

Materials and Gland Design Training

Rubber Technology

“Rubber” compounds are resilient (elastic) materials made from one or more cross-linked base polymers, reinforcing agents, processing aids, and performance-enhancing additives.

Polymers

Polymers are long chains of repeating units. On the molecular level, they resemble extremely long spaghetti strands.

Monomer = the unit that repeats in a polymer

Isomer = Polymer made from one monomer

Dimer or Copolymer = Polymer with two monomers

Trimer or Terpolymer = Polymer with three monomers

Polymers tangle themselves together like in a large bowl of spaghetti

Polymers

Base polymer determines chemical resistance, rough temperature limits, and rebound resilience

In some materials, the high and low temp limits can be modified by other compounding ingredients.

Provides "baseline" for abrasion resistance, compression set resistance, permeability

These can (and almost always are) modified – up or down – by other compounding ingredients.

Cure Systems

Polymer chains must be “glued” together (cross-linked) to achieve resilience and elasticity.

- Sulfur: simplest cure system, used in nitrile and EP
- Organic Peroxides: improved compression set in EP, improved compression set & high temp limit in nitrile, standard cure system for silicone.
- Bisphenol: best cure system available for fluorocarbon (specialty FKMs need to be peroxide-cured, but it's not the first choice.)
- Others: specialty materials have special cure chemistry

Fillers

Reinforcing agents add mechanical strength and resistance to abrasion, permeation, and compression set

- Carbon black: standard for black compounds
- Silica: standard for non-black compounds

Fillers lower the cost of a compound but reduce compression set resistance and elongation

- Carbon black: lower grades or excessive amounts provide no performance benefit for seals
- Clay: commonly used in "generic" seal compounds

Plasticizers

Oils and / or polymers used to lower the low temp limit of nitrile and make the material flow better (see Process Aids, next)

- Reduce resistance to compression set
- In “generic” materials, they are used to offset the hardening influence of high levels of filler
- Can extract into process fluids, resulting in seal shrinkage & hardening

O-Ring Polymers

- Nitrile (NBR)
- Hydrogenated Nitrile (HNBR)
- Polyacrylate (ACM)
- Vamac (AEM)
- Neoprene (CR)
- Ethylene-Propylene (EPR, EPDM)
- Butyl (IIR)
- Polyurethane (AU, EU)
- Fluorocarbon (FKM)
- Tetrafluoroethylene-Propylene (TFE/P)
- Perfluoroelastomer (FFKM)
- Hifluor (FKM)
- Silicone (VMQ)
- Fluorosilicone (FVMQ)

Low Temp Nitrile (NBR)

-70 F / -50 F to +180 F / +275 F

Recommended For

- MIL Hydraulic Fluids
 - MIL-STD-5606
- General Purpose
- Petroleum Oils
- Silicone Fluids

N0304-75

N0756-75

Not Recommended For

- Ozone (Air)
- Ketones
- Automotive Brake Fluid
- Aircraft Brake Fluid
- Steam and Hot Water

MIL-STD-25732

AMS-R-83461

Neoprene (Chloroprene – CR)

-35 F to + 250 F

Recommended For

- Refrigerants
- Ammonia
- High aniline point petroleum oils
- Weak / dilute acids
- Silicate ester lubricants

Not Recommended For

- Ketones
- Phosphate ester fluids

C1124-70

AMS 3209

Ethylene Propylene (EPR, EPDM)

-65 F to + 300 F

Recommended For

- Water and Steam
- Alcohols
- Ketones
- Automotive Brake Fluid
- Aircraft Brake Fluid
- Amines
- Air

E1267-80

E0515-80

Not Recommended For

- Petroleum oils
- Di-Ester Based Synthetic Lubricants

Good for practically anything that dissolves in water.

NAS 1613

Butyl (IIR)

-75 F to + 250 F

Recommended For

- Water and Steam
- Alcohols
- Ketones
- Automotive Brake Fluid
- Aircraft Brake Fluid
- Amines
- Air
- Low permeation

Not Recommended For

- Petroleum oils
- Di-Ester Based Synthetic Lubricants
- Short term resilience

B0612-70

Excellent gas permeation resistance.

Good rocket fuel resistance.

A-type Fluorocarbon (FKM)

-15 F to + 400 F

Recommended For

- Petroleum oils
- Silicone Fluids
- Acids (Black ONLY)
- Aromatic solvents
- Halogenated hydrocarbons
- Air

V1164-75

V1226-75

V0709-90

Not Recommended For

- Ketones
- Steam and Hot Water
- Amines
- Low Temperature
- Automotive Brake Fluid
- Aircraft Brake Fluid

AMS 7276

AMS 7259

GLT Fluorocarbon (FKM)

-40 F to + 400 F

Recommended For

- HTS Turbine oils
- Petroleum oils
- Silicone Fluids
- Aromatic solvents
- Halogenated hydrocarbons
- Air

VM835-75

Not Recommended For

- Ketones
- Steam and Hot Water
- Automotive Brake Fluid
- Aircraft Brake Fluid

AMS-R-83485

Low Temp Fluorocarbon (FKM)

-50 F to + 400 F

Recommended For

- Petroleum oils
- Silicone Fluids
- Acids (Black ONLY)
- Aromatic solvents
- Halogenated hydrocarbons
- Air

V1289-75

Not Recommended For

- Ketones
- Steam and Hot Water
- Amines
- Automotive Brake Fluid
- Aircraft Brake Fluid

