

Section II – Basic O-Ring Elastomers

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Basic O-Ring Elastomers

2.0 Elastomers

The basic core polymer of an elastomeric compound is called a rubber, produced either as natural gum rubber in the wild, on commercial rubber plantations or manufactured synthetically by the chemical industry. Today, more than 32 synthetic rubbers are known, the most important ones are listed in Table 2-1.

Modern elastomeric sealing compounds generally contain 50 to 60% base polymer and are often described simply as “rubber.” The balance of an elastomer compound consists of various fillers, vulcanizing agents, accelerators, aging retardants and other chemical additives which modify and improve the basic physical properties of the base polymer to meet the particular requirements of a specific application.

Elastomers used in producing seals, and particularly those used in O-rings, will usually provide reliable, leak-free function if fundamental design requirements are observed.

“Cross-linking” between the polymer chains is formed during the vulcanization process, see Figure 2-1. Cross-linking of the molecules changes the rubber from a plastic-like material to an elastic material.

After vulcanization, including any required “post-cure,” an elastomer compound attains the physical properties required for a good sealing material. As with all chemical reactions, temperature is responsible for the speed of reaction. Only when the ideal process temperature is constant during the entire vulcanization time, will the optimum degree of curing be reached. For this reason, the conditions of vulcanization are closely controlled and recorded as part of the Parker quality assurance process.

2.1 Introduction to Elastomers

Before reviewing the available elastomers and their general properties, it is necessary to fully understand the terms “polymer,” “rubber,” “elastomer” and “compound” as they are used in this handbook.

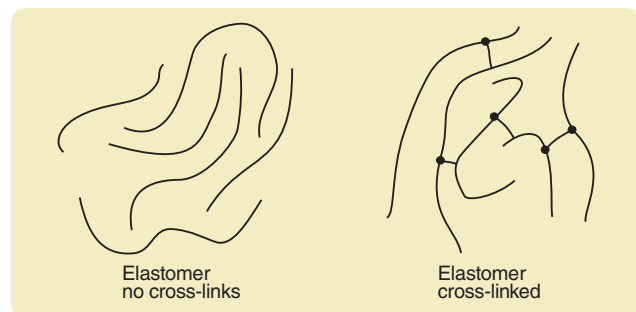


Figure 2-1: Schematic Representation of Polymer Chains Before and After Vulcanization

2.1.1 Polymer

A polymer is the “result of a chemical linking of molecules into a long chain-like structure.” Both plastics and elastomers are classified as polymers. In this handbook, polymer generally refers to a basic class of elastomer, members of which have similar chemical and physical properties. O-rings are made from many polymers, but a few polymers account for the majority of O-rings produced, namely Nitrile, EPDM and Neoprene.

Synthetic Rubber

Chemical Name	Abbreviation	
	DIN/ISO 1629	ASTM D1418
M-Group (saturated carbon molecules in main macro-molecule chain):		
Polyacrylate Rubber	ACM	ACM
Ethylene Acrylate	—	AEM
Chlorosulfonated Polyethylene Rubber	CSM	CSM
Ethylene Propylene Diene Rubber	EPDM	EPDM
Ethylene Propylene Rubber	EPDM	EPM
Fluorocarbon Rubber	FPM	FKM
Tetrafluorethylene Propylene Copolymer	FEPM	FEPM
Perfluorinated Elastomer	—	FFKM
O-Group (with oxygen molecules in the main macro-molecule chain):		
Epichlorohydrin Rubber	CO	CO
Epichlorohydrin Copolymer Rubber	ECO	ECO
R-Group (unsaturated hydrogen carbon chain):		
Butadiene Rubber	BR	BR
Chloroprene Rubber	CR	CR
Isobutene Isoprene Rubber (Butyl Rubber)	IIR	IIR
Chlorobutyl Rubber	CIIR	CIIR
Isoprene Rubber	IR	IR
Nitrile Butadiene Rubber	NBR	NBR
Styrene Butadiene Rubber	SBR	SBR
Hydrogenated Nitrile	—	HNBR
Carboxylated Nitrile	XNBR	XNBR
Q-Group (with Silicone in the main chain):		
Fluorosilicone Rubber	FMQ	FVMQ
Methyl Phenyl Silicone Rubber	PMQ	PMQ
Methyl Phenyl Vinyl Silicone Rubber	PMVQ	PVMQ
Methyl Silicone Rubber	MQ	MQ
Methyl Vinyl Silicone Rubber	VMQ	VMQ
U-Group (with carbon, oxygen and nitrogen in the main chain):		
Polyester Urethane	AU	AU
Polyether Urethane	EU	EU

Table 2-1: The Most Important Types of Synthetic Rubber, Their Groupings and Abbreviations

2.1.2 Rubber

Rubber-like materials first produced from sources other than rubber trees were referred to as “synthetic rubber.” This distinguished them from natural gum rubber. Since then, usage in the industry has broadened the meaning of the term “rubber” to include both natural as well as synthetic materials having rubber-like qualities. This handbook uses the broader meaning of the word “rubber.”

2.1.3 Elastomer

Though “elastomer” is synonymous with “rubber,” it is formally defined as a “high molecular weight polymer that can be, or has been modified, to a state exhibiting little plastic flow and rapid, nearly complete recovery from an extending or compressing force.” In most instances we call such material before modification “uncured” or “unprocessed” rubber or polymer.

When the basic high molecular weight polymer, without the addition of plasticizers or other diluents, is converted by appropriate means to an essentially non-plastic state and tested at room temperature, it usually meets the following requirements in order to be called an elastomer:

- A. It must not break when stretched approximately 100%.
- B. After being held for five minutes at 100% stretch, it must retract to within 10% of its original length within five minutes of release.

Note: Extremely high hardness/modulus materials generally do not exhibit these properties even though they are still considered elastomers.

The American Society for Testing and Materials (ASTM) uses these criteria to define the term “elastomer.”

2.1.4 Compound

A compound is a mixture of base polymer and other chemicals that form a finished rubber material. More precisely, a compound refers to a specific blend of chemical ingredients tailored for particular required characteristics to optimize performance in some specific service.

The basis of compound development is the selection of the polymer type. There may be a dozen or more different ones to choose from. The rubber compounder may then add various reinforcing agents such as carbon black, curing or

vulcanizing agents (such as sulfur or peroxide, activators, plasticizers, accelerators, antioxidants, or antiozonants) to the elastomer mixture to tailor it into a seal compound with its own distinct physical properties. Since compounders have thousands of compounding ingredients at their disposal, it seems reasonable to visualize two, three, or even one hundred-plus compounds having the same base elastomer, yet exhibiting marked performance differences in the O-ring seal.

The terms “compound” and “elastomer” are often used interchangeably in a more general sense. This usage usually references a particular type or class of materials such as “nitrile compounds” or “butyl elastomers.” Please remember that when one specific compound is under discussion in this handbook, it is a blend of various compounding ingredients (including one or more base elastomers) with its own individual characteristics and identification in the form of a unique compound number. For example, N0674-70 or V1164-75.

2.2 Basic Elastomers for O-Ring Seals

The following paragraphs briefly review the various elastomers currently available for use in O-rings and other elastomeric seals. If any of the rubber terms used in the descriptions are confusing, consult the “Glossary of Seal and Rubber Terms” in the Appendix, Section X. Service recommendations mentioned in this section are necessarily abbreviated. For more comprehensive and specific information on this important subject, see the Fluid Compatibility Tables in Section VII.

2.2.1 Acrylonitrile-Butadiene (NBR)

Nitrile rubber (NBR) is the general term for acrylonitrile butadiene copolymer. The acrylonitrile content of nitrile sealing compounds varies considerably (18% to 50%) and influences the physical properties of the finished material.

The higher the acrylonitrile content, the better the resistance to oil and fuel. At the same time, elasticity and resistance to compression set is adversely affected. In view of these opposing realities, a compromise is often drawn, and a medium acrylonitrile content selected. NBR has good mechanical properties when compared with other elastomers and high wear resistance. NBR is not resistant to weathering and ozone. See Figure 2-2.

Heat resistance

- Up to 100°C (212°F) with shorter life @ 121°C (250°F).

Cold flexibility

- Depending on individual compound, between -34°C and -57°C (-30°F and -70°F).

Chemical resistance

- Aliphatic hydrocarbons (propane, butane, petroleum oil, mineral oil and grease, diesel fuel, fuel oils) vegetable and mineral oils and greases.
- HFA, HFB and HFC hydraulic fluids.
- Dilute acids, alkali and salt solutions at low temperatures.
- Water (special compounds up to 100°C) (212°F).

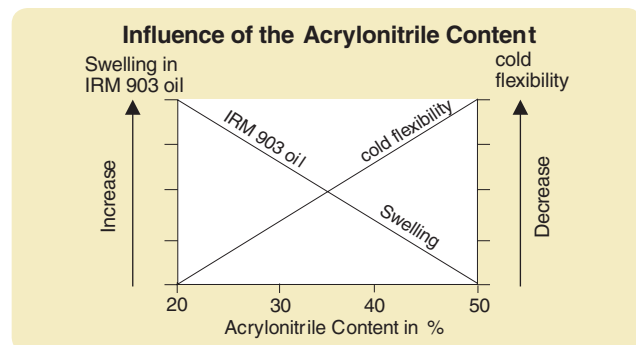


Figure 2-2: Influence of the Acrylonitrile Content

Not compatible with:

- Fuels of high aromatic content (for flex fuels a special compound must be used).
- Aromatic hydrocarbons (benzene).
- Chlorinated hydrocarbons (trichloroethylene).
- Polar solvents (ketone, acetone, acetic acid, ethylene-ester).
- Strong acids.
- Brake fluid with glycol base.
- Ozone, weather and atmospheric aging.

2.2.2 Carboxylated Nitrile (XNBR)

Carboxylated Nitrile (XNBR) is a special type of nitrile polymer that exhibits enhanced tear and abrasion resistance. For this reason, XNBR based materials are often specified for dynamic applications such as rod seals and rod wipers.

Heat resistance

- Up to 100°C (212°F) with shorter life @ 121°C (250°F).

Cold flexibility

- Depending on individual compound, between -18°C and -48°C (0°F and -55°F).

Chemical resistance

- Aliphatic hydrocarbons (propane, butane, petroleum oil, mineral oil and grease, diesel fuel, fuel oils) vegetable and mineral oils and greases.
- HFA, HFB and HFC hydraulic fluids.
- Many diluted acids, alkali and salt solutions at low temperatures.

Not compatible with:

- Fuels of high aromatic content (for flex fuels a special compound must be used).
- Aromatic hydrocarbons (benzene).
- Chlorinated hydrocarbons (trichloroethylene).
- Polar solvents (ketone, acetone, acetic acid, ethylene-ester).
- Strong acids.
- Brake fluid with glycol base.
- Ozone, weather and atmospheric aging.

2.2.3 Ethylene Acrylate (AEM, Vamac)

Ethylene acrylate is a terpolymer of ethylene and methyl acrylate with the addition of a small amount of carboxylated curing monomer. Ethylene acrylate rubber is not to be confused with polyacrylate rubber (ACM).

Heat resistance

- Up to 149°C (300°F) with shorter life up to 163°C (325°F).

Cold flexibility

- Between -29°C and -40°C (-20°F and -40°F).

Chemical resistance

- Ozone.
- Oxidizing media.
- Moderate resistance to mineral oils.

Not compatible with:

- Ketones.
- Fuels.
- Brake fluids.

2.2.4 Ethylene Propylene Rubber (EPR, EPDM)

EPR copolymer ethylene propylene and ethylene-propylene-diene rubber (EPDM) terpolymer are particularly useful when sealing phosphate-ester hydraulic fluids and in brake systems that use fluids having a glycol base.

Heat resistance

- Up to 150°C (302°F) (max. 204°C (400°F)) in water and/or steam).

Cold flexibility

- Down to approximately -57°C (-70°F).

Chemical resistance

- Hot water and steam up to 149°C (300°F) with special compounds up to 260°C (500°F).
- Glycol based brake fluids (Dot 3 & 4) and silicone-based brake fluids (Dot 5) up to 149°C (300°F).
- Many organic and inorganic acids.
- Cleaning agents, sodium and potassium alkalis.
- Phosphate-ester based hydraulic fluids (HFD-R).
- Silicone oil and grease.
- Many polar solvents (alcohols, ketones, esters).
- Ozone, aging and weather resistant.

Not compatible with:

Mineral oil products (oils, greases and fuels).

2.2.5 Butyl Rubber (IIR)

Butyl (isobutylene, isoprene rubber, IIR) has a very low permeability rate and good electrical properties.

Heat resistance

- Up to approximately 121°C (250°F).

Cold flexibility

- Down to approximately -59°C (-75°F).

Chemical resistance

- Hot water and steam up to 121°C (250°F).
- Brake fluids with glycol base (Dot 3 & 4).
- Many acids (see Fluid Compatibility Tables in Section VII).
- Salt solutions.
- Polar solvents, (e.g. alcohols, ketones and esters).
- Poly-glycol based hydraulic fluids (HFC fluids) and phosphate-ester bases (HFD-R fluids).
- Silicone oil and grease.
- Ozone, aging and weather resistant.

Not compatible with:

- Mineral oil and grease.
- Fuels.
- Chlorinated hydrocarbons.

2.2.6 Chloroprene Rubber (CR)

Chloroprene was the first synthetic rubber developed commercially and exhibits generally good ozone, aging and chemical resistance. It has good mechanical properties over a wide temperature range.

Heat resistance

- Up to approximately 121°C (250°F).

Cold flexibility

- Down to approximately -40°C (-40°F).

Chemical resistance

- Paraffin based mineral oil with low DPI, e.g. ASTM oil No. 1.
- Silicone oil and grease.
- Water and water solvents at low temperatures.
- Refrigerants
- Ammonia
- Carbon dioxide
- Improved ozone, weathering and aging resistance compared with nitrile.

Limited compatibility

- Naphthalene based mineral oil (IRM 902 and IRM 903 oils).
- Low molecular weight aliphatic hydrocarbons (propane, butane, fuel).
- Glycol based brake fluids.

Not compatible with:

- Aromatic hydrocarbons (benzene).
- Chlorinated hydrocarbons (trichloroethylene).
- Polar solvents (ketones, esters, ethers).

2.2.7 Fluorocarbon (FKM)

Fluorocarbon (FKM) has excellent resistance to high temperatures, ozone, oxygen, mineral oil, synthetic hydraulic fluids, fuels, aromatics and many organic solvents and chemicals. Low temperature resistance is normally not favorable and for static applications is limited to approximately -26°C (-15°F) although certain compounds are suitable down to -46°C (-50°F). Under dynamic conditions, the lowest service temperature is between -15°C and -18°C (5°F and 0°F).

Gas permeability is very low and similar to that of butyl rubber. Special FKM compounds exhibit an improved resistance to acids and fuels.

Heat resistance

- Up to 204°C (400°F) and higher temperatures with shorter life expectancy.

Cold flexibility

- Down to -26°C (-15°F) (some to -46°C (-50°F)).

Chemical resistance

- Mineral oil and grease, ASTM oil No. 1, and IRM 902 and IRM 903 oils.
- Non-flammable hydraulic fluids (HFD).
- Silicone oil and grease.
- Mineral and vegetable oil and grease.

- Aliphatic hydrocarbons (butane, propane, natural gas).
- Aromatic hydrocarbons (benzene, toluene).
- Chlorinated hydrocarbons (trichloroethylene and carbon tetrachloride).
- Gasoline (including high alcohol content).
- High vacuum.
- Very good ozone, weather and aging resistance.

Not compatible with:

- Glycol based brake fluids.
- Ammonia gas, amines, alkalis.
- Superheated steam.
- Low molecular weight organic acids (formic and acetic acids).

2.2.8 Fluorosilicone (FVMQ)

FVMQ contains trifluoropropyl groups next to the methyl groups. The mechanical and physical properties are very similar to VMQ. However, FVMQ offers improved fuel and mineral oil resistance but poor hot air resistance when compared with VMQ.

Heat resistance

- Up to 177°C (350°F) max.

Cold flexibility

- Down to approximately -73°C (-100°F).

Chemical resistance

- Aromatic mineral oils (IRM 903 oil).
- Fuels.
- Low molecular weight aromatic hydrocarbons (benzene, toluene).

2.2.9 Hydrogenated Nitrile (HNBR, HSN)

Hydrogenated nitrile is a synthetic polymer that results from the hydrogenation of nitrile rubber (NBR). Superior mechanical characteristics, particularly high strength, helps reduce extrusion and wear.

Heat resistance

- Up to 150°C (300°F)

Cold flexibility

- Down to approximately -48°C (-55°F)

Chemical resistance

- Aliphatic hydrocarbons.
- Vegetable and animal fats and oils.
- HFA, HFB and HFC hydraulic fluids.
- Dilute acids, bases and salt solutions at moderate temperatures.
- Water and steam up to 149°C (300°F).
- Ozone, aging and weathering.

Not compatible with:

- Chlorinated hydrocarbons.
- Polar solvents (ketones, esters and ethers).
- Strong acids.

2.2.10 Perfluoroelastomer (FFKM)

Perfluoroelastomer (FFKM) currently offers the highest operating temperature range, the most comprehensive chemical compatibility, and the lowest off-gassing and extractable levels of any rubber material. Parker's proprietary formulations deliver an extreme performance spectrum that make them ideal for use in critical applications like semiconductor chip manufacturing, jet engines and chemical processing equipment.

Heat resistance

- Up to 320°C (608°F).

Cold flexibility

- -18°C to -26°C (0°F to -15°F).

Chemical resistance

- Aliphatic and aromatic hydrocarbons.
- Chlorinated hydrocarbons.
- Polar solvents (ketones, esters, ethers).
- Inorganic and organic acids.
- Water and steam.
- High vacuum with minimal loss in weight.

Not compatible with:

- Fluorinated refrigerants (R11, 12, 13, 113, 114, etc.)
- Perfluorinated lubricants (PFPE)

2.2.11 Polyacrylate (ACM)

ACM (acrylic rubber) has good resistance to mineral oil, oxygen and ozone. Water compatibility and cold flexibility of ACM are significantly worse than with nitrile.

Heat resistance

- Up to approximately 177°C (350°F).

Cold flexibility

- Down to approximately -21°C (-5°F).

Chemical resistance

- Mineral oil (engine, gear box, ATF oil).
- Ozone, weather and aging.

Not compatible with:

- Glycol based brake fluid (Dot 3 and 4).
- Aromatics and chlorinated hydrocarbons.
- Hot water, steam.
- Acids, alkalis, amines.

2.2.12 Polyurethane (AU, EU)

Polyurethane elastomers, as a class, have excellent wear resistance, high tensile strength and high elasticity in comparison with any other elastomers. Permeability is good and comparable with butyl.

Heat resistance

- Up to approximately 82°C (180°F).

Cold flexibility

- Down to approximately -40°C (-40°F).

Chemical resistance

- Pure aliphatic hydrocarbons (propane, butane).
- Mineral oil and grease.
- Silicone oil and grease.
- Water up to 50°C (125°F).

Not compatible with:

- Ketones, esters, ethers, alcohols, glycols.
- Hot water, steam, alkalis, amines, acids.

2.2.13 Silicone Rubber (Q, MQ, VMQ, PVMQ)

Silicones have good ozone and weather resistance as well as good insulating and physiologically neutral properties. However, silicone elastomers as a group, have relatively low tensile strength, poor tear strength and little wear resistance.

Heat resistance

- Up to approximately 204°C (400°F) special compounds up to 260°C (500°F).

Cold flexibility

- Down to approximately -54°C (-65°F) special compounds down to -115°C (-175°F).

