had suitable dynamic properties. The low temperature rotary leakage problem was solved when the Standard Kalsi Seals in –11 (85-90 Shore A HNBR) material were replaced by Wide Footprint seals manufactured with –10 (80 ±5 Shore A HNBR) material, and excessive shaft runout due to excessive bearing clearance was brought under control.

Elastomers can be specially compounded for increased low temperature properties, usually at the expense of high temperature properties. Typically, this is a poor trade-off in most Kalsi Seal applications. For example:

- The acrylonitrile content of NBR can be reduced to improve low temperature flexibility, but at the expense of swell resistance. Limited experience also shows that HNBR cold temperature flexibility is affected by acrylonitrile content.
- Plasticizers can be added to increase low temperature flexibility, but tend to compromise heat resistance, are leached out by certain fluids and may be volatilized at high temperature, causing seal shrinkage and associated leakage.

Cold-room rotary seal testing

Where low temperature rotary seal performance is of paramount concern, the customer may wish to rent or build a special refrigerated cold room so that the actual assembled equipment can be tested at various temperatures under actual static and dynamic operating conditions. One such commercial facility is in Edmonton, Alberta, Canada.

Most of our lab testing of rotary seals is directed at our more typical oilfield, downhole applications, where elevated temperatures are encountered. At present, we do not have a refrigerated cold room for seal testing.

5. Elastomer abrasion resistance

Abrasive wear is a complex action that includes third body-induced wear, fatigue, and adhesion. Abrasion resistance testing (DIN, Taber, etc.) is typically performed by loading a test specimen against a moving abrasive surface for a set period of time. Abrasion testing results can vary widely from test to test for a single batch of a given compound. Therefore, such tests can only be used as a rough comparison between elastomers. It is important to understand that such tests are necessarily artificial, because potential in-service influences, such as swelling, elevated temperature, etc. are not present. To obtain application specific testing results, many organizations have developed specialized equipment to simulate service conditions. Papers on this subject are available through a number of organizations including the Energy Rubber Group Inc., a division of the American Chemical Society.

In published literature, most references rate NBR and FKM as having “good” resistance to abrasion. HNBR is ranked as having “excellent” abrasion resistance, and EPDM is ranked as having “good” to “excellent” resistance. In abrasion resistance comparison tests, the 85 to 90 Shore A HNBR (-11) material had about 2.6 times the abrasion resistance of the 90 Shore A FKM (-6) material, and about 2.4 times that of a 90 Shore A NBR material. However, in actual rotary seal tests, both HNBR and NBR are far superior to FKM in terms of ability to tolerate asperity contact between the rotary seal and the shaft during high differential pressure operation.

Anecdotal information suggests that the –11 compound provides somewhat longer service life, as compared to the softer –10 (80 ±5 Shore A HNBR) compound, when exposed to environmental abrasives in low pressure lubricant retention applications. In addition to inherent elastomer abrasion resistance, the functional abrasion resistance of Kalsi Seals can be significantly influenced by seal geometry and various hardware-related factors (see the Engineering section). Elastomer hardness can also influence seal abrasion related to reverse pressure induced seal distortion; harder elastomers are more resistant to such reverse pressure distortion.

Tear strength testing may also provide abrasion resistance insight, because elastomers with low tear strength are more prone to crack propagation and subsequent material loss due to dynamic stress. In the published literature, FKM and NBR are rated as having “fair” to “good” tear resistance. HNBR and EPDM are rated as “good” to “excellent”. Tear strength testing, which is performed before and after a period of elevated temperature media exposure, measures the force needed to propagate cuts.

6. Elastomer compression set resistance

Compression set is a measurement of permanent deformation (i.e. lack of rebound) of a seal after a specified period of time and amount of compression at a specific temperature. It is usually expressed as a percentage of the original amount of dimensional compression. Compression set can be calculated using Equation 1. As with most forms of elastomer degradation, compression set increases as a function of increasing temperature, and is influenced by media compatibility.

