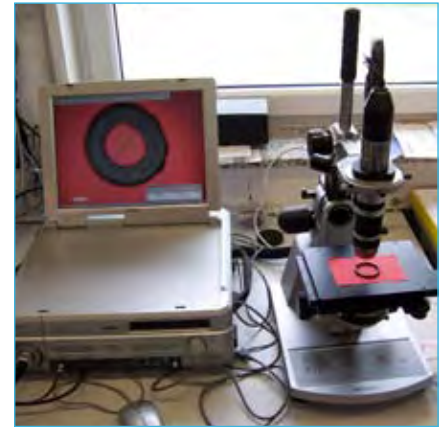


### 5. Designing with Rubber

In designing an O-ring seal, it is important to determine the O-ring compound early, as the compound selected may have an influence on the gland design. The application determines the rubber compound, the primary factor being the fluid to be sealed. But the elastomer must also resist extrusion when exposed to the maximum anticipated pressure and be capable of maintaining good physical properties through the full temperature range expected.

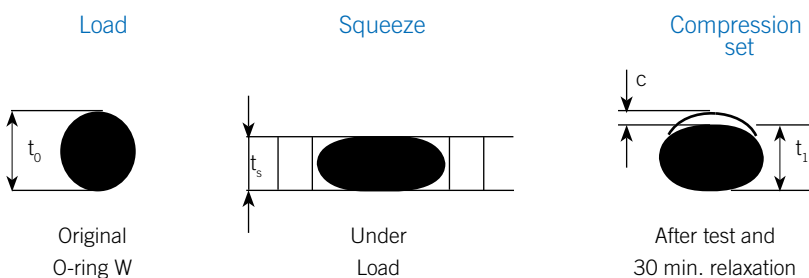
This chapter discusses the next criteria that must be considered like compression set, hardness, tensile strength, chemical compatibility, thermal effects, pressure, and extrusion. Data and procedures enabling the designer to meet particular requirements or obtain specific performance from the seal will be found in this chapter.



#### Compression Set and Squeeze

Compression set is the percentage of deflection that the elastomer fails to recover after a fixed period of time under a specific squeeze and temperature. Compression set is a very important sealing factor, because it is a measure of the expected loss of resiliency or "memory" of a compound. Compression set is generally determined in air and measured as a percentage of original deflection. Although it is desirable to have a low compression set value, this is not so critical as it might appear because of actual service variables. For instance, an O-ring may continue to seal after taking a 100% compression set, provided the temperature and system pressure remain steady and no motion or force causes a break in the line of seal contact. Also, swelling caused by contact with the service fluid, may compensate for compression set. The condition most to be feared is the combination of high compression set and shrinkage. This will lead to seal failure unless exceptionally high squeeze is employed. Compression set is calculated as follows:

$$C = \frac{t_0 - t_1}{t_0 - t_s} \times 100 \%$$



Compression set illustration

### 5. Designing with Rubber

Lower compression set values indicate improved remaining seal capacity. Compression set values generally increase with increased temperature and time.

For O-rings the minimum squeeze should be about .007 inch. (0,175mm). The reason is that with a very light squeeze almost all elastomers quickly take 100% compression set. A good compression set resistant compound can be distinguished from a poor one only when the squeeze is more than .005 inch. (0,127mm)

Most O-ring seal applications cannot tolerate the no squeeze condition, the exceptions are the floating ring designs in special pneumatic and rotary applications.

The most commonly used standards for the expression of compression set are ASTM D 395 and DIN 53517 / ISO 815.

Table 3A-1a gives compression set values for standard Eriks compounds, (Squeeze 25%).

#### Note:

It is important to notice that the compression set changes with time and depends on cross section diameter. This table shows these different values, measured on the same compound.