Chemical resistance

- Animal and vegetable oil and grease.
- High molecular weight chlorinated aromatic hydrocarbons (including flame-resistant insulators, and coolant for transformers).
- Moderate water resistance.
- Diluted salt solutions.
- Ozone, aging and weather.

Not compatible with:

- Superheated water steam over 121°C (250°F).
- Acids and alkalis.
- Low molecular weight chlorinated hydrocarbons (trichloroethylene).
- Hydrocarbon based fuels.
- Aromatic hydrocarbons (benzene, toluene).
- Low molecular weight silicone oils.

2.2.14 Tetrafluoroethylene-Propylene (AFLAS)

This elastomer is a copolymer of tetrafluoroethylene (TFE) and propylene. Its chemical resistance is excellent across a wide range of aggressive media.

Heat resistance

- Up to approximately 232°C (450°F).

Cold flexibility

- Down to approximately -9°C (15°F).

Compatible with

- Bases.
- Phosphate Esters.
- Amines.
- Engine Oils.
- Steam and hot water.
- Pulp and paper liquors.

Not compatible with:

- Aromatic Fuels.
- Ketones.
- Chlorinated hydrocarbons.

2.3 Compound Selection and Numbering Systems

The base elastomer and the hardness of the *finished* product are the main factors which enable a given compound to resist heat, chemical and other physical influences.

The Parker compound code contains all the essential information needed to identify the polymer family as well as the special property description and hardness.

In the Type I numbering system, the base polymer of the compound is identified by the prefix letter:

- A = Polyacrylate
- B = Butyl or chlorobutyl
- C = Neoprene
- E = Ethylene-propylene or ethylene propylene diene
- F = Parofluor Ultra
- H = Hifluor
- K = Hydrogenated nitrile
- L = Fluorosilicone
- N = Acrylonitrile butadiene (nitrile),
hydrogenated nitrile and carboxylated nitrile
- P = Polyurethane
- S = Silicone
- V = Fluorocarbon, AFLAS, Parofluor and Hifluor
- Z = Exotic or specialty blends

In the Type II numbering system, the special property description is identified by a second letter:

- A = General purpose
- B = Low compression set
- E = Ethylene acrylate
- F = Fuel resistant or fully fluorinated
- G = High fluorine content
- J = NSF/FDA/WRAS approvals
- L = Internally lubed
- M = MIL/AMS approvals
- P = Low temperature or AFLAS
- W = Non-black compound
- S = Carboxylated

The shore hardness range of a compound is indicated by the suffix numbers, e.g. "70" means that the material's hardness is 70±5 Shore A.

The individual sequential compound number is shown between the suffix and the prefix.

Type I Example: N0674-70 where

- N = Acrylonitrile-butadiene or simply nitrile
- 0674 = Individual sequential compound identifier
- 70 = Nominal Shore A hardness

Type II Example: NA151-70 where

- N = Acrylonitrile-butadiene or simply nitrile
- A = General purpose
- 151 = Individual sequential compound identifier
- 70 = Nominal Shore A hardness

2.3.1 Selection of Base Polymer

System operating temperatures and compatibility with the media to be sealed are the two most important parameters which must be considered when selecting a base polymer. Only when these two factors are identified (including any lubricants and potential cleaning fluids), can a reliable recommendation be given concerning selection of the proper elastomer base. For the seal designed, a compromise often has to be made between specifying high quality, sealing grade materials and cheaper commercial products (which usually contain less base polymer and more inexpensive fillers).

The application temperatures given in Figure 2-3 refer to long-term exposure to non-aggressive media. At higher temperatures, new crosslink sites may be formed between the polymer chains and lead to a loss of seal flexibility. The stiffness in the polymer chains may be observed as excessive compression set in highly filled (loaded) compounds. This condition prevents an O-ring cross-section from returning to its original, pre-compressed shape after deformation forces are removed. During compression, a seal changes its original shape to effect a seal and over time, and with excessive temperature, elastic memory loss in the elastomer seal element can cause leakage. Exceeding the normal maximum temperature limit for a given compound always results in reduced service life.

Practically all elastomers undergo a physical or chemical change when in contact with a sealed medium. The degree of change depends on the chemistry of the medium and on the system temperature. An aggressive medium becomes more active with increasing temperature. Physical changes are caused by three mechanisms which can work concurrently when:

- a. The elastomer absorbs a medium.
- b. Plasticizers and other components of the compound are dissolved and extracted or leached out by the media.
- c. Chemical reactions between the elastomer and the sealed medium.

The result is often volume change, i.e. swelling or shrinkage of the elastomer seal. The degree of volume change depends on the type of medium, molecular structure of the rubber compound, system temperature, geometrical seal shape (material thickness), and the stressed condition of the rubber part (compression or stretch). When deformed and exposed to a medium, rubber, when confined in a gland, swells significantly less than in free state (up to 50%) due to a number of factors including lessened surface area in contact with the medium.

The limit of permissible volume change varies with the application. For static seals, a volume change of 25% to 30% can be tolerated. Swelling leads to some deterioration of the mechanical properties, and in particular, those properties which improve extrusion resistance.

In dynamic applications, swelling leads to increased friction and a higher wear rate. Therefore, a maximum swell of 10% should generally not be exceeded. Shrinkage should also be avoided because the resulting loss of compressive force will increase the risk of leakage.

The extraction of plasticizer from a seal material is sometimes compensated for by partial absorption of the contact medium. This situation however, can still lead to unexpected shrinkage and resultant leakage when an elastomer dries out and the absorbed fluids evaporate.

A chemical reaction between sealed or excluded medium and the elastomer can bring about structural changes in the form of further crosslinking or degrading. The smallest chemical change in an elastomer can lead to significant changes in physical properties, such as embrittlement.

The suitability of an elastomer for a specific application can be established only when the properties of both the medium and the elastomer are known under typical **working** conditions. If a particular seal material suits a medium, it is referred to as being “compatible” with that medium. See Table 2-2 for a comparison of the properties of commonly used elastomers.

2.4 Physical and Chemical Characteristics

In addition to the basic elastomer descriptions, it is helpful have more information on the important physical and chemical properties of various elastomer compounds. This information is needed to provide a clearer picture of how physical and chemical properties interact and affect the proper selection of an effective seal material. Among the more basic physical properties that have to be considered are:

2.4.1 Resistance to Fluid

As used throughout this handbook, the term “fluid” denotes the substance retained by the seal. It may be a solid, a liquid, a gas, a vapor or a mixture of all. (The term “medium” — plural “media” — is often used with this same meaning intended.)

The chemical effect of the fluid on the seal is of prime importance. The fluid must not alter the operational characteristics or reduce the life expectancy of the seal significantly. Excessive chemical deterioration of the seal must be avoided. It is easy, however, to be misled on this point. A significant amount of volume shrinkage usually results in premature leakage of any

Temperature Range for Common Elastomeric Materials

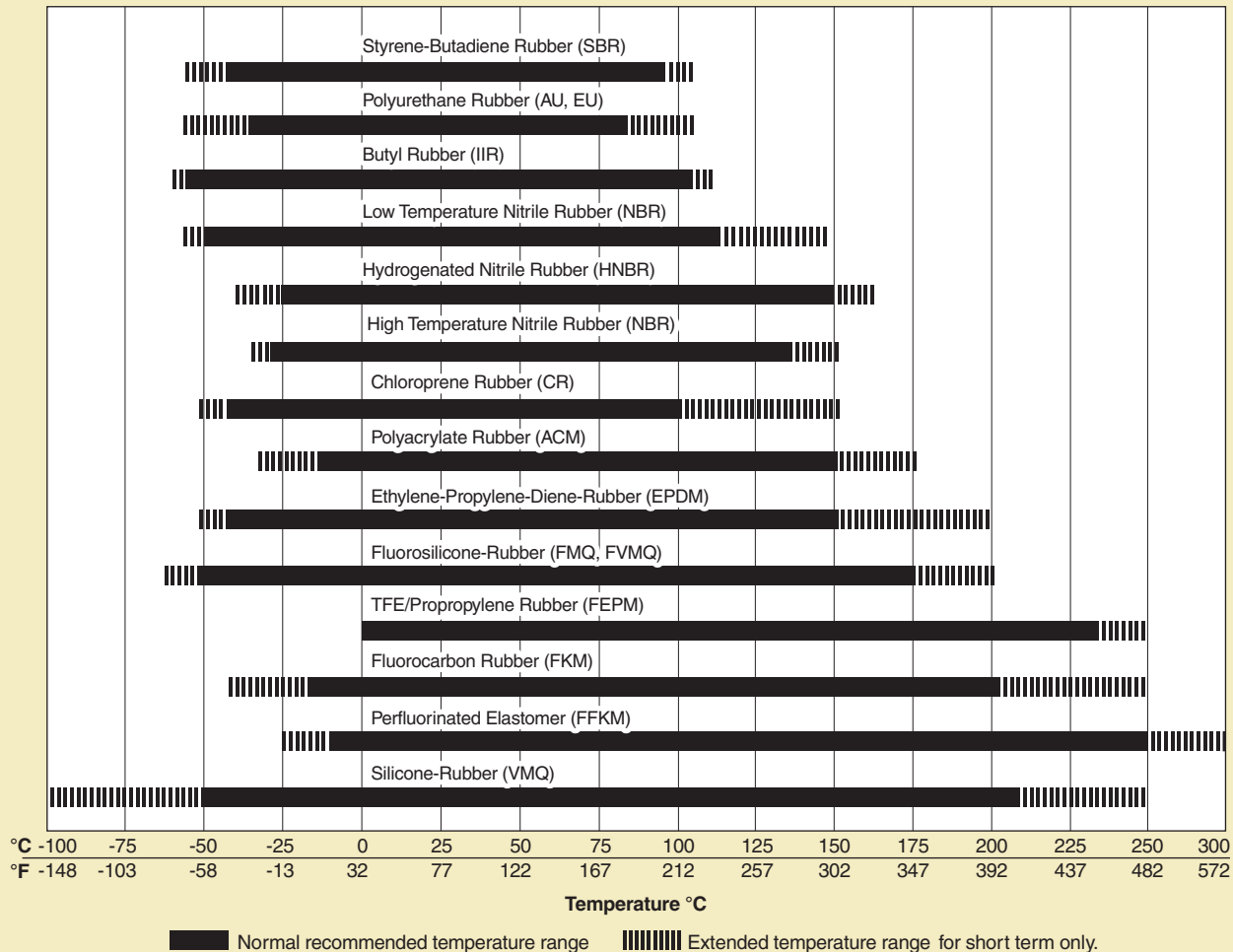


Figure 2-3: Temperature Range for Common Elastomeric Materials

O-ring seal, whether static or dynamic. On the other hand, a compound that swells excessively in a fluid, or develops a large increase or decrease in hardness, tensile strength, or elongation, will often continue to serve well for a long time as a static seal in spite of such undesirable conditions.

2.4.2 Hardness

Throughout the seal industry, the Shore A type durometer scale, manufactured by a variety of manufacturers, is the standard instrument used to measure the hardness of most rubber compounds. It should be noted that there are other hardness scales used to describe elastomers (B, C, D, DO, O, OO) but these are typically not used by the rubber seal industry.

The durometer has a calibrated spring which forces an indenter point into the test specimen against the resistance of the

rubber. The indicating scale reads the hardness of the rubber. If there is no penetration, the scale will read 100, as on a flat glass or steel surface. (For specimens that are too thin or provide too small an area for accurate durometer readings, Micro Hardness Testing is recommended).

In the O-ring industry, another hardness scale is used due to the curved surface of the O-ring cross-section causing problems with accurately reading Shore A. The scale is IRHD (International Rubber Hardness Degrees). The size and shape of the indenter used in IRHD readings is much smaller, thus allowing for more accurate measurements on curved surfaces such as an O-ring cross-section. Unfortunately, there is not a direct correlation between the readings of Shore A and IRHD Scales.

Comparison of Properties of Commonly Used Elastomers
(P = Poor – F = Fair – G = Good – E = Excellent)

Elastomer Type (Polymer)	Parker Compound Prefix Letter	Abrasion Resistance	Acid Resistance	Chemical Resistance	Cold Resistance	Dynamic Properties	Electrical Properties	Flame Resistance	Heat Resistance	Impermeability	Oil Resistance	Ozone Resistance	Set Resistance	Tear Resistance	Tensile Strength	Water/Steam Resistance	Weather Resistance
AFLAS (TFE/Prop)	V	GE	E	E	P	G	E	E	E	G	E	E	PF	PF	FG	GE	E
Butadiene		E	FG	FG	G	F	G	P	F	F	P	P	G	GE	E	FG	F
Butyl	B	FG	G	E	G	F	G	P	G	E	P	GE	FG	G	G	G	GE
Chlorinated Polyethylene		G	F	FG	PF	G	G	GE	G	G	FG	E	F	FG	G	F	E
Chlorosulfonated Polyethylene		G	G	E	FG	F	F	G	G	G	F	E	F	G	F	F	E
Epichlorohydrin	Y	G	FG	G	GE	G	F	FG	FG	GE	E	E	PF	G	G	F	E
Ethylene Acrylic	A	F	F	FG	G	F	F	P	E	E	F	E	G	F	G	PF	E
Ethylene Propylene	E	GE	G	E	GE	GE	G	P	G	G	P	E	GE	GE	GE	E	E
Fluorocarbon	V	G	E	E	PF	GE	F	E	E	G	E	E	E	F	GE	F	E
Fluorosilicone	L	P	FG	E	GE	P	E	G	E	P	G	E	G	P	F	F	E
Isoprene		E	FG	FG	G	F	G	P	F	F	P	P	G	GE	E	FG	F
Natural Rubber		E	FG	FG	G	E	G	P	F	F	P	P	G	GE	E	FG	F
Neoprene	C	G	FG	FG	FG	F	F	G	G	G	FG	GE	F	FG	G	F	E
HNBR	N, K	G	E	FG	G	GE	F	P	E	G	E	G	GE	FG	E	E	G
Nitrile or Buna N	N	G	F	FG	G	GE	F	P	G	G	E	P	GE	FG	GE	FG	F
Perfluorinated Fluoroelastomer	V, F	P	E	E	PF	F	E	E	E	G	E	E	G	PF	FG	GE	E
Polyacrylate	A	G	P	P	P	F	F	P	E	E	E	E	F	FG	F	P	E
Polysulfide		P	P	G	G	F	F	P	P	E	E	E	P	P	F	F	E
Polyurethane	P	E	P	FG	G	E	FG	P	F	G	G	E	F	GE	E	P	E
SBR or Buna S		G	F	FG	G	G	G	P	FG	F	P	P	G	FG	GE	FG	F
Silicone	S	P	FG	GE	E	P	E	F	E	P	FG	E	GE	P	P	F	E

Table 2-2: Comparison of Properties of Commonly Used Elastomers

Softer sealing materials, with lower hardness readings, will flow more easily into the microfine grooves and imperfections of the mating parts (the gland, bore, rod or seal flanges). This is particularly important in low-pressure seals because they are not activated by fluid pressure. Conversely, the harder materials offer greater resistance to extrusion. Referring back to the O-ring seal diagrams, Figures 1-4 through 1-7, it can be seen that a harder O-ring will have greater resistance to extrusion into the narrow gap between the piston and bore. There are certain applications in which the compressive load available for assembly is limited. In these situations, Figures 2-4 through 2-8 are helpful, providing compression load requirements for O-rings of different hardnesses, for each of the five standard O-ring cross-sections.

In dynamic applications, the hardness of the O-ring is doubly important because it also affects both breakout and running friction. Although a harder compound will, in general, have a lower coefficient of friction than a softer material, the actual running and breakout friction values are actually higher because the compressive load required to achieve the proper squeeze and force the harder material into a given O-ring cavity is so much greater.

For most applications, compounds having a Shore A durometer hardness of 70 to 80 is the most suitable compromise. This is particularly true of dynamic applications where 90 durometer or harder compounds often allow a few drops of fluid to pass with each cycle, and 50 durometer compounds tend to abrade, wear, and extrude very quickly.

Normally durometer hardness is referred to in increments of five or ten, as **60** durometer, **75** durometer, etc. — not as **62** durometer, **66** durometer or **73** durometer. This practice is based on:

- (1) The fact that durometer is generally called out in specifications with a tolerance of ± 5 (i.e., 65 ± 5 , 70 ± 5 , 90 ± 5);
- (2) The inherent minor variance from batch to batch of a given rubber compound due to slight differences in raw materials and processing techniques; and
- (3) The human variance encountered in reading durometer hardness. On a 70-durometer stock, for example, one person might read 69 and another 71. This small difference is to be expected and is considered to be within acceptable experimental error and the accuracy of the testing equipment.

2.4.3 Toughness

Toughness is not a measured property or parameter but rather a qualitative term frequently used to summarize the combination of resistance to physical forces other than chemical action. It is used as a relative term in practice. The following six terms (paragraphs 2.4.4 through 2.4.9) are major indicators of, and describe the “toughness” of a compound.

2.4.4 Tensile Strength

Tensile strength is measured as the psi (pounds per square inch) or MPa (Mega Pascals) required to rupture a specimen of a given elastomer material when stressed. Tensile strength is one quality assurance measurement used to insure compound uniformity. It is also useful as an indication of deterioration of the compound after it has been in contact with a fluid for long periods. If fluid contact results in only a small reduction in tensile strength, seal life may still be relatively long, yet if a large reduction of tensile strength occurs, seal life may be relatively short. Exceptions to this rule do occur. Tensile strength is **not** a proper indication of resistance to extrusion, nor is it ordinarily used in design calculations. However, in dynamic applications a minimum of 1,000 psi (7 MPa) is normally necessary to assure good strength characteristics required for long-term sealability and wear resistance in moving systems.

2.4.5 Elongation

Elongation is defined as the increase in length, expressed numerically, as a percent of initial length. It is generally reported as ultimate elongation, the increase over the original dimension at break. This property primarily determines the stretch which can be tolerated during the installation of an O-ring. Elongation increases in importance as the diameters of a gland become smaller. It is also a measure of the ability of a compound to recover from peak overload, or a force localized in one small area of a seal, when considered in conjunction with tensile strength. 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 quality assurance measure on production batches of elastomer materials.

2.4.6 O-Ring Compression Force

O-ring compression force is the force required to compress an O-ring the amount necessary to maintain an adequate sealing line of contact. See Table 2-3 and Figures 2-4 through 2-8. It is very important in some applications, particularly in face-type seals where the available compression load is limited. The factors that influence compression force for a given application, and a method of finding its approximate magnitude are explained in Section III, O-Ring Applications.