AMS spec in draft

Parofluor ULTRA (FFKM)

+5 F to + 600 F

Recommended For

- Engine exhaust
- Semicon Chip fab operations
- Jet engine oil
- (Practically everything)

FF200-75

FF350-75

Not Recommended For

- Refrigerant gases
- Low cost applications
- Low temperatures

AMS 7257

Aflas (TFE/P)

+15 F to + 450 F

Recommended For

- Petroleum oils
- Alcohols
- Silicone Fluids
- Bases
- Amines
- Air
- Steam / Hot water

V1006-75

Not Recommended For

- Low Temperature
- Gasoline

AMS 7

Silicone (VMQ, PVMQ)

-175 F to + 500 F

Recommended For

- Dry Heat
- Temperature Extremes
- Environmental Seals
- Air

S0469-40 S0604-70

S0595-50 S1224-70

S0899-50 S0383-70

S0613-60 S0355-75

S0455-70 S0614-80

Not Recommended For

- Ketones
- Dynamic Applications
- Long-Term Gas and Vacuum Sealing
- Petroleum oils
- Automotive Brake Fluid

AMS 3301 AMS 3302 AMS 3303

AMS 3304 AMS 3305 AMS 3337

AMS 3345 AMS 3357 AMS 7267

A-A-59588 MIL-G-21569

Fluorosilicone (FVMQ)

-100 F to + 350 F

Recommended For

- Petroleum oils
- Gasoline
- Dry Heat
- Temperature Extremes
- Environmental Seals
- Air

LM158-60

LM159-70

L1077-75

LM160-80

L1186-80

Not Recommended For

- Ketones
- Dynamic Applications
- Long-Term Gas and Vacuum Sealing
- Automotive Brake Fluid

AMS-R-25988 AMS 3325

AMS 7xxx for 70 duro in draft

**AMS 7xxx for other duros
planned for next 2 years**

Gland design

What makes a reliable O-ring design?

Squeeze

- Seal deforms significantly (~25%)
- Rubber does not compress or lose volume

Stretch

Gland fill

- Volume-to-void ratio

Surface finish

- Balance of machining costs with application & testing needs

Installation

- Protect seal from sharp edges
- Provide lead-in chamfers

Squeeze

Compression expressed as a percentage of the free-state cross-sectional thickness of the O-ring.

$$\frac{\text{(O-Ring C/S)} - \text{Gland Depth}}{\text{(O-Ring C/S)}}$$

- Face : 20-30%
- Static Male/Female: 18-25%
- Reciprocating: 10-20%
- Rotary: 0-10%