**Table 3A-1a**

Material	Hardness IRHD ± 5	Compression set 22h/100°C, 25%, on O-ring 3.53 mm.	Temp. Range	
			°C	°F
NBR 36624	70	max. 20%	-30+120	-22+248
NBR 47702	90	max. 30%	-30+120	-22+248
EPDM 55914	70	max. 30%	-50+120	-58+248
EPDM 55914 PC	70	max. 25% (150 °C)	-50+150	-58+302
Silicone 71477	70	max. 40% (200 °C)	-60+220	-76+428
Neoprene 32906	70	max. 25%	-35+110	-31+230
Viton® black 51414	70	max. 18% (200 °C)	-20+200	-4+392
Viton® green 51414	70	max. 19% (200 °C)	-20+200	-4+392
Viton® black 514320	90	max. 18% (200 °C)	-20+200	-4+392
Quad-Rings®/X-Rings in NBR/FKM/EPDM	70/90	-	-30+120	22+248

**NBR 36624 O-rings**

Cross section mm	1,78	3,53	6,99
Compression set 22h/100°C (212°F)	14,8	12,8	9,2
Compression set 70h/100°C (212°F)	23,9	22,7	16,8

### 5. Designing with Rubber

#### O-ring Hardness

The hardness of an O-ring is important for several reasons.

The softer the elastomer, the better the seal material conforms to the surfaces to be sealed and lower pressure is required to create a seal. This is particularly important in low pressure seals that are not activated by fluid pressure.

The softer the elastomer, the higher the coefficient of friction. In dynamic applications however, the actual running and breakout friction values of a harder compound with lower coefficients of friction are higher because the load required to squeeze the harder material into the O-ring groove is much greater.

The softer the elastomer the more risk that at high operating pressure the elastomer of the O-ring will extrude into the clearance gap between the mating seal surfaces.

The harder materials offer greater resistance to flow.

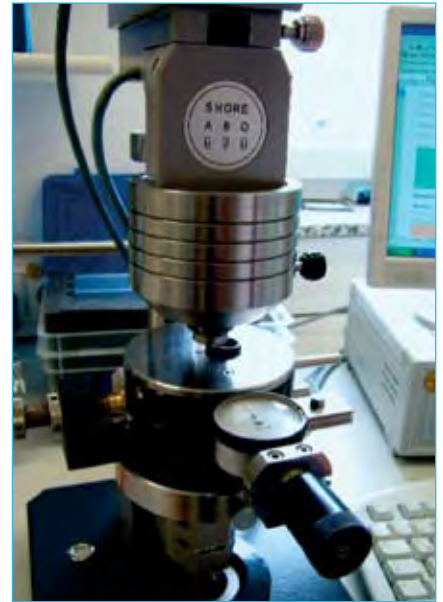
With an increase in temperature, elastomers first become softer and then eventually harder as the rubber curing process continues with the application of heat.

The hardness of most elastomers is indicated by a durometer rating on a gauge manufactured by the Shore Instrument Company or equivalent. Most elastomers are measured on the Shore "A" scale. Shore A hardness of 35 is soft; 90 is hard. Shore "D" gauges are recommended where the Shore "A" rating is greater than 90. The most common standards for measuring hardness are ASTM D2240, DIN 53505, BS 2719, and ISO 7619. These standards define a gauge reading on a standard sample with a thickness of 0,25 in. (6 mm.). Always use standard hardness discs 1.28 in. diam. by 0,25 in. thick (ø32 x6 mm.), or 6 in.x 6 in.x 0.075 in. (150x150x2 mm.) sheets piled up to a minimum of 0,25 in. (6 mm.) to determine durometer hardness.

It has been almost impossible to obtain reliable and reproducible hardness readings on seals with curved surfaces and variable cross sections such as O-rings. This problem has plagued the industry for years and is acknowledged in some standard tests. Like ASTM Method D 2240-00, paragraph 6.2.1 states: "A suitable hardness determination cannot be made on an uneven or rough point of contact with the indenter". Also MIL-P-5510B, paragraph 4.4.2. states : "Test specimens for the purpose of batch testing shall consist of one compression molded hardness specimen 0,25 in. thick and 1 in. diameter minimum ( 6 mm. thick and 25 mm. diameter)." The specification states in a note "Hardness shall not be determined from actual packings."