O-Ring Compression Force

Durometer Range	Diameter	Compression Load
Less than normal	Less than 25.4 mm (1")	Middle third of range
Less than normal	Over 25.4 mm (1")	Lower half of range
Over normal	Less than 25.4 mm (1")	Upper third of range
Over normal	Over 25.4 mm (1")	Upper half of range

Table 2-3: O-Ring Compression Force

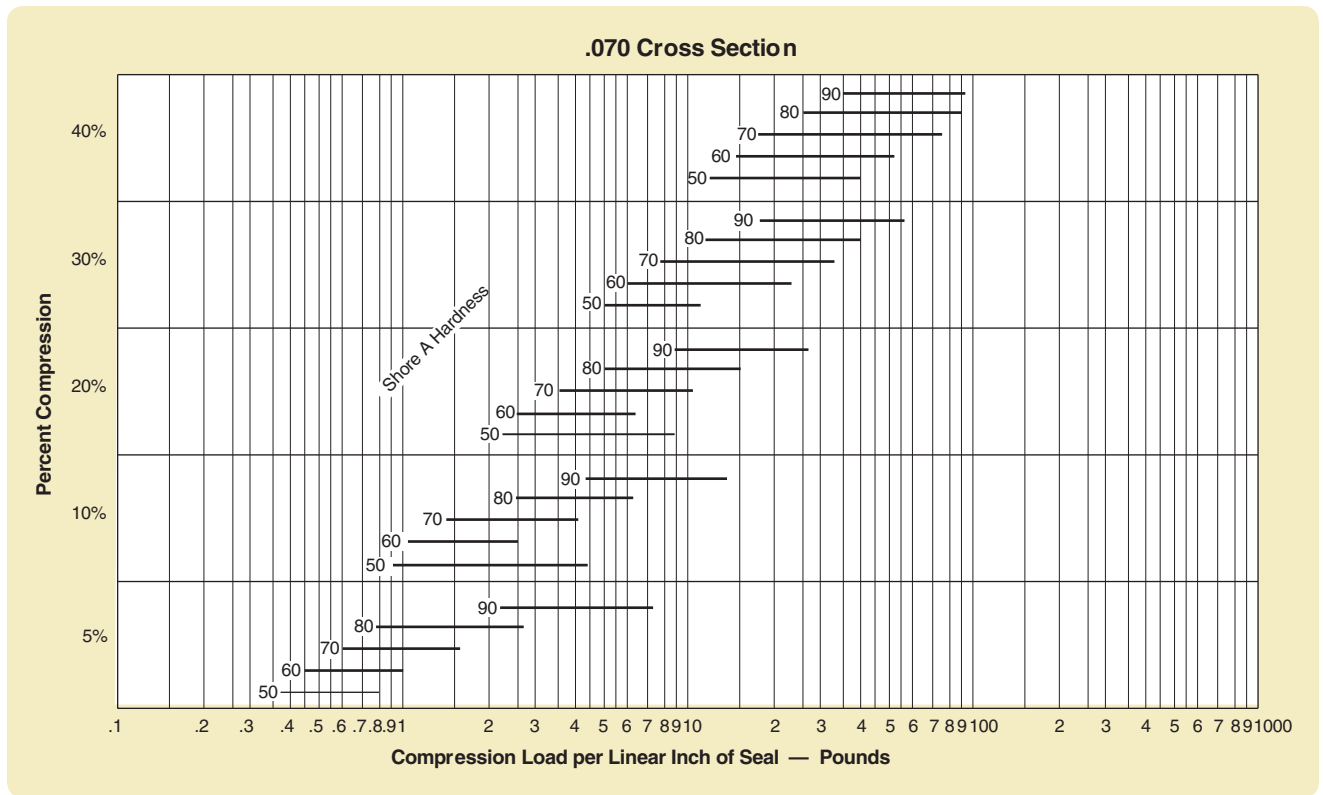


Figure 2-4: .070 Cross Section

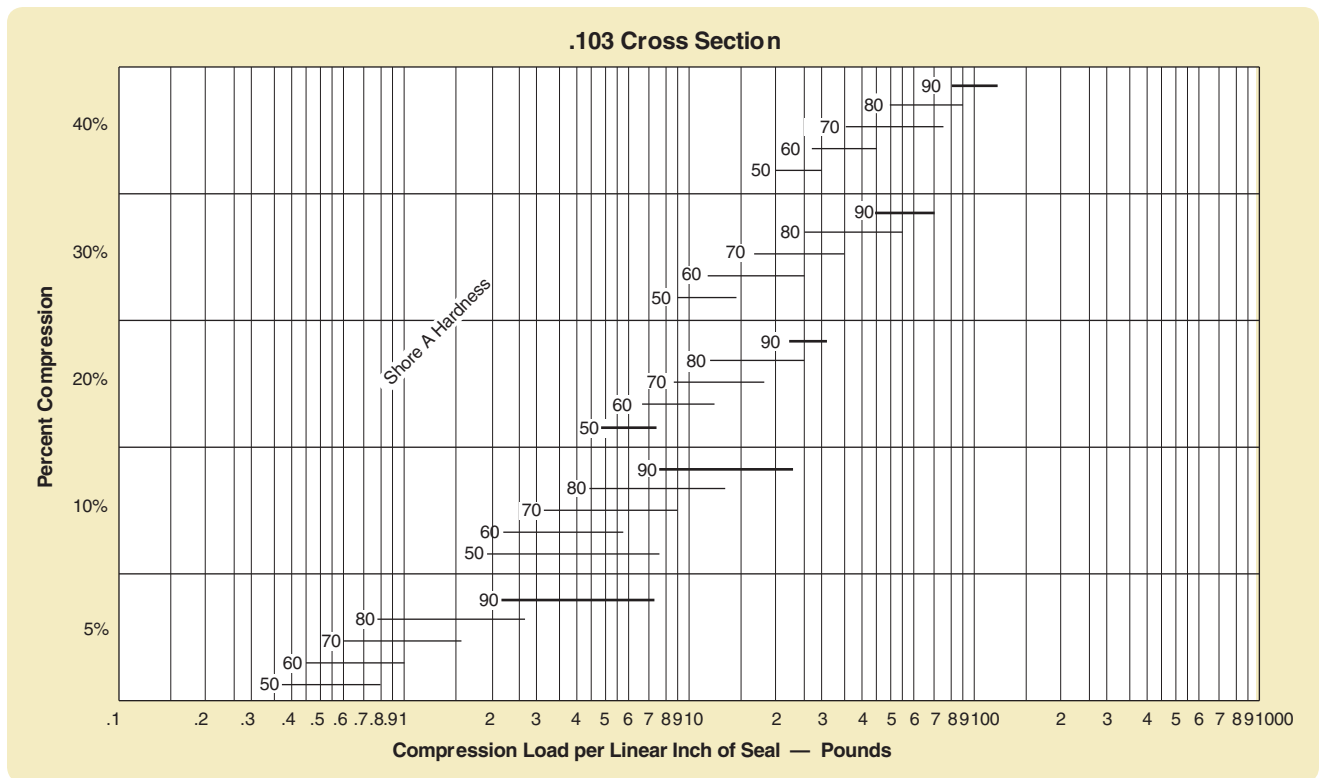


Figure 2-5: .103 Cross Section

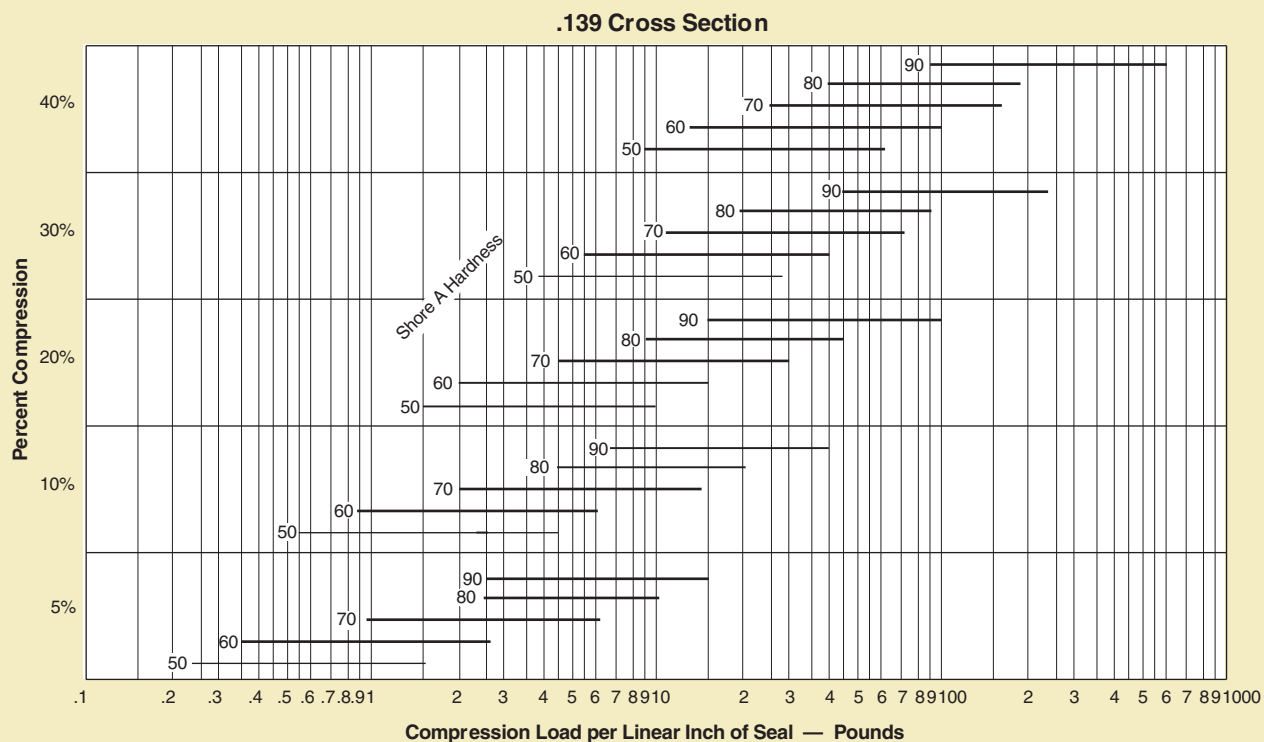


Figure 2-6: .139 Cross Section

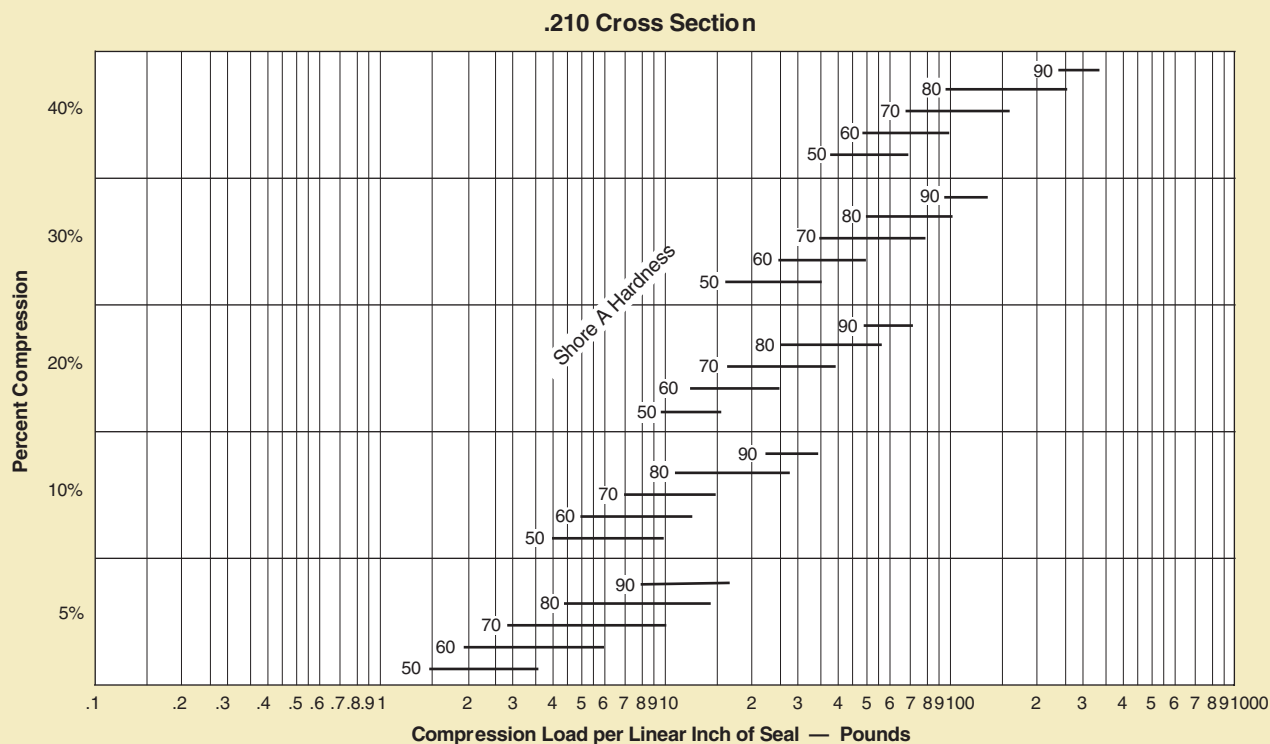


Figure 2-7: .210 Cross Section

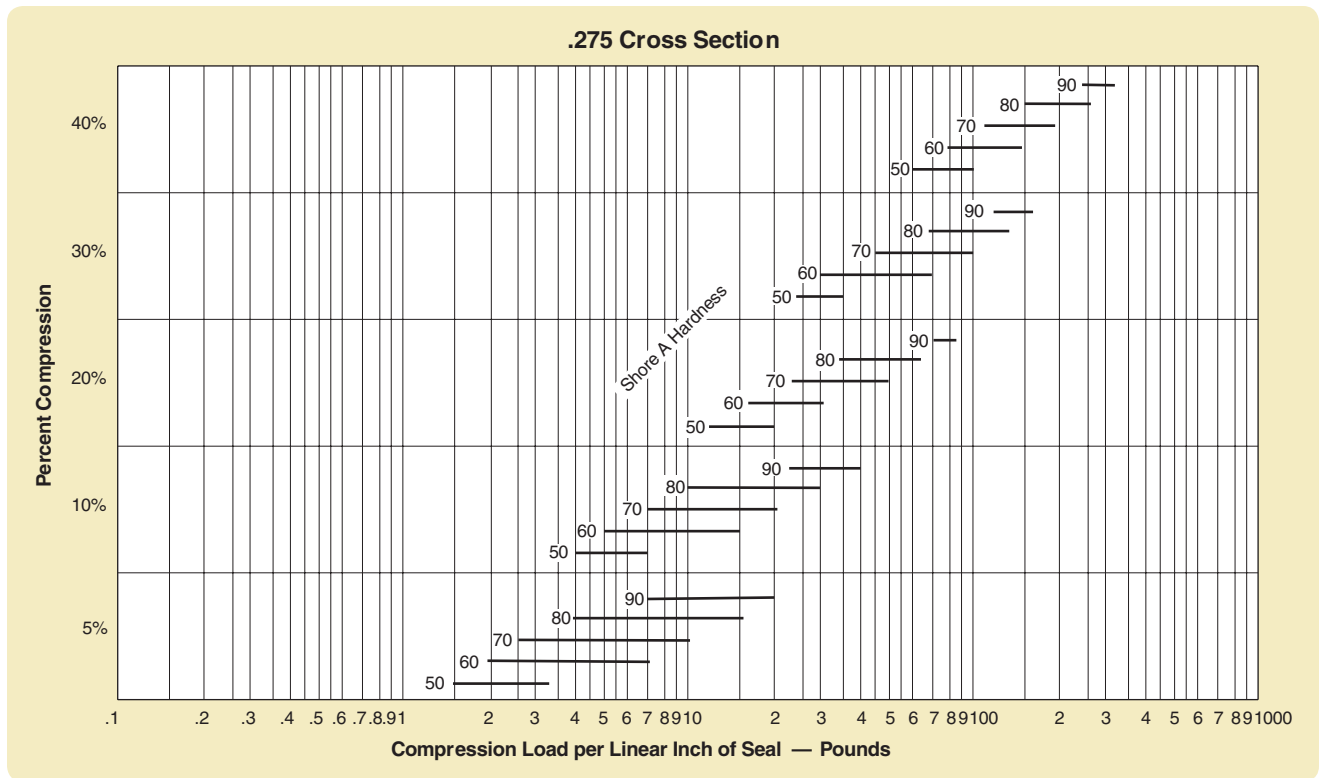


Figure 2-8: .275 Cross Section

2.4.7 Modulus

Modulus, as used in rubber terminology, refers to stress at a predetermined elongation, usually 100%. It is expressed in pounds per square inch (psi) or MPa (Mega Pascals). This is actually the elastic modulus of the material.

The higher the modulus of a compound, the more apt it is to recover from peak overload or localized force, and the better its resistance to extrusion. Modulus normally increases with an increase in hardness. It is probably the best overall indicator of the toughness of a given compound, all other factors being equal.

2.4.8 Tear Resistance

Tear strength is relatively low for most compounds. However, if it is extremely low (less than 100 lbs./in.) (17.5 kn/m), there is increased danger of nicking or cutting the O-ring during assembly, especially if it must pass over ports, sharp edges or burrs. Compounds with poor tear resistance will fail quickly under further flexing or stress once a crack is started. In dynamic seal applications, inferior tear strength of a compound is also indicative of poor abrasion resistance which may lead to premature wear and early failure of the seal. Usually however, this property need not be considered for static applications.

2.4.9 Abrasion Resistance

Abrasion resistance is a general term that indicates the wear resistance of a compound. Where "tear resistance" essentially concerns cutting or otherwise rupturing the surface, "abrasion resistance" concerns scraping or rubbing of the surface. This is of major importance for dynamic seal materials. Only certain elastomers are recommended for dynamic O-ring service where moving parts actually contact the seal material. Harder compounds, up to 90 durometer, are normally more resistant to abrasion than softer compounds. Of course, as with all sealing compromises, abrasion resistance must be considered in conjunction with other physical and chemical requirements.

2.4.10 Volume Change

Volume change is the increase or decrease of the volume of an elastomer after it has been in contact with a fluid, measured in percent (%).

Swell or increase in volume is almost always accompanied by a decrease in hardness. As might be surmised, excessive swell will result in marked softening of the rubber. This condition will lead to reduced abrasion and tear resistance, and may permit extrusion of the seal under high pressure.

For static O-ring applications volume swell up to 30% can usually be tolerated. For dynamic applications, 10 or 15% swell is a reasonable maximum unless special provisions are made in the gland design itself. This is a rule-of-thumb and there will be occasional exceptions to the rule.

Swell may actually augment seal effectiveness under some circumstances. For instance, (1) swell may compensate for compression set. If a seal relaxes 15% and swells 20%, the relaxation (compression set) tends to be canceled by the swell (see Table 2-4), (2) absorbed fluid may have somewhat the same effect on a compound as the addition of plasticizers, softening and thus providing more seal flexibility at the low temperature end of its operating range. These “potential” good effects however, should not be relied upon when choosing a compound for an application. Awareness of these facts is of interest as they can and frequently do contribute to enhanced seal performance. The amount of volume swell after long-term immersion — stabilized volume — is seldom reported because it takes several readings to identify. The usual 70-hour ASTM immersion test will indicate a swelling effect, whereas a long-term test shows shrinkage. Thus swell indicated by short-term testing may only be an interim condition.

Shrinkage or decrease in volume is usually accompanied by an increase in hardness. Also, just as swell compensates for compression set, shrinkage will intensify the compression set effect causing the seal to pull away from sealing surfaces, thus providing a leak path. It is apparent then, that shrinkage is far more critical than swell. More than 3 or 4% shrinkage can be serious for dynamic seals. In some instances, fluids may extract plasticizers, causing the seal to shrink when the fluid is temporarily removed and the seal is allowed to dry out. Such shrinkage may or may not be serious; depending on its magnitude, gland design, and the degree of leakage tolerable *before* the seal re-swells and regains its sealing line of contact. However, even if the seal does re-swell there is

the danger that it may not properly reseal itself. If any shrinkage is a possibility in an application, it must be considered thoroughly and carefully.

2.4.11 Compression Set

Compression set is generally determined in air aging and reported as the percent of deflection by which the elastomer fails to recover after a fixed time under specified squeeze and temperature. Zero percent (0%) indicates no relaxation has occurred whereas 100% indicates total relaxation; the seal just contacts mating surfaces but no longer exerts a force against those surfaces.

Compression set may also be stated as a percent of original thickness. However, percent of original deflection is more common. See Figure 2-9.

