A Review of the Common Elastomers Used for Sealing Liquids and Gases

Stanley Soderstrom, Patriot Rubber
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ASTM International, developer of more than 13,000 safety and performance industry standards since 1898, classifies elastomers by the chemical composition of their polymer chains. That is, the molecular backbone of the rubber that defines its basic physical characteristics.

Of the seven ASTM classifications of elastomers (M, O, R, Q, T, U, and Z), this review will focus on the three classifications (M, R, and Q) commonly used for industrial sealing applications.[1]

M and R class elastomers are organic elastomers containing carbon-carbon polymer chains. Q class elastomers (silicones) are inorganic elastomers with no carbon-carbon bonds in their polymer chains.

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Elastomer (e-las-to-mer) *noun* **-** any rubbery material composed of long chainlike molecules, or polymers, which can recover their original shape after being stretched to great extents. Under normal conditions the long molecules making up an elastomeric material are irregularly coiled. With the application of force, however, the molecules straighten out in the direction in which they are being pulled. Upon release, the molecules spontaneously return to their normal compact, random arrangement.[2]

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"M" Class Elastomers have saturated carbon chains of polyethylene (the M deriving from the more correct term polymethylene). Elastomers with saturated carbon chains exhibit superior resistance to heat, light, and ozone, versus elastomers with unsaturated carbon chains. ASTM classifications of these elastomers end with the letter "M."

<u>Types</u>: **EPDM**, **FKM** (Viton™), **FFKM**

EPDM (ethylene/propylene) organic elastomers are built on hydrocarbon-based polymers and are used widely throughout industry due to their excellent weathering properties and good chemical resistance properties. The polymer chain of EPDM is a terpolymer made of ethylene (making it an M class elastomer) and propylene, and a partially unsaturated diene in the side chain. Fillers, plasticizers, and additional chemicals give EPDM its final performance characteristics.

EPDM elastomers offer poor resistance to oils and fuels, but they are great for nearly everything else! EPDM is ideal for outdoor use due to its excellent resistance to ozone and weathering. And with proper use, EPDM can last decades.

EPDM elastomers provide excellent ozone, weather, and water permeability resistance, and offer very good low temperature flexibility. EPDM possesses very good tensile strength and compression set properties, and good abrasion and tear-resistance properties. EPDM is a good insulator of electricity and offers good chemical resistance.

EPDM elastomers offer poor resistance to most oils, gasoline, kerosene, aromatic and aliphatic hydrocarbons (petroleum), halogenated solvents (solvents used in products such as paints, cleaners, glues, and adhesives), and concentrated acids. EPDM elastomers offer poor flame resistance, and do not respond well to environments that create repeated thermal shock.

Typical service temperature range: -70°F to +300°F, with special compounds to +400°F.
Typical hardness (Shore A): 40 to 95.

FKM (fluorocarbon) organic elastomers, commonly referred to as Viton™, are built on a polymer chain of vinylidene $C{=}CH_2$ with fluorine $CF_2{=}CH_2$.

There are literally dozens of different FKM elastomers, varying in fluorine content, viscosity, and curing method. Typically, the higher the fluorine content, the better the chemical resistance. Lower viscosity FKM elastomers are used for extruded and complex part shapes. And curing can help with specific physical properties. For example, bisphenol-cured elastomers possess better compression set performance, while peroxide-cured elastomers typically offer better chemical resistance.

FKM elastomers possess excellent high temperature resistance, but will harden as temperatures lower, possibly affecting their ability to deform and create a tight seal at very low temperatures. When specifying an FKM solution, it is critical to accurately define any low temperature requirements.

FKM elastomers possess excellent resistance to weather, ozone, oxygen, UV, mineral oil, synthetic hydraulic fluids, fuels, and many organic solvents such as benzene, kerosene, toluene, xylene, etc.

Post curing of FKM elastomers produces a low outgassing compound for aerospace applications. Low compression set means long service life for auto and other mobility applications. Peroxide-cured FKM elastomers offer improved steam resistance for food processing applications.

Gas permeability of FKM is very low and like that of butyl rubber, making FKM ideal for vacuum sealing applications. Special FKM compounds exhibit an improved resistance to acids and fuels. And FKM elastomers offer good flame retardance.

Limitations of FKM elastomers include intermediate tear strength, and little resistance to oxygenated solvents (alcohols, ethers, esters, and ketones). FKM is not recommended for situations requiring good low temperature flexibility.

Examples of FKM elastomers:

Based on chemical composition, FKM elastomers can be divided into the following types:

Type-1 - composed of vinylidene fluoride (VDF) and hexafluoropropylene (HFP), a general purpose elastomer with good overall performance. Fluorine content is approximately 66% by weight.