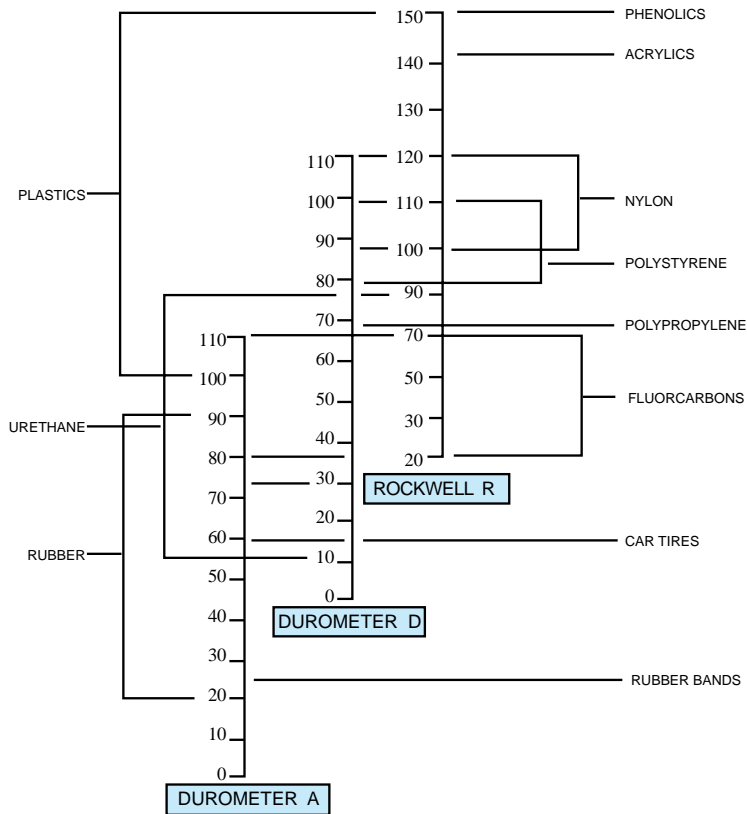
However, for specimens that are too thin or provide too small an area for accurate Shore durometer readings, the Wallace Micro Hardness Tester is the most recommended method. Measurements in Micro-IRHD are more accurate for O-rings. This method of measurement is recorded in the standards ASTM D1415 and DIN 53519. Differences between IRHD and Shore "A" are negligible on the 6 mm thick sample.

Normally, durometer hardness is referred to in increments of five or ten, as in 60 durometer, 70 durometer, 75 durometer, etc. Not as 62, 66, or 72 durometer. This practice is based on the fact that hardness is generally called out in specifications with a tolerance of  $\pm 5$  and also on the inherent variance from batch to batch of a given rubber compound due to slight differences in raw materials and processing techniques and the variability encountered in reading durometers.



### 5. Designing with Rubber

#### Durometer Ranges Rubber-Plastics



#### IRHD and Shore A



IHRD-Micro  
DIN 53 519 Teil 2  
Norm : 2 mm sheet  
Time : 30 sec.

Shore A DIN 53 505  
Norm : 6 mm sheet  
Time : 3 sec.

### 5. Designing with Rubber

#### Tensile Strength and Elongation

Tensile strength is a measurement of the amount of force required to rupture an elastomeric specimen. Tensile strength is a fair production control measurement used to insure uniformity of the compound, and also useful as an indication of deterioration of the compound after it has been in contact with a fluid for long periods of time. If a large reduction in the tensile strength occurs, the life of a seal may be relatively short. Exceptions to this rule do occur.

Elongation is an increase in length expressed numerically as a percentage of initial length at the point of rupture. This property primarily determines the stretch which can be tolerated during the installation of a seal.