Although it is generally desirable to have low compression set properties in a seal material, this is not so critical as it might appear from a practical design standpoint, because of actual service variables. It is easy to go overboard on this property from a theoretical standpoint. Remember that a good balance of all physical properties is usually necessary for optimum seal performance. This is the eternal sealing compromise the seal designer always faces.

For instance, a seal may continue to seal after taking a 100% compression set provided temperature and system pressure remain steady and no motion or force causes a break in the line of seal contact. Also, as mentioned previously, swelling caused by contact with the service fluid may compensate for compression set. Table 2-4 shows the results of a laboratory test that illustrates this phenomenon.

Note that in air and in the fluid that caused slight shrinkage, the compound took a set of approximately 20 to 25%. In the fluid that caused a 20% swell, there was no measurable compression set. The condition most to be feared is the combination of high compression set and shrinkage. This will always lead to seal failure unless exceptionally high squeeze is employed. See Figures 2-10 through 2-17.

Compression Set vs. Volume Change

Parker Compound: Butyl		Temperature: 74°C (165°F)	
Time: 168 hrs.		Deflection used: 25%	
	Air	Fluorolube	Fluoroester
Volume Change %	0	+19.5	-0.4
Set % of Original Deflection	25.4	0	20.7

Table 2-4: Compression Set vs. Volume Change

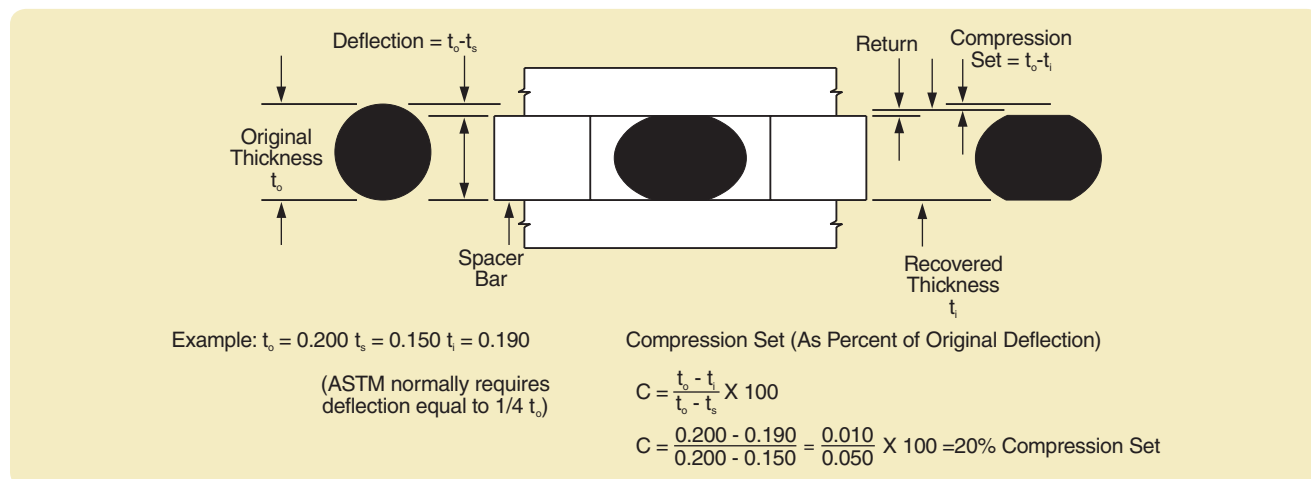


Figure 2-9: Compression Set

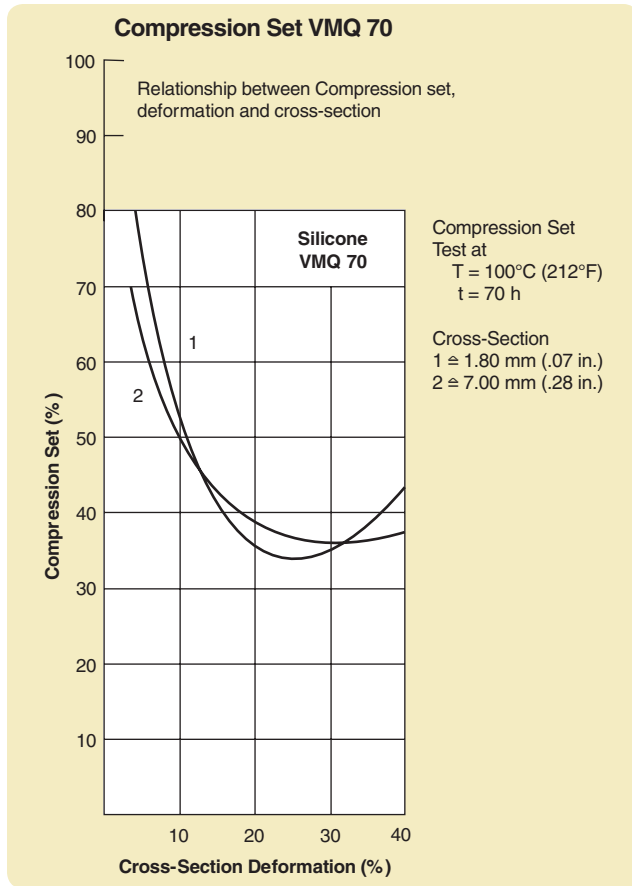


Figure 2-10: Compression Set VMQ 70

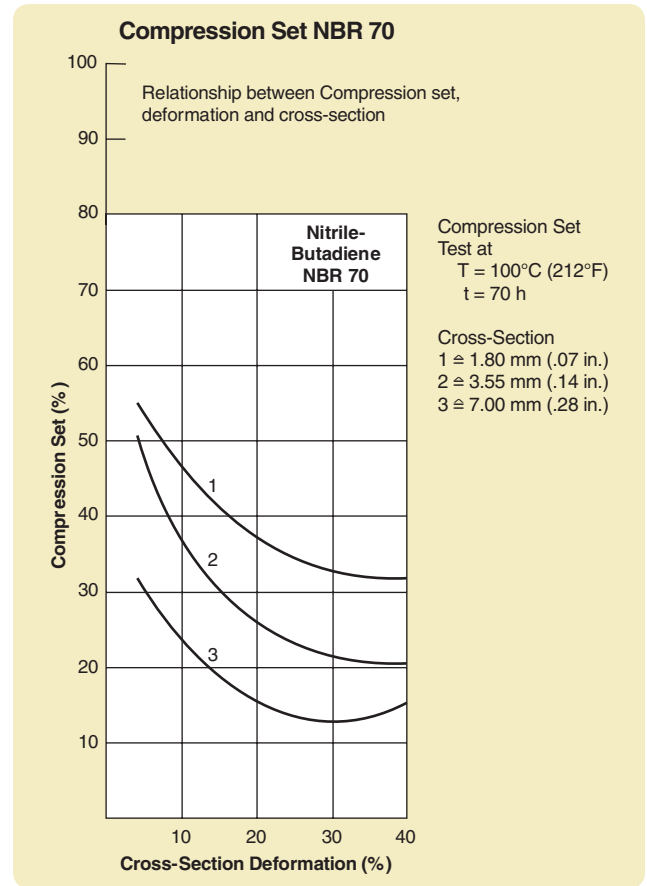


Figure 2-11: Compression Set NBR 70

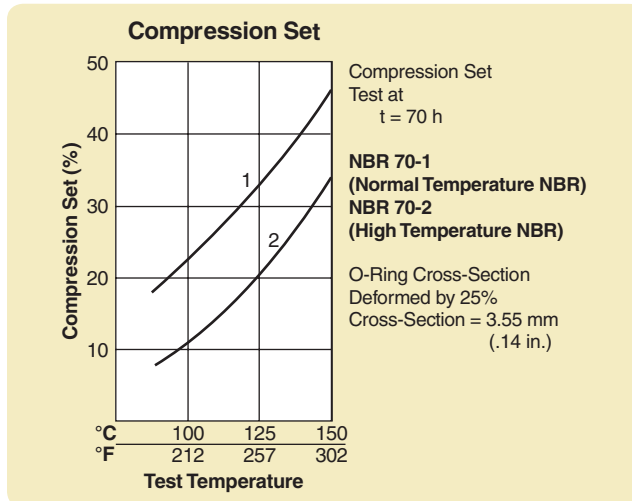


Figure 2-12: Compression Set vs. NBR 70 Compounds

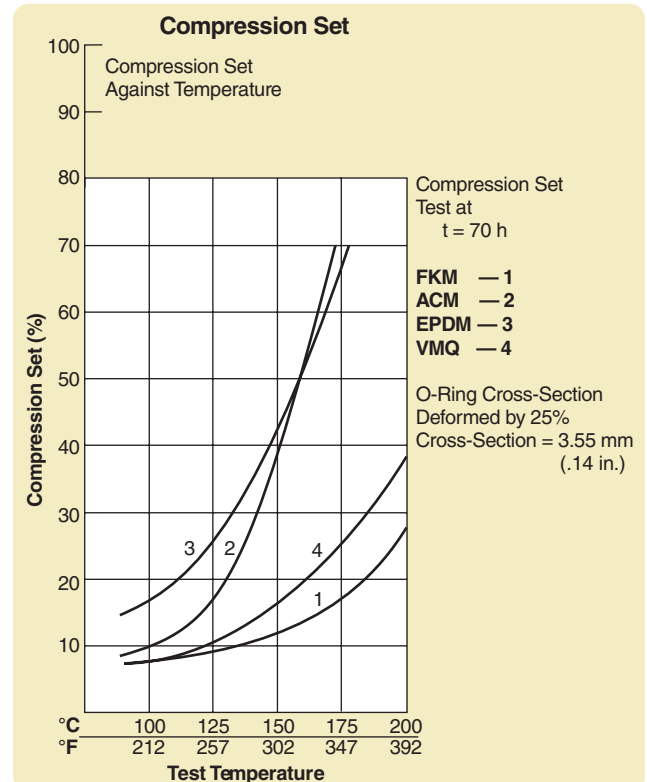


Figure 2-13: Compression Set vs. Polymer Family

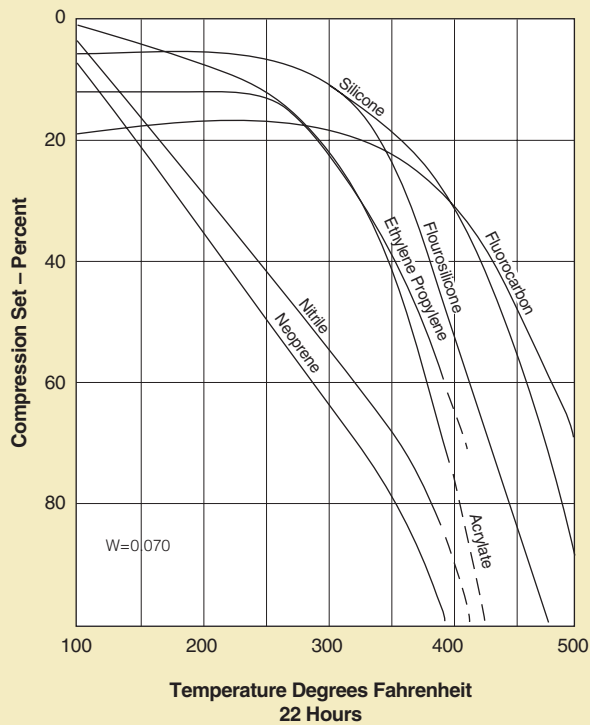


Figure 2-14: Compression Set .070 Cross Section

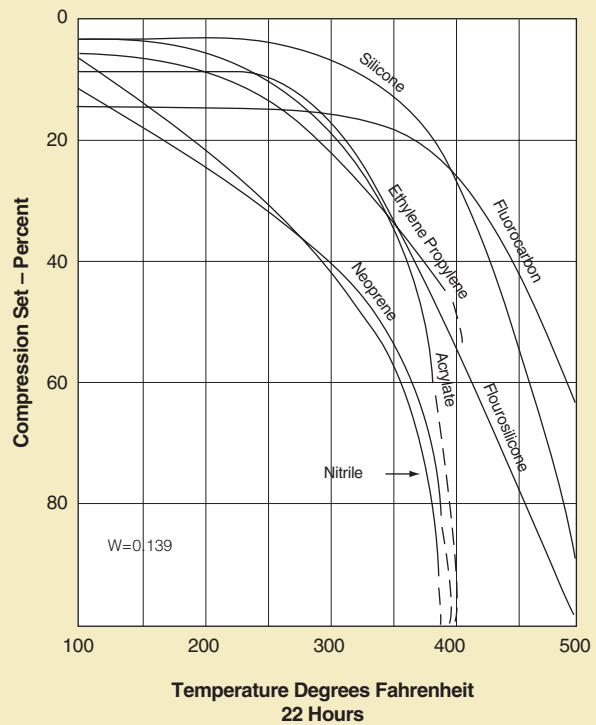


Figure 2-15: Compression Set .139 Cross Section

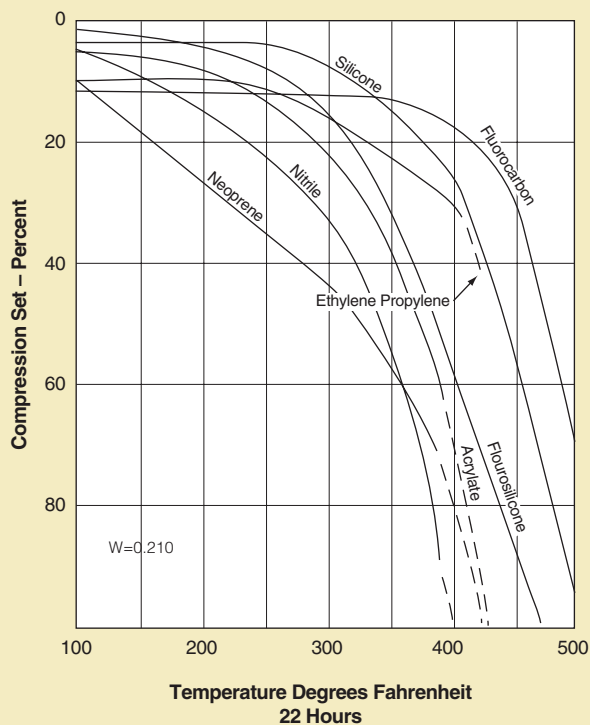


Figure 2-16: Compression Set .210 Cross Section

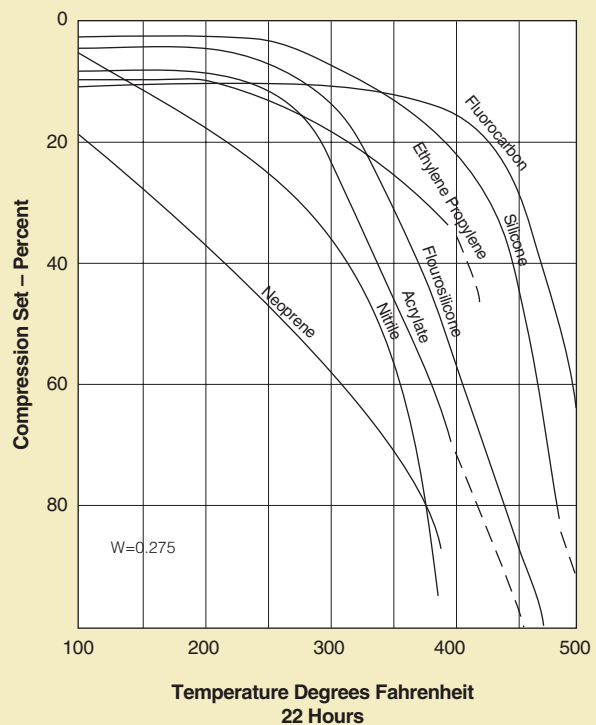


Figure 2-17: Compression Set .275 Cross Section

2.4.12 Thermal Effects

All rubber is subject to deterioration at high temperature. Volume change and compression set are both greatly influenced by heat. Hardness is influenced in a rather complex way. The first effect of increased temperature is to soften the compound. This is a physical change, and will reverse when the temperature drops. However, it must be considered in high pressure applications because a compound that is sufficiently hard to resist extrusion at room temperature may begin to flow and extrude through the clearance gap as the temperature rises, due to this softening effect.

With increasing time at high temperature, chemical changes slowly occur. These generally cause an increase in hardness, along with volume and compression set changes as mentioned above. Changes in tensile strength and elongation are also involved. Being chemical in nature, these changes are not reversible.

With the exception of the cryogenics field, the tendency is to overlook the effects of low temperatures on elastomeric seal compounds as they are generally reversible as the temperature rises.

Any changes induced by low temperature are primarily physical and, as stated, are reversible. An elastomer will almost completely regain its original properties when warmed. There are several tests that are used to define low temperature characteristics of a compound, but there does not seem to be much correlation among them. Perhaps the best of the low temperature tests is TR-10 or Temperature Retraction Test.

The TR-10 test results are easily reproducible and are used extensively in many different specifications, not only for assuring low temperature performance but occasionally as a quality assurance measure as well. From experience, we have found that most compounds will provide effective sealing at 8°C (15°F) below their TR-10 temperature values. However, careful study of the paragraphs on "temperature" later in this section and in Section III should be made before selecting a compound for low temperature service.

If low pressures are anticipated at low temperature, hardness should be considered along with the low temperature properties of the compound. As temperature decreases, hardness increases. Low pressures require a soft material that can be easily deformed as it is forced against mating surfaces. It is possible that a 70 durometer compound at room temperature might harden to 85 durometer at -34°C (-30°F) and fail to respond to low pressure at this temperature.

On the other hand, the same type of compound with 40 durometer hardness at room temperature may register only 75 durometer at -34°C (-30°F) and provide somewhat better response. In moderate pressure service, low temperature hardness increase is seldom of consequence. However, hardness is only one of several factors to consider when low temperature performance is involved.

Flexibility, resilience, compression set and brittleness are perhaps more basic criteria for sealing at low temperature than measured hardness. This may be demonstrated by

reference to Figure 2-18 that shows the variation in hardness for several elastomers at low temperatures.

It is significant that many of the materials for which hardness is plotted in Figure 2-18 are considered good for seal service at temperatures considerably below that at which durometer hardness tends to reach a maximum. This clearly illustrates that durometer measurements alone are not reliable determinants of low temperature seal performance. The swelling or shrinkage effect of the fluid being sealed must also be taken into account. If the seal swells, it is absorbing fluids which may act in much the same way as a low temperature plasticizer, allowing the seal to remain more flexible at low temperature than was possible before the absorption of the fluid.

If the seal shrinks, something is being extracted from the compound. The greater part of the leached material is usually the plasticizer provided by the compounder for low temperature flexibility. This being the case, the seal may now lose some of its original flexibility at low temperature. It may become stiff at a temperature 2°C to 5°C (5°F to 10°F) higher than that at which it is rated.

Crystallization is another side effect of low temperature operation that must be considered, especially for dynamic applications. (Crystallization is the re-orientation of molecular segments causing a change of properties in the compound). When a compound crystallizes it becomes rigid and has none of the resilience that is so necessary for an effective seal.

This phenomenon manifests itself as a flat spot on the O-ring and is sometimes misinterpreted as compression set. The flatness will gradually disappear and the seal will regain its original resilience upon warming. Initially, it may take two or three months for a compound to crystallize at a low or moderate temperature. However, on succeeding exposures to low temperature, crystallization sets in much more rapidly.