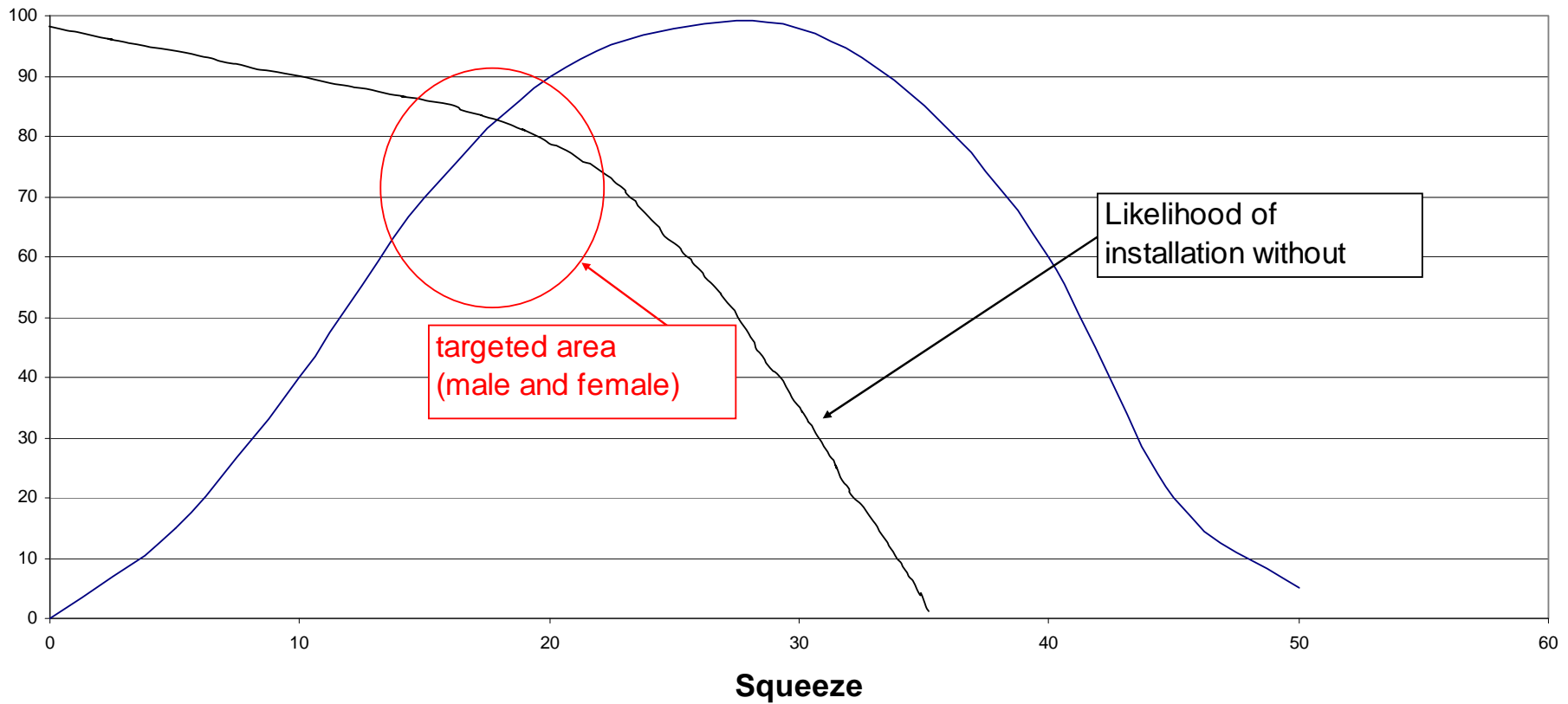
Squeeze and Service Life

O-Ring Service Life



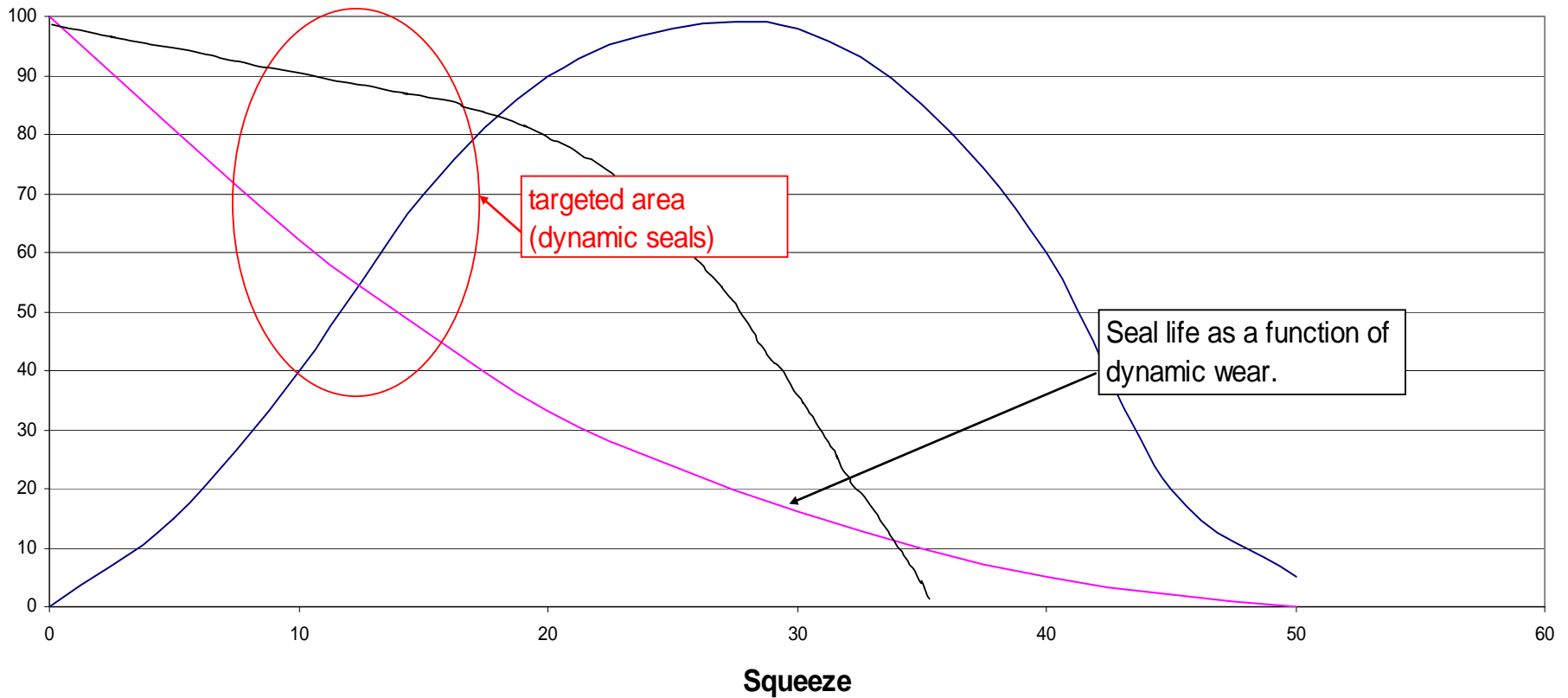
Squeeze and Service Life

O-Ring Service Life



Squeeze and Service Life

O-Ring Service Life



Gland Fill

O-Ring volume as a percentage of Gland volume.

$$\frac{\text{(O-Ring Volume)}}{\text{(Gland Volume)}}$$

About 25% void space or 75% nominal fill

- Need space in groove to allow for volume swell, thermal expansion, and increasing width due to squeeze
- Narrower groove for sealing vacuum or gas
- O-Ring can get squeezed out into clearance gap or get squeezed in two directions if fill approaches 100%.
- Greater than 100% is impossible – rubber materials are not compressible.
 - Results in pinching, tearing, or incomplete assembly.

Stretch

Groove diameter as a percentage of O-ring free-state ID.

$$\frac{(\text{Groove Diameter}) - (\text{O-Ring ID})}{(\text{O-Ring ID})}$$

General rule is 0-5%

Excessive stretch can overstress material

- Thins cross section and reduces squeeze
- The % cross section reduction due to stretch is equal to about half of the % ID stretch
- Possible breakage during installation

O-rings can be stretched diametrically to about half of the elongation percentage shown on a test report.