An adverse change in the elongation of a compound after exposure to a fluid is a definite sign of degradation of the material. Elongation, like tensile strength, is used throughout the industry as a check on production batches of compound.

Tests are performed on dumb-bell shaped samples on a machine pulling them apart axially at a constant speed of 500 mm per minute, during which the force and elongation of the sample are recorded.

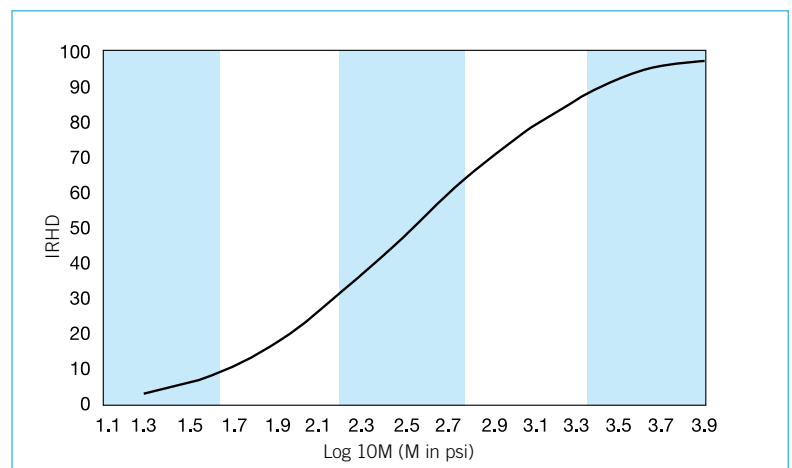
Standards tests for Tensile strength and Elongation are ASTM D412, DIN 53505, and BS 903, Part A3.



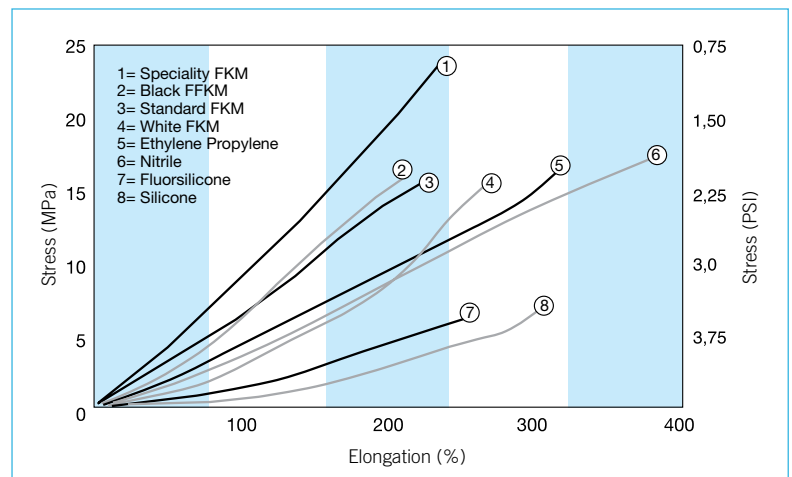
#### Modulus

Modulus, as used by the rubber industry, refers to stress at a predetermined elongation, usually 100%. It gives a comparison for good extrusion resistance. Modulus normally increases with increase in hardness and is probably the best indicator of the strength of a compound, all other factors being equal.

#### Hardness (IRHD) versus Young's Modulus (M)



#### Stress versus Strain



### 5. Designing with Rubber

#### Tensile Stress-Strain

Tensile strength is the maximum tensile stress reached in stretching a test piece (either an O-ring or dumbbell).

Elongation: the strain or ultimate elongation is the amount of stretch at the moment of break.

Modulus: also called 'Mod.100'; this is the stress required to produce a given elongation. In the case of Mod 100, the modulus would be the stress required to elongate the sample 100%.

In elastomers, the stress is not linear with strain. Therefore, the modulus is neither a ratio nor a constant slope - but rather denotes a specific point on the stress-strain curve.

