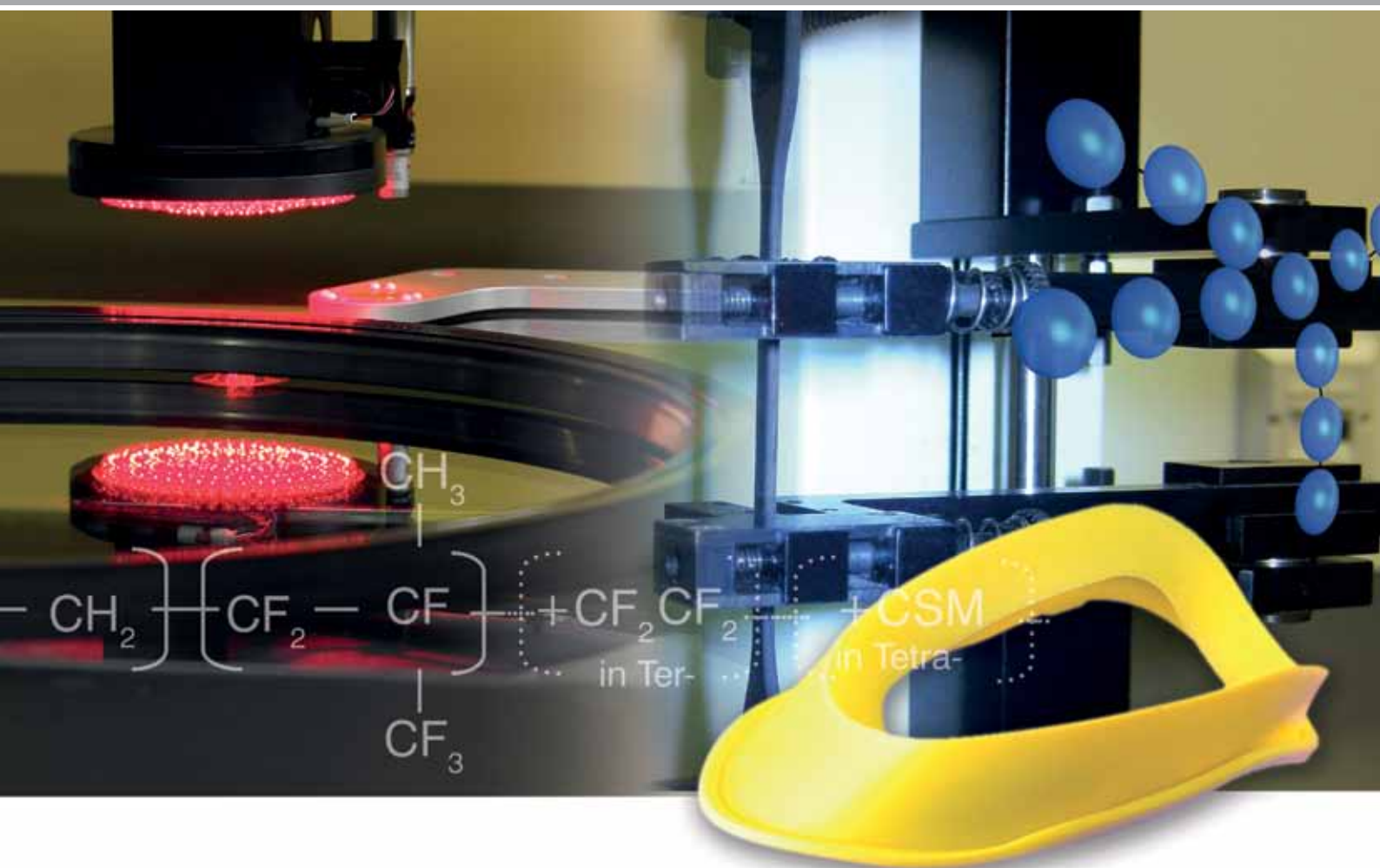


James Walker®

Elastomer Engineering Guide



Elastomer Engineering Guide



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Introduction to elastomer engineering

This guide has been produced by James Walker to provide engineers with a reference source to a wide range of essential information on elastomers and their applications. The aim is to bring together in one place the core information on elastomer engineering that might otherwise be time-consuming to obtain.

It may also be a useful educational resource for those looking for an introduction to elastomer engineering in practice. For more information on any topic on this guide, please contact your local James Walker company via the contact details on the back page.

History of elastomers

Rubber was first brought to Europe in 1493 from the Americas by Columbus, but it remained little more than a novelty for over 200 years. Interest eventually began to grow, and in 1770 Joseph Priestley noted its ability to rub out pencil marks, hence the name 'rubber'.

This was followed by a rapid growth in technical developments and applications in the 19th century. Rubber began to be used as containers, flexible tubing, elastic bands and waterproofing, spurred by developments from Charles Macintosh and Thomas Hancock. Charles Goodyear's discovery of vulcanisation using sulphur increased the natural strength and durability of rubber by cross-linking the molecules of the soft gum rubber into a tougher material.

Other technological advances included improved compounding techniques which enabled the use of anti-oxidants and accelerators, and the incorporation of carbon black to improve strength. This led to a vast increase in the number of applications, which included seals, belts, flooring, electrical insulators, springs, and pneumatic tyres.

As the number of applications increased, demand for the raw material grew rapidly. South America, particularly Brazil, was the prime source of natural rubber until the early 1900s. Then, British Asian colonies, using rubber trees from seeds smuggled



Figure 1: Uncured sheets being sulphur coated and sun dried using the old solarisation method of vulcanisation.

out of the Amazon basin, began to compete with traditional sources.

The period between World Wars I and II witnessed the first development of a true synthetic substitute for natural rubber, ie, sodium polymerised butadiene, which was produced in Germany as Buna rubber and in the USSR as SK rubber. In the 1930s, Germany developed the emulsion copolymerisation of butadiene-styrene (Buna S), whereas sodium polybutadiene continued as the principal general purpose synthetic rubber in the Soviet Union.

The advent of World War II highlighted the importance of rubber as a raw material. When the Axis powers gained control of nearly all the world's supplies of natural rubber, this led to an urgent stepping up in the development of synthetic rubbers, particularly in the USA. Production of styrene-butadiene rubber (SBR), then called GR-S, began in a US government plant in 1942. Over the next three years, government-financed construction of 15 SBR plants brought annual production to more than 700,000 tonnes.



Figure 2: Elastomer moulding after World War II at James Walker.

A wide variety of synthetic rubbers have since been developed, and in the early 1960s production of natural rubber was surpassed by that of synthetic elastomers. By 1990, two-thirds of world rubber production consisted of synthetic varieties.

Fundamental properties of elastomers

Elastomers are based on polymers which have the property of elasticity. They are made up of long chains of atoms, mainly carbon, hydrogen and oxygen, which have a degree of cross-linking with their neighbouring chains. It is these cross-linking bonds that pull the elastomer back into shape when the deforming force is removed.

The chains can typically consist of 300,000 or more monomer units. They can be composed of repeated units of the same monomer, or made up of two or more different monomers. Polymers made up of two types of monomer are known as copolymers or dipolymers, while those made from three are called terpolymers.

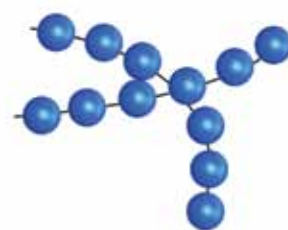


Figure 3: Single monomer units polymerised to form a polymer.

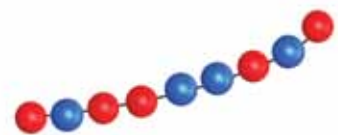


Figure 4: Two different monomers form a copolymer (or dipolymer).



Figure 5: Three different monomers form a terpolymer.

Introduction to elastomer engineering

Elastomers are arguably the most versatile of engineering materials. They behave very differently from plastics and metals, particularly in the way they deform and recover under load.

They are complex materials that exhibit unique combinations of useful properties, the most important being elasticity and resilience. All elastomers have the ability to deform substantially by stretching, compression or torsion and then return almost to their original shape after removal of the force causing the deformation.

Their resilience enables them to return quickly to their original shape, enabling for example dynamic seals to follow variations in the sealing surface.

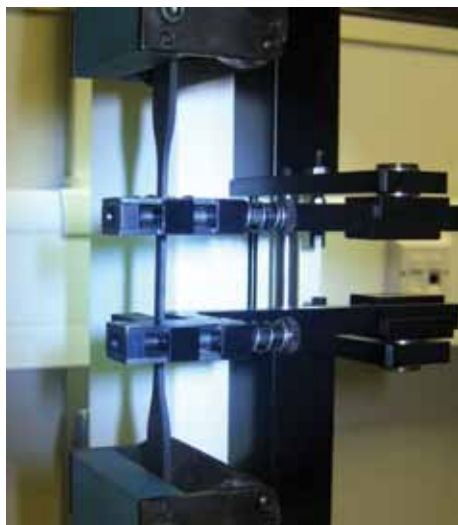


Figure 6: Elastomer sample undergoing tensile testing.

Elasticity

Elasticity is the ability of a material to return to its original shape and size after being stretched, compressed, twisted or bent. Elastic deformation (change of shape or size) lasts only as long as a deforming force is applied, and disappears once the force is removed.

The elasticity of elastomers arises from the ability of their long polymer chains to reconfigure themselves under an applied stress. The cross-linkages between the chains ensure that the elastomer

returns to its original configuration when the stress is removed. As a result of this extreme flexibility, elastomers can reversibly extend by approximately 200 – 1000%, depending on the specific material. Without the cross-linkages or with short, uneasily reconfigured chains, the applied stress would result in a permanent deformation.

Resilience

Resilience as applied to elastomers is essentially their ability to return quickly to their original shape after temporary deflection. In other words, it indicates the speed of recovery, unlike compression set, which indicates the degree of recovery.

When an elastomer is deformed, an energy input is involved, part of which is not returned when it regains its original shape. That part of the energy which is not returned is dissipated as heat in the elastomer. The ratio of energy returned to energy applied to produce the deformation is defined as the material's resilience.

Most elastomers possess a number of other useful properties, such as:

- Low permeability to air, gases, water and steam
- Good electrical and thermal insulation
- Good mechanical properties
- The ability to adhere to various fibres, metals and rigid plastics.

Also, by proper selection of compounding ingredients, products with improved or specific properties can be designed to meet a wide variety of service conditions.

This remarkable combination of properties is the reason elastomers serve a vast number of engineering needs in fields dealing with sealing, shock absorbing, vibration damping, and electrical and thermal insulation.

Most types of elastomers are thermosets, which gain most of their strength after vulcanisation – an irreversible cross-linking of their polymer chains that

occurs when the compound is subjected to pressure and heat. Thermoplastic elastomers, on the other hand, have weaker cross-linking and can be moulded, extruded and reused like plastic materials, while still having the typical elastic properties of elastomers.

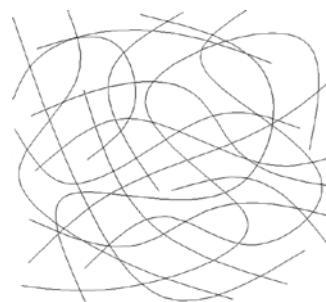


Figure 7: Before curing, the long molecular chains can slide past each other, exhibiting little elasticity.

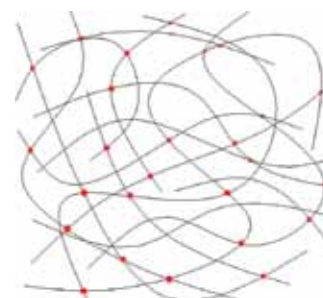


Figure 8: After curing the chains are cross-linked, which ensures they return to position when the deforming force is removed.

Introduction to elastomer engineering

Elastomer products and applications

The beneficial properties of elastomers have led them to be used in a vast range of applications, from hydraulic and pneumatic seals in industrial machinery through to precision pharmaceutical mouldings. Their applications can be divided into two broad categories, 'Sealing' and 'Non-sealing'.



Sealing applications

Seals are precisely formed, moulded or machined shapes that seal fluids or gases by conforming to the sealing surfaces and supplying adequate sealing force to prevent passage of the sealed medium. Initial sealing interference with the surfaces increases as the system pressure grows, since the pressure is transmitted omnidirectionally in the seal.

This helps to ensure effective sealing performance.

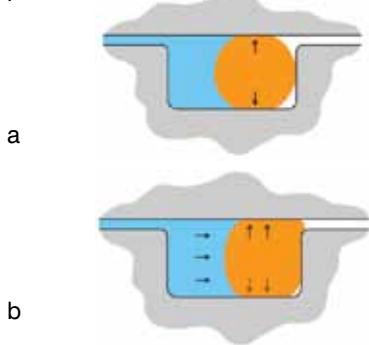


Figure 9: Cross-section of an 'O' ring showing (a) initial sealing force and (b) the increase in sealing force due to system pressure.

The inherent elastic properties of elastomers make them a natural choice for sealing applications. They are designed in geometry and formulation to resist the pressure, motion and environment to which they are exposed in service. In some cases, where the elastomer material is not inherently strong enough to withstand the environment in which it is exposed, additional components can be bonded or included in the seal design to increase the elastomer's performance envelope, such as engineering plastics or metallic components.

Seals are used in applications such as instrument stems, rods, shafts, flanges, cylinders and pump pistons. They are widely used in the food industry, including in bottle lifters, keg seals, manway joints, hopper seals, cones and pipe seals.

Seals are constructed using virtually all types of elastomers with a wide range of reinforcements, fillers, additives and cross-linking technology. The versatility of elastomer systems offers value in the 'fine tuning' of elastomer properties to specific service conditions. However, there may be complex trade-offs in properties of elastomers, such as high compression set resistance but poor dynamic performance or high heat resistance but low chemical resistance to specific fluids.

Non-sealing applications

Elastomers are also widely employed in non-sealing applications. Elastomeric belts, for example, are used in a great number of applications including drive systems and power transmission. They are usually composite products that rely upon reinforcing structures and specific construction techniques to perform in their intended applications. As in many reinforced rubber products, fabrics and other materials such as glass fibre are often used to bear much of the load.

Flexible hoses are also typically constructed of reinforced elastomers and may be multi-layered by design. They are most commonly used to transfer fluids from one point to another or to transmit energy, such as in hydraulic applications. They can also be used as a connector to help absorb surges and

vibration or as a conduit to pass other hoses, pipes or wires.

Elastomers are also used in personal protection and diving products. These include face masks, nasal units, fixing straps, neck seals, ankle and wrist seals, regulator valves and mouthpieces.

Liquid silicone elastomers often find application in products that require high precision, such as electrical connectors, multi-pin connectors, infant products where smooth surfaces are desired such as bottle nipples, medical applications as well as kitchen goods such as baking pans and spatulas. Silicone rubber is frequently overmoulded onto other parts made of different plastics.

Another use is for expansion joints, which are flexible connectors typically consisting of a fabric-reinforced elastomer construction, often with metal reinforcements. Industrial gaiters and bellows are another significant application for the protection of moving components from the elements and other contamination.

Elastomers also have many uses in civil engineering, for example for mounting structures to reduce effect of external noise, vibration or seismic forces; accommodating thermal movement (bridge bearings, expansion joints, pipe couplings, etc); acting as a barrier to water (water stops, plant linings, tunnel gaskets) and a wide variety of others including roofing membranes, rubberised asphalt, rail pads, inflatable formers and concrete texturing.