O-Rings

O-Rings are easy to design -- It's the O-Ring groove that needs special attention.

Static

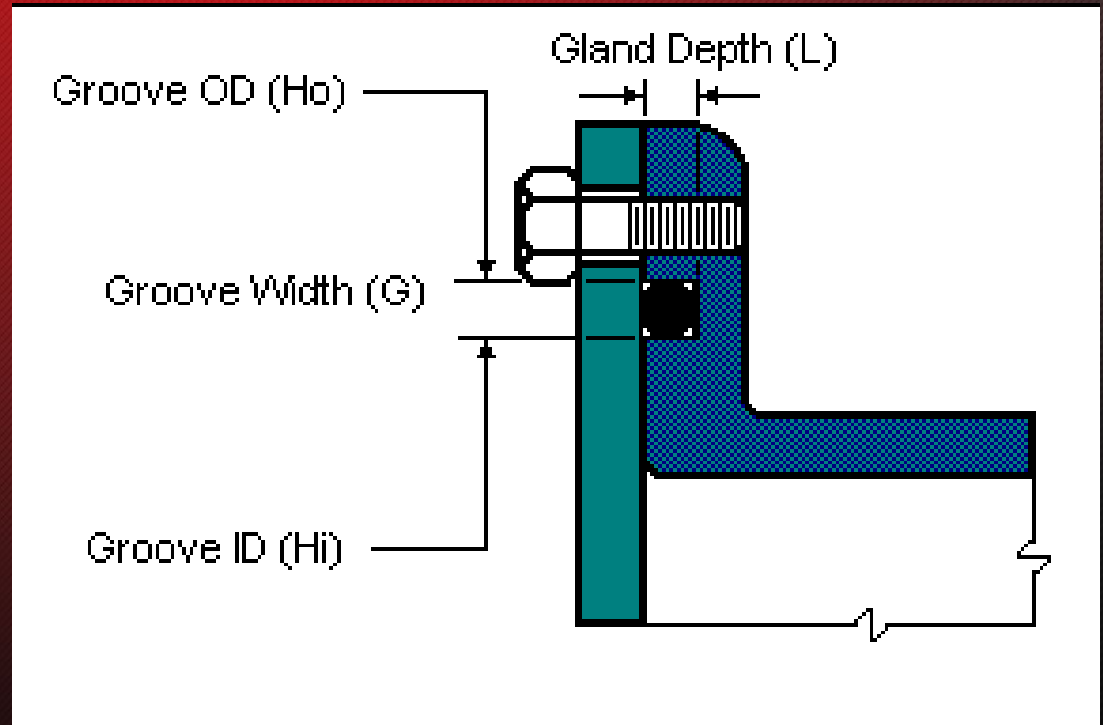
- Face Seal
- Dovetail Seal
- Radial (Male / Female) Seal
- Crush Seal
- Tube Fitting Seal

Dynamic

- Radial (Male / Female) Seal
- Rotary Seal (Female only)