Type-2 - composed of VDF, HFP, and tetrafluoroethylene (TFE), a terpolymer with a fluorine content of 68% to 69% by weight, resulting in better chemical and heat resistance. Compression set and low temperature flexibility may be affected negatively.

Type-3 - composed of VDF, TFE, and perfluoromethylvinylether (PMVE). The addition of PMVE provides better low temperature flexibility compared to copolymers and terpolymers. Typically, the fluorine content of Type-3 FKM elastomers ranges from 62% to 68% by weight.

Type-4 - composed of propylene, TFE, and VDF. While base resistance is increased in Type-4 FKM elastomers, their swelling properties, especially in hydrocarbons, are worsened. Typically, they have a fluorine content of about 67% by weight.

Type-5 - composed of VDF, HFP, TFE, PMVE, and ethylene. Known for base resistance and high-temperature resistance to hydrogen sulfide.

Typical service temperature range: -15°F to +400°F, with special compounds from -40°F to +500°F.
Typical hardness (Shore A): 45 to 90.

FFKM (perfluoroelastomer) elastomers are built on fully fluorinated polymer chains.

FFKM elastomers possess the highest operating temperature range of any elastomer, the best chemical compatibility of any elastomer, and the lowest outgassing and extractable levels of any elastomer.

FFKM elastomers can tolerate continuous operating temperatures of 482°F, minimum, even when exposed to hydrocarbons and other highly corrosive fluids.

FFKM elastomers are used in the chemical and petroleum industries, geothermal drilling and pumping applications, the manufacturing of semiconductors, high temperature applications, and for paint and coating operations.

FFKM elastomers combine the toughness of an elastomeric material with the chemical inertness of Teflon™. They resist attack by nearly all chemical reagents and provide long-term service where corrosive additives can cause other elastomers to swell or degrade. In addition, FFKM elastomers are less likely to cold flow than Teflon™ seals.

FFKM elastomers can swell significantly when exposed to some fluorinated solvents, fully halogenated freons, and uranium hexafluoride. In addition, FFKM elastomers should not be exposed to molten or gaseous alkali metals. As the thermal coefficient of expansion for FFKM elastomers is stated by manufacturers to be "about 50% greater than that of FKM elastomers," gland volume may have to be increased to allow for this expansion in elevated temperature situations.

Because of its high cost, FFKM is generally used when no other elastomer is appropriate.

Typical service temperature range: -15°F to +600°F.
Typical hardness (Shore A): 65 to 90.

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"R" Class Elastomers are the general-purpose elastomers. These "diene" elastomers have unsaturated carbon chains, causing them to be susceptible to attack by oxygen, and especially ozone. ASTM classifications of these elastomers end with the letter "R."

Types: **SBR**, **NR** (Natural Rubber), **CR** (Neoprene), **NBR** (Buna-N), **HNBR**, **IIR** (Butyl)

SBR (styrene-butadiene), also known as Government Rubber-Styrene, was the elastomer substituted for natural rubber during World War II. Compounded properties are like those of natural rubber.

SBR is used to manufacture car tires but is seldomly used in modern sealing applications. It has been replaced by better performing materials.

SBR is not recommended for exposure to petroleum oils, most hydrocarbons, strong acids, or ozone.

Typical service temperature range: -50°F to +200°F.
Typical hardness (Shore A): 40 to 90.

NR (natural rubber) is the vulcanized product of latex from rubber trees. Until the invention of synthetic elastomers in the 1930's, NR was the only polymer available for producing seals.

NR is used in brake systems, food and beverage applications, and tire production. NR is great for absorbing vibration. NR features high tensile strength, high abrasion resistance, and high tear resistance. And with a good surface friction, NR adheres very well to metals. NR features good resistance to organic acids and alcohols, with moderate resistance to aldehydes (formaldehyde).

NR is not widely used in the sealing industry due to poor compression set performance and lack of resistance to many fluids. NR is widely banned for medical applications.

Typical service temperature range: -50°F to +150°F.
Typical hardness: 40 to 90.

CR (polychloroprene), also known as Neoprene, was one of the earliest of the synthetic materials to be developed as an oil-resistant substitute to natural rubber (NR).

CR possesses excellent resistance to weathering and has found numerous applications in the transportation and refrigeration industries. CR is found in many other sealing applications due to its broad base of desirable working properties, such as good resistance to petroleum oils, good resistance to ozone, sunlight and oxygen, relatively low compression set, outstanding physical toughness, and reasonable production cost.

Limitations of CR include poor resistance to strong oxidizing acids, esters, ketones, and hydrocarbons. Because nitrile (NBR) is economically competitive with Neoprene, and generally has superior performance characteristics in most situations, it has largely replaced Neoprene in the seals used today.