The automotive sector is another large user of elastomers, with tyres being by far the largest application by volume. Another key use is in suspension systems, where the components can be designed with very specific dynamic properties. Other areas where elastomers make an appearance include exhaust mounts, anti-impact devices, weather strips, windscreen wipers, seat foam and interior trims.

Elastomer types

Over the last century or so, a large number of basic and specialty elastomers have been developed to meet a wide range of applications and operating environments. Their properties vary widely in terms of their elasticity, temperature range, strength, hardness, compatibility, environmental resistance, etc, and there is also a large range in their costs.

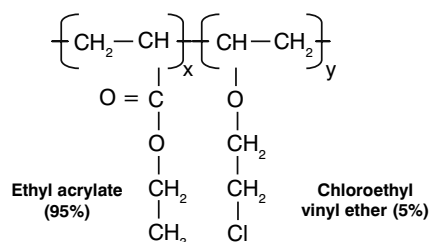
The principal types of elastomers are outlined here. It should be noted that their basic properties can be substantially modified by compound design (see section on Compounding on p11).

Thermoset elastomers

Thermoset elastomers are vulcanised (cured) to produce a degree of cross-linking between the polymer chains. The cross-linking is irreversible, unlike with thermoplastic elastomers which will soften and flow above a given temperature.

Acrylic (ACM)

(alkyl acrylate copolymer)

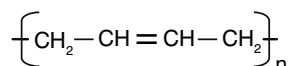


Outstanding resistance at normal and high temperatures to oil and oxygen. Good weathering and ozone resistance. Poor resistance to moisture, acids and bases. Commonly used in automotive transmission seals and hoses. Also used in adhesive formulations.

Bromobutyl (BIIR)

Butyl rubber modified by the introduction of a small amount of bromine, giving improved ozone and environmental resistance, stability at high temperatures and compatibility with other diene rubbers in blends. Also increased adhesion to other rubbers and metals. Similar properties to chlorobutyl.

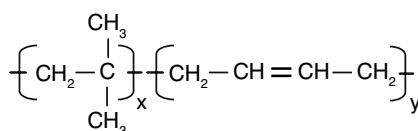
Butadiene (BR) (polybutadiene)



Widely used in blends with natural rubber and styrene butadiene rubber for tyres, where it reduces heat build-up and improves abrasion resistance. Low hysteresis, good flexibility at low temperatures, high abrasion resistance in severe conditions. Also used in shoes, conveyor and transmission belts.

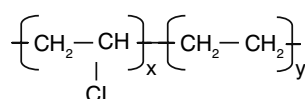
Butyl (IIR)

(isobutylene-isoprene copolymer)



Low permeability to gases and hence used for inner tubes. High damping at ambient temperatures. Good ozone, weathering, heat and chemical resistance but not oil resistant. Other uses include wire and cable applications, pharmaceutical closures and vibration isolation.

Chlorinated polyethylene (CPE)

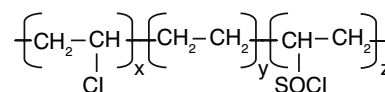


Good chemical resistance to hydrocarbon fluids and elevated temperatures. Poor mechanical strength: mechanical properties may deteriorate above 100°C. Uses in the wire and cable industry, as well as for pond liners.

Chlorobutyl (CIIR)

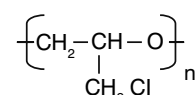
Butyl rubber modified by the introduction of a small amount of chlorine, giving improved ozone and environmental resistance, stability at high temperatures and compatibility with other diene rubbers in blends. Also increased adhesion to other rubbers and metals. Similar properties to bromobutyl.

Chlorosulfonyl polyethylene (CSM)



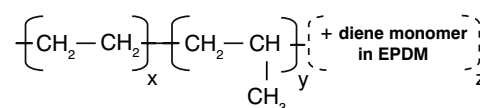
Good resistance to oxygen, ozone and light. Oil resistant and with low gas permeability. Its excellent UV stability makes it useful as roof sheeting and for pond liners, as well as wire and cable applications, coated fabrics and hoses.

Epichlorhydrin (CO/ECO)



High resistance to ageing, oxidation, ozone and hot oil. Good resistance to hydrocarbon solvents, moderate low temperature flexibility, poor electrical properties and abrasion resistance. Attacked by strong mineral and oxidising agents and chlorine. Main use is in the automotive sector for seals, hoses, gaskets and 'O' rings.

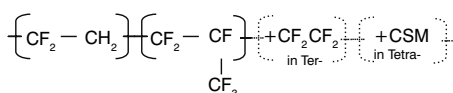
Ethylene propylene (EPM/EPDM)



Excellent ozone/weathering resistance; excellent hot water and steam resistance; good resistance to inorganic and polar organic chemicals. Low resistance to hydrocarbons. Typical temperature range: -45°C to +150°C (-49°F to +302°F), up to +180°C (+356°F) in steam. Mineral oil/grease lubricants should not be used to aid assembly.

Elastomer types

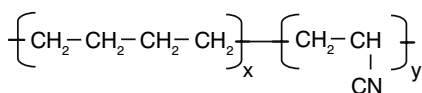
Fluorocarbon (FKM)



Excellent ozone/weathering resistance; good heat resistance. Limited resistance to steam, hot water and other polar fluids (except Tetra-) although new peroxide cured grades with no metal oxides are better. Attacked by amines, limited low temperature capabilities (except specialised grades). Typical temperature range: -20°C to +230°C (-4°F to +446°F). Properties vary significantly with type.



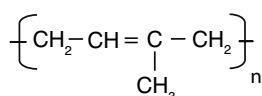
Hydrogenated nitrile (HNBR)



Derived from conventional nitrile by hydrogenation of the unsaturated bonds in the butadiene unit of the polymer. Good oil/fuel and chemical resistance and good weathering resistance. Excellent mechanical properties including tensile strength, tear, modulus, elongation at break and abrasion. Wide temperature range and can be compounded for excellent resistance to rapid gas decompression. Disadvantages include cost and limited resistance to aromatics. Typical temperature range: -40°C to +160°C (-40°F to +320°F). Special grades can be sulphur cured for dynamic applications but then the maximum temperature falls. As with nitrile, many properties can be influenced by varying its acrylonitrile to butadiene ratio.

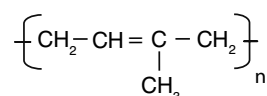
Common Name	Natural Rubber	SBR	EPDM	Neoprene	CSM	Nitrile	Acrylic	Vamac®
Chemical Name	Polyisoprene	Styrene Butadiene Rubber	Ethylene Propylene Diene Monomer Rubber	Polychloroprene Rubber	Chlorosulfonyl Polyethylene Rubber	Acrylonitrile Butadiene Rubber	Polyacrylic Rubber	Ethylene Acrylic Rubber
Nomenclature	NR	SBR	EPDM	CR	CSM	NBR	ACM	AEM
Relative Cost	1	1	1.5	1.5	1.5	1.5	3.5	4
Hardness Range (IRHD)	30-95	40-95	30-85	30-90	40-85	40-100	50-85	45-90
Colours	Full Range	Full Range	Limited Range	Full Range	Full Range	Limited Range	Black	Limited Range
Heat Resistance								
Maximum Continuous	75°C	85°C	130°C	95°C	130°C	100°C	150°C	150°C
Maximum Intermittent	105°C	115°C	150°C	125°C	160°C	130°C	180°C	180°C
Minimum Temperature	-60°C	-55°C	-50°C	-40°C	-25°C	-50°C to -5°C	-20°C	-40°C

Table 1: Basic data for main elastomer types.

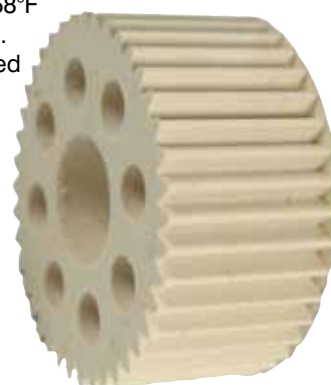
Isoprene (IR)
(synthetic cis-polyisoprene)

Similar chemical structure to natural rubber, but less easy to process and can have lower tensile and tear strength. Its relative purity provides better performance at lower temperatures. Can be used interchangeably with natural rubber in all but the most demanding applications.

Natural (NR)



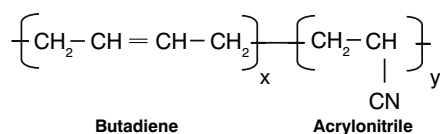
High resilience and tensile strength; good abrasion resistance; low cost. Poor oil resistance and weathering resistance. Typical temperature range: -50°C to +100°C (-58°F to +212°F). Can be used with some dilute inorganic chemicals and polar organics.



Elastomer types

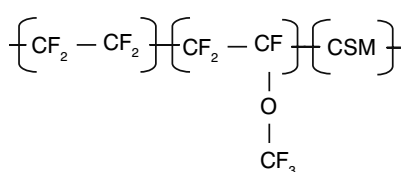
Epichlorohydrin	Butyl	Silicone	HNBR	Fluorocarbon	Fluorosilicone	Kalrez®	Common Name
Epichlorohydrin Rubber	Polyisobutylene Rubber	Polysiloxane	Hydrogenated Nitrile Rubber	Fluorocarbon Rubber	Fluorosilicone Rubber	Perfluorocarbon Rubber	Chemical Name
ECO	IIR	Q	HNBR	FKM	FQ	FFKM	Nomenclature
4	4	11	20	30	40	1000	Relative Cost
40-85	40-85	40-80	50-95	50-95	40-80	65-90	Hardness Range (IRHD)
Limited Range	Limited Range	Full Range	Limited Range	Limited Range	Limited Range	Limited Range	Colours
140°C	120°C	205°C	150°C	205°C	180°C		Heat Resistance Maximum Continuous
160°C	135°C	300°C	180°C	250°C	200°C	325°C	Maximum Intermittent
-30°C	-50°C	-60°C (special grades -80°C)	-30°C	-40°C to 0°C	-60°C	0°C (special grades -25°C)	Minimum Temperature

Nitrile (NBR)



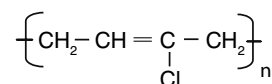
Good aliphatic hydrocarbon oil/fuel resistance and resilience. Limited weathering resistance and only modest temperature resistance. Typical temperature range: -30°C to +120°C (-22°F to +248°F). Widely used in sealing applications. Low temperature grades available down to -50°C (-58°F). As with hydrogenated nitrile, many properties can be influenced by varying its acrylonitrile to butadiene ratio.

Perfluorocarbon (FFKM)



Ultimate in performance regarding heat and chemical resistance. Very expensive. Some grades are suitable for continuous use at 327°C (620°F), with chemical resistance being almost universal. However, their moderate mechanical properties deteriorate rapidly at elevated temperatures, and at temperatures below 0°C.

Chloroprene (CR)



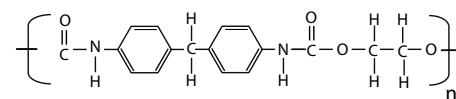
Good weather and ozone resistance, and fair resistance to inorganics. Resistant to many chlorofluorocarbons. Low cost. Moderate oil resistance and limited temperature resistance. Typical temperature range: -40°C to +120°C (-40°F to +248°F). Useful in pneumatic applications.

Polysulphide OT / EOT

(condensates of sodium polysulphides with organic dihalides).

Very good resistance to oils, fuels, solvents, oxygen and ozone. Impermeable to gases. Poor mechanical properties and poor heat resistance.

Polyurethane (AU, EU)

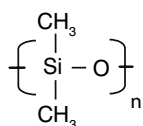


Very versatile, with good abrasion resistance, high tensile and tear strength, good resistance to aliphatic solvents and mineral oils, oxygen and ozone. Can be formulated to have high modulus with a high filler content. Poor heat resistance and can have poor creep resistance, particularly in moist conditions. Uses in seals, metal forming dies, liners, rollers, wheels, conveyor belts, etc.

Elastomer types

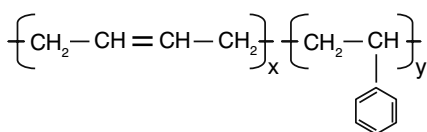


Silicone (Q)



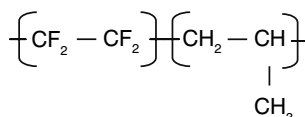
Only moderate physical properties but capable of retaining them over a very wide temperature range. Some types are affected by moisture. Good electrical resistance properties. Readily available in liquid form (LSR). Widely used in sectors such as pharmaceutical, medical, wire and cable, automotive and aerospace.

Styrene butadiene (SBR)



Needs reinforcing fillers for high strength, when it has similar chemical and physical properties to natural rubber, with generally better abrasion resistance but poorer fatigue resistance. Widely used in car and light vehicle tyres. Also conveyor belts, moulded rubber goods, shoe soles and roll coverings.

Tetrafluoroethylene propylene (FEPM) (eg, Aflas®)



Excellent ozone/weathering resistance; good heat resistance; excellent resistance to steam and radiation; good overall chemical resistance. Disadvantages include high compression set and high glass transition temperature. Difficult to process and has poor extrusion resistance especially at high temperatures. Typical temperature range: 0°C to 200°C (32°F to +392°F) or +260°C (+500°F) in steam.

Thermoplastic elastomers (TPE)

Thermoplastic elastomers have many of the physical properties of vulcanised rubbers but can be processed as thermoplastics. Since their commercial introduction in the 1960s, they have become a significant part of the elastomer industry, and are used in applications as diverse as adhesives, footwear, medical devices, automobile parts and asphalt modification.

They require little or no compounding, with no need to add reinforcing agents, stabilisers or cure systems. Their disadvantages are the relatively high cost of raw materials, poor chemical and heat resistance, high compression set and low thermal stability.

Thermoplastic urethane elastomers (TPAU, TPEU, TPU)

Thermoplastic polyurethanes are available in a more limited hardness range than the styrenics, and are characterised by excellent strength and toughness, and oil resistance. Of the two major types, polyester and polyether, the latter has better hydrolytic stability and low temperature performance.

The electrical properties of the

polyurethanes are not good enough for use as primary insulation, but their general toughness leads to their use in cable jacketing. Other uses include fabric coatings, bellows and automotive body components.

Styrenic block copolymers (SBS, SIS, SEBS)

Styrenic block copolymers are the largest volume and lowest priced member of the thermoplastic elastomer family. They are readily mixed with other polymers, oil and fillers, enabling versatile tuning of product properties. They are used in enhancing the performance of bitumen in road paving and roofing applications, particularly under extreme weather conditions. They are also widely applied in adhesives, sealants, coatings and in footwear.

Copolyether ester elastomers

These materials are strong, tough and oil resistant, but are only available in a limited hardness range. They are also resistant to oxygen and ozone.

They are used in moulded goods applications requiring exceptional toughness and flex resistance together with moderate heat and chemical resistance. Applications include cable jackets, tubing, automotive bellows, gear wheels and business machine parts.

Polyester amide elastomers

Similar properties to copolyether ester elastomers, except service temperatures are lower. Good strength and toughness as well as being oil resistant. Also resistant to oxygen and ozone. Limited hardness range and hydrolytic stability.

Elastomer compounding

Compounding

The basic properties of elastomers are highly dependent on the polymers used in their manufacture. These properties can be modified, however, through the appropriate addition of compounding ingredients. Some are added to accelerate cross-linking, others improve processability, while others improve the properties of the finished product.

Some compounds are required to deliver the highest levels of performance in the end product, with cost being a secondary issue. In this case compounding requires the use of materials selected to give the required characteristics without the inclusion of non-essential ingredients which could compromise performance.