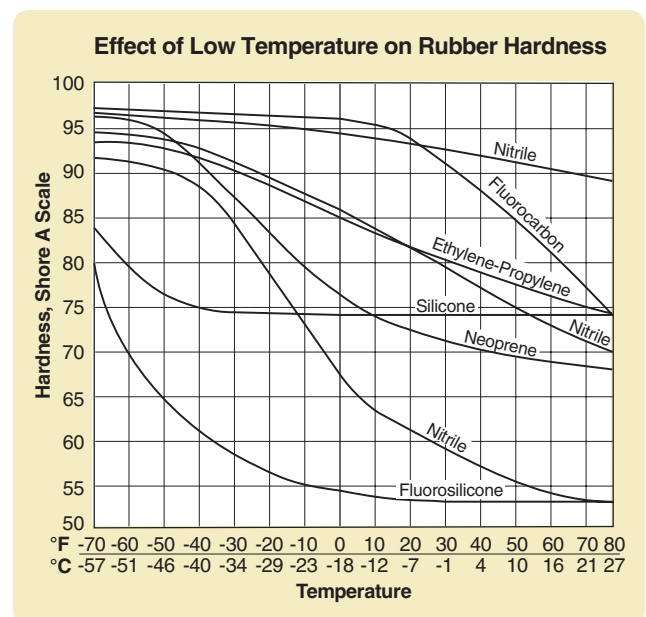


Figure 2-18: Effect of Low Temperature on Rubber Hardness

The end result of crystallization is seal leakage. For example, seals which have been known to function satisfactorily in an air conditioning unit through the first summer, have failed during storage because the system was not turned on to pressurize the seals through a long, cold winter. One way to test for the crystallization effect is to use a double temperature drop. After conditioning at a moderately low temperature for a long period — say two months — temperature is lowered another 30°C (86°F) or so and leakage checked at .7 to 1.4 Bar (10 to 20 psi) pressure. Certain types of polychloroprene (Neoprene) have a pronounced tendency to crystallize. Spring-loading the seal can compensate for crystallization.

2.4.13 Resilience

Resilience is essentially the ability of a compound to return quickly to its original shape after a temporary deflection. Reasonable resilience is vital to a moving seal. Resilience is primarily an inherent property of the elastomer. It can be improved somewhat by compounding. More important, it can be degraded or even destroyed by poor compounding techniques. It is very difficult to create a laboratory test which properly relates this property to seal performance. Therefore, compounding experience and functional testing under actual service conditions are used to insure adequate resilience.

2.4.14 Deterioration

This term normally refers to chemical change of an elastomer resulting in permanent loss of properties. It is not to be confused with reversible or temporary property losses. Both permanent and temporary property losses may be accompanied by swell. The temporary condition is due to physical permeation of fluid without chemical alteration.

2.4.15 Corrosion

Corrosion is the result of chemical action of a fluid and/or the elastomer compound upon the metal surfaces of the seal gland cavity. This handbook is primarily concerned with corrosive effects caused by the compound alone, although it should be noted that fluid corrosion of the gland metal will cause a change of surface finish that can seriously affect the seal, especially in a dynamic application. When rubber seals were first used, there were numerous instances in which the compound itself did act adversely upon metal causing actual pitting of the gland surface. Certain elastomer compounding ingredients, such as uncombined sulfur or certain types of carbon black were found to cause the problem.

Currently, compounding expertise, modern chemicals and supplier testing has made reports of this type of corrosion rare. However, due to frequent introduction of new and improved compounding ingredients, continuous attention to potential corrosive effects is necessary.

A. Corrosion Caused by Free Sulphur — Rubber compounds often are vulcanized using an accelerator containing the element sulfur. A large percentage of the sulfur under the influence of heat (vulcanization) forms bridges (cross-links) between the elastomer molecule chains. This sulfur

remains chemically fixed and cannot be extracted. However a smaller portion of the sulfur remains free and not fixed in the elastomer structure.

Free sulfur in contact with many metals and alloys (e.g. silver, copper, lead) tends to form metal sulfides which cause discoloring and corrosion damage. Further, a reaction between metal and sulfur can lead to the failure of a dynamic seal if rubber adheres to the metal surface after a long downtime. In all cases where there is dynamic action expected at the seal interface, use of a sulfur-free compound is recommended.

B. Corrosion Caused by the Formation of Hydrochloric Acid — Hydrochloric (HCl) acid can be formed in certain environmental conditions when free chloride is present in an elastomer.

Compounds in the CR, ECO, CO and to a lesser extent in ACM polymer groups tend to cause corrosion if the formula does not contain sufficient amounts of inhibitors and stabilizers (e.g. metal oxides) which retard free chloride. Hydrochloric acid also can be formed around compounds which are free from chloride (e.g. SBR, NR) if they contain chloro-paraffin combinations which are used as flame retardants.

C. Electrochemical Corrosion — The formation of small galvanic cells is the main mechanism responsible for corrosion of metals. A galvanic cell is formed across two dissimilar metals. An electrolyte is required for the function of a galvanic cell. Alloys made up from different metal phases or crystals can be damaged when small local cells are formed.

Electrochemical corrosion in the zone of a sealing element (e.g. an O-ring) does not necessarily mean that the elastomer is always the cause. It is very difficult to say how far electrochemical corrosion depends on the elastomer. It is generally assumed that condensate accumulates between the rubber and the metal which, together with other impurities, causes electrochemical corrosion. The propensity to corrode depends on the type of metal alloy(s), surface roughness, state of the metal, temperature and humidity.

2.4.16 Permeability

Permeability is the tendency of gas to pass or diffuse through the elastomer. This should not be confused with leakage which is the tendency of a fluid to go around the seal. Permeability may be of prime importance in vacuum service and some few pneumatic applications involving extended storage but is seldom consequential in other applications. It should be understood that permeability increases as temperatures rise, that different gases have different permeability rates, and that the more a seal is compressed, the greater its resistance to permeability. Refer to O-Ring Applications, Section III for additional information on permeability and vacuum service.

2.4.17 Joule Effect

If a freely suspended rubber strip is *loaded* and stretched and subsequently heated, the strip will contract and lift the load. Conversely, an *unloaded* strip when heated expands to the

coefficient of expansion for that rubber. This phenomenon of contraction is termed the *Joule effect* and occurs only when heating a stretched rubber object.

Example:

O-ring as radial shaft seal. The O-ring with an inner diameter smaller than the shaft is fitted under tension. The O-ring heats up due to friction and contracts. The result is increased friction and temperature. Failure of the O-ring is characterized by a hard, brittle O-ring surface.

In practice an O-ring of larger inner diameter must therefore be selected. An inner diameter between 1% to 3% larger than the shaft is recommended and the outer diameter of the gland should ensure that the O-ring is compressed on the shaft surface.

The width of the gland should be slightly less than the cross-section diameter. The O-ring always should be fitted into the bore and never on to the shaft.

2.4.18 Coefficient of Friction

Coefficient of friction of a moving elastomer seal relates to a number of factors including material hardness, lubrication and surface characteristics of surrounding materials. Generally, breakout friction is many times that of running friction. This varies with several factors, primarily hardness of the seal material. When only the hardness is changed, an increase in hardness will increase breakout friction while a decrease will lower breakout friction. In those instances where seal external lubrication is impossible, Parker offers several compounds having self-contained lubricants. These compounds are also desirable where continuous presence of a lubricant is uncertain, and where minimal friction is essential. For more friction data see O-Ring Applications and Dynamic O-Ring Sealing, Sections III and V, respectively.

2.4.19 Electrical Properties

Elastomers may be good insulators, semiconductors or conductors. The type of material and compound (electrically conductive carbon black) are selected to electrical requirements criteria:

Electrically insulating: $> 10^9$ ohms-cm - SBR, IIR, EPDM, VMQ, FKM.

Anti-static, as semiconductor: 10^5 to 10^9 ohms-cm - NBR, CR.

Electrically conductive: $< 10^5$ ohms-cm - Special Compounds. See Parker Chomerics Division.

Many elastomers must be minimally conductive to prevent electrostatic charging, e.g. fuel tank seals, drive belts, medical equipment, etc. When special conductive compounds are required, care should be taken to ensure that conductive parts of the compound formula will not be dissolved or extracted by the medium being sealed, thus changing the electrical properties. See Figure 2-19.

For shielding purposes against electromagnetic interference (EMI), compounds filled with conductive-particles have been developed with a volume resistivity of $< 10^{-2}$ Ohm-cm.

Please contact Parker regarding any special compound requirements and specific physical properties when contemplating the use of conductive elastomers. For more in-depth information on conductive elastomers and EMI shielding, see Parker Chomerics product information.

2.4.20 Coefficient of Thermal Expansion

Coefficient of linear expansion is the ratio of the change in length per °C to the length at 0°C. Coefficient of volumetric expansion for solids is approximately three times the linear coefficient. As a rough approximation, elastomers have a coefficient of expansion ten times that of steel (an exception to this is perfluoroelastomer). This can be a critical factor at high temperature if the gland is nearly filled with the seal, or at low temperature if squeeze is marginal. See Table 2-5.

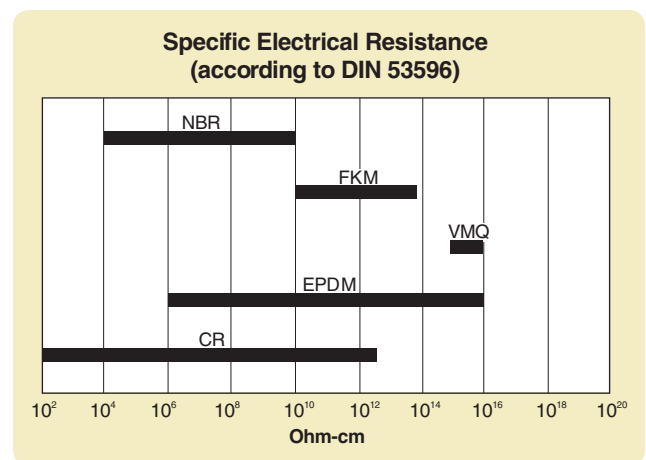


Figure 2-19: Specific Electrical Resistance (According to DIN 53596)

Linear Thermal Expansion of Typical Elastomers and Common Materials

Material	Contraction 24°C to -54°C (75°F to -65°F) (in./ft.)	Expansion 24°C to 191°C (75° to 375°F) (in./ft.)	Coefficient of Expansion (in./in./°F)
Nitrile — General Purpose	.108	.224	6.2×10^{-5}
Neoprene	.132	.274	7.6×10^{-5}
Parofluor			1.8×10^{-4}
Fluorocarbon Elastomer	.156	.324	9.0×10^{-5}
Kel-F	.144	.299	8.3×10^{-5}
Ethylene Propylene	.155	.320	8.9×10^{-5}
Silicone	.174	.360	1.0×10^{-4}
Low-Temperature Type Silicone	.193	.396	1.1×10^{-4}
Fluorosilicone	N/A	N/A	1.5×10^{-4}
High-Temperature Type Aluminum, 2017	.023	.047	1.3×10^{-5}
Stainless Steel, Type 302	.017	.035	9.6×10^{-6}
Steel, Mild	.012	.024	6.7×10^{-6}
Invar	.001	.002	6.0×10^{-7}

Table 2-5 : Linear Thermal Expansion of Typical Elastomers and Common Materials

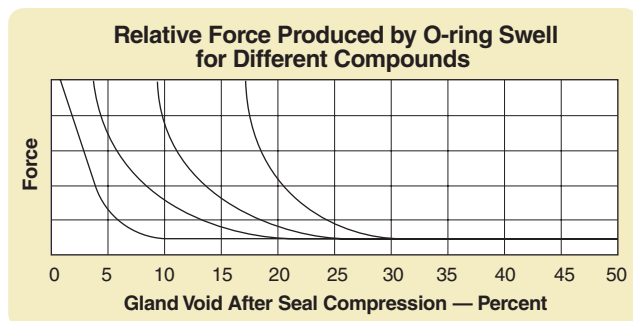


Figure 2-20: Relative Force Produced by O-ring Swell

There are certain reactions that in some circumstances cause a seal to exert relatively high forces against the sides of a groove. These forces are generated by thermal expansion of the rubber and/or swelling effect of a fluid.

If the seal is completely confined and the gland is 100% filled, the dominating force is the force of thermal expansion of the rubber. There have been instances where a seal has ruptured a steel gland due to expansion when heated.

Effective force exerted by the seal due to fluid swell is another potentially large factor if the gland volume exceeds that of the seal by only 5 to 10% (see Figure 2-20). Depending on the interaction between the rubber and the fluid being sealed, the effect may be quite pronounced even at larger gland void conditions.

2.4.21 Effects on Properties

In some of the foregoing paragraphs, it has been mentioned that various factors can alter the properties of rubber materials. Low temperatures cause reversible hardening of compounds, high temperatures may cause reversible and non-reversible changes of many kinds, and exposure to fluids can effect all the properties of a rubber material. Besides these more-or-less obvious effects, there are many additional ways in which the properties of a compound may be modified so that results by two different laboratories may not agree. Knowledge of some of these pitfalls may avoid misunderstandings.

2.5 Standard Test Procedures

There are standard ASTM procedures for conducting most of the tests on rubber materials. It is important to follow these procedures carefully in conducting tests if uniform and repeatable results are to be obtained. For instance, in pulling specimens to find tensile strength, elongation, and modulus values, ASTM D412 requires a uniform rate of pull of 508 mm (20 inches) per minute. In one test, tensile strength was found to decrease 5% when the speed was reduced to 50.8 mm (2 inches) per minute, and it decreased 30% when the speed was further reduced to 5.08 mm (0.2 inches) per minute. Elongation and modulus values decreased also, but by smaller amounts.

ASTM Compression Set D395 Test Method B, states, "The percentage of compression employed shall be approximately 25%." We have found significantly higher compression set values after compressing less than 25%, while results after 30 or 40% compression were sometimes smaller and sometimes greater than at 25%.

2.5.1 Test Specimens

ASTM test methods include descriptions of standard specimens for each test. Often, two or more specimens are required, but results from the different specimens will seldom agree. The way that properties vary with the size of the specimen is not consistent. For instance, as the cross-section increases, nitrile O-rings produce lower values of tensile strength, elongation, and compression set. Ethylene propylene rings produce a similar pattern for tensile and elongation values but not compression set, while in fluorocarbon compounds only the elongation shows this trend.

In fluid immersion tests, rings with smaller cross-sections have been found to swell more than larger rings. In observing explosive decompression tests, the smaller cross-sections had much better resistance to high-pressure gases.

When customers wish to monitor the Shore A hardness of O-rings they purchase, they will sometimes order compression set buttons from the same batch as the O-rings for purposes of conducting hardness tests. This is because durometer hardness readings taken on actual O-rings are notoriously variable. It is important, therefore, in reporting test results, to include both a description of the test specimens used as well as describing the test method itself in detail.

2.5.2 Test Method Variables

More difficult to avoid are differences in test results due to differences introduced by the human equation. In testing for durometer hardness, for example, the presser foot of the instrument is applied to the specimen "as rapidly as possible without shock — Apply just sufficient pressure to obtain firm contact between presser foot and specimen." Different operators will often disagree on the hardness of a compound because they use different speeds and different amounts of pressure. In gauging the hardness of an O-ring, which has no flat surface, operators may vary in the accuracy with which they apply the indenter to the actual crown of the O-ring, the point that gives the most reliable reading. The only industry recognized test for hardness of an O-ring is IRHD (see "Hardness" in this section).

In conducting the TR-10 low temperature test, the cold bath should be warmed at the rate of 1°C (34°F) per minute. Any different rate will result in somewhat different readings.

2.5.3 Effects of Environment on Testing

High humidity in the air will reduce the tensile strength of some compounds. Changes in a fluid medium can occur in service due to the effect of heat and contaminants. A rubber that is virtually unaffected by new fluid may deteriorate in the same fluid after it has been in service for a month. Tests are sometimes run in previously used fluid for this reason.

These are but a few examples to illustrate the fact that the properties of rubber compounds are not constant. They vary according to the conditions under which they are tested, and some of the variables may be rather subtle.

2.6 Aging

Deterioration with time or aging relates to the basic nature of the rubber molecule. It is a long chain-like structure consisting of many smaller molecules joined or linked together. Points at which individual molecules join are called bonds. Bond sites and certain other areas may be particularly susceptible to chemical reaction. At least three principle types of such reactions are associated with aging. They usually occur concurrently, but in varying degrees:

- Scission — The molecular bonds are cut, dividing the chain into smaller segments. Ozone, ultra-violet light, and radiation cause degradation of this type.
- Crosslinking — An oxidation process whereby additional intermolecular bonds are formed. This process may be a regenerative one. Heat and oxygen are principle causes of this type of aging process.
- Modification of Side Groups — A change in the complex, weaker fringe areas of the molecular construction due to chemical reaction. Moisture, for example, could promote this activity.

Note: all mechanisms by which rubber deteriorates with time are attributable to environmental conditions. It is *environment* and not age that is significant to seal life, both in storage and actual service. While selection and application of synthetic rubber seals to provide acceptable service life is the primary subject of this handbook, our concern in the next paragraph will be with seal life as it relates to storage conditions.

2.7 Storage

The effective storage life of an O-ring varies with the inherent resistance of each individual elastomer to normal storage conditions. ARP 5316 places elastomers into three groups according to “Age resistance generally associated with products fabricated from various rubbers.” Realize that this document, ARP 5316, is an Aerospace Recommended Practice, not a standard that must be met.

Where non-age sensitive elastomers are involved, considerable storage life *without* detectable damage is common even under adverse conditions. For materials falling into the 15 year category, which are subject to age deterioration, the following conditions are suggested for maximum life:

1. Ambient temperature not exceeding 49°C (120°F)
2. Exclusion of air (oxygen)
3. Exclusion of contamination
4. Exclusion of light (particularly sunlight)
5. Exclusion of ozone generating electrical devices
6. Exclusion of radiation

Generally, sealed polyethylene bags stored in larger cardboard containers or polyethylene lined craft paper bags ensure optimal storage life. However, in normal warehousing conditions, life of even the relatively age-sensitive elastomers is considerable. This is due to major improvements in modern compounding technique, and has been documented through

a number of investigations concerned with effects of long-term storage of elastomeric materials undertaken in the recent past. These include controlled laboratory studies of many years duration in addition to evaluation of seals recovered from salvaged World War II aircraft and other sources after exposure to widely varying conditions over many years.

2.8 Cure Date

To facilitate proper stock rotation on the shelves of Parker distributors and customers, Parker Seal supplies the cure date on all packaging. It is standard practice throughout the industry to indicate the cure date by quarter and calendar year. When determining the age of a part, the quarter of manufacture (cure) is not counted. For example, parts cured in January, February, or March of a given year are not considered to be one quarter old until July 1 of that same year. Cure dates are shown by a number indicating the quarter of cure followed by the letter Q (for quarter). For example, 2Q06 indicates the second quarter of 2006 (April, May, or June).

2.9 Age Control

Prior to ARP 5316, specification MIL-STD-1523A was the age control document for O-rings. Although cure date records are maintained for all Parker Seal elastomer products, not all of these products were subject to the age control limitations of MIL-STD-1523A. It required that the age of certain military nitrile O-rings shall not exceed 40 quarters from the cure date at the time of acceptance by the Government acquiring activity. The age control requirements of MIL-STD-1523A did not apply to any other polymer classes, such as fluorocarbon, butyl, ethylene propylene, silicone, fluorosilicone, polyurethane, etc. nor to nitrile compounds not covered by the specification.

Note: As of this printing, MIL-STD-1523A has been cancelled. It is included here for historical reference only. Refer to ARP 5316 as a guide (ARP 5316 is available through SAE).