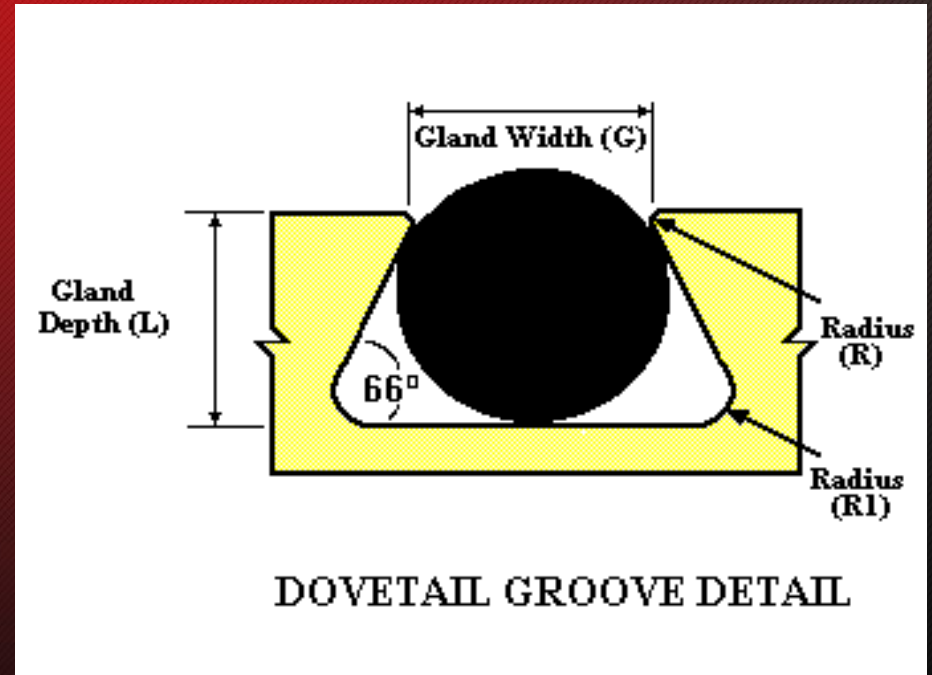
Face Seals

- No stretch
- 20 – 32% squeeze
- Up to 95% fill



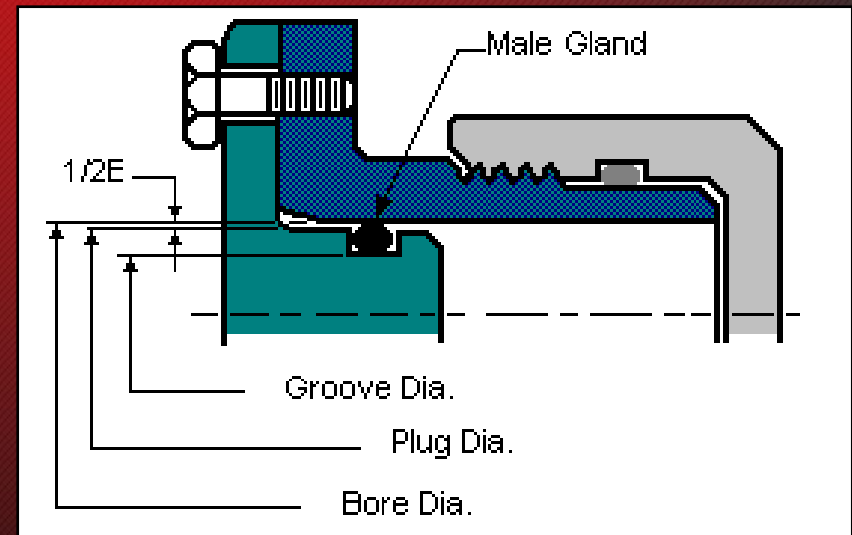
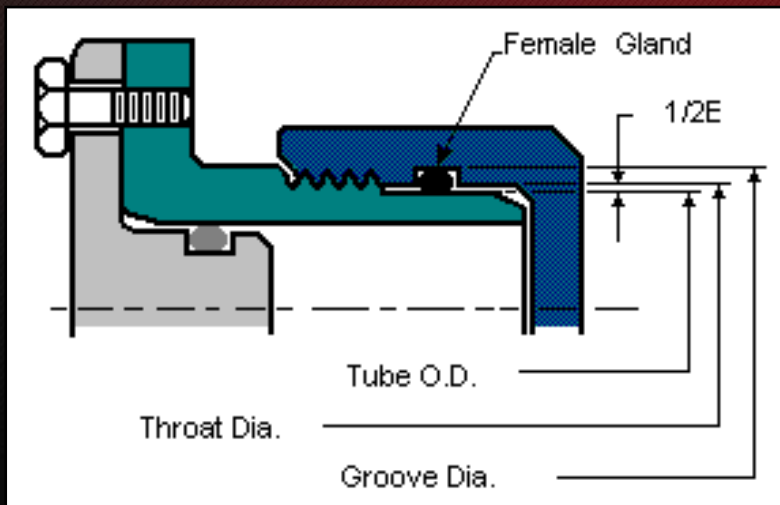
Dovetail / Half Dovetail

- No stretch
- Predesigned
- Hold O-Ring in Groove
- Expensive to machine



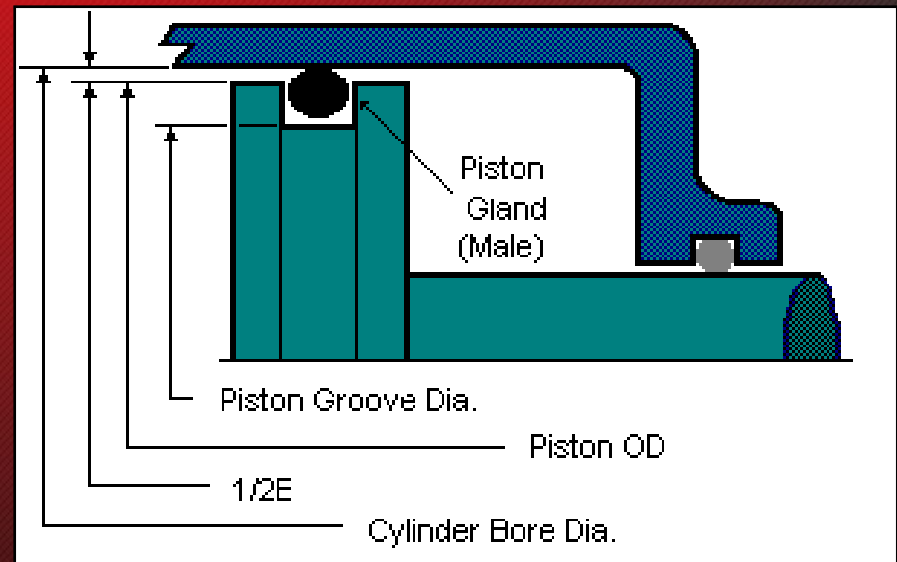
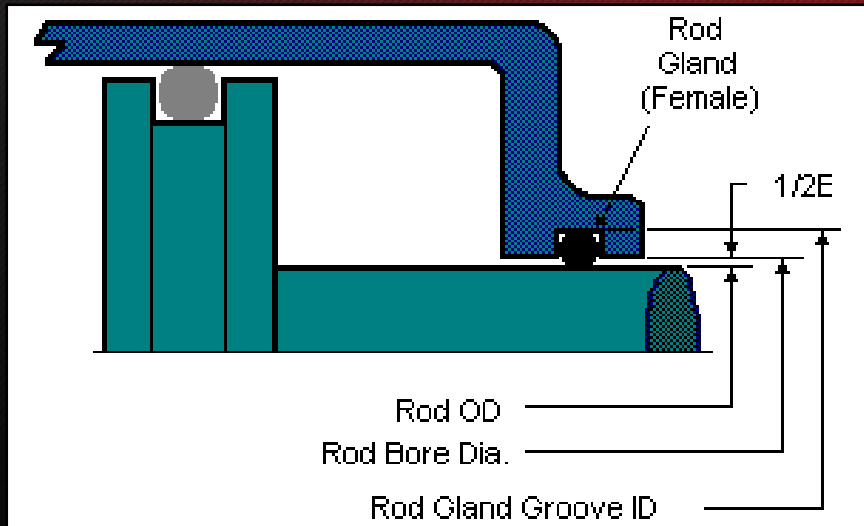
Male / Female Static Seals