In other applications, compounds may be designed to minimise cost, with extenders and diluents being added to reduce the proportion of high priced components in the mix. This inevitably leads to compromises in the mechanical and other properties, of course, but for certain applications this may be acceptable.

Other important factors that affect the quality of the resulting elastomer include the quality of the raw ingredients, the style of mixer and the quality control in mixing. End product properties can also be influenced by the processing of the compounded material into the final product shape.

Of the thermoplastic elastomers, styrenic block copolymers are the only type that is fully compoundable in a similar way to conventional thermoset elastomers. Although fillers such as carbon black can be added to cheapen the material, they do not have a reinforcement effect in thermoplastic elastomers.

The description of ingredients that follows gives a basic guide to their uses and properties.

Ingredients

Polymers

The polymer, or blend of polymers, is the fundamental component in determining the properties of the compound. It is selected to optimise service performance and processing requirements while also taking cost into account. Very high molecular weight polymers can for example produce extremely tough materials. They can however lead to problems with poor flow, poor joins and particularly backrinding.



Fillers

Fillers are added primarily to provide reinforcement and secondly to reduce cost. They fall into two basic categories: reinforcing or semi-reinforcing, and diluent (non-reinforcing, generally for cheapening).

The most popular reinforcing and semi-reinforcing fillers are carbon blacks, which are categorised primarily by means of particle size. Carbon blacks and non-black fillers become more reinforcing as particle size decreases. Highly reinforcing fillers can make a compound tough, which can result in poor flow. Carbon blacks are alkaline in nature and tend to accelerate cure.

Non-black fillers tend to be acidic and can retard cure as well as absorb moisture, which can result in blistering problems during the processing stage. Glycols help to overcome this retardation effect with acidic fillers.

Nano-fillers such as super-fine clays have a high surface area compared to their volume and can produce better mechanical performance. Although they are more expensive than conventional fillers, the same weight of material goes further because the particles are so much finer.

Diluent, or non-reinforcing, fillers have a large particle size and do not 'bond' to the polymer in the same way as reinforcing fillers. They are mainly added to reduce cost. Examples include soft clay, calcium carbonate, and talc.

Fine-ground natural silica is used to provide dimensional stability, improved thermal conductivity, and good electrical insulation properties at low cost.

Accelerators

These speed up the cure. Modifications in their levels can control the cure speed and elastomer properties. It is common to use more than one accelerator in a formulation. Peroxide cured materials often use what is known as a co-agent along with the peroxide which can act like an accelerator or modify the physical properties.



Activators

In most sulphur-cured rubbers, zinc oxide and stearic acid are added to help initiate the cure. In other rubbers, different materials are added which assist the cure in an indirect way.

Very fast cure systems can give problems with scorch/orange peel and backrinding. Peroxide cures can give sticky flashlines due to their inability to cure in the presence of air. Very high levels of some curatives can lead to fissuring/blistering either in mould or during post cure.

Blowing agents

Blowing agents are used in the manufacture of sponge rubber. Sodium bicarbonate was the first commercially used blowing agent, which reacts with stearic acid to produce carbon dioxide at vulcanisation temperatures. Today's commonly used blowing agents rely on the formation of nitrogen as the expansion agent.

Elastomer compounding

Bonding promoters

Most large volume elastomer products are bonded composites, such as tyres, hoses and belts. Bonding agents are often added to the compound to increase the bond strength between the different components. Agents include cobalt-based salts such as cobalt naphthenate or cobalt stearate as well as proprietary materials based on cobalt and boron complexes.

Co-agents

Co-agents are reactive substances which improve the effectiveness of peroxide cross-linking. Most of them are methacrylates or derivatives containing allyls ($\text{H}_2\text{C}=\text{CH}-\text{CH}_2-$), but polymeric materials with a high content of vinyl groups also react in a similar way. Sulphur and sulphur donors can also be used. Their effects may be explained by the co-agent suppressing undesirable side reactions between the polymer radicals.

Coupling agents

Coupling agents provide a stable bond between two otherwise poorly bonding surfaces, for example, silanes added to mineral fillers to bond to polymers.

Curatives

Added to form cross-links, these vary according to the type of elastomer. In sulphur-cured rubbers, sulphur donors as opposed to sulphur give better heat stability as they tend to give single sulphur cross-links. Peroxide cures give good thermal stability due to the short length of the cross-links between polymer chains. Fluorocarbons, along with some other polymer types, can have their own specialised cure systems.

Desiccants

For a number of applications, it is necessary to add a desiccant to remove traces of water introduced in fillers or produced from chemical reactions during vulcanisation. Failure to remove this water can result in uncontrolled porosity in the product and problems where the cure is sensitive to moisture.

The usual agent used for this purpose is calcium oxide (quicklime). It is difficult to disperse in its dry powder form so it is usually offered in a variety of carrying media to ensure adequate dispersion and help prevent moisture take up prior to incorporation in the compound.

Extenders

Extenders are compounding ingredients that are added to the elastomer to reduce the cost of the compound.

Flame retardants

Most elastomers support combustion, and the resulting by-products can be extremely hazardous. To improve their flame resistance a number of products may be added to the compound, either inorganic or organic. They include antimony trioxide, zinc borate, aluminium hydroxide and chlorinated paraffins.

Odorants and deodorants

This class of compounding ingredient was more common in the days when natural rubber was the main rubber for production. The early forms of natural rubber gave products with a distinct aroma and to overcome this a wide range of odorants was offered. Many of the synthetic rubbers have their own distinct aroma and often this has to be masked to make the final product acceptable to the user.

Peptisers

Peptisers are substances that act as chain terminating agents during mastication of rubber. While natural rubber is usually masticated and can be peptised, this is unnecessary for most synthetic rubbers. Peptisers may also act as pro-oxidants. They significantly reduce the time required to lower the viscosity of the rubber to a workable level, thereby cutting mixing time and energy.

Although many materials, such as some accelerators, are known to possess chemical peptising activity, in practice the choice is limited due to additional considerations such as health and safety, effect on vulcanisation characteristics and price.

Pigments

Although most rubber compounds are black, due to the widespread use of carbon black as a filler, coloured rubber compounds are frequently required to add appeal to consumer items. Colour coding of products is also often desirable.

Inorganic or organic pigments are available. Inorganic pigments are often dull and in some cases too opaque to provide the desired colour. They are insoluble and thus cannot bloom. Organic pigments generally give brighter shades but are more sensitive to heat and chemicals and are also relatively expensive. They can also fade badly in long-term exposure to sunlight.

Plasticisers/process aids

Plasticisers need to be compatible with the polymer. They reduce hardness with a given level of filler, and can help with filler incorporation and dispersion. Special types of plasticiser can improve the low temperature flexibility of some rubber types (eg, nitrile and neoprene). Process aids can also assist with filler dispersion, although they are normally added to improve processability downstream.

Elastomer compounding

High levels of plasticiser/process aid can bloom to the surface of make-up and give knitting problems (flow marks and poor joins) in the manufactured product. They can also create difficulties when bonding to metal. Excessive softening of the compound can lead to air trapping in the mould.

Plasticisers can also cause problems when a product is subjected to thermal cycling and/or certain solvents, as they can leach out at high temperatures and adversely affect the low temperature properties.

Pre-dispersed ingredients

Some types of ingredient that are difficult to disperse, for example, certain accelerators and anti-oxidants can be obtained pre-mixed in an inert polymer. The concentrations are normally 75 to 80%. When in this form, the ingredients are more readily dispersed during a mix. Some powders such as peroxides are supplied absorbed onto an inert filler or dampened with oil which helps dispersion, and health and safety. Occasionally, liquids are used absorbed onto a powder which aids handling, and can give a faster incorporation into the mix. In some cases these ingredients can be dispersed into the polymer.

Process aids

A process aid is an ingredient that is added in a small dosage to an elastomer compound to influence the performance of the compound in factory processes or to enhance physical properties by aiding filler dispersion. Examples include physical peptisers, lubricants, silicone modified processing additives and anti-stick agents.

Protectants/antidegradants

These materials are added to inhibit attack by oxidation and ozone. Antidegradants fall into two broad groups – amines (staining) and phenolics (non-staining), with the latter able to be used in non-black compounds. Some anti-ozonants (such as waxes) can bloom to the surface and give similar problems to plasticisers/process aids.

Retarders

Retarders are used to prevent premature curing, or scorching, of compounds during processing and storing. During mixing and further processing in a calender, extruder or moulding press, the elastomer is continuously subjected to heat which can result in premature curing, or pre-curing. To prevent this, retarders are mixed with the compound. Excessive use of retarders results in porosity in compounds and they are rarely used today.

Tackifiers

Tackifiers are compounding ingredients introduced to enhance the surface tack of uncured elastomers. They are usually low-molecular weight compounds.

Other ingredients

There are a range of other ingredients that are sometimes added to compounds to achieve specific properties. These range from the inclusion of iron powder to enable seal fragments in food to be detected with a metal detector, to radiation shielding for use in x-ray environments. The effects on moulding vary enormously depending on the ingredient.

The selected ingredients are combined to produce a formulation for the mix. Table 2 shows an example of a simple formula designed to produce a 90 IRHD nitrile for an application involving contact with a hydrocarbon fuel.

Table 2: Example formulation for a 90 IRHD nitrile compound for fuel resistance.

Nitrile rubber 41% ACN	100	High ACN content for fuel resistance
Zinc oxide	5	Cure activator
Stearic acid	1	Cure activator
SRF carbon black	120	Semi-reinforcing filler to obtain hardness
Adipate plasticiser	6	To aid processing
Sulphur	2	Curative
Accelerator	1	To control cure rate
Anti-oxidant	1	To reduce the effects of ageing

Quantities relate to 100 phr (parts per hundred rubber).

Elastomer compounding

Compound design

Elastomer compounds can be designed for specific purposes by modifying their characteristics through varying the quantities of their constituents. This can range from compounding using diluent fillers and basic ingredients to keep costs down, through to the use of specific additives to produce properties such as high tensile strength or wear resistance.

Varying quantities and the selection of ingredients can heavily influence the end properties of the compound, as illustrated in the following examples.

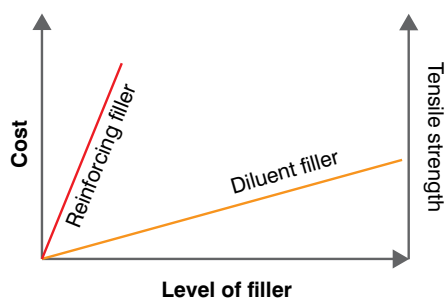


Figure 10: Effects of varying concentration of reinforcing and diluent fillers.

Figure 10 shows the effect on price and performance of varying the concentration of reinforcing and diluent fillers. The reduction in cost by increasing the levels of diluent filler content when compared to the reinforcing filler content needs to be balanced against the lower performance.

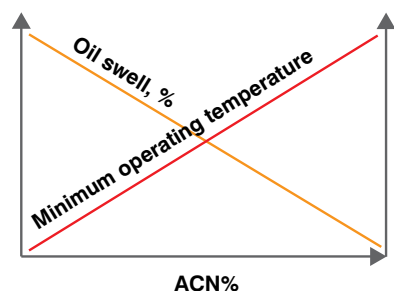


Figure 11: Effects of varying ACN content.

The effect of varying the acrylonitrile (ACN) content in a nitrile elastomer is shown in Figure 11. Increasing the concentration of ACN can be seen to improve oil resistance, while

decreasing its concentration improves low temperature flexibility. This is due to the influence of the ACN as a plastic modifying the rubber influence of the butadiene.

Mixing

Three types of processes are used for mixing the compound ingredients.

Open mill. Here the rubber is banded around the front roll and the ingredients incorporated in the nip.

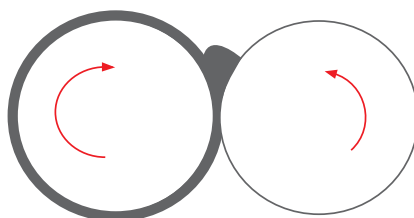


Figure 12: Two-roll mill.

Internal mixer. The internal mixer has the advantage of being totally enclosed. It mixes a batch of material in about 4 to 6 minutes as opposed to up to 30 minutes on an open mill. In most cases the compound exits the mixer onto a two-roll mill where it is cooled and compressed into sheet form ready to be supplied to the manufacturing process.

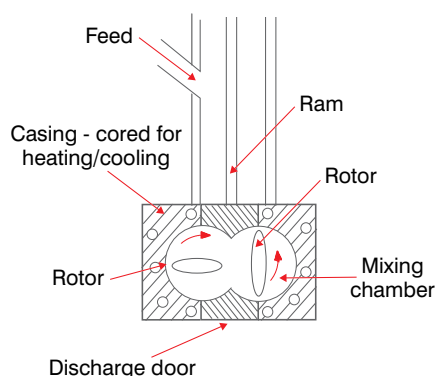


Figure 13: Internal mixer.

Continuous mixer. This machine is similar to a long screw extruder, with the ingredients added via hoppers along the barrel. It is mainly used where only a few ingredients are added.

Mixing process

The mixing cycle is crucial in dispersing the ingredients sufficiently so that the elastomer's physical and fluid resistance properties can be optimised.

In a conventional cycle the polymer is added first and mixed for a short time to ensure homogeneity and to soften sufficiently to accommodate the fillers. The fillers are added in one or more stages depending on their levels, with the ram being lowered after each addition to ensure the material is fully compressed into the chamber.

These days most fillers are automatically weighed and fed directly into the mixer for accuracy and to avoid contamination. These records are automatically stored in the mixing computer system. If plasticisers are used they are usually added with the fillers to aid dispersion.

It is important to optimise the chamber volume fill so that the shear on the compound is maximised.

The curatives are added late in the cycle to minimise their residence time since the mixer heats up due to friction. In some cases the curatives will be added in a second stage, either in the mixer or mill, to avoid starting the cure process or reducing its efficiency.

Some polymers such as EPDM do not need the initial softening and can be mixed 'upside down', with some of the fillers and oils added first, before the cycle continues as normal.

The material is dumped from the mixer at a pre-set temperature and/or energy value to ensure consistency of the final compound. Again this full cycle is recorded in the mixing computer.

The compound is then milled for initial cooling and to ensure homogeneity with soft compounds. A secondary cooling takes place in cooling racks or a specialised take-off unit which can apply anti-tack as needed.

Elastomer compounding

Quality checking

The initial stage of quality checking to ensure the material meets the required standards normally includes the following tests.

Cure characteristics. How an elastomer cures over time is measured on a rheometer. As the compound cures between the hot platens it becomes stiffer. This is measured via a strain gauge connected to an oscillating rotor in contact with the elastomer. The resistance of the material to the oscillating motion is plotted on a graph against time, known as a rheograph, which enables the moulding characteristics to be predicted.

See also the *Materials & product testing* section on page 20.

Hardness. Testing the hardness of the compound using an indenter provides a check that the correct levels of filler have been incorporated. The hardness should normally fall within +5 and -4 IRHD of the specified value. The strict process and quality control regimes in place at James Walker manufacturing sites however, ensures any variation in compound hardness is minimal and far below the industry standard range outlined here.

Details on the test procedure are given on page 20.

Density. This is a measure of the weight per unit volume. It gives an indication of whether the correct quantities of ingredients have been added.

Weight. This test checks the weight of the compound after leaving the mixer and compares it to the input weight of the mix to confirm all the constituents have been added.