Typical service temperature range: -40°F to +250°F, with special compounds to -60°F to +250°F.
Typical hardness (Shore A): 40 to 90.

NBR (acrylonitrile-butadiene), also known as nitrile rubber and Buna-N, offers excellent fuel and oil resistance, but is still susceptible to attack from oxygen and ozone.

NBR is the most widely used and economical elastomer and is often used in low-temperature military applications, off-road equipment, automotive, aircraft, and marine fuel systems, and can be compounded for FDA applications. NBR combines excellent resistance to petroleum-based oils and fuels, silicone greases, hydraulic fluids, water, and alcohols, with a good balance of physical properties such as low compression set, high tensile strength, and high abrasion resistance. Use of carboxylated nitrile adds excellent abrasion resistance.

Limitations of NBR include poor tolerance to ozone, and potential leaching of phthalate plasticizers used in the compounding of NBR elastomers.

Typical service temperature range: -30°F to 200°F, with special compounds to -70°F to 275°F.
Typical hardness (Shore A): 40 to 90.

HNBR (hydrogenated nitrile) is the product of the hydrogenation of NBR rubber, resulting in varying degrees of saturation of the acrylonitrile-butadiene chain, along with a range of enhanced physical strength and chemical resistance properties.

HNBR is commonly used in oil field applications due to its excellent resistance to oil and oil related products such as detergents, antioxidants, and anti-wear agents. HNBR is also an excellent material for sealing automotive fuel systems.

HNBR is not recommended for exposure to ethers, esters, ketones, or chlorinated hydrocarbons.

Typical service temperature range: -55°F to 300°F.
Typical hardness (Shore A): 50 to 90.

IIR (isobutylene-isoprene), also known as Butyl, is an all-petroleum product offering excellent gas permeability resistance and excellent aging stability.

IIR is especially effective in airtight sealing applications, such as bicycle inner tubes. It also features good to excellent resistance to ozone and sunlight aging. IIR also features excellent shock dampening capabilities.

Only slightly affected by oxygenated solvents and other polar liquids, IIR is often utilized in seals for hydraulic systems using synthetic fluids. It is good with MEK, and silicone fluids and greases.

Because it is a petroleum product, IIR has poor resistance to hydrocarbon solvents and oils, and diester-based lubricants.

Typical service temperature range: -75°F to 250°F.
Typical hardness (Shore A): 40 to 80.

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"Q" Class Elastomers have silicon and oxygen in their polymer chains. ASTM classifications of these elastomers end with the letter "Q."

<u>Types</u>: **MQ**, **VMQ**, **PMQ**, **FVMQ**

Unlike the organic elastomers presented above, inorganic silicone elastomers do not have carbon-carbon chains, but rather very flexible siloxane chains, allowing them to remain flexible throughout a broad range of temperatures.

Silicone elastomers possess both high temperature resistance and low temperature flexibility. They are inert and possess good biocompatibility for use in food and medical applications. Silicone elastomers have good ozone, UV, and weather resistance.

Silicone elastomers possess low thermal conductivity, low chemical reactivity, and low toxicity. Silicone repels water, and does not stick to most substrates, but sticks to some very well, like glass. Silicone elastomers resist creasing and wrinkling, and with the addition of metal fillers and conductive carbon black, silicone elastomers can be formulated to be electrically insulative or electrically conductive (for EMF/RF applications).

Silicone elastomers have high permeability, meaning gas can easily pass through them, and they offer excellent sound dampening and anti-vibration qualities. And silicone elastomers are naturally flame retardant.

MQ (polydimethyl siloxane) has a glass transition temperature (T_g) of -127°C. Other silicone elastomers add a vinyl (**VMQ**) or phenyl (**PMQ**) to the polymer, or both (**PVMQ**).

Silicone elastomers are not very durable. As a group, they possess poor tensile strength, poor tear resistance, and little wear resistance. Silicones are relatively expensive and can be attacked by certain solvents.

Typical service temperature range: -65°F to 400°F, with special compounds to -175°F to 500°F.
Typical hardness (Shore A): 5 to 80.

Include a fluorine with a VMQ to get **FVMQ** (fluorosilicone). FVMQ elastomers combine the high and low temperature stability of VMQ with the fuel, oil, and solvent resistance of FKM elastomers.
FVMQ elastomers are used in aerospace fuel systems, and auto fuel emission control systems. FVMQ is used primarily for static sealing and low outgassing applications.

Typical service temperature range: -100°F to 350°F.
Typical hardness (Shore A): 40 to 80.

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References:

1 “Standard Practice for Rubber and Rubber Latices,” ASTM International Standard D1418
2 “Engineering with Rubber: How to Design Rubber Components,” Alan N. Gent