Tensile tests are used for controlling product quality and for determining the effect of chemical or thermal exposure on an elastomer. In the latter case, it is the retention of these physical properties, rather than the absolute values of the tensile stress, elongation or modulus, that is often significant.

#### Tear strength

The tear strength or tear resistance is relatively low for most compounds. This test measures the force to perpetuate a nick or cut. Seal compounds with poor tear resistance will fail quickly under further flexing or stress, once a crack is started. Low tear strength of a compound is also indicative of poor abrasion resistance which may lead to early failure of an O-ring used as a dynamic seal.

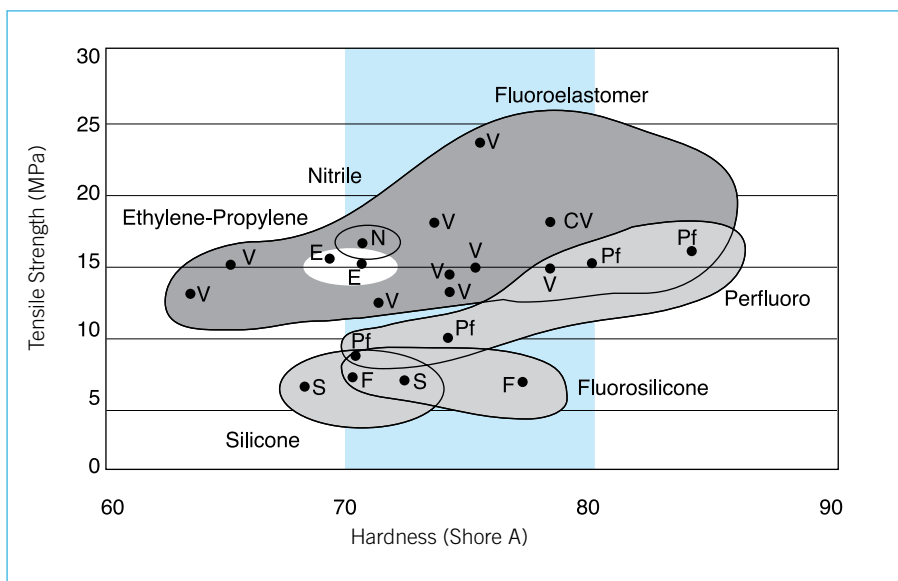
#### Volume change

Volume change is the increase or decrease of the volume of an elastomer after it has been in contact with a medium. It is measured as a percentage (%). Increase by swell or decrease by shrinkage in volume is almost always accompanied by a change in hardness.

Volume swell is caused by absorption of gaseous or liquid medium by the O-ring. In static applications, even extreme volume swell can sometimes be tolerated. Actually an O-ring can swell only until 100% gland fill and further increase of volume is not possible, regardless of how much volume swell is observed in a full immersion test. If the free state swell exceeds 50 percent; however, a radially squeeze assembly may be almost impossible to take apart because of the friction generated.

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 plasticizers from the compound. Decrease in volume is usually accompanied by an increase in hardness. Also, as swell compensates for compression set, 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.



### 5. Designing with Rubber

#### Chemical Compatibility

The chemical guide is intended to assist the user in determining the suitability of various elastomers in many different chemical environments. The ratings are based on a combination of published literature, laboratory tests, actual field experience, and informed judgments. ERIKS uses the DuPont Performance Elastomers guide.