- Up to 5% stretch
- 20 - 30% squeeze
- 70 - 90% fill



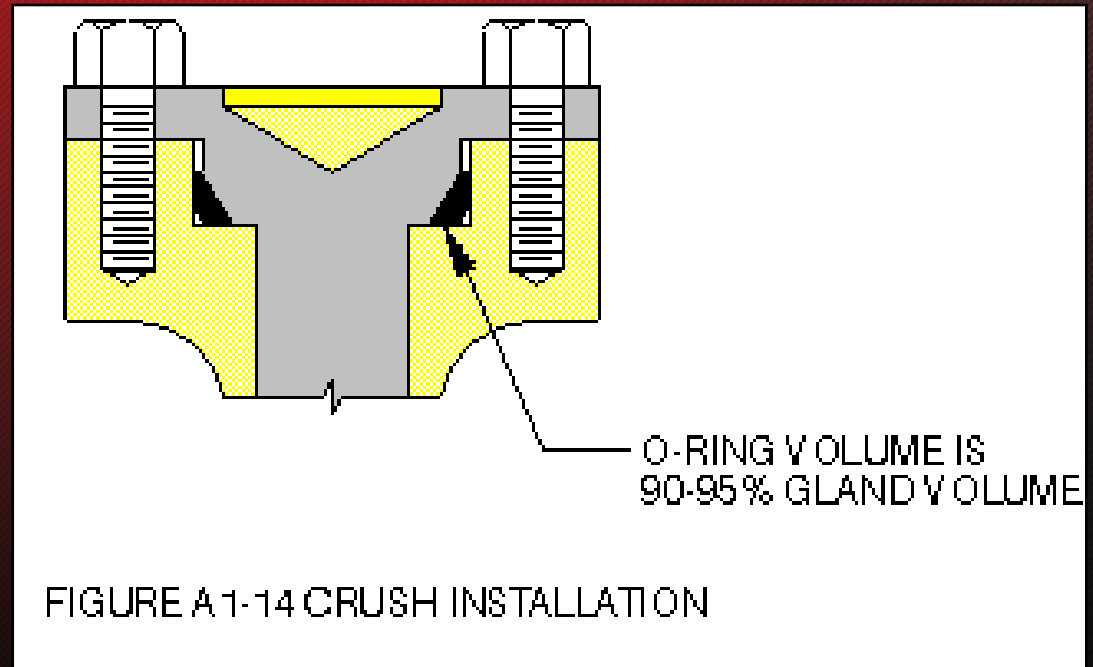
Male / Female Dynamic Seals

- Up to 5% stretch
- 10 - 20% squeeze
- 70 to 90% fill



Crush Seals

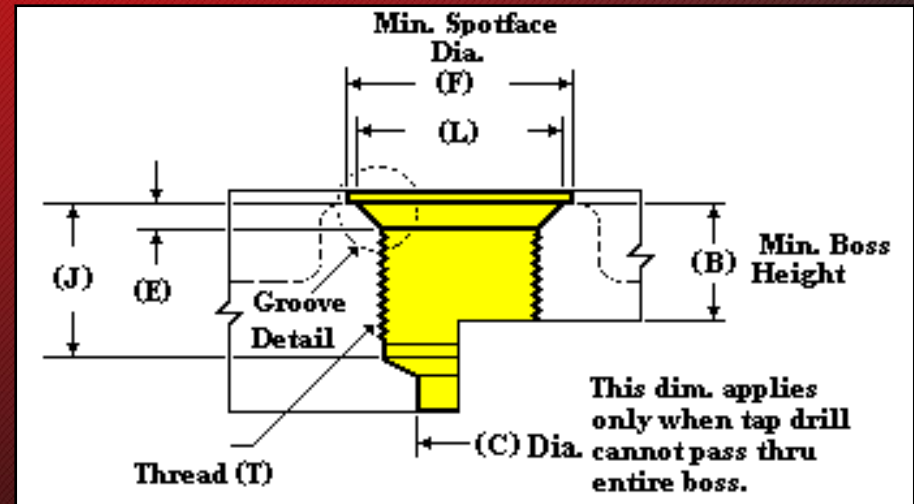
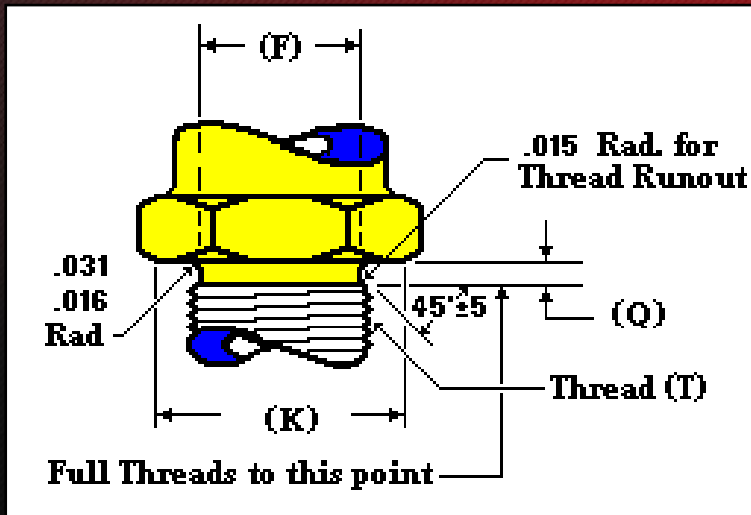
- No stretch
- Squeeze N/A
- 90 - 95% fill