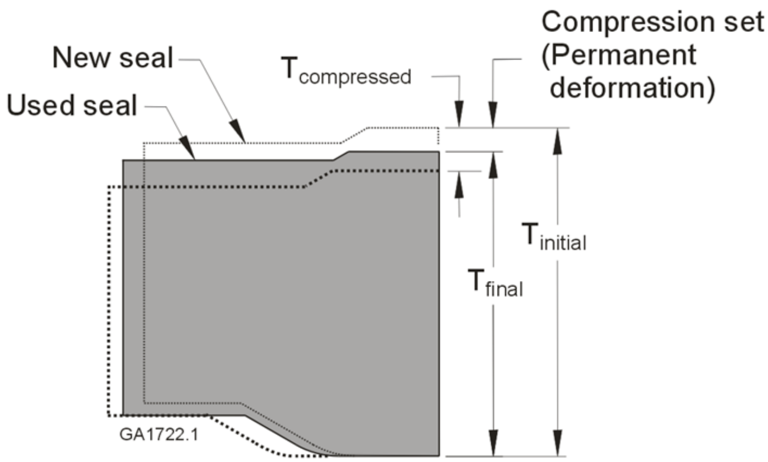

Figure 2

The permanent deformation (i.e. lack of rebound) of a seal after use is called "compression set". It is usually expressed as a percentage of the original compression for comparative purposes, but can also be expressed as a dimension.

Equation 1, Compression set of elastomeric element:

$$CS_{percent} = \frac{T_{initial} - T_{final}}{T_{compressed}} \times 100$$

$CS_{percent}$ = Percent compression set.
$T_{initial}$ = Initial specimen thickness.
T_{final} = Final specimen thickness.
$T_{compressed}$ = Compressed specimen thickness

Kalsi Seals are installed with initial radial compression, and establish static sealing by blocking the leakage path. Seal life is ultimately limited by the ability of the seal to remain resilient and maintain sufficient contact force against its mating counter-surface. Therefore good compression set resistance is a very desirable characteristic, and is routinely tested by Kalsi Engineering as a quality control measure.

Figure 3

Kalsi Seals are thoroughly inspected to assure conformance to our demanding design specifications. Inspection occurs at several different stages of the manufacturing process. A detailed independent inspection is performed before final acceptance of the seals into inventory. In this photo, a seal is being inspected for surface defects.

The compression set resistance of HNBR is superior to NBR. FKM typically has excellent compression set resistance. Larger seal cross-sections tend to have better compression set resistance than smaller seal cross-sections.

7. High pressure rotary seal extrusion resistance

Introduction

When exposed to differential pressure, Kalsi Seals must bridge the gap between the rotating and stationary components. This gap has to be relatively small so the seal material can bridge it and resist the pressure. Typical extrusion damage is illustrated in Figure 4.

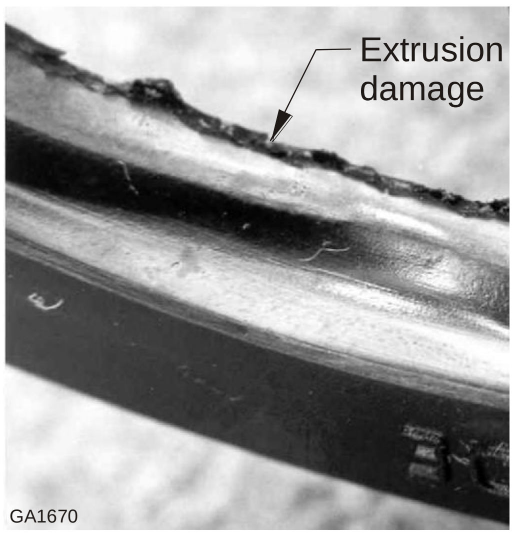

Figure 4
Example of high pressure extrusion damage

Elastomer extrusion resistance

Elastomer extrusion resistance is primarily a function of the elastic modulus of the compound, which is a measure of deformation resistance. Different formulations within a given elastomer family can have very different extrusion resistance characteristics. Elastomer hardness and modulus values are somewhat related with elastomers typically being classified by hardness, rather than modulus. Hardness is an indentation measurement performed by an instrument called a Durometer gauge (Figure 5). In North America, durometer is usually expressed in Durometer Shore points, although international rubber hardness degrees (IHRD) are also encountered. The maximum Shore A value is 100 points, representing no indentation, as would occur with a non-resilient material such as glass. Shore A hardness is often specified with a ±5 point tolerance due to measurement uncertainty. More recent compound additives can produce higher modulus values without proportionately large increases in Durometer hardness.

Figure 5
Example of Durometer gauge with stand

Kalsi Seals are presently categorized by hardness, because hardness is routinely used for quality control of finished product. Uniformly sized laboratory test buttons are used in the standard hardness testing procedure (ASTM Test Method D 2240-00) because other cross-sections can give misleading results due to shape effects. Nevertheless, hardness testing can be used for quality control on some sizes and shapes of seals, provided it is understood that the resulting values do not necessarily agree with values obtained using test buttons.