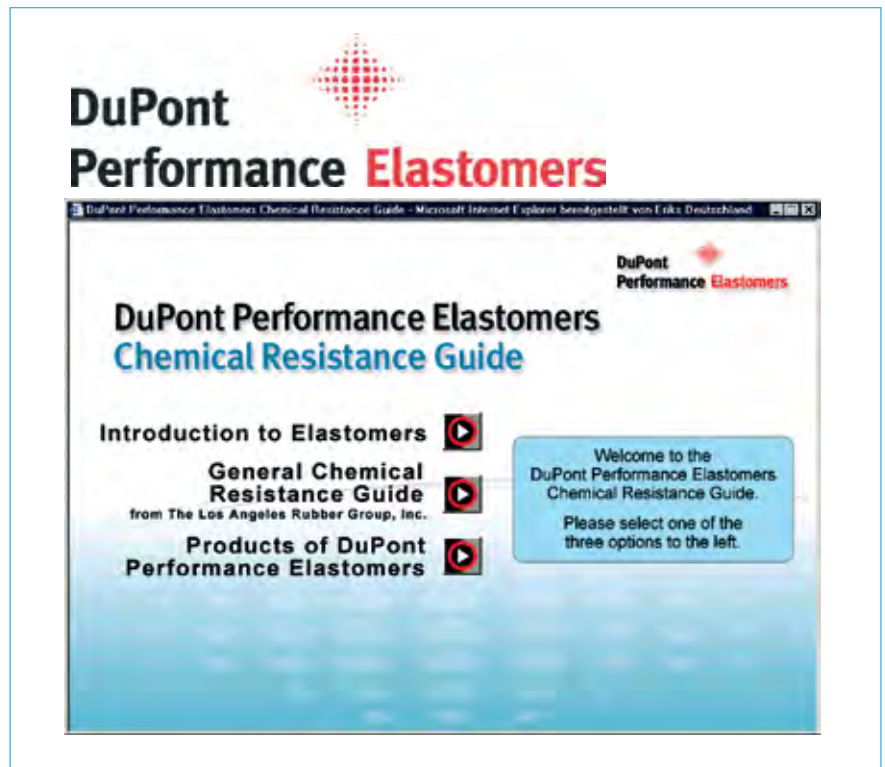
Note: Volume swell is only one indicator of elastomer fluid compatibility and may be based on the solubility parameter alone. Fluid attack on the backbone of the polymer may show up as a change in physical properties such as tensile strength, elongation at break, and hardness.

Elevated temperatures and extended exposure times may create more aggressive conditions.

In some cases, specific elastomer compounds within a material family may provide improved compatibility. Please contact the Application Engineering Department for assistance or consult the Dupont Performance internet chemical resistance guide - where you can find the latest information.

Elastomers can swell and/or degrade in chemical environments through reactions with the polymer backbone and cross-link system, or by reactions with the filler system. In the semiconductor industry, this degradation can be seen in increased contamination and reduced seal life.

Chemical Compatibility Guide Rating System			
Rating	Description	Volume Change	Comments
A	Little or no effect	< 10%	Elastomer may exhibit slight swelling and/or loss of physical properties under severe conditions.
B	Possible loss of physical properties	10-30%	Elastomer may exhibit swelling in addition to a change in physical properties. May be suitable for static applications.
C	Noticeable change	30-50%	Elastomer exhibits a noticeable change in swelling and physical properties. Questionable performance in most applications.
U	Excessive change	> 50%	Elastomer not suitable for service.



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### 5. Designing with Rubber

#### Attack mechanisms: Chemical Compatibility

- The process of chemical degradation or chemical incompatibility is very complex. In general, degradation of the polymer backbone and cross-link may occur by means of:
- nucleophilic attack - nucleophiles are ions or molecules that can donate electrons. This is the main cross-linking mechanism. In certain chemical media, nucleophilic attack can result in increased cross-linking and embrittlement.
- dehydrofluorination - in fluorocarbon elastomers the attack of aliphatic amines can result in the formation of unsaturated bonds in the polymer backbone.
- polar attack - swelling caused by electrostatic interactions between the dipole and polymer chain

Degradation may also occur due to interactions of the chemical environment and elastomer filler systems. This type of degradation may be caused by oxidation of fillers, or by chemical attack of certain fillers or process aids.

In many applications special considerations should be made for contamination or vacuum performance. Contamination is critical in semiconductor fabrication and medical applications. This may take the form of particle generation, extractable ions or other residual gas contamination.