$$\text{Legs} = 1.321 \times \text{CS of O-Ring}$$

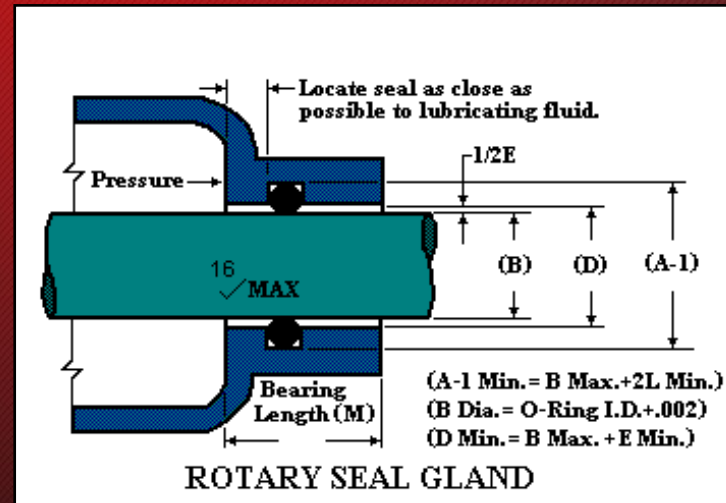
Tube Fitting Seals

- Predesigned
- 3-xxx O-Rings



Rotary Seals

- No stretch!
- 0 to 11% squeeze
- 90% gland fill
- Low fluid pressure
 - 800 psi max
- Low speed (1500 fpm max)
 - $FPM = RPM \times \text{shaft dia (inches)} \times 0.26$



O-Ring Failure

Diagnosis and Correction

O-Rings can Fail in many ways

Often an O-Ring fails from a combination of problems

- Extrusion and/or nibbling
- Compression Set
- Exceeding seal temperature limits
- Spiral Failure
- Explosive Decompression
- Abrasion
- Cuts From Installation and/or Sharp Edges
- Chemical Attack

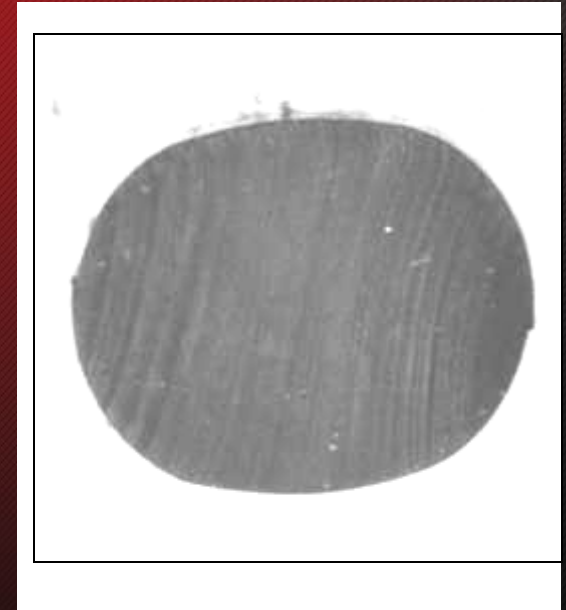
Compression Set

Looks like the seal has been flattened or deformed.

- Usually symmetrical.

Happens whenever rubber is compressed -- is accelerated by too much or too little squeeze, high temperatures, and incompatible fluids.

Can be lessened by using a more compression set resistant compound, adjusting the squeeze (if incorrect), lowering the temperature.



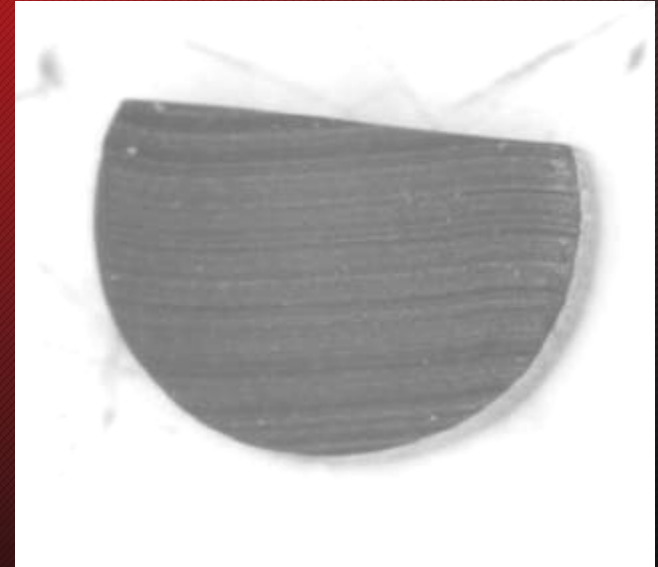
Abrasion

Looks like the seal is sanded off or flattened.