Field experience has demonstrated that the current **STORAGE CONDITIONS** are much more important in determining the useful life of elastomeric seals than is **TIME**. Controlling storage time only serves to de-emphasize the need for adequate control of storage conditions. Adhering to this time-based storage philosophy may result in deteriorated seals, or in the wasteful destruction of perfectly good seals.

2.10 Shrinkage

All rubber compounds shrink to some extent during the molding process. The finished elastomeric part will be smaller than the mold cavity from which it was formed. Exactly how much smaller the part is we call the “shrinkage factor.” The basic nitrile polymer was one of the first synthetic polymers produced. As a result, it has become the standard or “measuring stick” for shrinkage variations between polymer families. This standard shrinkage factor is often called “AN” shrinkage. For other compounds, individual shrinkage factors can lead to different tolerances and, thus, different designs. If, with the

variation of compound and hardness, the ability to fall within expected dimensional tolerances is compromised, is necessary to manufacture compensating mold tooling in order to remain within the specified tolerances, whatever they may be.

For more information on shrinkage, see “Shrinkage” in the Appendix, Section X.

2.11 Compound Selection

This section gives background information to help in understanding the factors involved in the process, and provide some guidance when recommended limits must be exceeded or when unlisted fluids are encountered. Compound selection may be classified in two categories — the pioneering type and the non-pioneering type.

If no pioneering were ever encountered, it would be possible to skip all the other sections of this handbook and select the proper compound for an application from the tables. Since non-pioneering applications will include the greater part of all design work normally encountered, this category will be discussed first.

2.11.1 Non-Pioneering Design

The term “non-pioneering design” refers to reapplication of proven design. Three such cases come to mind immediately:

1. When using the same fluid, gland design practices, and operating conditions, the same compounds utilized in past design may be trusted to give successful results.
2. When the military service or other customer requires the use of some specific compound by citing a formulation, compound designation, or specification, the designer must locate the compound that meets such criteria and no option exists as to compound choice. By use of such specifications, the problem becomes “non-pioneering” in that known successful solutions are relied on. For such design conditions, Tables 8-3, 8-4 and 8-5 list the most used specifications and indicate applicable Parker compounds.
3. There is a third case of “non-pioneering design” in which the designer can use past successes of others as a basis for a design foreign to his own experience. The sections on Static and Dynamic O-Ring Sealing (Sections IV and V, respectively) provide gland design data based on “average” operating conditions, established by widespread field contact developed from years of experience with O-rings. In similar fashion, many stock compounds have proven to be very satisfactory in certain fluids when used in glands of normal design. Provided operating conditions are within specified limits, gland design presents nothing new, and no problems should arise. The Fluid Compatibility Tables in Section VII provide specific seal compound recommendations for service with a variety of fluids. Each foregoing category is based on successful practice under similar service conditions. This is the heart of the non-pioneering approach.

2.11.2 Pioneering Design

This implies that there is something new and therefore unknown or at least unproven about the design. There are at least two recognizable levels in this area that we elect to call “minor pioneering” and “major pioneering.”

- A. Minor Pioneering applies when only a slight departure from previous practice is involved. If new operating conditions apply or some change in gland design is made but neither is radically different from the past design conditions, the previous design data will certainly apply as a starting point. If a fluid is new to the user, but is listed in the Fluid Compatibility Table in Section VII, influence of the fluid retains “minor pioneering” status. (If the new fluid is foreign to the user’s experience and not listed in the table, the problem has suddenly become “major pioneering.”) Each designer makes his own choice of how to test a new design and his decision should be based on how far the application deviates from known successful usage.
- B. Major Pioneering applies when there is radical departure from previous practice. The most likely example is the use of a new fluid, foreign to anyone’s past experience. If the fluid’s chemical nature can be related to another fluid with known effect on a compound, this may reduce the problem to “minor pioneering.”

For example, if the fluid is a silicate ester, it can be surmised that its effect on the seal will be similar to MLO-8200, MLO-8515, or OS 45 type III and IV, since these also have a silicate ester base. In the case of petroleum base fluids, comparison of the aniline point of the fluid with that of standard test fluids gives a fair estimate of the fluid’s effect on a seal material.

It is fortunate that major engineering problems constitute only a very small percentage of the total work, for they do not normally offer a direct and immediate answer. However, by using the Fluid Compatibility Tables in Section VII it should be relatively simple to select one or two compounds for trial. The most likely compound should then be put on simulated service test. If performance is satisfactory, the answer is at hand. If not, a more accurate analysis and a better compound selection may be made based on test results.

In summary, selecting an applicable compound is a matter of finding a “reasonable” starting point and proving the adequacy of such a selection by functional testing.

2.12 Rapid Methods for Predicting the Compatibility of Elastomers with Mineral Based Oils

2.12.1 Aniline Point Differences

In view of the ever increasing number of operating oils and sealing materials, it is desirable that a means be established to enable interested parties to employ suitable combinations of oil and rubber without the need for carrying out lengthy immersion tests on each combination.

A well-known rapid method for material selection is based on the aniline point of the oil, which is the lowest temperature at which a given amount of fresh aniline dissolves in an equal volume of the particular oil. Oils with the same aniline points usually have similar effect on rubber. The lower the aniline point, the more severe is the swelling action. The ASTM reference oils cover a range of aniline points found in lubricating oils.

ASTM Oil No. 1 has a high aniline point 124°C (225°F) and causes slight swelling or shrinkage.

IRM 902 (formally ASTM Oil No. 2) has a medium aniline point of 93°C (200°F) and causes intermediate swelling.

IRM 903 (formally ASTM Oil No. 3) has a low aniline point 70°C (157°F) and causes high or extreme swelling of seal compounds.

With mineral oil as a medium, changes in physical properties are the result of two different processes:

- A. Oil diffuses into the rubber causing swelling which is usually limited and differs from one elastomer to another.
- B. Chemical components of the elastomer can be dissolved or extracted from the compound resulting in shrinkage.

The processes can be concurrent and the resulting volume change may not be noticeable.

The effect depends not only on the construction of the elastomer, but also on the sealed fluid itself. The base elastomer contains between 15% and 50% acrylonitrile (ACN). The higher the ACN content, the better the compatibility with oil. In the same way, a high content of aliphatics, e.g. as in paraffin based oils, leads to a low tendency to swell (also with low ACN content). Conversely, aromatic based oils cause

swelling, which for some elastomers does not tend to reach equilibrium, e.g. with NBR. A high ACN content is necessary to resist swelling resulting from naphthalene based oils.

Any other commercial oil with the same or similar aniline point can be expected to have a similar effect on a particular sealing material as the corresponding ASTM oil. However, it has been found that the aniline point method is not always reliable. Some commercial oils of the same aniline point can differ significantly in their swelling power because they contain different sorts and amounts of additives.

2.12.2 Elastomer Compatibility Index

A rapid and more accurate method for predicting the compatibility of commercial rubbers in mineral based oils involves the use of a representative reference compound called standard NBR 1. The action of mineral oils can be evaluated against this standard rubber in terms of the Elastomer Compatibility Index or ECI. Table 2-6 lists the ECI for various oils.

Previous work has shown that there is an approximate linear relationship between the equilibrium percentage volume changes of NBR 1 in a range of mineral oils and those of any commercial nitrile in the same oils. In other words, if equilibrium percentage changes in the volume of different commercial nitrile rubbers in different mineral oils are plotted against those of standard elastomer NBR 1, a straight line can be obtained for each nitrile compound. This enables interested parties to predict the volume change of a particular rubber material in any mineral oil if the compatibility index of this oil (i.e. the percentage volume change of NBR 1) is known.

The straight-line graph for a particular compound is called the swelling behavior, or SB of the compound. Figure 2-21 gives an example of such a graph.

ECI for Various Oils	
Type of Oil	ECI
ASTM Oil Number 1	2.2 - 3.2
BP Energol HLP 100	3.7 - 4.7
Esso Nuto H-54 (HLP 36)	5.9 - 6.9
Houghton HD 20W/20	6.9 - 7.9
Esso Nuto H-44 (HLP 16)	7.1 - 8.1
DEA Rando Oil HDC (HLP 36)	7.7 - 8.7
Fina Hydran 31	8.5 - 9.5
Shell Tellus 923 (HLP 16)	9.2 - 10.2
ASTM Oil Number 2 (IRM 902)	9.4 - 10.4
Esso-Trafo oil 37	12.5 - 13.5
Agip F. 1 Rotra ATF	12.6 - 13.6
Mobil Vac HLP 16	14.0 - 15.0
Shell Tellus 15	14.7 - 15.7
Essocis J 43	15.0 - 16.0
Shell oil 4001	16.3 - 17.3
Texaco Rando Oil AAA	16.5 - 17.5
BP Energol HP 20	19.0 - 20.0
ASTM Oil Number 3 (IRM 903)	23.0 - 24.0
Shell Tellus 11	32.9 - 33.9
Shell Oil JYO	34.5 - 35.5

Table 2-6: ECI for Various Oils

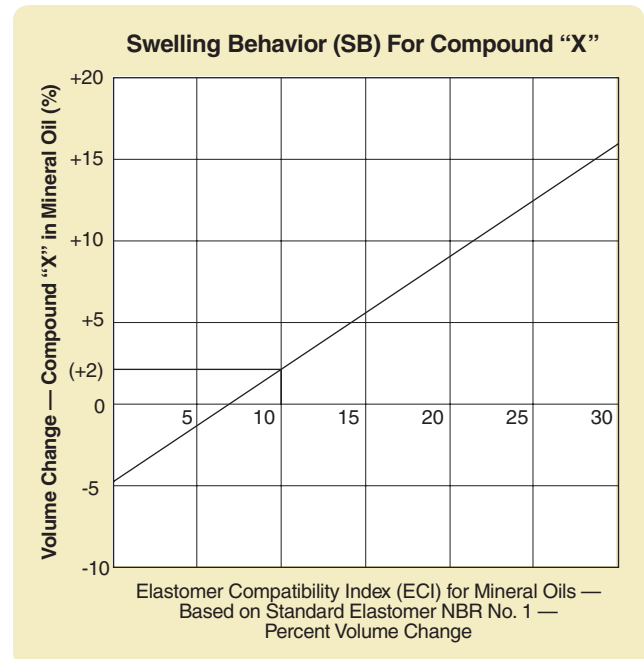


Figure 2-21: Swelling Behavior (SB) for Compound "X"

Example using Figure 2-21:

To find the volume change of Compound "X" in a mineral oil having an ECI of 10 for volume, follow the 10% vertical ECI line until it intersects the slanted line. Follow the horizontal line from that point to the vertical axis. Compound "X" will have a volume swell of approximately 2% in that oil.

By using the ECI, the volume change of the above materials can be predicted in a mineral oil media, thus saving valuable laboratory time. The ECI for an oil is initially determined in the laboratory (see Table 2-6). The ECI values can be plotted on a compound specific graph (Figures 2-22 and 2-23) and the expected volume change can be read directly from the vertical axis. In this way, a decision can be made regarding elastomer compatibility with given oils. The procedure, originally developed by Parker, has been standardized under International Standard ISO 6072.

The weight change of a test elastomer, e.g. NBR 1 to ISO 6072, is measured after immersion in the respective oil for 168 hours at 100°C (212°F). The ECI is then simply read from Figure 2-24 plotting the weight change.

2.13 Operating Conditions

The practical selection of a specific Parker compound number depends on adequate definition of the principle operating conditions for the seal. In approximate order of application, these conditions are *Fluid, Temperature, Time, Pressure and Mechanical Requirements*.

2.13.1 Fluid

Fluid includes the fluid to be sealed, outside air, any lubricant, or an occasional cleaning or purging agent to be used in the system. For example, in pipelines it is common practice to pump a variety of fluids in sequence through a line with a pig

(floating plug) separating each charge. In a crankcase, raw gasoline, diesel fuel, gaseous products of combustion, acids formed in service, and water from condensation, can all be expected to contaminate the engine oil. In both these cases, the seal compound must be resistant to all fluids involved including any lubricant to be used on the seal. Therefore, whenever possible, it is a good practice to use the fluid being sealed as the lubricant, eliminating one variable.

Thus far only the effects of fluids on seal compounds have been discussed. Consideration must also be given to the effect of the compound on system fluids. For example:

- A. Some rubber compounding ingredients, such as magnesium oxide or aluminum oxide, used in compounds that cause chemical deterioration of fluorinated refrigerants. When choosing a compound for use with fluorinated refrigerants, it should not contain any of the ingredients that cause this breakdown.
- B. Compounds containing large amounts of free sulfur for vulcanization should not be used in contact with certain metals or fluids, because the sulfur will promote corrosion of the metal or cause chemical change of the fluid.
- C. Compounds for food and breathing applications should contain only non-toxic ingredients.
- D. Seals used in meters or other devices that must be read through glass, a liquid, or plastic, must not discolor these materials and hinder vision.

Sound judgment, then, dictates that all fluids involved in an application be considered. Once this is done, it is a simple matter to check the Fluid Compatibility Tables in Section VII to find a compound suitable for use with all the media.

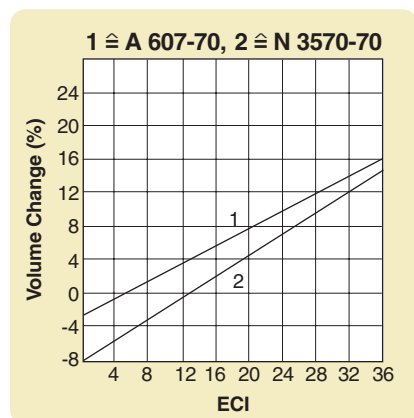


Figure 2-22: Swelling Characteristics of Parker Compounds

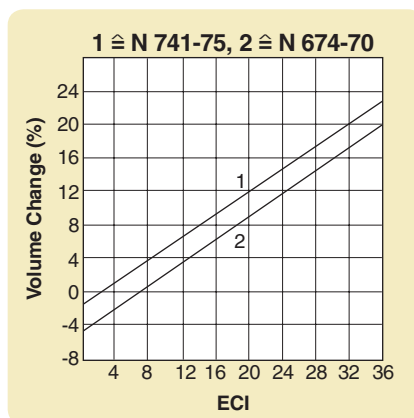


Figure 2-23: Swelling Characteristics of Parker Compounds

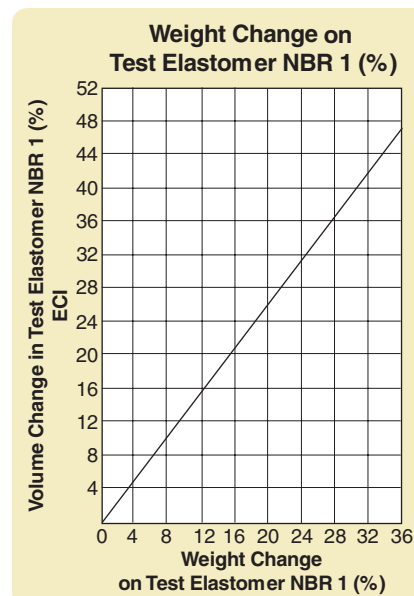


Figure 2-24: Weight Change on Test Elastomer NBR 1 (%)

2.13.2 Temperature

Temperature ranges are often over-specified. For example, a torch or burner might reach temperatures of 400°C to 540°C (750°F to 1000°F). However, the tanks of gas being sealed may be located a good distance from this heat source and the actual ambient temperature at the seal might be as low as 121°C to 149°C (250°F to 300°F).

A specification for aircraft landing gear bearing seals might call out -54°C to 760°C (-65°F to 1400°F), yet the bearing grease to be sealed becomes so viscous at -54°C (-65°F) it cannot possibly leak out. At the high end, there is a time-temperature relationship in the landing rollout that allows rapid heat dissipation through the magnesium wheel housing on which the seals are mounted. This, combined with low thermal conductivity of the seal, limits heat input to the seal so that temperature may never exceed 71°C (160°F). As a result, a more realistic temperature range would be -34°C to 82°C (-30°F to 180°F).

Parker has applied a realistic temperature range with a margin of safety when setting the general operating temperature range for seal compounds. The maximum temperature recommendation for a compound is based on long term functional

service. If it is subjected to this temperature continuously, it should perform reliably for 1,000 hours. Time at less than maximum temperature will extend life. Similarly, higher temperature will reduce it.

The high temperature limits assigned to compounds in Figure 2-25 are conservative estimates of the maximum temperature for 1,000 hours of continuous service in the media the compounds are most often used to seal. Since the top limit for any compound varies with the medium, the high temperature limit for many compounds is shown as a range rather than a single figure. This range may be reduced or extended in unusual fluids.

Since some fluids decompose at a temperature lower than the maximum temperature limit of the elastomer, the temperature limits of both the seal and the fluid must be considered in determining limits for a system.

Low temperature service ratings in the past have been based on values obtained by ASTM Test Methods D736 and D746. Currently, Method D2137 is in wide use. The present ASTM D2000 SAE 200 specification calls for the ASTM D2137 low temperature test. For O-rings and other compression seals, however, the TR-10 value per ASTM D1329 provides a better

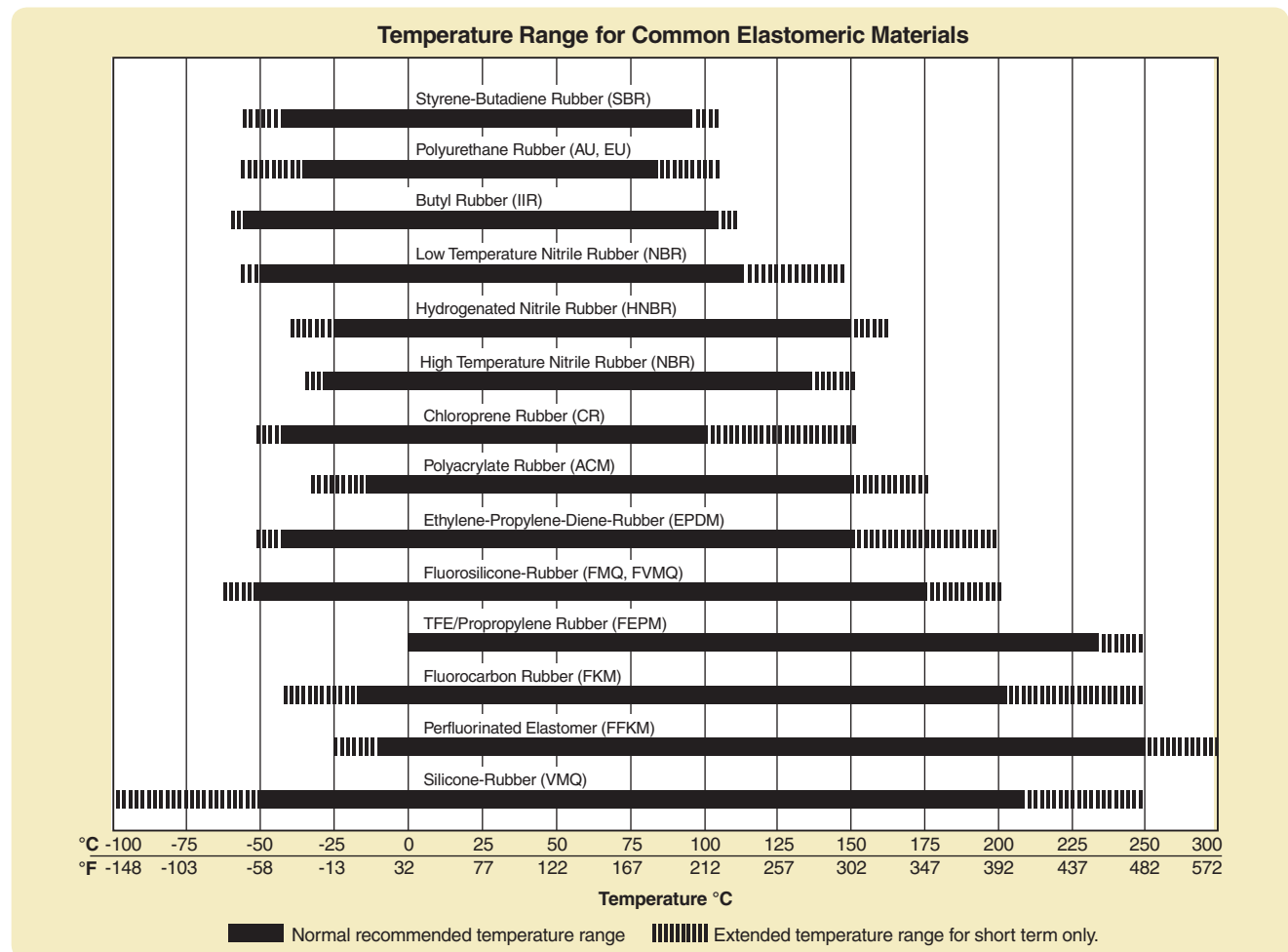


Figure 2-25: Temperature Capabilities of Principal Elastomers Employed in Seals

means of approximating the low temperature capability of an elastomer compression seal. The low temperature sealing limit is generally about 8°C (15°F) below the TR-10 value. This is the formula that has been used, with a few exceptions, to establish the recommended low temperature limits for Parker Seal Group compounds shown in Figure 2-25 and the Fluid Compatibility Tables in Section VII. This is the lowest temperature normally recommended for static seals. In dynamic use, or in static applications with pulsing pressure, sealing may not be accomplished below the TR-10 temperature, or approximately 8°C (15°F) higher than the low-limit recommendation in the Parker Handbook.