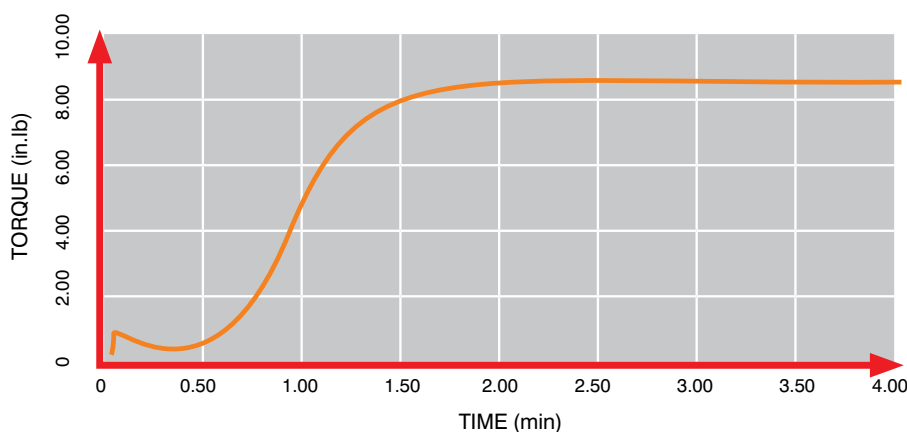


Figure 14: Typical rheometer trace showing progress of cure against time.

Manufacturing techniques

Manufacturing

The manufacturing of products in elastomers involves a number of often complex operations to turn the raw material sheets into a finished product suitable for use. The operation can be spilt into three distinct areas of activity:

Material preparation This includes all the operations up to the point of moulding.

Moulding This includes turning the material into a cross-linked product.

Post moulding operations This involves finishing the product and ensuring that it meets all the necessary quality requirements.

Material preparation

Elastomers

The elastomer from the mixer is normally available either as a sheet of predetermined thickness or split into rolls of material of known thickness and width. The latter option is often used where the material is fed directly into an injection moulding machine. A number of options are available in the development of the pre-form (blank) to be used in the moulding process. These include calendered sheet, strip form material and extrusion.

Calendering

A calender is similar to a mill and has two or more rollers (known as bowls) that can be adjusted to change the size of the nip which controls the thickness of the elastomer sheet. These bowls can be mounted horizontally or vertically and range in size from small laboratory devices to devices weighing several tonnes.

The material from the mixer is fed between the nips on the calender and pulled away from the bowl by a manual or mechanical device. The desired sheet thickness is achieved by adjusting the nips.

The calender process allows a high degree of control on the thickness of the rubber sheet. This sheet is generally then used either to stamp a shape for placing into a mould in the next process, or to manufacture cross-linked elastomer sheeting from which gaskets or other finished products can be cut.

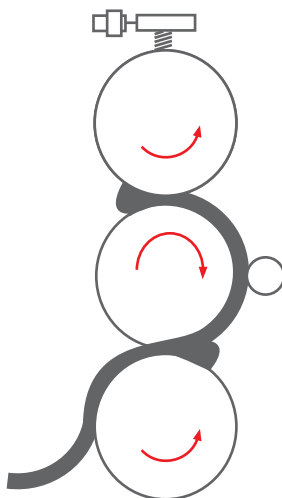


Figure 15: Typical calender.

Strip

If the elastomer is to be fed directly into an injection moulding machine, the sheet from the mixing stage can be slit to create strips of elastomer. These are then fed directly into the screw feed of the injection moulding machine.

Extrusion

There are two main types of extruders: screw and ram.

Screw extruders. Screw extruders have a screw housed within a barrel, with the screw turned by mechanical means. The elastomer is first fed into the barrel via a hopper and then forced down the barrel by the screw whilst heat is added (created by the shearing action and via the heated barrel and screw). At the end of the barrel, in the extruder head, is a die through which the material is forced out. The die is profiled to produce elastomer shaped for the next stage of processing.

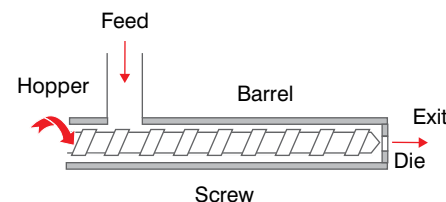


Figure 16: Screw extruder.



Figure 17: Screw extruder producing extrusion for the manufacture of 'O' rings.

Ram extruders. For a ram extruder the elastomer needs to be rolled and warmed, usually by placing it in a bath of hot water or taking it directly from the mill/calender. This roll is then placed into the cylinder housing the ram. The head of the extruder containing the die is then locked in place at the front of the extruder and the ram traversed forward, forcing the material out of the die orifice. When the material exits the die it can either be pulled off in lengths or cut to length/weight by a rotating blade affixed to the front of the machine. For most materials (silicone being an exception) the extruder cylinder and head are heated.

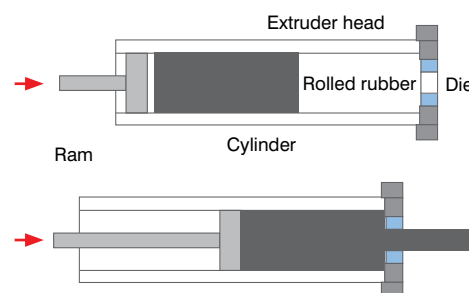


Figure 18: Ram extruders.

Manufacturing techniques

In some cases, the extrusion profile created is the finished product and needs to be cross-linked to retain its shape. This, for example, is the process used for the manufacture of windscreen wiper blades. For products manufactured using this technique, the extrusion is cured either as it exits the machine through a hot box, or by other means following the extrusion process, such as autoclaving.

Non-elastomeric components

If non-elastomeric components are required to be added to the elastomer when the product is formed in the moulding process, for example metal parts for reinforcement, these need to be prepared to ensure that they bond to the elastomer. Depending on the component material, different bonding techniques are required. In all cases involving bonding agents, the surface of the component needs to be treated to remove any grease or oils. Where possible a key is created on the surface of the component to which any bonding agents are applied. Once the component is treated it should be appropriately stored so that the preparation is not affected by moisture or other elements in the atmosphere.



Figure 19: Compression moulding press.



Moulding

Three principal moulding techniques are used to manufacture elastomer products: compression moulding, injection moulding and transfer moulding.

Compression moulding

Compression moulding describes the forming process in which an elastomer profile is placed directly in a heated mould, then softened by the heat, and forced to conform to the shape of the mould as the press closes the mould.

The presses are mostly hydraulically driven and can be either upstroking, where the lower platen moves up and the upper platen is fixed, or downstroking, where the upper platen is driven downwards and the lower platen remains fixed.

The advantages of compression moulding are the lower cost of the moulds, the large sizes of mouldings possible and the relatively quick changeover between different moulds.

The main disadvantage is output, as they are generally loaded and unloaded manually and the elastomer is often placed into the cavity 'cold' so cure times are longer. Some difficulties that can occur are positioning the blank in the cavity and the 'flash' that results from the additional material placed in the cavity to ensure compression in the cavity when the mould shuts. Another disadvantage of this type of moulding is the care and time required to manufacture the blank (weight and profile) to place into the cavity.

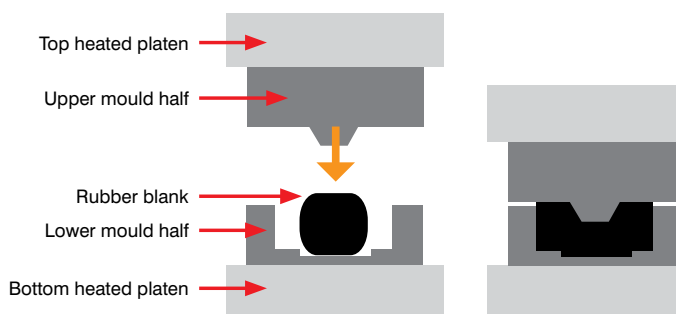


Figure 20: Open mould (left) with elastomer blank placed in cavity, and (right) mould closed forming the finished product profile.

Manufacturing techniques

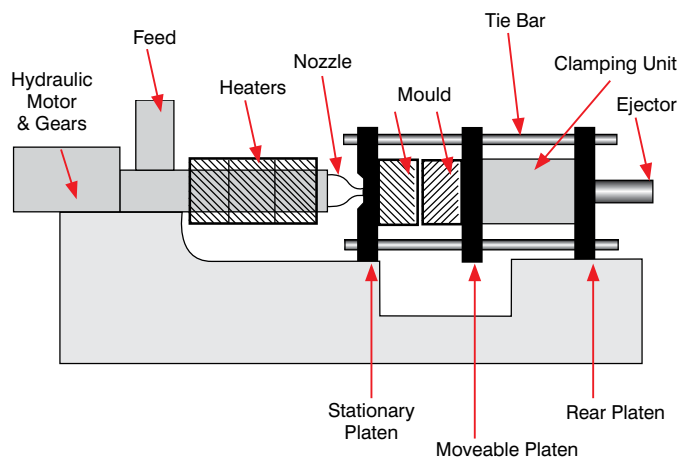


Figure 21: Horizontal injection moulding machine.



Figure 22: Injection moulding machine.

Injection moulding

Injection moulding machines are either vertically or horizontally run. An example of a horizontal machine is shown in Figure 21.

Injection moulding is a process where heated elastomer is injected into a closed cavity via a runner system. Uncured elastomer is fed into the injection cylinder where it is preheated and accurately metered into the mould. This is done by controlling the pressure, injection time and temperature.

The advantages of injection moulding are its suitability for moulding delicate parts, shorter cycle times compared with compression moulding, the high levels of automation that can be introduced in the process and lower levels of flash since the mould is shut when the material is injected.

The main disadvantages of injection moulding are the costs of the tool, the longer changeover times resulting from the more complex tooling and the waste of material in the runner system where a hot runner system is employed (for thermoset materials). Material waste also occurs when jobs are run sequentially with either differing materials or different colours, which requires extensive purging of the machine.

In the case of liquid silicone rubber (LSR), the injection machine can also be used to mix the two LSR constituents before injection into the mould.

Transfer moulding

Transfer moulding is a combination of injection moulding and compression moulding and takes place on a compression press. Elastomer of set weight is placed in the transfer pot, and, as with compression moulding, the pot is closed by the press forcing the elastomer down the sprues and into the cavity. A small amount of excess material flows out of the cavity through vents, with other excess material lying in the sprue

grooves and a mat of material left in the transfer pot.

The advantage of this process over conventional compression moulding is the ability to form delicate parts and to mould parts having inserts requiring specific positioning within the product. It also has simpler blank requirements and faster cure times, since the elastomer heats up quickly as it is transferred from the pot to the cavity.

The main disadvantages are the additional cost of the tooling, the additional waste material due to the pot and sprue, and difficulties that can be experienced when transferring high hardness or high molecular weight materials.

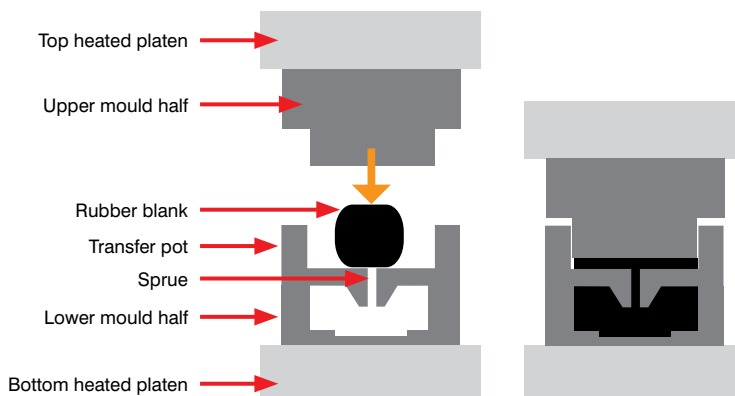


Figure 23: Transfer moulding process showing mould open (left) with the elastomer blank in the transfer pot, and mould shut (right) with the elastomer injected into the cavity.

Manufacturing techniques

Post-moulding operations

Following the moulding process a number of operations may need to be performed to finish the product. These include post-curing, removal of flash and injection sprues, other trimming requirements, testing, etching, inspecting and packaging the product.

Trimming

Various trimming techniques are available depending on the size and shape of the component and the type of elastomer used. They include cryogenic, where the part is cooled below its glass transition temperature and tumbled and blasted with beads to remove the flash, buffing using abrasive wheels and belts, cutting the finished shape using cutting dies, formers, knives and in some cases scissors, using lathes to trim and chamfer components, and rota finishing where components are rotated amongst abrasive stones or other abrasive media.



Figure 24: Component (left) before and (right) after trimming.

Post-curing

For many heat resistant elastomers, such as fluorocarbon and silicone materials, it is necessary to supplement the press cure with an oven post-cure to eliminate residues from peroxides and complete the curing process.

With some materials a post-cure is required in an autoclave. This is a device which generally uses steam to post-cure the components under pressure. An additional benefit of this type of post-curing is that it provides a comprehensive 'wash' of the products and is often used to finish products for food or pharmaceutical applications.

Another use of autoclaves is to cure products (not to be confused with post-curing, as in this instance it is the primary curing process) that are too big or unsuitable to be moulded. Examples of such products are extrusions and sheetings.

Product testing

In some cases the products manufactured need to be non-destructively tested to ensure they meet the required specifications. This normally takes the form of a hardness test.

Destructive testing of representative samples is also often carried out (compression set and immersion testing).

Inspection

One of the final steps in the manufacturing process is finished part inspection. This can be carried out by hand, with an inspector visually examining and measuring the products. Alternatively, for reasonably simple components, inspection can be performed by machine, using a contact or non-contact system, in some cases working fully autonomously. Autonomous measurement is particularly suited to high volume production runs for products such as 'O' rings.



Figure 25: Non-contact inspection.

Packaging

The finished products need to be packaged appropriately before shipping, xsp protection from dirt and dust, etc, some components may need to be sealed against moisture or contamination by other fluids, or protected against UV light.

Material & product testing

Material & product testing

The test methods and terminology used to characterise the physical properties of elastomers can differ from those of other materials. The following is an overview of terms and methods.

Cure characteristics

How a rubber cures over time is measured on a rheometer. As the compound cures between the hot platens it becomes stiffer. This is measured via a strain gauge connected to an oscillating rotor in contact with the rubber. The stiffness (resistance to torque) of the material is plotted on a graph against time, known as a rheograph (*Figure 26*). This information predicts the moulding characteristics, since the rheograph shows the time available to load the press (red box), the time of cure (blue box) and the final state of cure (green box).

The final state of cure shown in the green box is not always a flat line (plateau). For some rubbers the cure continues, as shown by the upper dashed line. This is known as a marching modulus. In time however this line would plateau. For other materials, such as natural rubbers, a reversion of the cure can occur, as shown by the lower dashed line. This is due to the heat breaking the actual polymer chains rather than the cross links formed during the curing stage.

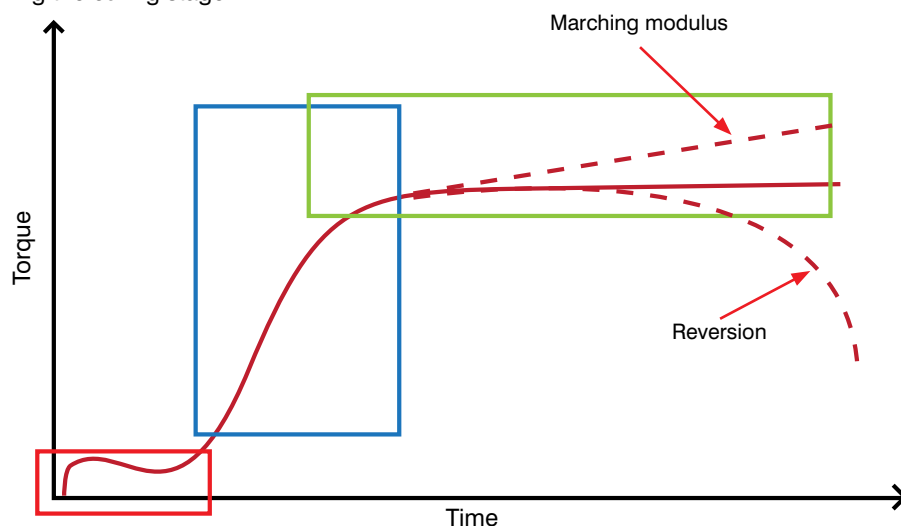


Figure 26: A rheograph enables moulding characteristics to be predicted.