- Asymmetrical.

Happens whenever a rough surface or fine particles rub the seal.

Lubricating the ring better, smoothing out the surfaces, and cleaning out the seal area will reduce seal abrasion.



Low Temperature Failure

Seal leaks at low temperatures only.

As seal materials cool to within 15°F of their minimum operating temperature, they lose resilience. Any movement may allow leakage of low viscosity liquids and gases. Low temperature changes are not permanent and do not damage the seal.

Use a seal material with improved low temperature performance.

High Temperature Failure

Rubber “melts” or becomes brittle.

Every rubber polymer has a temperature above which it begins to break down. Thermal degradation is permanent and irreversible.

Use a seal material with improved high temperature performance or cool the seal gland area.

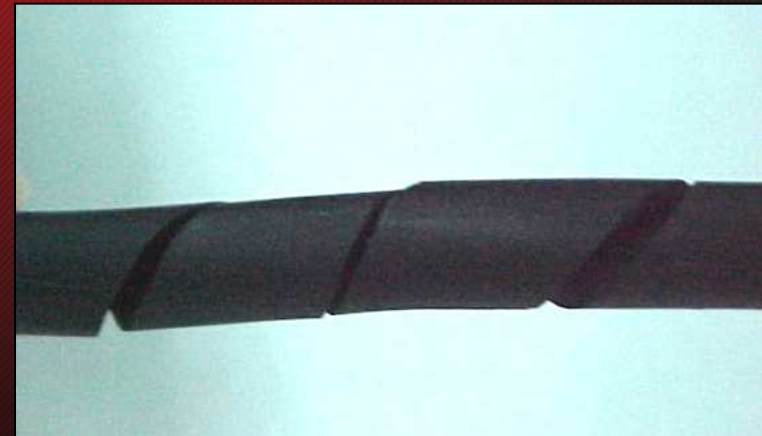
Extrusion and Nibbling

- Looks like one side of the seal is chewed off.
- Is caused by high pressure “pushing” the O-Ring into a gap between the metal surfaces.
- Is prevented by using a more extrusion-resistant compound, adding a back-up ring, lowering the pressure, or reducing the size of the low pressure clearance gap.



Spiral Failure

- Looks like a split wrapping around the ring.
- Happens when the seal on a piston or rod “grips” instead of slides in one spot (common with long, slow strokes).
- Can happen on static seals with pressure cycling.
- Can be prevented by using a smoother surface, lubricating uniformly, using a stiffer rubber compound, or using an engineered seal.



Explosive Decompression

- Looks like blisters and splits on the surface of the seal.
- Happens when gas pressure drops suddenly.
- Can be avoided by dropping the pressure slowly, or use a more explosive decompression resistant material (like V1248-95).



Cuts and Physical Damage

- Looks like the seal has been cut by a knife.
- Happens when the corners of the groove aren't rounded off, when the ring gets pinched, or when it passes over sharp metal edges.
- Fix it by "breaking" the corners of the groove, chamfering the parts to eliminate pinching, and covering sharp edges when the ring is installed.

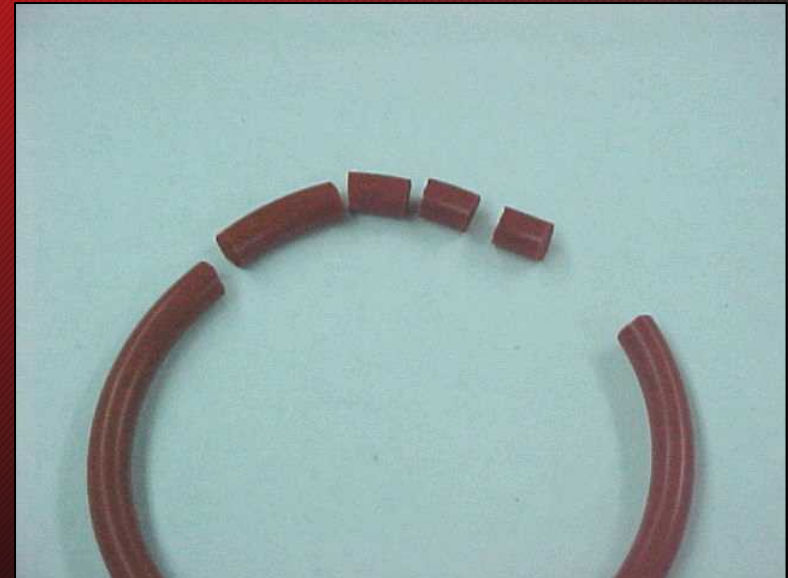


Chemical Attack

The seal swells a lot, shrinks, loses physical properties, or gets brittle.

The seal and the fluid don't work together

- Excessive swell, brittleness, and dramatic loss in physical properties: find a compatible base polymer.
- Shrinkage: the fluid is probably extracting something from the rubber -- change compounds (changing the base polymer usually isn't required.)



Cracks in Nitrile Rubber

- Nitrile rubber forms lots of tiny, little cracks along the OD or ID -- especially where it's stretched.
- Nitrile is not compatible with ozone or UV light. There is ozone in the air around us, and this can be enough to destroy an O-Ring.
- If the seal must be exposed to the environment, keep it lubed with a petroleum- or silicone- based fluid or use an ozone-resistant seal material.