These recommendations are based on Parker tests. Some manufacturers use a less conservative method to arrive at low temperature recommendations, but similar compounds with the same TR-10 temperature would be expected to have the same actual low temperature limit regardless of catalog recommendations.

A few degrees may sometimes be gained by increasing the squeeze on the O-ring section, while insufficient squeeze may cause O-ring leakage before the recommended low temperature limit is reached.

The low temperature limit on an O-ring seal may be compromised if the seal is previously exposed to extra high temperature or a fluid that causes it to take a set, or to a fluid that causes the seal compound to shrink. Conversely, the limit may be lowered significantly if the fluid swells the compound. See Figure 2-26.

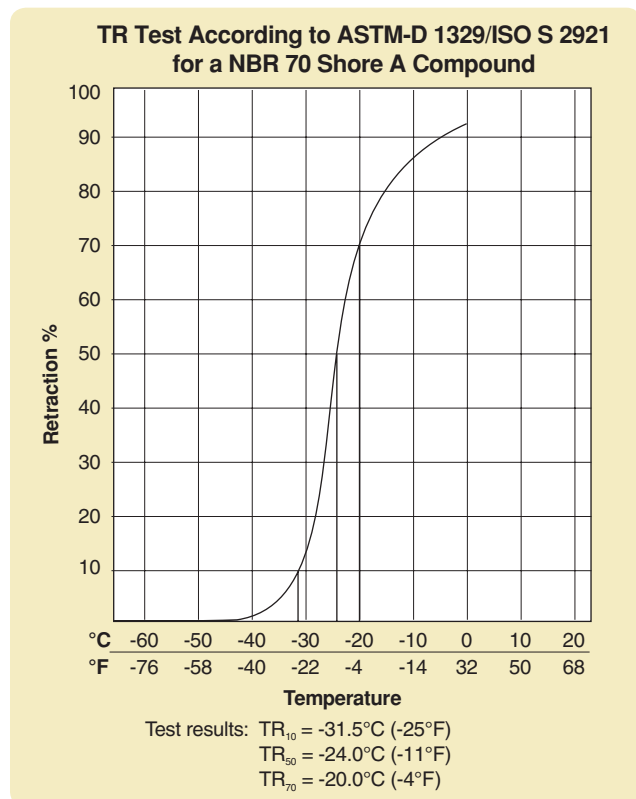


Figure 2-26: TR Test According to ASTM-D 1329/ISO S2921 for a NBR 70 Shore A Compound

With decreasing temperature, elastomers shrink approximately ten times as much as surrounding metal parts. In a rod type assembly, whether static or dynamic, this effect causes the sealing element to hug the rod more firmly as the temperature goes down. Therefore, an O-ring may seal below the recommended low temperature limit when used as a rod type seal.

When excessive side loads are encountered on maximum tolerance rods or glands, and the pressure is in the low range, leakage may occur at temperatures 5° or 8°C (10° or 15°F) above the TR-10 value. It may be necessary to add as much as 22°C (40°F) to the low temperature shown in the tables for this type of service. See Figure 2-27.

2.13.3 Time

The three obvious “dimensions” in sealing are fluid, temperature, and pressure. The fourth dimension, equally important, but easily overlooked, is time.

Up to this point, temperature limits, both high and low, have been published at conventional short-term test temperatures. These have little bearing on actual long-term service of the seal in either static or dynamic applications. A comparison of the temperature limits of individual compounds in this guide with previous literature will reveal that for comparable materials the upper temperature limit is more conservatively expressed. The narrower temperature range does not imply that the compounds discussed are inferior to others. Rather, those high temperature values based on continuous seal reliability for 1,000 hours are being recommended.

As illustrated by the graph (Figure 2-28), short term or intermittent service at higher temperatures can be handled by these materials.

For example, an industrial nitrile (Buna-N) compound, N0674-70, is recommended to only 121°C (250°F), yet it is known to seal satisfactorily for five minutes at 538°C (1,000°F) and at 149°C (300°F) for 300 hours. Therefore, when the application requires a temperature higher than that recommended in the compound and fluid tables, check the temperature curve to determine if the total accumulated time at high temperature is within the maximum allowable limit. The sealing ability of a compound deteriorates with total accumulated time at temperature. The curves show the safe, cumulative time at a given temperature for specific elastomers used as static seals. For dynamic seal applications, temperatures as much as 14°C (25°F) below those indicated may be more realistic.

2.13.4 Pressure

The system operating pressure is always a consideration as it effects the choice of seal materials in several ways. First is hardness, as may be required to resist extrusion in dynamic designs or where there is a large gap between sealed members in static applications. Second is at-rest vs operating conditions and requirements for “leakless” at rest conditions which would suggest due consideration be given to the long-term compression set properties of a given material.

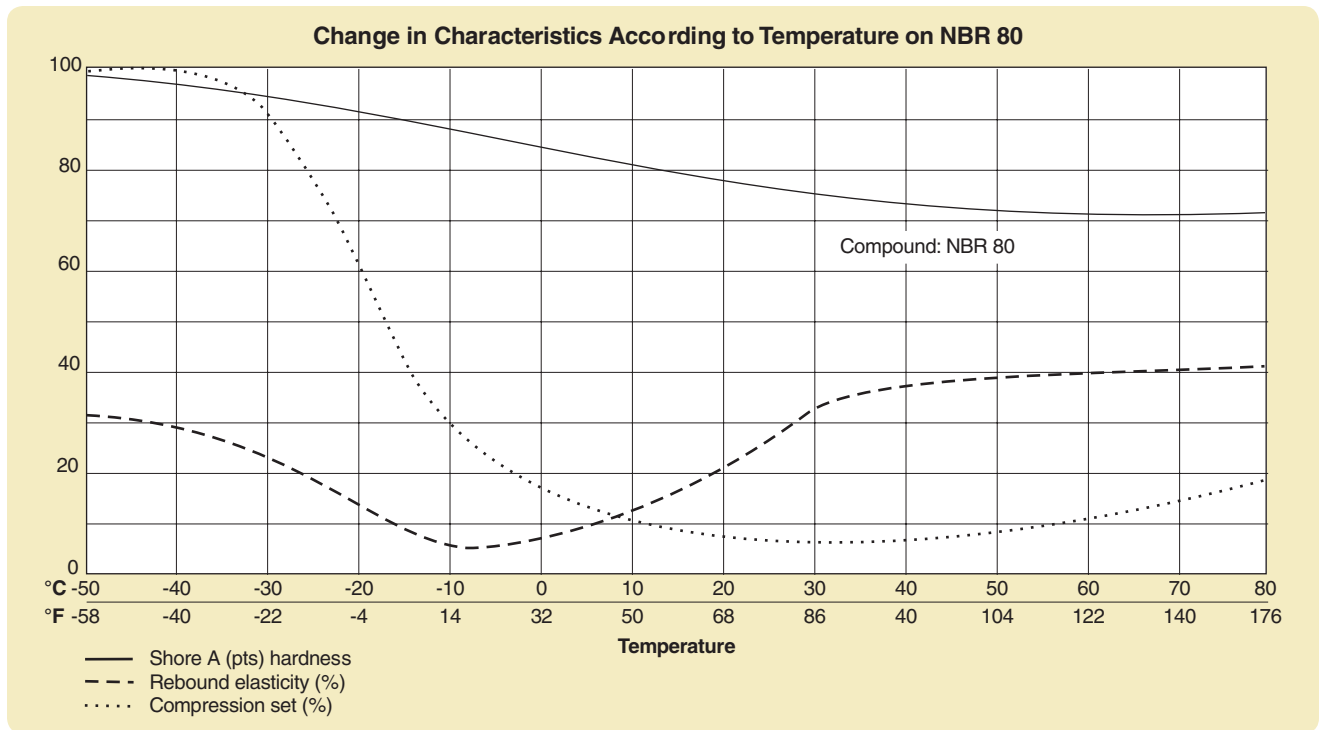


Figure 2-27: Change in Characteristics According to Temperature on NBR 80

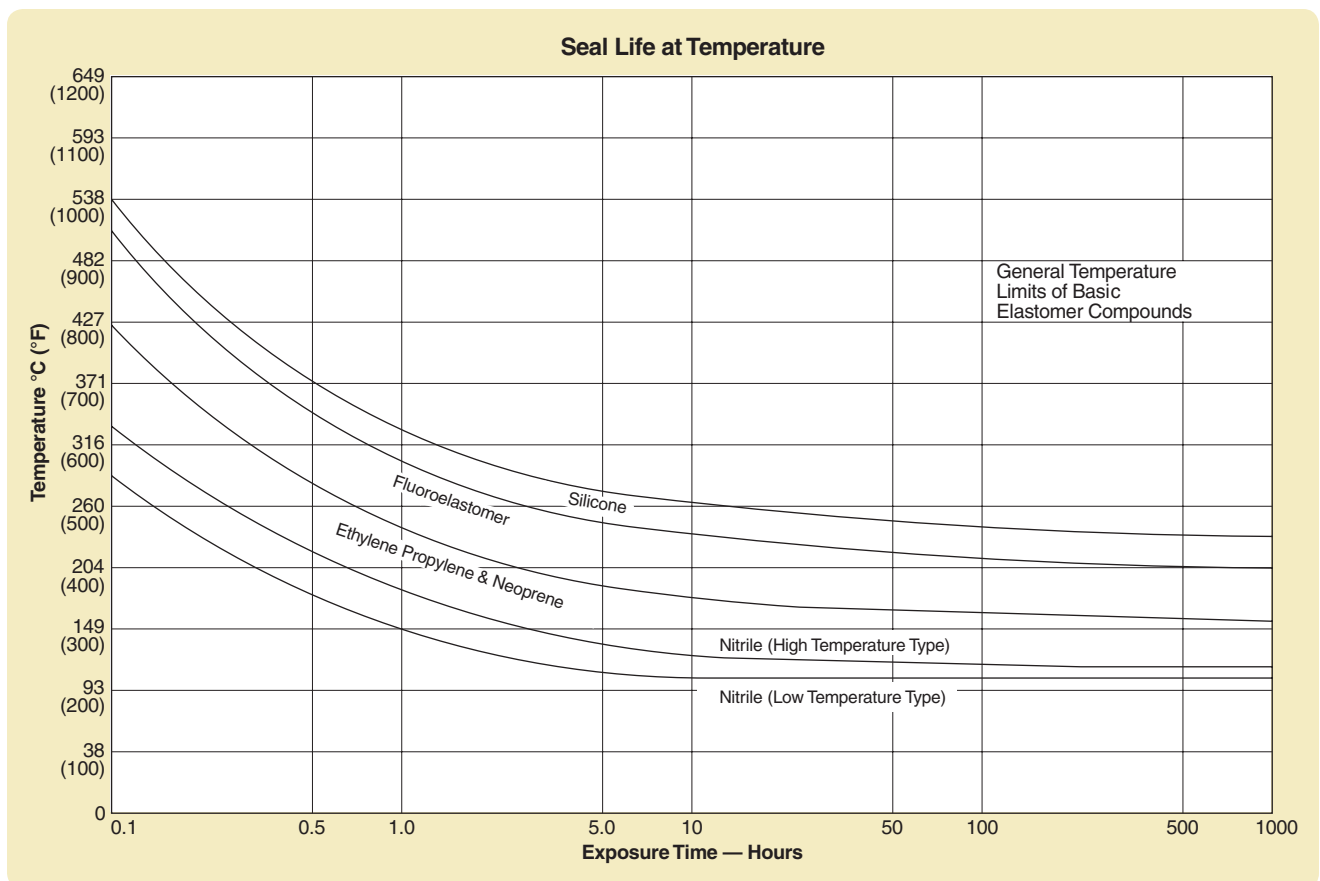


Figure 2-28: Seal Life at Temperature

2.13.5 Mechanical Requirements

An important consideration in selecting the proper seal material should be the nature of its mechanical operation, i.e. reciprocating, oscillating, rotating, or static. How the seal functions will influence the limitations on each of the parameters (fluids, temperature, pressure, and time) previously discussed.

Static applications require little additional compound consideration. The prime requisite of a static seal compound is good compression set resistance.

Dynamic applications, due to movement, are more involved. All properties must approach the optimum in a dynamic seal compound, resilience to assure that the seal will remain in contact with the sealing surface, low temperature flexibility to compensate for thermal contraction of the seal, extrusion resistance to compensate for wider gaps which are encountered in dynamic glands, and abrasion resistance to hold to a minimum the wearing away or eroding of the seal due to rubbing.

2.14 Selecting a Compound

Having discussed the major aspects of seal design that affect compound selection, here is a summary of the necessary steps to follow, always keeping in mind that standard compounds should be used wherever possible for availability and minimum cost.

1. If military fluid or rubber specifications apply, select the compound from Table 8-2 or 8-3 in Section VIII, Specifications.
2. For all other applications, locate all fluids that will come in contact with the seal in the Fluid Compatibility Tables in Section VII.
3. Select a compound suitable for service in all fluids, considering the mechanical (pressure, dynamic, static) and temperature-time requirements of the application.
4. If a compound of different durometer from that listed in the Fluid Compatibility Tables in Section VII must be used, contact the O-Ring Division for a harder or softer compound in the same base polymer.

2.15 Compound Similarity

General purpose O-ring compounds are listed by polymer and Shore A durometer hardness for ease of selection. Note that the last two digits of Parker O-Ring compound numbers indicate this type A hardness. For example, compound E0540-80 is an 80-durometer material. The one exception is compound 47-071, which is a 70-durometer compound.

Butadiene, chlorosulfonated polyethylene, isoprene, natural rubber, and a few other elastomers do not generally perform as well as the listed polymers in seal applications, and Parker does not normally offer O-rings in these materials.

See Table 2-2 for comparison of similar properties by polymer family.

2.16 Testing

An elastomer is seldom under the same confinement conditions when laboratory physical property tests are made as when installed as a seal. The usual compression, lack of tension, and limited room for expansion when installed, all result in a different physical response from what is measured on an identical but unconfined part.

Example:

A silicone compound tested in hydrocarbon fuel in the free state may exhibit 150% swell. Yet seals of such a compound confined in a gland having volume only 10% larger than the seal, may well perform satisfactorily. Complete immersion may be much more severe than an actual application where fluid contact with the seal is limited through design. The service could involve only occasional splash or fume contact with the fluid being sealed. Different parts made from the same batch of compound under identical conditions will give varying results when tested in exactly the same way because of their difference in shape, thickness, and surface to volume relationship (see Figure 2-29). Humidity alone has been found to affect the tensile strength of some compounds.

Correlation between test data and service conditions is not a simple problem; it is an industry-wide problem. Until improvement can be made, manufacturers and users must use the available data to the best of their ability. In essence, it is the misapplication of data, not the measurements, which causes difficulty. However, with data in some other form, such

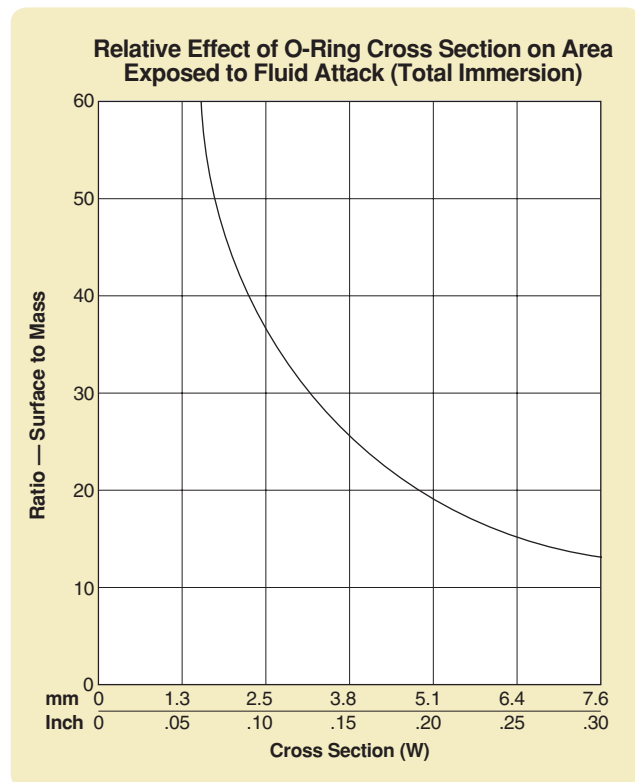


Figure 2-29: Relative Effect of O-ring Cross Section on Area Exposed to Fluid Attack (Total Immersion)

misapplication might be greatly reduced. ASTM Designation D471 (Standard Method of Test for Change in Properties of Elastomeric Vulcanizates Resulting from Immersion in Liquids) states: "In view of the wide variations often present in service conditions, this accelerated test may not give any direct correlation with service performance. However, the method yields comparative data on which to base judgment as to expected service quality and is especially useful in research and development work."

2.17 Specifications

Specifications are important, but so is progress. Therefore, even though it may be more difficult to prepare, a performance specification is recommended. This allows new developments and improvements to be adopted without any appreciable effect on the specification.

Avoid specifying how to compound materials or process compounds. Let the seal manufacturer examine the performance desired. A vendor should be allowed to supply his best solution to a problem. It is not only possible, but also probable that a well-qualified supplier knows of materials and/or processes that will solve the problem and one should be permitted to use them.