Elastomer hardness selection should be based on anticipated service conditions. Harder compounds and smaller extrusion gaps should be used for high differential pressure applications. For example, rotary sealing service conditions in the 500 to 1,500 psi (3.45 to 10.34 MPa) differential pressure range typically dictate the use of an 85 to 90 Shore A elastomer. The maximum practical application of differential pressure is limited by elastomer modulus, extrusion gap size, dynamic runout, pressure fluctuation, and overall life requirements. See the Engineering section of this handbook for typical extrusion gap recommendations, and the use of floating backup rings or floating seal carriers to minimize extrusion gap clearance. Elastomer hardness and modulus decrease at elevated temperature, resulting in a reduction in extrusion resistance. See the Engineering section for tips on managing seal operating temperature.

Elastomer softening can also result from environmental media exposure, and the softening/swelling is typically limited to the regions near the exposed surfaces. If the seal had positive[3] differential pressure, for example, the softening/swelling is typically limited to the region near the extrusion gap; i.e. the region where the rotary seal is already most prone to extrusion damage. When necessary, a high pressure rotary seal can be protected from the environment by a low pressure barrier seal to provide a compatible lubricant on both sides of the high pressure seal (see Engineering section).

Harder elastomers are associated with higher rotary torque and heat generation. In solid cross-section seals, harder elastomers have greater compressive force and increased breakout friction, and also require more force to install. Dual Durometer Kalsi Seals are offered that provide a harder material at the dynamic extrusion gap, but use a lower hardness energizing material to minimize compressive force, installation force, breakout torque, running torque and seal-generated heat without compromising extrusion resistance. A special treatment is available at added cost that reduces breakout torque.

Modulus testing

Modulus testing is performed by securing a test specimen by the jaws of a tensile testing machine, and then stretching the test specimen at a specified rate while continuously measuring force and the percentage of stretch, until the specimen breaks. The stress is calculated at the break point, and at several different amounts of stretch, based on the measured force and the area of the specimen. The stress is reported as tensile modulus at several different levels of strain. When reporting the modulus, abbreviations are used to describe the level of strain. For example, the M-100 value is stress at 100% strain. The modulus (stress) at lower strain levels is generally more indicative of extrusion resistance characteristics. Because the stress-strain relation for elastomers is always non-linear, a single modulus value cannot be applied over a broad stress range.

An alternative to elastomers for high pressure sealing

In many high pressure seal applications, -303 plastic lined Kalsi Seals will be the preferred choice. The dynamic lip of these seals is formed from a plastic that has a significantly higher modulus of elasticity and lower breakout friction, compared to elastomers. As described in the catalog section of this rotary seal handbook, in 7,500 psi rotary testing we were able to achieve seal life in excess of 1,000 hours when plastic

[3] Where the lubricant pressure is higher than the environment pressure.

lined Kalsi Seals were used in conjunction with the floating backup ring arrangement that is described in the engineering section of the handbook. Figure 6 compares the extrusion resistance of the most extrusion resistant elastomeric dynamic lip material and the most extrusion resistant plastic liner material when tested at ~6,000 psi (~41.37 MPa) for 100 hours. The plastic lined seal is in much better condition than the all elastomer seal.

674-3-303 Extra Wide Plastic Lined Kalsi Seal

655-7-115 Extra Wide Enhanced Lubrication Kalsi Seal

Figure 6
Plastic liners provide significantly improved extrusion resistance

These photos compare the most extrusion resistant elastomeric dynamic lip material to the most extrusion resistant plastic liner material when tested at 252 ft/minute (1.28 m/s) and ~6,000 psi (~41.37 MPa) for 100 hours with an ISO 150 viscosity grade lubricant at ~130°F (~54.4°C). The tests were conducted with backup rings that defined a diametric extrusion gap clearance of ~0.004” (~0.1mm).

8. Explosive decompression resistance

In high pressure applications involving compressed gases, rotary seal elastomers can become permeated by the compressed gases. The degree of permeation is related to the type of elastomer, the ambient pressure, temperature and the type of gas. If the pressure is suddenly reduced, the gas trapped within the elastomer expands and causes blisters and other surface and internal defects that may affect subsequent rotary seal performance. This phenomenon is known as “explosive decompression”. Nitrile based elastomers tend to offer good resistance to explosive decompression. In general, harder compounds resist explosive decompression better than softer compounds, and smaller cross-section seals may offer better resistance compared to larger cross-sections. In applications with positive differential pressure and/or rotary seal spring loading (see

Engineering section), very little of the surface area of the seal is actually exposed to the process fluid, which may help to reduce explosive decompression.