Hardness – BS ISO 48

The hardness quoted for an elastomer usually refers to the result obtained from a “standard” test piece, see BS ISO 48. Results obtained from a non-standard test piece e.g. seal, are normally referred to as “apparent hardness”. The results obtained from measuring the hardness of a material batch, using a standard test piece, may differ from the results obtained from testing product manufactured from the same batch.



Figure 27: Hardness machine.

Tensile strength – BS ISO 37

This is a measure of the stress required to rupture a standard test piece. Tensile strength is a useful quality control tool to monitor inter-batch consistency. It does not however give any indication of extrusion resistance for example.

Temperature has a marked effect on the strength properties of elastomers, whether tensile, tear or compressive. Room temperature testing rarely gives an accurate indication of their strength at elevated temperatures: for example, at 100°C (212°F) some elastomers retain only 10 per cent of their room temperature strength. To create a more meaningful result, tensile testing can be performed at elevated temperatures.



Figure 28: Tensile testing machine.

Elongation at break – BS ISO 37

This refers to the elongation (percentage strain) measured at the point of rupture. A high value is important if substantial stretching is required during fitting, and also in applications where seals are energised across relatively large gaps.

Material & product testing

Modulus – BS ISO 37

In elastomer terminology this is defined as the stress at a particular strain or elongation (whereas in metals it is the ratio of stress to strain as this is a linear relationship). Modulus tends to increase with hardness, with higher modulus materials, in the main, being more resistant to deformation and extrusion (see Figure 29).

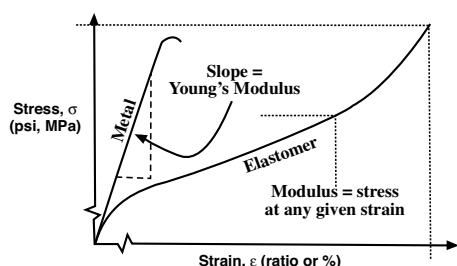


Figure 29: Comparison of modulus for elastomers and metals.

Compression set – BS ISO 815-1 & -2

In any seal, at a constant temperature, a mechanically loaded elastomer will exhibit time dependent relaxation. If the seal is subsequently unloaded, the elastomer will recover towards its original shape to an extent defined by chemical and physical degradation. Such relaxation and recovery phenomena are determined primarily by the viscoelastic nature of elastomers and by the chemical reactions that occur between the material and the environment.

Compression set is widely used for assessing recovery. Standard methods require a compressed sample to be exposed for a fixed time, at a fixed temperature, and then allowed to recover (generally for 30 minutes) at room temperature. Compression set is expressed as the percentage of the original deformation not recovered after this recovery period: 0 per cent indicating full recovery, 100 per cent indicating no recovery.

As many types of elastomer recover more quickly at elevated temperatures, the test is used primarily as a quality control tool; high compression set is not conducive to long term sealability. Compression

set is highest at the extremes of an elastomer's operating capability: irreversible at high temperatures because of chemical degradation, and reversible at low temperatures because of physical stiffening and 'freezing'.



Figure 30: Example of compression set apparatus.

Compression stress relaxation (CSR) testing

A compression stress relaxometer measures the residual sealing force of elastomer samples as they are held between parallel plates under a constant strain.

Compression jigs can be placed in various environments, for example an oven. The jig is placed in the relaxometer, and a reading taken. After this the jig is replaced in the conditioning environment, allowing changes in sealing force to be plotted over time.



Figure 31: Compression stress relaxometer.

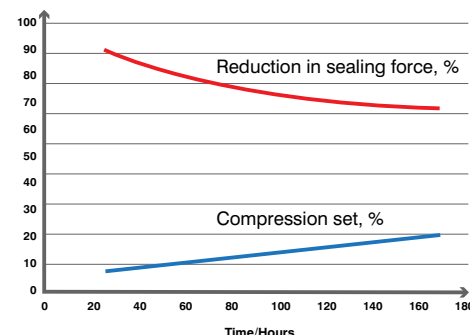


Figure 32: Compression set and corresponding reduction in sealing force for a sample nitrile elastomer at 100°C.

Fluid resistance – BS ISO 1817

Immersion of samples in various fluids at differing temperatures, followed by testing for volume change, tensile strength change, hardness change, etc, will give a reliable indication of how well the material will perform under similar service conditions. Complications arising from solubility parameters mean that this is an important test, see page 27.

Material & product testing



Figure 33: Example of Gehman test equipment.

Low temperature testing

Torsion modulus – BS 903 Pt. A13/ ISO 1432. Also known as the Gehman test, this is used to measure the torsion modulus by twisting a strip test piece, at room temperature and several reduced temperatures, to give a temperature-modulus curve. The result is often quoted as the temperatures at which the modulus is two, five, ten or 50 times the value at room temperature. However, a more useful measure is the temperature at which the modulus increases to a predetermined value, normally 70MPa (10,153psi), which corresponds to the limit of technically useful flexibility.

Temperature retraction – BS ISO 2921. This test is carried out by elongating a test specimen and freezing it in the elongated position. The specimen is then allowed to retract freely whilst the temperature is slowly raised at a uniform rate. The percentage retraction can be calculated at any temperature from the data obtained. In practice, the temperature corresponding to 30% retraction (TR30) roughly correlates to the limit of useful flexibility. Often however a figure of 10% retraction (TR10) is quoted.

Tear Strength – BS ISO 34-1 & -2

Tear strength is a measure of the resistance of an elastomer to tearing. It is measured using a tensile test machine operating at a constant rate of traverse until the test piece breaks.



Figure 34: Temperature retraction test equipment.

Various types of test pieces can be used, and depending on the method employed the maximum or median force achieved is used to calculate the tear strength.

Abrasion resistance

Abrasion damage can occur when there is dynamic motion against an abrasive counterface, or when the sealed environment is intrinsically abrasive and either passes across or impinges upon the seal.

Standard abrasion tests depend on producing relative motion between a rubber sample and an abrasive surface, pressed together by a predetermined force. Unfortunately, such tests do not correlate particularly well with application experience, or with each other! Machines in national standards include:

- Akron Machine (BS ISO 4649), where a rubber disc is rotated so as to drive, by its edge, an abrasive wheel, the two being pressed together by a constant force. The abrasive action is produced by tilting the plane of the disc relative to the wheel.
- National Bureau of Standards Machine (ASTM D1630), where a rubber test block is pressed, by constant force, against a rotating cylinder.
- Conti Machine (DIN ISO 4649) which is similar to the above, but the test block is traversed slowly along the length of the cylinder so as not to pass repeatedly

over the same abrasive surface. This procedure avoids loss of cutting power and clogging of the abrasive media with detritus.

- Pico Machine (ASTM D2228) which abrades by means of knives of controlled geometry and sharpness.

It is sometimes wrongly believed that tensile strength is related to abrasion resistance, and while a high tensile strength compound can have good abrasion resistance the converse can also be true. Abrasion resistance is related more to polymer type and the nature/level of compounding ingredient used. High modulus and high tear strength can be better correlated to abrasion resistance but the relationships are not definitive. Abrasion resistant elastomers must therefore be specifically developed.

Air ageing – BS ISO 188

Exposure to air or oxygen-rich environments at elevated temperatures can cause gradual loss of mechanical properties. Many of these changes occur at a molecular level and are irreversible. They include chain and/or crosslink scission, crosslink formation and crosslink translocation. Samples (tensile, hardness, etc) are placed in ovens at a controlled elevated temperature for a pre-determined time, removed, allowed to cool and then tested and compared against the original properties for the material at room temperature.

Ozone testing, weathering and UV

Deterioration in physical properties can occur when elastomers are exposed to weather. This includes cracking, peeling, chalking, colour changes and other surface defects that ultimately may lead to failure. The most important causes of deterioration are ozone and sunlight.

Ozone resistance is determined by the appearance and magnitude of cracks formed on the elastomer surface when subject to surface tensile strain in an atmosphere containing specific levels of ozone.

Material & product testing

Radiation testing

Radiation interacts with elastomers in two ways: chain scission, which results in reduced tensile strength and elongation; and cross-linking, which increases tensile strength but reduces elongation and finally leads to embrittlement.

Radiation testing is usually carried out with sequential exposure to radiation and heat. Combined radiation and thermal ageing can be performed to act as spot checks. Testing consists of visual inspection, followed by compression set measurements and hardness tests.

Permeation testing

Permeability tests are carried out in a test cell maintained at constant temperature and divided by a disc test piece into high pressure and low pressure sides. The high pressure is held constant and the volume of gas permeating into the low pressure side can be measured by a capillary tube.



Electrical testing

Elastomers are used extensively in electrical applications because they provide an excellent combination of flexibility and electrical properties.

The anti-static and conductive properties of elastomers are determined by measuring their electrical resistance. Measurements are obtained by placing a disc of elastomer of known thickness between two electrodes and measuring the current flow. Electrical strength is

measured by increasing the voltage until electrical breakdown occurs. Patterned surfaces should be wetted beforehand with a conductive solution.

Material analysis

Differential scanning calorimetry

Differential scanning calorimetry (DSC) is the most frequently used thermal analysis technique. It compares the exothermic and endothermic reactions of samples with a reference while subject to controlled heating. The technique enables the accurate determination of cure characteristics, glass transition temperature, crystallisation and melting point. The technique is valuable for failure analysis and compound development.

Infrared spectroscopy

Infrared spectroscopy (FTIR) involves passing infrared radiation onto or through a sample. The pattern of peaks and troughs in the spectra produced then enables the components in the elastomer to be identified. This technique is valuable in identifying materials, failure analysis and compound development.

Chemical compatibility

Many chemical species cause degradation to elastomeric compounds, either by attacking the polymer or some of its compounding ingredients. Degradation caused, for example, by water and amines is irreversible. It is often seen as elastomer hardening or softening, increased compression set, cracking, and in the most extreme cases, dissolution.

After immersion in the test fluid under defined conditions of time, concentration and temperature, samples can be tested for hardness and swell. This may be followed by elongation at break testing.

A table showing the chemical compatibility of the main elastomers is given in the *Material selection* section on page 25.

Thermogravimetric analysis

Thermogravimetric analysis (TGA) is another thermal analysis technique and provides information complementary to DSC. TGA continuously weighs the sample to high accuracy as it is heated. During the heating, different components of the elastomer burn off at different temperatures and the loss in weight provides a precise indication of the components present in the formulation. The technique is valuable for compound development, process control and failure analysis.

Material & product testing

Product testing

Environmental testing

Environmental testing is used to predict how products will behave in actual conditions of use. Test pieces are placed in a controlled environment, such as low or high temperatures or pressures, and can be tested for properties such as sealing performance.



Figure 35: Low temperature environment chamber for testing sealing on static 'O' rings.

Specific application testing

It is important to replicate operating conditions. One of the best ways to do this in a controlled environment is to replicate these conditions on specific test equipment. For example if the application is rotary, testing can be conducted using different shaft speeds, pressures, shaft finishes, media, temperature, etc.



Figure 36: Example of bespoke test equipment for evaluating a rotary cartridge assembly.

RGD testing

Although rapid gas decompression (RGD), also known as explosive decompression (ED), is generally found in the oil and gas industry, it can be experienced in any application where there is a rapid drop in gas pressure. RGD damage has been noted in sealing applications ranging from paint guns and fire extinguishers to systems containing refrigerants.

RGD damage consists of structural failure in the form of blistering, internal cracking and splits caused when the gas pressure, to which the seal is exposed, is rapidly reduced.

The elastomeric components of a system are, to a greater or lesser extent, susceptible to the permeation and diffusion of gases dissolving in their surface. With time, these components will become saturated with whatever gases are in the system. Under these conditions – as long as the internal gas pressure of the elastomer remains at equilibrium with the ambient pressure – there is minimal damage, if any, and no deterioration in performance of the elastomeric component occurs (unless caused by other factors such as chemical or thermal degradation or by extrusion damage).

When the external gas pressure is removed or pressure fluctuations occur, large pressure gradients are created between the interior and the surface of the elastomeric component. This pressure differential may be balanced by the gas simply diffusing/permeating out of the elastomer, especially if any external constraints are not removed.

However, if the physical properties of the elastomeric compound cannot resist crack and blister growth during the permeation process, then structural failure is the inevitable result.

RGD damage can manifest itself in various ways from internal splits that are not visible on the surface of the seal to surface blisters, fractures and complete fragmentation.

Testing is usually carried out on constrained 'O' rings which are placed in a

test vessel. After purging the vessel with test gas to remove any air, the vessel is heated and pressurised with test gas to the chosen pressure and temperature and held for an exposure period.

Decompression is then performed at a predetermined rate while maintaining the test temperature as constant as possible. After a hold period at ambient pressure the pressure cycling is repeated for typically five to ten cycles.

The seals are then externally examined for visual appearance and cut into four radial sections. Magnification is used to examine the cross-sections for internal cracks, and the samples are rated for RGD damage according to the number and lengths of any cracks found.



Figure 37: RGD test rigs.

Load deflection testing

The results of this test are highly dependent upon sample dimensions, due to the 'shape factor' effect when testing elastomers. The 'shape factor' is the ratio of the area of the test sample compared to the area of the sample that is 'free-to-bulge'.

Material selection

Material selection

When selecting elastomers for specific applications, a number of criteria need to be considered, including the expected service conditions, chemical compatibility with service fluids, physical factors such as temperature, life prediction and design considerations.

The main considerations can be broken down as:

Static or dynamic: If there is movement, is it rotary, linear, due to thermal expansion or pressure cycling?

Temperature: Continuous, minimum, maximum, thermal cycling, glass transition temperature shift.

Application: Clearance gaps, surface finish.

Media: Chemical compatibility, solubility parameter.

Pressure: Continuous, maximum, fluctuations, rate of decompression.

Aesthetics: Colour, surface finish, avoidance of split lines, etc.

Cost: Primary consideration, trade off in performance, cost of failure, total cost of ownership (TCO).

Approvals and specifications:

International standards, such as ISO, industry standards or customer specific.

Static or dynamic

When considering a material for an application, it is important to understand whether the material will be subjected to static or dynamic conditions. For example, if the material is subjected to dynamic forces then it may require enhanced abrasion resistance and excellent thermal conductivity properties. The application details required for a dynamic application would include whether it is a rotary, reciprocating or vibrating environment. It would also be important to understand whether the application would be subjected to thermal cycling, as this small amount of dynamic movement may also need to be considered in selecting the correct elastomer.

Temperature

The important considerations when selecting appropriate materials for applications involving temperature are to know the maximum and minimum continuous operating temperatures, intermittent maximum and minimum exposure temperatures and times, system pressure for low temperature applications, whether there will be thermal cycling and also environmental factors involving knowledge of the media to which the elastomer will be exposed.

High temperature applications

The limit to the upper temperature at which an elastomer can be used is generally determined by its chemical stability, and will vary for different elastomers. Elastomers can be attacked by oxygen or other chemical species, and because the attack results in a chemical reaction, their potency will increase with temperature.