#### Test methods:

ISO 1817 (Liquids)

ASTM D471, D1460, D3137 (Liquids)

#### Volume Swell:

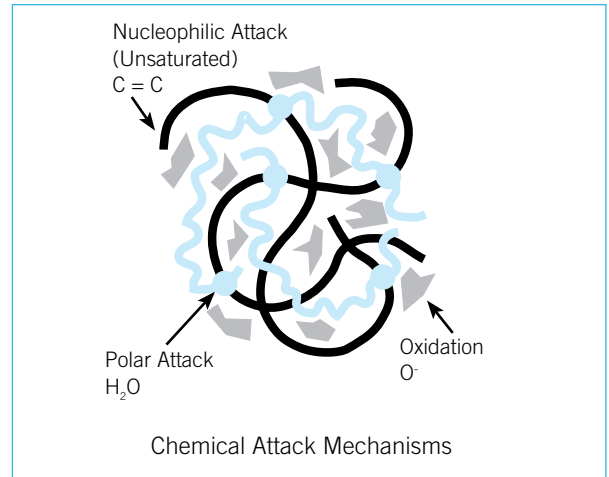
The most common measure of chemical compatibility is volume swell. The following formula is used in reporting volume swell measurements. This takes into account dimensional changes in all three dimensions, and is more precise than specific dimensional change readings for most sealing applications.

#### Volume Swell:

$$VS (\%) = \frac{(\text{Weight in Air-Wt. in Water})_{\text{final}} - (\text{Wt. in Air - Wt. in Water})_{\text{initial}}}{(\text{Weight in Air - Weight in Water})_{\text{initial}}} \times 100$$

#### Note:

The "Weight in Water" measurement is performed by suspending a sample in a container of water and recording its weight. This takes into consideration that the density of a solid is equal to its weight in air divided by the difference of its weight in air and its weight in water.





### 5. Designing with Rubber

#### Thermal Effects

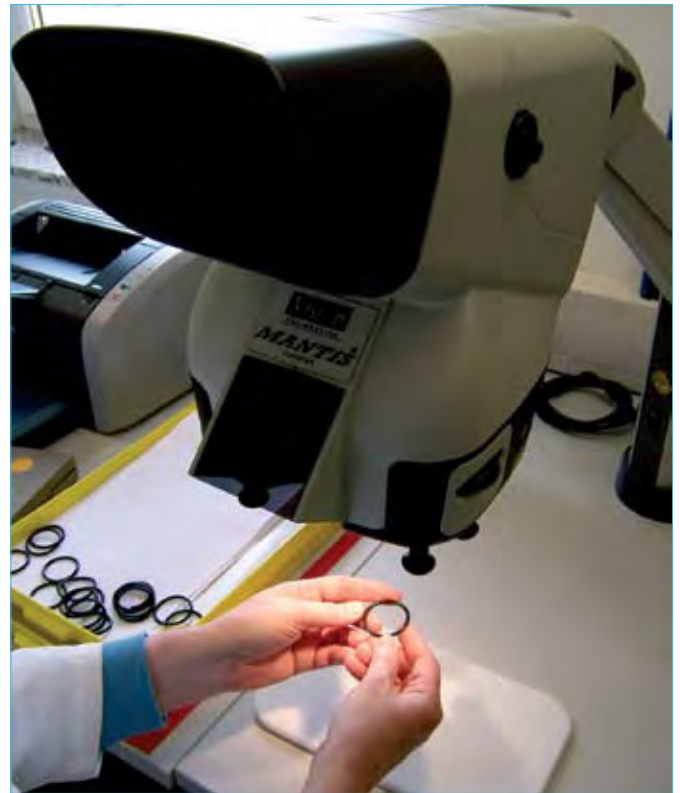
All rubber is subjected to deterioration at high temperature. Volume change and compression set are both influenced by heat. Hardness is influenced in a complex way. The first effect of high temperature is to soften the compound. This is a physical change, and will reverse when the temperature drops. In high pressure applications the O-ring may begin to flow through the clearance gap as the temperature rises, due to this softening effect. With increasing time at high temperature, chemical changes occur. These generally cause an increase in hardness, along with volume and compression set changes. Changes in tensile strength and elongation are also involved. Being chemical in nature, these changes are not reversible. The changes induced by low temperature are primarily physical and reversible. An elastomer will almost completely regain its original properties when warmed.