It must be recognized that physical properties provide a means of screening new materials for an application by setting realistic minimums. These can be established when experience with certain properties gives a good indication of the suitability of a new material for the application. These properties also permit control of a material after it has proven satisfactory for an application. Therefore, a brief discussion of the main points

that should be considered when preparing the physical and chemical test portions of a specification follows. The discussion is in the order that specifications are usually written and tests carried out. There are three major points that must always be considered when preparing any specification. These are:

1. Different size parts give different results (see Figure 2-30). All parts with varying cross section or shape will not meet specific properties set up on another particular part or on test specimens cut from a standard 6" x 6" x 0.075" test sheet. Therefore, always designate the actual parts on which the tests are to be conducted for both qualification and control. For example, call for a particular size O-ring if the standard ASTM 6" x 6" x 0.075" test platens are not to be used.
2. Always use standard hardness discs (1.28" dia. = 1 in² by 1/4" thick) or 6" x 6" x 0.075" sheets plied up to a minimum thickness of 1/4" 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 both specification and test standards. For example: ASTM Method D2240, paragraph 6-1 states: "A suitable hardness determination cannot be made on a rounded, uneven, or rough surface."
3. It is recommended that standard test methods be used whenever possible. Consider the case of the deviation from the standard methods of taking instantaneous durometer readings. Occasionally, fifteen or thirty second delayed durometer readings are specified. A delayed

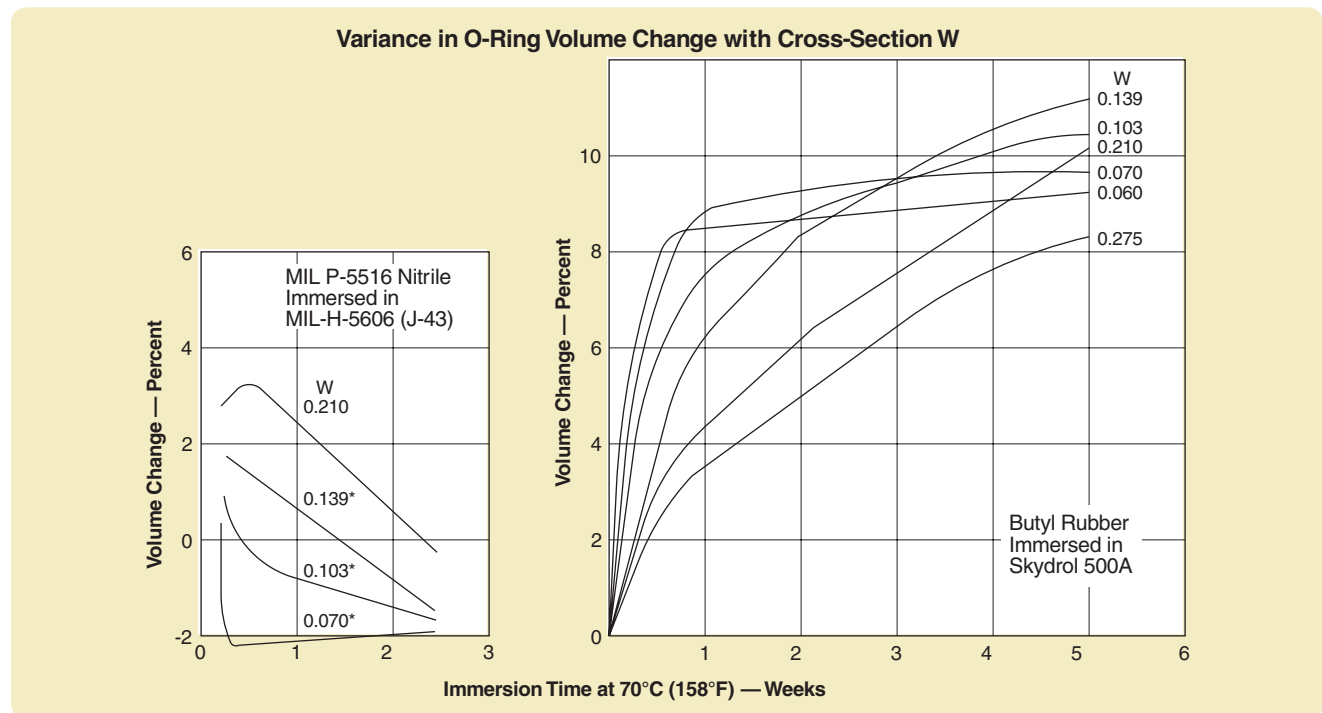


Figure 2-30: Variance in O-ring Volume Change With Cross-Section W

*Averages of many samples

durometer reading results in a lower durometer value than would be obtained with the standard instantaneous reading. This usually causes widespread confusion and enlarges the problem of correlation.

Where feasible, designate a standard test method for each test required by a specification (either ASTM or ISO Test Method). These methods are widely used and help to assure correlation among laboratories. Correlation of results is perhaps the hardest thing to assure when preparing a specification. However, adhering to the procedures described above minimizes this problem.

Every well-written specification should contain both qualification and control sections. Although these two sections may be combined in the actual specification, they are discussed separately.

2.18 Qualification Testing

Functional requirements should always be given first. One functional test is worth more than a thousand physical and chemical property tests. The following discussion will lead to a specification for qualification of new seal compounds after the known functional requirements appear to correlate with field or laboratory, chemical or physical results. Thus the first step is to set the original physical property limits that will assure that the mechanical properties desired in the seal are present. These are in addition to the functional tests.

2.18.1 Original Physical Properties

Original Physical Properties (before exposure to service conditions) are those measurable attributes of an elastomer formulation which define certain physical parameters used in determining the suitability of a given elastomer material for a given class of service. Certain of these properties are also used in quality assurance testing to maintain batch control and assure consistency between individual manufacturing lots of compound. Original Physical Properties are also used in limiting/delimiting rubber specifications. These properties are:

a. Durometer

Durometer or Hardness is measured in points with a Shore A instrument. Determine the durometer best suited for the application and round off (50, 65, 70, 85). A standard ± 5 point tolerance is established to allow the vendor a realistic working range and permit normal variations experienced in reading durometer.

b. Tensile Strength

Determine the minimum tensile strength necessary for the application. Always take into consideration the inherent strength of the elastomers most likely to be used to meet the specification (most silicones have tensile strengths in the range of 34.5 to 62.1 Bar (500 to 900 psi); therefore, it would be foolhardy to specify a minimum tensile strength requirement of 138 Bar (2,000 psi) for a silicone material).

Once the minimum tensile strength has been set, multiply it by 1.20 (for example: 69 Bar $\times$ 1.20 = 82.8 Bar (1,000 psi $\times$ 1.20 = 1200 psi)). This is the minimum limit set for tensile strength in the qualification section. It provides for the normal tensile strength variation of $\pm 15\%$ experienced between production batches of a compound.

c. Elongation

Investigate and determine the maximum amount of stretch a seal must undergo for assembly in the application. Multiply this figure by 1.25 to allow a safety factor and to provide for normal production variation of $\pm 20\%$.

d. Modulus

Choose a minimum modulus that will assure a good state of cure, good extrusion resistance, and good recovery from peak loads. Keep in mind the original tensile and elongation figures established in (b.) and (c.). Modulus is directly related to these two properties.

e. Specific Gravity

A value for specific gravity should not be set in the qualification section of the specification but the value should be reported "as determined." This value will then be used in the control section.

2.18.2 Aged Physical Control

The second step is to determine the resistance of the seal to the anticipated service environment. This is done by measuring change in volume and physical properties of test samples after exposure to various conditions for a specified time at a specified temperature (i.e., 70 hours at 100°C (212°F)). Recommended times, temperatures and test fluids for accelerated tests can be found in ASTM D471. It is usually desirable to use the actual service fluid. This does, however, add another variable to the tests since commercial fluids are not as tightly controlled as test fluids. This fluid variation accounts for some of the differences in test results.

a. Hardness Change

This is usually controlled to avoid excessive softening (causing extrusion) or hardening (causing cracking, lack of resilience, and leakage).

b. Tensile Strength Change

Tensile strength change can limit a compounder severely. A reasonable plus or minus limit is usually set as insurance against excessive deterioration and early seal failure. Each individual fluid dictates its own specific limits. For example, a nitrile compound tested in petroleum based IRM 903 (formerly ASTM oil No. 3), at 100°C (212°F), can be expected to lose a maximum of 35% tensile strength and the same compound tested in MIL-L-7808 (di-ester base fluid) can be expected to lose a maximum of 70% tensile strength. Experience will probably dictate the limits. However, a 10% tolerance is never considered realistic since this much variance in tensile strength can be experienced on two test specimens cut from the same sample.

c. Elongation Change

Experience will dictate this limit as noted under tensile change. Once limits are set, tolerances will apply as discussed in the Control Section on Elongation.

Remember that every designer should set limits for the control of all of these properties based on his past experience in the same or similar application. Excessive hardening, gain of tensile strength, and loss of elongation after immersion are indications of over aging. Excessive softening, loss of tensile strength, and gain of elongation are good indications of reversion toward the original state before cure.

d. Volume Change

1. Determine the maximum amount of swell that can be tolerated in the application (usually 15% to 20% for dynamic and 50% for static).
2. Determine the maximum amount of shrinkage that can be tolerated in the application (usually 3-4% for both dynamic and static). Take into consideration dry-out cycles that may be encountered in service and include a dry-out test after the immersion test to provide a control for dry-out shrinkage. Remember that shrinkage is a prime cause of failure.
3. Set the minimum and maximum limits necessary for control of the volume change of the compound in each fluid that will be encountered in the application, or a representative test fluid.
4. Once again it is necessary to stress the difference between test results on different size seals. For instance, an O-ring with cross-section of .070 inch will not have the same volume swell as will an O-ring of the same compound with a .210 cross-section when tested under the same conditions. Furthermore, this difference is at its peak during the first 70 hours (a popular standard test time) and most accelerated testing is specified within this time period. It sometimes requires longer to approach equilibrium value, depending on time and temperature.

Figure 2-30 shows two graphs that depict these phenomena. Besides the extreme variation among different cross-section O-rings in the first two weeks of testing, notice that .070 section nitrile O-rings swell much less than the .210 section O-rings and that the reverse is true with the butyl compound.

For these reasons, qualification volume swell testing must be limited to definite test samples. A more realistic time (i.e., four or eight weeks depending on the fluid and the elastomer) would give results much more indicative of the stabilized swelling characteristics of a material. Normally neither the customer nor the manufacturer can afford such time for prolonged testing.

Expecting all size seals from a given compound to fall within a set volume swell limit at the most critical time period (70 hours) is unrealistic. Short-term test results are quite useful, but only if their inherent limitations are understood.

e. Compression Set

Compression set is usually measured as the amount that a material fails to recover after compression. A realistic value for compression set is all that is necessary to assure a good state of cure and resilience of a compound. Compression set varies with the elastomer, the type and amount of curing agents, other compounding ingredients in the compound, the temperature of the test, and the thickness of the test specimen. For more information, see "Physical and Chemical Characteristics" earlier in this section (paragraph 2.4).

f. Low Temperature Resistance

Low temperature resistance is measured by determining the flexibility of an elastomer at a given low temperature.

1. The lowest temperature at which the seal is expected to function should be determined.
2. The low temperature test method that most nearly simulates the actual service requirement should be chosen to give the best possible assurance that the seal which passes this test will function in the application. Parker believes that the Temperature Retraction Test (TR-10) is the best method for determining a compound's ability to seal at low temperatures. Most low temperature tests are designed to indicate the brittle point of a material. This only tells at what low temperature the compound is most likely to be completely useless as a seal in a standard design, but very little about the temperature at which it is useful. This is not the case with TR-10 that consists of stretching 3 or 4 samples 50%, freezing them, then warming them gradually at a constant rate, and finally recording the temperature at which the samples have returned to 9/10 of the original stretch (1/10 return). This temperature (TR-10) then is the lowest temperature at which the compound exhibits rubber-like properties and therefore relates to low temperature sealing capabilities. Functional tests indicate that O-rings will usually provide reliable dynamic sealing at or below the TR-10 value. Static O-rings normally function satisfactorily to about -8°C (15°F) below this.

2.19 Process Control

The purpose of process control is to ensure uniformity of purchased parts from lot to lot. Process control may be based on the requirements of the qualification section or actual qualification test results. Both of these methods have inherent weaknesses. When a material is qualified to a specification close to the specification limits, normal production variation may cause the material to fall outside the limits. This could result in unnecessary rejection of good parts. Therefore it is suggested that control be based on actual test results of the material in question.

One should be careful not to be trapped by writing a specification based on one test report having only a single set of values. Any single set of tests made on a particular batch, or laboratory samples, is very unlikely to reflect mean values

that can be duplicated day-in and day-out in production. Seal manufacturers have accumulated years of test experience on popular, successful compounds. This information is available from Parker on request. With Parker's CBI program it is practical to refer to the batch from which any seal was made, as well as compound statistical capability and history.

Many of the typical tests for determining a compound's physical and chemical properties that are specified in the qualification section are unnecessary to provide good control of an approved material. Discussion will be limited to only those properties really pertinent to the control section of the specifications.

a. **Hardness** is often specified as a control. It is frequently problematic because of inherent difficulties in measuring durometer with seal specimens rather than standard hardness discs, or platen plies.

A tolerance of ± 5 points is the standard allowance for experimental error caused by reading techniques and production variance from batch to batch of the same compound. This tolerance is sometimes erroneously applied to the original qualification results. For example, if the qualification section specified 70-durometer ± 5 and the qualification value was a 68-durometer reading, the control section would specify 68 ± 5 . It is more desirable to keep the original qualification hardness and tolerance remain in effect (i.e., both qualification and control values of 70 ± 5). This practice is less likely to result in unnecessary rejection of usable parts.

b. **Tensile Strength**, a tolerance of $\pm 15\%$ is standard for any given compound. This tolerance was taken into consideration when establishing the tensile strength qualification limit of 1200 psi for dynamic seals (see qualification section, tensile strength). If a part qualified at the minimum, 82.8 Bar (1200 psi), and the control tolerance is applied, it

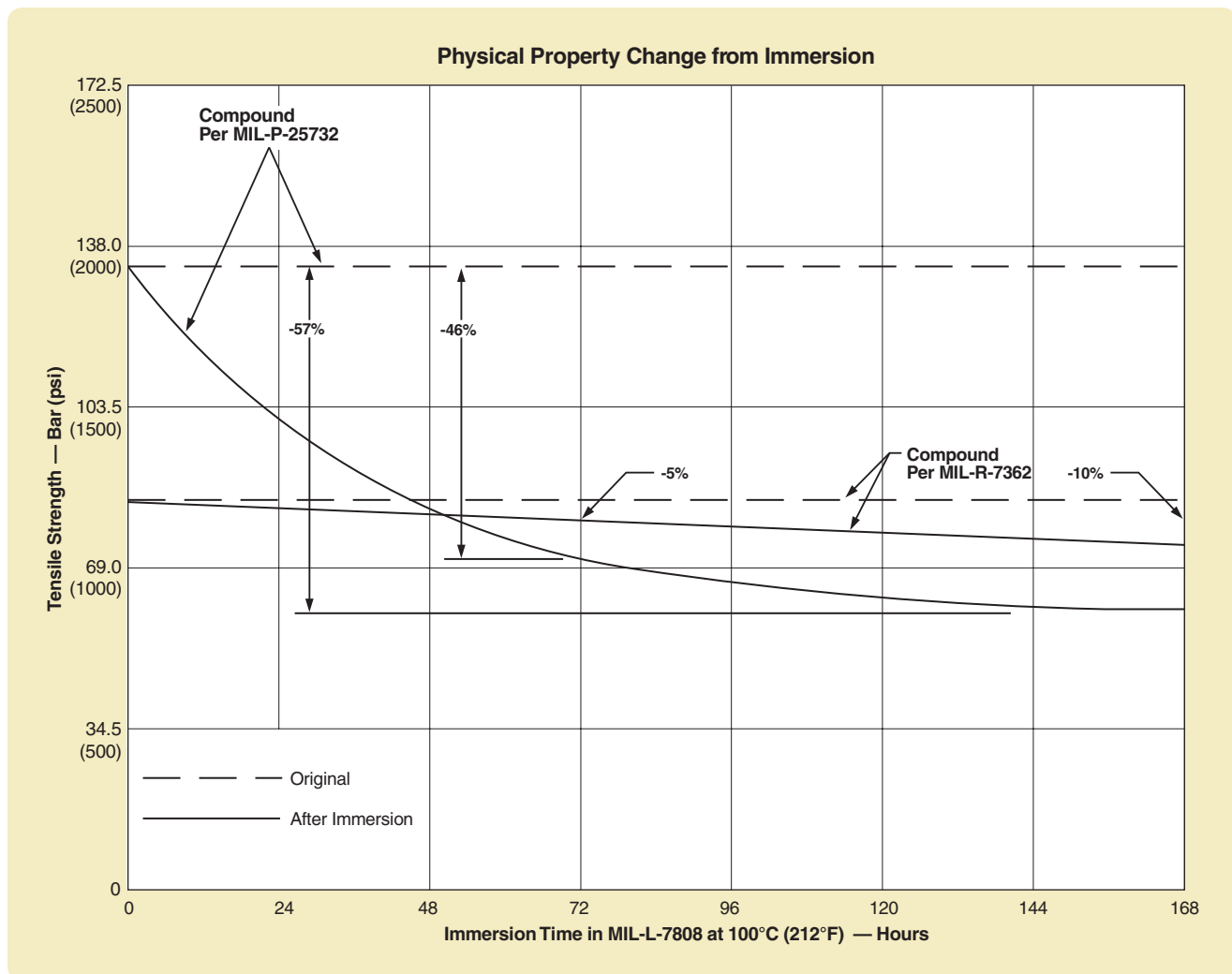


Figure 2-31: Physical Property Change from Immersion

is possible to receive a part with a tensile strength of 70.4 Bar (1020 psi). This value, 70.4 Bar (1020 psi), remains above the (69 Bar (1,000 psi) minimum that is usually required for dynamic applications as previously stated.

- c. **Elongation**, a tolerance of $\pm 20\%$ is standard. Again this must be taken into consideration as part of the safety factor, when setting a limit for elongation for qualification.
- d. **Modulus**, a tolerance of $\pm 20\%$ is standard but is seldom used for control.
- e. **Specific Gravity** of a compound having been established during qualification, a tolerance of $\pm .02$ may be applied. Specific gravity is the easiest and quickest control test available to the industry today. It is also the most accurate if the stringent $\pm .02$ tolerance is applied. Specific gravity is the only test some purchasers use.
- f. **Volume Change**, a plus or minus tolerance on this property is frequently unrealistic. A combination of variance in commercial fluids and sample size gives such an accumulation of negative factors that it is not always feasible to use volume swell as a control. It can be done if, (1) a controlled test fluid is used or control of the commercial fluid eliminates its variance, (2) time of the test is extended, (3) a volume swell history over a long period of time is established on every seal on which a check is desired, and (4) when testing small size seals multiple samples are used for each weighing, thus minimizing inaccuracy (for example: if the balance being used is accurate to .01 gram and a small seal with a weight of .03 gram is being tested, it is easy to see where a result on this size seal can be extremely inaccurate).

If controls are established for the above properties and a compound complies, specifying additional tests is not necessary.

Guard against specifying unrealistically high physical properties that may in reality be detrimental to a seal due to the greater percentage drop-off of these properties after short periods of exposure to fluids (see Figure 2-31). In many applications, a compound in accordance with MIL-R-7362 has outperformed MIL-P-25732 material at both high and low temperature.

Remember, building in too much of a safety factor in the specification can lead to costs that are prohibitive because the best looking laboratory reports are desired. If the compounder is forced to develop a material that is extremely difficult to process, manufacturing costs will increase due to higher scrap rates. The customer ultimately bears these costs.

Each seal supplier has developed numerous nitrile compounds to meet various specifications, all written to accomplish the same thing — to obtain a seal suitable for use with a petroleum base hydraulic fluid. The result is different compounds available for the same service, any one of which would perform satisfactorily in almost all the applications.

Only the more common physical and chemical property tests have been discussed. When preparing a specification and in need of assistance, please call on a Parker Seal representative in your area. They will be more than happy to help you.