Degradative chemical reactions are generally of two types. The first are those that cause breakage of the molecular chains or cross-links, softening the rubber because they weaken the network. The second are those that result in additional cross-linking, hardening the rubber, and often characterised by a hard, cracked or degraded skin forming on the elastomer component.

It is also important to understand the full application details so the right material selection can be made. Elastomers significantly weaken at elevated temperatures and in the case of seals, can result in a significant reduction in extrusion resistance. For applications involving elevated temperatures, especially at high pressures, anti-extrusion elements may also need to be used, either incorporated into the seal design or added as an additional component when fitting the seal.

Low temperature applications

When elastomers are cooled to sufficiently low temperatures they exhibit the characteristics of glass, including hardness, stiffness and brittleness, and do not behave in the readily deformable manner usually associated with elastomers. As temperatures are raised, the segments of the polymer chain gain sufficient energy to rotate and vibrate. At high enough temperatures full segmental rotation is possible and the material behaves in the characteristic rubbery way. The usefulness of an elastomer at low temperatures is dependent on whether the material is above its glass transition temperature (T_g), where it will still behave elastically, or below its T_g , where the material will be hard and relatively brittle.

Elastomers between their useful low temperature flexibility and brittle point go through a stage which is referred to as 'leathery' (see Figure 38).

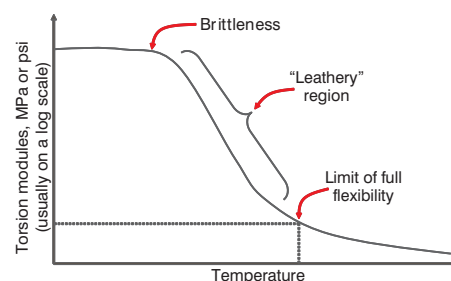


Figure 38: Variation of torsion modulus with temperature.

The low temperature performance of a material can be categorised in a number of ways and specific laboratory tests are performed to give low temperature limits based on sample flexibility and retraction properties. These tests are described in greater detail in the *Material testing* section on page 20.

Material selection

Tg shift. According to conventional theory the free volume of an elastomer is constant at any particular temperature. This is why elastomers are generally considered incompressible: ie, their volume will not change regardless of any deforming force, although the shape will alter. It is here that conventional theory breaks down when considering high applied pressures, because the free volume can be reduced.

This manifests itself as a Tg shift. Applying pressure to an elastomer in a hydraulic or gas system results in an increase in Tg at a rate of approximately 1°C per 5.2MPa (1.8°F per 750psi). Hence a system pressure of 103MPa (15,000 psi) will reduce the low temperature limit of the compound by approximately 20°C (36°F), ie, if the elastomer had a low temperature limit of -40°C (-40°F) at atmospheric pressure, at 103MPa (15,000 psi) it will have a low temperature limit of -20°C (-4°F). The Tg shift can be seen in Figure 39.

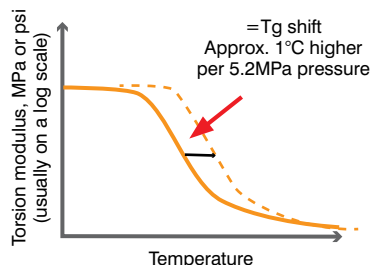


Figure 39: Effect of pressure on torsion modulus.

In dynamic applications, Tg can also rise with an increase in frequency. For example, between 1 and 50Hz, Tg can rise by about 10°C.

Other important considerations for low temperature applications. There are some applications where acceptable elastomer performance can be achieved at temperatures far lower than the recommended minimum temperature. In these instances the following must be taken into consideration:

- If an elastomer is cooled below its minimum recommended operating temperature prior to applying system pressure (gas or liquid), bypass leakage can occur.

- However, if pressure is applied before the temperature is reduced, the elastomer can often operate at temperatures far below its recommended minimum operating temperature.
- Reducing the temperature of an elastomer causes it to harden and lose flexibility. This occurs gradually and the compound changes from flexible to brittle, becoming progressively more leathery. The leathery phase for some compounds can span a broad temperature range.
- Reducing the temperature of an elastomer to its brittle point or below has no detrimental effects on its chemical resistance and its physical properties will return to original values once the temperature is returned to ambient.
- Subjecting an elastomer component to changes in applied stress and strain, shock loading or impact, when at or below the brittle point, can result in damage and fracture of the elastomer.

Thermal cycling. It is also important to understand whether the elastomer will be subjected to thermal cycling. Even for elastomers that cycle within their upper and lower temperature limits, some problems can result where elastomers have been heavily plasticised or had other additives included to gain low temperature flexibility or to reduce cost. In these cases the additives can leach out at elevated temperatures and reduce the low temperature capability of the elastomer when it is next cycled.

Application

When considering elastomeric materials, there are certain application conditions which need to be known ahead of selecting an appropriate material, which are in addition to knowing the temperature, pressures, media and whether the conditions are static or dynamic. These include the surface finish of the materials in contact with the elastomer, any extrusion gaps which may exist in the application and housing design.

Media

Fluids can affect elastomers in two ways: physical interaction, such as swelling, and chemical interaction. The first is generally reversible, while the other is not.

Physical interaction

The degree and type of physical interaction depend on a number of factors, including the cross-link density and type, the filler level and type, the polymer type, the type and viscosity of the media and the solubility parameters of the polymer and media.

The effects of the physical interaction of fluids (elastomers are fluids) are normally observed as the swelling of an elastomer through fluid absorption from its environment. This is generally reversible. The magnitude of the effect depends on the environmental fluid, the elastomer and the temperature, and reflects the readiness with which the elastomer and its surroundings mix, ie, the relative magnitudes of the solubility parameters of the two components.

Solubility parameter (δ) is a thermodynamic property related to the energy of attraction between molecules. Thus if a fluid has a solubility parameter close to that of an elastomer then attraction (and mixing potential) will be high, and high volume swell will result. The level of volume swell will decrease as the difference in solubility parameters increases between an elastomer and its environment. Fluid viscosity also has a significant effect.

The effect of high volume swell is to degrade physical properties (such as tensile strength, modulus and tear strength) and to reduce the elastomer's hardness. These actions can give rise to seal damage due to extrusion between metal parts, amongst other things. In general, volume swells greater than 10 per cent have a negative effect whilst lower levels of swell can benefit by increasing or maintaining sealing contact stress.

Material selection

Occasionally elastomer shrinkage is observed, which occurs as a result of constituents within the elastomer such as process aids, plasticisers and protective systems being leached out. This is rare but can cause loss of seal interference, increase of hardness, system contamination, reduced low temperature flexibility and a reduction in the ageing characteristics of the material.

Case history

An example of the dangers of unexpected solubility effects concerns a solubility parameter analysis of a 70:30 mixture of iso-octane:methanol with low ACN nitrile. A weighted average of the solubility factors for the mixture indicates an expected volume swell of 20%. However, as *Figure 40* shows, the volume swell in practice was almost 60%. It can be seen from *Table 3* that the solubility parameter for a low nitrile is 9.3, which matches the solubility parameter of the 70:30 mix of iso-octane:methanol.



Figure 40: Variation of volume swell for low ACN nitrile in blends of iso-octane:methanol.

Chemical interaction

Many chemical species cause degradation to elastomeric compounds, either by attacking the polymer or some of its compounding ingredients. Degradation caused (for example) by water and amines is irreversible. It often results in seal hardening or softening, increased compression set, cracking, and in extreme cases, dissolution. Such degradation is often highly dependent on exposure temperature, in terms of both the reaction initiating in the first place, and then the rate at which the reaction proceeds. Laboratory tests may not provide a true indication of reaction potential or elastomer compatibility, particularly if performed at reduced temperatures or exposure times.

Examples of agents that can cause chemical degradation are acids, bases, water, hydrogen sulphide, zinc bromide, oxygen, ozone, mercaptans, free radicals and biocides as well as ultraviolet and ionising radiation.

Fluids

• Iso-octane	6.9
• Hexane	7.3
• Di-ethyl ether	7.7
• Xylene	8.8
• Toluene	9.0
• MEK	9.6
• Ethanol	13.0
• Methanol	14.7
• Water	23.2

Polymers

• EPDM	8.2
• FEPM	9.0
• NBR (low)	9.3
• NBR (high)	11.0
• HNBR - as NBR	
• FKM	10.7 to 11.5

Table 3: Solubility parameter, δ , for selected fluids and polymers at 23°C.

Chemical compatibility chart

Key
1 Very good; 2 Good; 3 Fair; 4 Not recommended.
 * Fluoroelastomer grades are available that offer resistance to these chemicals.

Note: These figures are for guidance only. Service life will depend on type of application, whether static or dynamic specific pressure medium, temperature cycle, time of exposure, etc.

Material selection

Pressure

The effect pressure can have on the low temperature behaviour of elastomers and problems it can create with extrusion, have already been discussed in this section. Another important consideration when discussing pressure is to understand the direction or directions it is applied from, its magnitude and whether it fluctuates. The latter consideration can lead to significant elastomer damage if the pressure is reduced rapidly. This is referred to as rapid gas decompression (RGD), formerly known as explosive decompression.

Rapid gas decompression

Although rapid gas decompression (RGD) is generally found in the oil and gas industry, it can be considered a possibility in any application where there is a rapid drop in gas pressure above 50 bar.

RGD damage is structural failure in the form of blistering, internal cracking and splits caused when the gas pressure to which the elastomer is exposed is rapidly reduced.

The elastomeric components of a system are, to a greater or lesser extent, susceptible to the permeation and diffusion of gases dissolving in their surface. With time, these components will become saturated with whatever gases are in the system. Under these conditions, as long as the internal gas pressure of the elastomer remains at equilibrium with the ambient pressure, there is minimal damage (if any) and no deterioration in performance of the elastomeric component occurs – unless caused by other factors such as chemical or thermal degradation or by extrusion damage.

However, when the external gas pressure is removed or pressure fluctuations occur, large pressure gradients are created between the interior and the surface of the elastomeric component. This pressure differential may be balanced by the gas simply diffusing/permeating out of the elastomer, especially if any external constraints are not removed. But if the physical properties of the elastomeric compound cannot resist crack and blister growth during the permeation process, structural failure is the inevitable result. An example of an elastomer failing due to RGD can be seen on page 37 in the failure modes section.

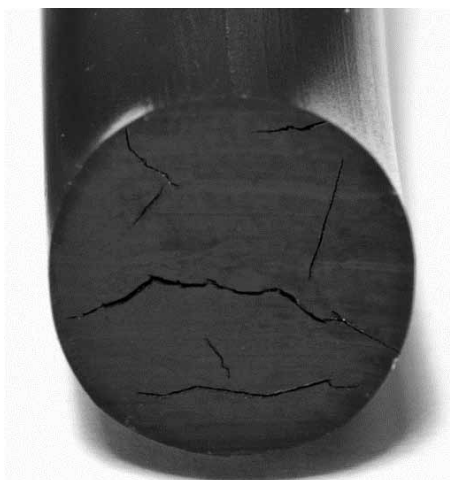


Figure 41: Cross-section of 'O' ring showing RGD damage.

Factors that influence RGD resistance are:

- Polymer type
- Compounding, mixing and processing
- Gas type/mix
- Temperature
- Pressure
- Rate of decompression
- Levels of squeeze and groove fill
- Number of pressure cycles
- Seal cross-section.

Aesthetics

Aesthetics need to be taken into account in applications where appearance is important, for example in consumer products.

Thermoplastic elastomers lend themselves to producing products with high gloss and are readily available in a variety of different colours.

Cost

Cost is almost invariably a primary consideration. It usually needs to be balanced against performance requirements, taking into account the total cost of ownership. A small reduction in price can lead to a disproportionate deterioration in quality.

Approvals and specifications

A variety of national and international standards organisations are responsible for preparing and issuing standards relating to elastomers. These include the International Organisation for Standardisation (ISO), the British Standards Institution (BSI), the American Society for Testing and Materials (ASTM), the Deutsches Institut für Normung (DIN), the European Association of Aerospace Industries (AECMA) and the Association Française de Normalisation (AFNOR).

The work of the international bodies is supported by national standards organisations, who are in turn supported by trade associations, companies, government departments and local authorities.

Designing with elastomers

Designing with elastomers

Designing elastomeric components used to be referred to as a black art, with the unpredictable nature of elastomers often being blamed for difficulties in assessing how the product would behave in service. With many modern tools now at the disposal of engineers and with advances in machining capability and manufacturing techniques, the design of engineering solutions using elastomers is now more of a predictable science. This section explains the role of these tools and the considerations required to ensure the right design.

Advanced product quality planning (APQP)

Advanced product quality planning (APQP) is a structured method of defining and establishing the steps necessary to develop products that meet customer requirements. It originated in the automotive industry, but can equally be applied to product design across all sectors.

APQP focuses on up-front quality planning, and subsequently determining if customers are satisfied by evaluating the output and supporting continual improvement. It consists of five phases:

- Plan and define program
- Product design and development verification
- Process design and development verification
- Product and process validation
- Launch, feedback, assessment and corrective action.

There are five major activities: planning, product design and development, process design and development, product and process validation, and production. The aim is to ensure effective communication both within the manufacturer and between manufacturer and customer.

Finite element analysis (FEA)

Finite element analysis (FEA) is a computer-aided engineering technique that provides an indication of the strength and/or deformation of a product under loading that might typically be experienced in its operating environment. The technique is commonly used at the design stage for components but can also be used to help determine why parts have failed.

FEA simulates the behaviour of a real component with an idealised mathematical model that includes the physical conditions in which it operates. The finite element model is then analysed by a finite element analysis solver, which calculates data reflecting the design behaviour to the applied boundary conditions, and can help to identify weaknesses or potential failures in the design.

Finite element analysis of elastomer components is more complex than when compared to thermoplastic or metallic parts, for example, since the composition of elastomers makes their behaviour more difficult to model.

Material selection

Selection of an appropriate elastomer material is obviously a crucial factor in satisfying the design requirements for a product. A wide range of basic elastomer types are available and within these there are an almost infinite number of variations of formulations that can be produced.

A number of criteria need to be considered when selecting elastomers for specific applications, including the expected service conditions, chemical compatibility with service media, physical factors such as temperature, life prediction and design considerations.

Descriptions of the main elastomer types are given on page 7.

Prototyping

After the initial design stage of product development it is useful to produce a prototype for assessment purposes. This assessment may consist of visual inspection as well as a variety of tests.