#### Thermal Expansion

Coefficient of linear thermal expansion is the ratio of the change in length per °F or °C to the original length at 0°F or 0°C. Coefficient of volumetric expansion for solids is approximately 3 times the linear coefficient. As a rough approximation, elastomers have a coefficient of thermal expansion 10-times that of steel. With Fluoroelastomers and Perfluoroelastomers the coefficient of thermal expansion is even greater. This can be a critical factor at high temperature if the gland is nearly filled with the O-ring or at low temperature if the squeeze is marginal. Leaking can be the result of seal failure at low temperature if the squeeze is small.

There are certain reactions which in some circumstances cause an O-ring to exert relatively high forces against the sides of the groove. If the seal is completely confined and the gland is 100% filled, the dominating force is the force of thermal expansion of the rubber. The groove must always be sufficiently wide to allow for the maximum expansion of the O-ring. There have been instances where a seal has ruptured a steel gland due to expansion when heated. Therefore it has to be considered that in no case a gland fill in excess of 95% is allowed.

This should be taken into consideration when designing O-ring grooves for applications in excess of 300°F (150°C). Please contact your ERIKS representative for assistance in groove design.



#### Thermal Expansion

Material	Thermal Stability	$\times 10^{-5} / ^\circ\text{C}$
FKM	200°C / 392°F	16
NBR	120°C / 250°F	23
VMQ	230°C / 450°F	59-79
FFKM	300°C / 570°F	23
EPDM	150°C / 300°F	16
Stainless	-	1.04
Aluminium	-	1.3
TEFLON	230°C / 450°F	5-8
KEL-F	280°C / 540°F	4-7
Polyimide	275°C / 530°F	5

### 5. Designing with Rubber

#### Selecting O-ring cross section diameter (CSD)

In general, when selecting O-rings, there are benefits to be gained from having both smaller and larger CSD. Some of the benefits are given below for both cases.

In static applications, where rapid high pressure cycling is not present, it is usually better to choose a larger CSD if possible. As noted above, larger CSD O-rings are less susceptible to the problems of compression set, swell, and incidental surface damage. Also, larger CSD O-rings are more stable and tend not to rotate on assembly. However, if the seal will be subjected to rapid high pressure cycling then it is better to choose a smaller CSD if possible. The smaller section seals are less susceptible to decompression problems.

In dynamic applications it may be better to choose a smaller O-ring CSD to avoid friction problems. In dynamic applications, the CSD is often governed to a great extent by the surface contact speed, as indicated in Table 2.

For dynamic applications with surface contact speeds less than 2,03 m/s the O-ring CSD is generally not critical. There are also some general rules relating O-ring CSD to O-ring ID as follows:

- If :  $0 < ID \leq 20$  mm      CSD = 1,78 or larger
- If :  $20 < ID \leq 100$  mm    CSD = 2,62 or larger
- If :  $100 < ID \leq 200$  mm    CSD = 3,53 or larger
- If :  $200 < ID \leq 300$  mm    CSD = 5,33 or larger

**Table 1 - Characteristics of CSD choice**

Larger section	Smaller section
More stable	Less stable
More friction	Less friction
Needs more space	Needs less space
Better compression set	Poor compression set
Less swell (%)	Possibly more swell (%)
Worse decompression	Better decompression
Larger tolerances	Closer tolerances
Less sensitive to damage	Sensitive to damage

**Table 2 - CSD and surface contact speed (Dynamic seals)**

O-ring CSD (mm)	Maximum surface contact speed (m/s)
1,78	7,62
2,62	3,04
3,53	2,03