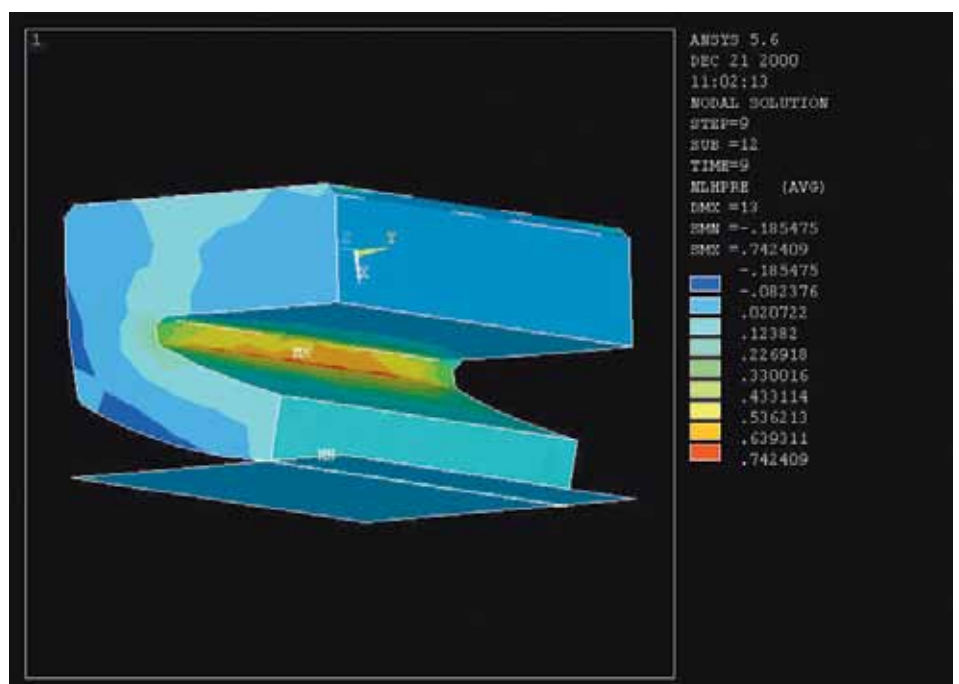


Figure 42: Example of finite element analysis.

Designing with elastomers

Prototyping is particularly appropriate with elastomeric materials, since their complicated nature means their performance is generally harder to predict than for plastics or metal components, for example.

Specification

Specifying elastomer components should cover a wide range of parameters such as the required performance of the product, its quality, the conditions under which it needs to operate, the standards it needs to adhere to, etc. The relevant standards may be international, such as the ISO, or they can be industry specific or defined by the customer.

Tolerances

Being flexible, elastomers do not lend themselves to the same level of tolerancing as rigid materials. Tolerancing needs to take into account shrinkage, which varies with the type of elastomer, and particularly hardness. Soft elastomers generally shrink more than harder varieties. Shrinkage is also affected by cure time, temperature, pressure, inserts, post-cure, etc.

As shrinkage in elastomers is a volume effect, complex shapes in the moulded product or the presence of inserts may have the effect of restricting the shrinkage in one dimension and increasing it in another.

Most insert materials such as metals, plastics or fabric have their own standard tolerances. However, when designing inserts for moulding to elastomers, other factors need to be considered, such as fit in the mould cavities, the location of the inserts with respect to other dimensions, proper hole spacing to match with mould pins, and the fact that inserts at room temperature must fit into a heated mould.

Precision moulding requires additional preparations for tooling, which may require extra features, cavity finishes or cavity flow provisions. In processing, very

close temperature control and timing of moulded cycles may also be necessary.

Surface finish

The surface finish of elastomeric components can be important in certain applications. For example, it can affect the coefficient of friction in dynamic applications such as seals. It can also be important where aesthetic considerations need to be taken into account, such as in consumer products.

Cost issues

The choice of material is obviously a prime factor in the cost of the finished part. The raw materials for specialised perfluoroelastomers, for example, can cost over a thousand times more than a basic natural elastomer.

A guide to selecting the appropriate elastomer is given in the *Material selection* section on page 25.

The manufacturing process to be employed is another factor affecting costs. Factors include the moulding technique, usually compression, injection or transfer moulding, with compression generally having the lowest mould costs and injection moulding the highest.

Manufacturing processes are discussed in the *Manufacturing techniques* section on page 16.

When making decisions on product design, the total cost of ownership (TCO) should be taken into account. As well as the cost of raw materials and manufacture, TCO estimation should include life expectancy, maintenance costs and the possibly massive costs of component failure.

Tool life expectancy

Tool life expectancy depends on many factors, including the mould material, the complexity of the mould, the required tolerance, and the quantity of parts to be produced.



Designing with elastomers

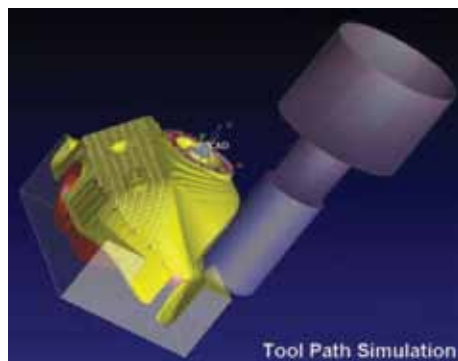
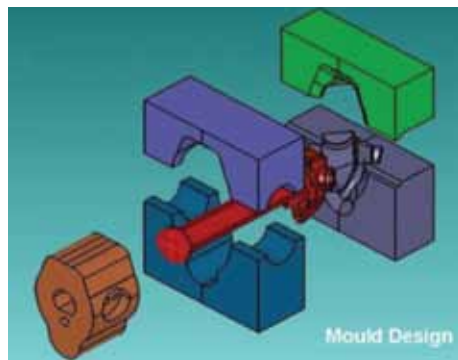


Figure 43: CAD/CAM images of mould design, tool path simulation and finished part.

CAD/CAM

The use of CAD/CAM systems for the design and manufacture of tooling for elastomer production increases productivity and can help to improve the quality of the design. It is particularly useful in the design of tooling for complex 3D parts.



In addition to enabling drafting from sketches on existing components, CAD/CAM systems accept design data in a variety of proprietary file formats. The data can be supplied in the form of 2D designs or as 3D models. 2D drawings are built up into 3D models by extruding, revolving or sweeping the 2D representation in space to create the base solid feature of the design.



When built up, the model can be visualised in three dimensions under simulated operating conditions and with the addition of any mating components.

Unlike traditional CAD/CAM modelling systems, parametric 3D modelling uses parameters to define the model's features, such as its length or radius, and geometric relationships between constituent parts such as relative position and tangency. This makes it easy to modify the model to allow for elastomer shrinkage for example, while ensuring the desired relationships remain as specified.



Before moving to full production of tooling on a machining centre, CAD/CAM can be used to produce a rapid prototype of the component. The prototype, which can be made in a variety of materials, mimics the function of the elastomer part. It can also be economic to produce production quality parts in relatively small numbers.

The production of complex 3D shapes on machining centres is made easier by the use of five-axis milling machines. By enabling the workpiece to be rotated, the required complexity and accuracy of the part can be produced in one setting, avoiding the need to use spark erosion in many cases.

Elastomer failure modes

Elastomer failure modes

Recent advances in life prediction techniques for elastomer components such as seals have made it possible for scheduled maintenance to be carried out at a predefined level of elastomer deterioration so that costly failures can usually be avoided.

However, because elastomer life predictions are usually based on Arrhenius principles, which consider only time/temperature dependent chemical (and occasionally physical) effects, unpredicted failures still occur, since there are many modes of failure that are not time/temperature/chemical dependent.

This section outlines the various modes and causes of degradation and failure that can occur in elastomeric components, and the ways in which they are analysed.

There are many factors that can affect the incidence of failures, including choice of material, processing techniques, component and housing design, storage conditions, inspection techniques, methods of fitting, system changes or system definition and human errors.

Failure in seals is generally identified through excessive fluid leakage. This is caused either by a loss of seal interference (seal contact stress), or loss of seal integrity (generally some form of physical damage). The causes of these may be classified under the following headings:

- Time/temperature dependent physical and chemical degradation
- Housing effects
- Application effects
- Rapid gas decompression
- Storage and handling effects
- Manufacturing defects
- Wear and fatigue
- Thermal cycling effects.

In an ideal world, elastomer failure analysis would be performed with full knowledge of the system variables, such as material design, product and housing design, precise environmental conditions, cycling conditions and length of service. In practice, however, failure analysis is largely based on experience combined with certain analytical techniques. An additional complication is that elastomer failure is often the result of a combination of factors.

Time/temperature dependent physical & chemical degradation

Most component failures occur in this category, as it encompasses the interaction of the elastomer with its environment. Modern techniques for life prediction have enabled end users and manufacturers to understand better and plan for this type of degradation. The following describes the main failure modes that they measure.

Compression set (and stress relaxation)

Compression set can be described as the ability of an elastomer to recover from an imposed strain. Stress relaxation is a measure of the ability of the elastomer to maintain contact stress.

The magnitude of these effects is strongly affected by temperature and the fluid environment. Low values are essential to maintain effective sealing, whereas high values may mean a loss of seal interference resulting in bypass leakage.

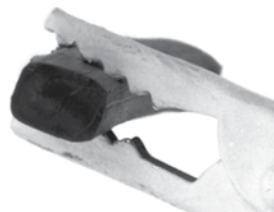


Figure 44.

The effects of compression set are clear in an 'O' ring, as can be seen in *Figure 44*. However, in elastomeric products of more complicated profile, knowledge of the original dimensions is often required.

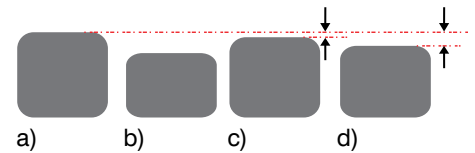


Figure 45: Effect of low and high compression set on an elastomer.

- a) Original unconstrained sample**
- b) Original sample compressed**
- c) Sample when compressive force has been removed showing low compression set**
- d) Sample when compressive force has been removed showing high compression set.**

Volume swell

Volume swell is a combination of chemical and physical interaction. All fluids (including polymers) interact, to an extent that is dictated by a multitude of factors.

Volume swell of less than 10 per cent is not usually a problem, particularly in static applications where it can be beneficial in increasing or maintaining seal interference and countering such effects as compression set. However, higher levels of volume swell (*see Figure 46*) may cause failure because of loss of physical properties, groove overfill, product extrusion or even metalwork fracture.



Figure 46.

Physical property changes that are frequently associated with volume swell, particularly at high levels, are softening and reduction of mechanical properties such as tensile and tear strengths.

Elastomer failure modes

Elastomer shrinkage

Many elastomer compounds contain ingredients that are designed to leach out over time, or that under certain conditions may be extracted or volatilised. If this is not compensated for by volume swell, the resultant shrinkage may, for example, cause a reduction or total loss of seal interference. Failures caused this way are rare.

Thermal expansion/contraction

Like all materials, elastomers expand and contract when exposed to temperature changes to an extent governed by their coefficient of thermal expansion. This effect must be compensated for at the design stage. It should be noted that volumetric thermal expansion coefficients for elastomers are at least an order of magnitude higher than those for steels.

Compression fracture

If elastomers are over-compressed, due to either poor product/housing design or excessive volume swell/thermal expansion, compressive fracture may occur in the plane parallel to the applied force. On occasions this failure mode may be confused with certain types of rapid gas decompression failure. However, compression fracture, as shown in *Figure 47*, is usually very rare.



Figure 47.

Chemical degradation

The effects of chemical degradation (unlike physical swell) are irreversible and range from hardening or softening, surface crazing and large property change, to fracture, complete fragmentation or even dissolution. In some instances, very low levels of a chemical (fractions of a percent) can cause gross chemical degradation. It is therefore important that full environmental data are provided prior to material selection, regardless of the presumed insignificance of some components.

Radiation, free radicals and many chemical species can cause material degradation. Common chemical species that cause elastomer degradation are:

- Water
- Oxygen
- Ozone
- Sour gases (H_2S , CO_2)
- Acids
- Bases
- Corrosion inhibitors (eg, amines)
- Mercaptans
- Aromatic hydrocarbons
- Brines (especially heavy brines).

Figures 48 & 49 illustrate the visible characteristics of some forms of chemical degradation/attack. Other forms may not be so obvious and require identification by analytical techniques such as infrared spectroscopy (eg, hydrolysis of NBR or HNBR).



Figure 48.



Figure 49.

Housing effects

These effects are often the most obvious when analysing seal failure, and are usually the easiest to remedy. It is important however not to confuse these with rapid gas decompression damage, as frequently happens.

Extrusion damage

This occurs when housing clearances are too large or when a seal that has no or inadequate anti-extrusion elements is forced into or through a clearance. It manifests itself in various forms and is normally evident on the low-pressure side unless swell, thermal expansion or pressure trapping has occurred.

Classical extrusion into a small clearance occurs over medium to long periods of time and results in lace-like debris – see *Figure 50*. Extrusion may also happen catastrophically over a localised portion of the seal due to sudden failure of portions of any anti-extrusion device – see *Figure 51*.



Figure 50.



Figure 51.

Elastomer failure modes

It can also be due to housing dilation at high pressures causing the clearance to increase – see *Figure 52*. In this instance the rigid gland ring was unable to deform in order to close the clearance and exacerbated the situation by forming a knife-edge.



Figure 52.

Nibbling

This type of damage, shown in *Figure 53* and diagrammatically in *Figure 54*, is normally observed when pressure cycling occurs. When system pressure is applied the housing lifts or dilates, causing the clearance to increase. A nub of rubber extrudes into this clearance and is subsequently ‘nibbled’ off when the pressure is dropped and the clearance reduced.



Figure 53.

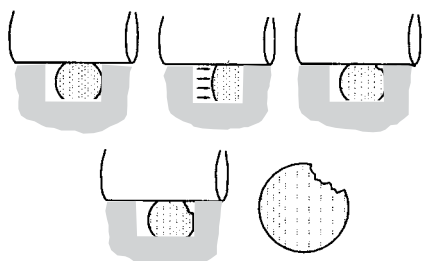


Figure 54.

This can have serious effects on double acting seals, especially if dynamic. On a pressure reversal, the nibbled fragments may be forced across the seal/housing interface causing a leakage path.

Shaving effect

This is normally associated with a continuous application of pressure, and occurs most often with ‘O’ rings and other designs that may rotate in a housing. Here the seal is forced into a clearance and, with time, unwinds into that clearance: hence the shaving effect. The result of this is shown in *Figure 55* and schematically in *Figure 56*.



Figure 55.

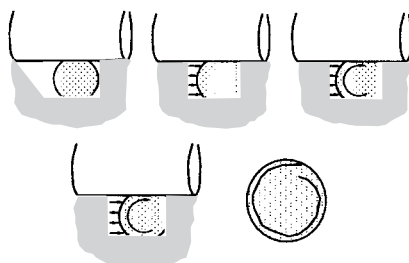


Figure 56.

The thickness of the shaving correlates directly to the dimensions of the housing clearance under pressure conditions. Any sharp housing edges at the clearance will cause extrusion damage to be initiated more easily, and thereafter cause the rate of extrusion to be higher than when acceptable radii are present.

Port damage

This occurs during installation or application, when the product passes over a hole or port, especially if these have sharp edges – see *Figures 57 & 58*.



Figure 57.



Figure 58.

Other housing effects causing seal damage

The relationship between seal and housing size must be considered with account taken of thermal expansion and equilibrium volume swell. Surface finish, eccentricity of housing components and lead-in chamfers should also be considered as factors that may lead, directly or indirectly, to seal failure.

Elastomer failure modes

Application effects

The modes of failure described under this heading are often a combination of component design and mode of application. The resultant effects may be extrusion damage, abrasive wear or others. While these may be the eventual causes of failure, it is the reasons behind them that need to be identified and remedied.

Air entrainment/dieseling

A small amount of air may become trapped in any closed system, although this is most often encountered in reciprocating applications. Severe damage can occur when the air is entrained near an elastomer.

Additionally, air entrained in a hydrocarbon fluid in a rapidly cycling dynamic application may become highly dangerous if no automatic venting is provided or if compression is rapid.

Seal failure can occur in two ways: by rapid gas (air) decompression or by dieseling. Dieseling is when a pocket of air/oil mist self ignites when the rise in pressure is fast enough to cause a significant increase in temperature and hence create ignition. This can cause severe localised damage to a seal, and can melt any plastic components.

Figure 59 shows a schematic of a typical case in an inclined cylinder where air may become trapped adjacent to the piston seal (and gland seal). Figure 60 shows the catastrophic effect that dieseling may have on seals. It is important to eliminate this problem by ensuring that the minimum of air is present and that, if possible, adequate venting is provided.

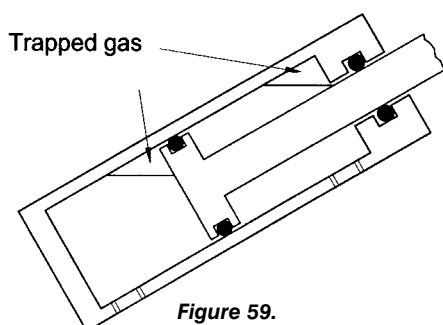


Figure 59.



Figure 60.



Figure 61.

On a lesser scale, air entrainment may cause delamination of the fabric plies in a double acting piston seal, as shown in Figure 61.

Short-stroke failure

It is essential that contact faces of dynamic seals are suitably lubricated. In multi-lip reciprocating applications, this lubrication is effected by the relative movement of the rod or cylinder across the seal. A short-stroke in this context refers to the distance travelled as a ratio of overall stack depth.

Practice has shown that a minimum stroke length of $2\frac{1}{2}$ times the stack depth is required to provide lubrication to all contact lips, although the fluid mechanics underlying this are unclear.

It is ironic that for more arduous, high pressure applications the tendency has been to increase the number of sealing rings and therefore the depth of the stack. This is often seen in PBR seal stacks that may be metres in length, and can result in the stroke length being insufficient to transport lubricant to the entire contact area of the seal.

In this situation, the sealing elements towards the low pressure side can run dry and abrasive wear occurs. This is worsened at elevated pressures because contact stresses are higher. As the seal

wears, abraded particles are dragged towards the forward sealing edge where they may act as a grinding paste or create an uneven contact area ultimately resulting in leakage.

Figure 62 shows the effects of lubrication starvation in an 'O' ring. Figure 63 shows the short-stroke failure of a rubber/fabric seal.



Figure 62.

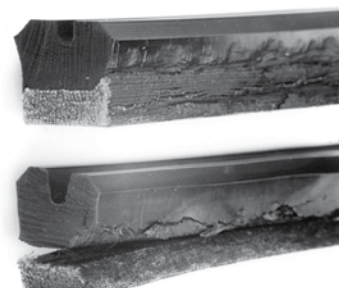


Figure 63.

For short-stroke applications, it is important to use shallow seals, even single element (unit) seals, as multi-lip packings can reduce seal life and cause premature failure.

Pressure trapping

This can develop in the annular clearance between two double acting seals, where inter-seal pressures many times system pressure may build up. It can cause seal failure, system lock-up or metalwork fracture. Most modern squeeze seals and 'O' rings can perform as double acting seals. Extrusion of such seals into the applied pressure can be seen in typical cases as shown schematically in Figure 64.

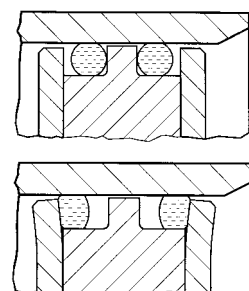


Figure 64.

Elastomer failure modes

During multiple reversals, this type of sealing arrangement can act as a pump, causing inter-seal cavity pressure to build up due to viscous drag past the unenergised seal. The effect is that both seals become permanently energised, resulting in higher friction and wear, an increased tendency for extrusion damage, piston seizure, catastrophic seal failure and potential fracture of metalwork.

Figures 65 & 66 show seal damage caused by pressure trapping. The most important characteristic is damage on the high-pressure side. To avoid this type of failure, two double-acting seals should never be used on the same component. If opposed seals are necessary then at least one of them should be a true single acting seal, so that any inter-seal pressure build-up is automatically vented.



Figure 65.



Figure 66.

Spiral twist

This type of failure is rarely seen in seals other than 'O' rings. It generally occurs when 'O' rings are used in reciprocating applications as rod or piston seals, or when an installation requires stab-in, particularly when seal compression levels are high.

The mechanism is that the 'O' ring becomes fixed at one or more points around its circumference, preventing even roll around its circumferential axis. This may be caused by housing eccentricity, 'O' ring pinching or uneven lubrication.

Bunching

Bunching causes both circumferential compression and tension in different areas of a seal simultaneously. It is encountered on slow rotary applications, especially if subject to reversals such as in swivels, or where seal assembly requires the use of threaded gland nuts.

With such relative motion there is a high level of linear drag which, if accompanied by uneven squeeze, causes part of the seal to be pushed or bunched up, causing other parts to be stretched. This again causes reduction in seal section with the potential for seal leakage. At its worst it may result in tensile fracture of the seal or seal components.

Rapid gas decompression

Rapid gas decompression (RGD) damage is the name given to structural failures in the form of blistering, internal cracking and splits caused when the gas or condensate pressure to which the seal is exposed falls from high to low.

The elastomeric components of a system are, to a greater or lesser extent, susceptible to the permeation and diffusion of gases dissolved in their surface. With time, these components will become saturated with whatever gases are in the system. As long as the internal gas pressure of the elastomer remains at equilibrium with the environment, there is minimal damage, and no deterioration in performance occurs.

However, when the external gas pressure is removed, or pressure fluctuations occur, large pressure gradients are created between the interior and the surface of the seal and the dissolved fluid may actually go through a phase (and therefore volume) change. This pressure differential may be balanced by the gas simply diffusing/permeating out (the reverse of the uptake process) especially if any external mechanical constraints (eg, housings) are not removed. However if the physical and chemical characteristics of the elastomer compound cannot resist crack and blister growth during the outgassing process then structural failure is the inevitable outcome.

Although there is no fixed rule, RGD conditions, and therefore potential damage, should be considered a possibility at pressures above 5MPa (725psi) in gas or dissolved gas systems with decompression rates greater than 1MPa (145psi) per hour.

There are various features of RGD damage that may be related to operating conditions, type of gas or, more often, to the type of seal material. It is also worth noting that, while there may be no evidence of RGD damage on the surface of the seal, there may be internal damage which could impair the performance and life of re-used seals.

Fracture surfaces in constrained seals are generally in the plane perpendicular to the applied pressure. There is often an identifiable nucleation site for each flaw and, on occasions, contamination or undispersed particulate matter may be observed at this site.

Irreversible blistering is often seen in materials with poor filler/polymer interactions such as high fluorine-containing elastomers. Most failure however is through cracking and fracture as seen in Figures 67 and 68.



Figure 67.



Figure 68.

Elastomer failure modes

Storage and handling effects

Vulcanised elastomers will degrade if stored under unsuitable conditions of temperature, humidity, light and oxygen/ozone. Such effects as hardening, softening, cracking and crazing may render the product unsuitable for use or significantly reduce its service life.

Careful choice of storage conditions should minimise these effects. Additionally, components should be stored in a relaxed condition free from tension, compression or other deformation.

Care should be taken to ensure that good handling and fitting practice is observed, using correct tools and following manufacturer's instructions whenever possible. *Figure 69* shows the level of seal damage that may result simply from poor fitting procedures.



Figure 69.

Wear and fatigue

Wear or abrasion damage can be caused by dynamic motion, or when the sealed environment is intrinsically abrasive and either passes across or impinges upon the seal. Wear patterns created by dynamic motion are generally in the direction of the motion (ie, axial wear in reciprocating seals and circumferential wear in rotary seals). *Figure 70* shows abrasive wear.



Figure 70.

The exception to this is lip cracking in rotary applications. Damage here, as shown in *Figures 71 & 72*, is perpendicular to the direction of motion. The damage frequency is a function of material design, particularly modulus and frictional characteristics. It happens due to a wave being forced ahead of the motion, which produces contact peaks and non-contact troughs ('slip-stick'). It causes heat build-up at the contact bands which ultimately leads to cracking. This effect is known as a Schallamach wave.

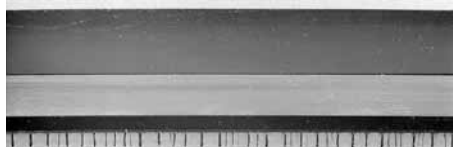


Figure 71.



Figure 72.

Lower friction, higher modulus materials (*Figure 71*) will exhibit an increased number of shallower cracks compared with higher friction, lower modulus materials (*Figure 72*). This is because heat build-up is less and 'stick' is reduced. Optimised materials for this type of application do not exhibit lip cracking as they enable a stable hydrodynamic film to be established.

Thermal cycling

While thermal cycling can induce mechanical damage, it may also cause by-pass leakage with no damage to the seal whatsoever. This generally happens when seals are cycled from high to low temperatures, especially if pressure is cycled simultaneously.

More often, by-pass leakage occurs in seals made from thermoplastics and those with a tendency to high temperature flow. Such materials (eg, Aflas®) should not be subjected to large thermal transients or rapid thermal cycling. Similar effects are noted if elastomers are used below or approaching their limit of elastomeric flexibility (glass transition temperature, T_g) as they cannot respond, or at least only very slowly, to any system change, such as the application of pressure.

Bonding failure

In rubber to metal bonding, the bond strength is generally greater than the strength of the elastomer, so the failure mode is usually within the elastomer.

Bond failures are relatively rare, and may be due, for example, to insufficient degreasing of the metal or premature curing of the bonding agent.

Aesthetics

Where aesthetic appearance is important, such as in consumer products, a deterioration in visual appearance can be considered a failure mode. An example is colour fading due to exposure to ultraviolet radiation in sunlight.

Glossary of terms

A

Abrasion: The surface loss of a material due to frictional forces applied to it.

Abrasion resistance: The ability to resist mechanical wear. A material with a high abrasion resistance helps to maintain the material's original appearance and structure.

Abrasion resistance index: A measure of the abrasion resistance of a rubber relative to that of a standard rubber under the same specified conditions, expressed as a percentage.

Accelerated life test: The testing of a material by subjecting it to conditions in excess of its normal service parameters in an effort to approximate, in a short time, the deteriorating effect of normal long-term service conditions.

Accelerator: A chemical which speeds up the vulcanisation reaction. This allows the rubber to cure in a shorter timeframe, at a lower temperature or both.

Acid acceptors: Mostly used in fluoroelastomers to absorb the acid produced by the chemical reactions that take place during curing and to some degree during service. Acid acceptors are usually metal oxides.

Acid resistance: The ability of a material to resist attack as a result of exposure to acids. The degree of attack is both temperature and concentration dependant.

ACM: Abbreviation for acrylic rubbers.

ACN: Abbreviation for acrylonitrile.

Activator: A substance, which by chemical interaction promotes a chemical action of a second substance. Most commonly used in elastomers to activate accelerators.

Aftercure: The amount of cure received after the termination of the cure proper. The term is also applied to the continuation of the curing effect that results from exposure of the article to heat in use, or from accelerated ageing. See **Post cure**.

Age resistance: The ability of a given material to resist deterioration of its properties caused by ageing.

Ageing: The irreversible change of material properties during exposure to a deteriorating environment. This can include environments such as UV, oxygen and those containing ozone gases. Ageing can also refer to the controlled exposure of rubber samples to a variety of deteriorating influences to allow for the evaluation of anti-oxidants and anti-ozonants.

Agglomerate: A cluster of particles of one or more compounding materials loosely held together. One of the primary roles of the mixing process is to break down agglomerates and promote good dispersion.

Air traps: A rubber moulding defect that can occur either at the surface of the moulding due to air being trapped between the mould and the material, or within the moulding. The use of vacuum technology both at the extrusion and press stage can greatly reduce the risk of air traps.

Amorphous: Having no definite shape; non-crystalline.

Aniline point: The lowest temperature at which equal parts of aniline and a test liquid (usually oil) will mix or blend. In general, the lower the aniline point of an oil, the more a given rubber compound will swell, therefore the test indicates if an oil is likely to damage an elastomer with which it has come into contact.

ANSI: American National Standards Institute.

Antidegradants: These are materials added to a rubber compound to reduce the effect of deterioration caused by oxidation, ozone, light and/or combinations of these.

Anti-extrusion ring: A ring installed on the low pressure side of a seal to stop the sealing material being extruded into the clearance gap. The requirement for the fitting of such devices is dependent on the pressures, sealing materials and extrusion gap.

Antiflex cracking agent: A material added to a rubber compound to reduce cracking caused by cyclic deformations.

Anti-oxidant: A material added to a rubber compound to reduce deterioration caused by oxidation.

Anti-ozonant: A material added to a rubber compound to reduce damage resulting from the effects of ozone.

Anti-tack: Substance applied to the surface of an elastomer to stop it adhering either to itself or other elastomers.

Arrhenius principle: An empirical relationship stating that the rate of a chemical reaction increases exponentially with temperature.

ASTM: Abbreviation for American Society for Testing and Materials.

Atmospheric cracking: Cracks on the surface of a material as a result of exposure to atmospheric conditions. This is usually as a result of sunlight and/or ozone.

AU: Abbreviation for polyester type polyurethane rubbers.

Autoclave: A vessel that vulcanises rubber products in a pressurised steam environment.

Axial squeeze: Compression applied to the top and bottom of a seal's surface.

B

Back-up ring: See **Anti-extrusion ring**.

Backrinding: Tearing or distortion of a moulded rubber product at the line of separation of the mould pieces. Factors which can have an influence on backrinding are blank weight, blank shape, temperature, moulding pressure and breathe cycles.

Banbury mixer: The type of internal mixer designed by FH Banbury.

Bank: This term can relate to the amount of rubber adjacent to the nip of the rolls on both mills and calenders.

Barrel: That part of an extruder in which the screw rotates or the ram moves.

Bias: The angle at which the textile material is cut with respect to the running edge of the fabric.

Blank: A measured weight or dimension of a rubber compound suitable to fill the cavity of a compression or transfer mould. Usually the blank weight/volume is slightly higher than the finished component to allow for full compression in the cavity.

Glossary of terms

Bleeding: The flow of a compounding material, often oils or lubricants, from the surface of vulcanised or unvulcanised rubber. Can also be referred to as leaching.

Blemish: An unwanted imperfection on the surface of a moulded product.

Blister: A surface or internal imperfection, produced by entrapped air, gases or other volatiles normally as a result of the manufacture process.

Bloom: A solid or liquid material that has migrated to the surface of a rubber material normally leaving a waxy or milky deposit.

Blow: The volume expansion that occurs in the production of cellular or sponge rubber resulting from the action of a blowing agent incorporated into the compound.

Blowing agent: A compounding ingredient introduced into an elastomer which produces a gas by chemical or physical action during the processing stage. Used in the manufacture of sponge rubbers.

Bonding agent: A material used to promote the bonding of rubber to other materials during the processing stage.

BR: Abbreviation for rubber based on butadiene.

Breakdown: The plasticising of raw rubber prior to the incorporation of compounding ingredients. This is normally the first stage of the mixing process.

Breakout friction: The force required to initiate sliding between a rubber seal and the surface in which it is in contact.

Brittle point: The highest temperature at which a rubber specimen will break under a measured sudden impact. This is one indication of low temperature flexibility.

Brittleness: The tendency of an elastomer to crack when deformed or impacted.

BS: Abbreviation for British Standard.

BSI: Abbreviation for British Standards Institution.

Bumping: The operation of opening and closing the press rapidly in the first stages of the cure. This action is designed to drive out any trapped air in the mould cavity. Also referred to as breathing.

Buna N: A general term for the copolymer butadiene and acrylonitrile, also referred to as NBR or nitrile.

Buna S: Butadiene and acrylonitrile copolymer. This material is also referred to as SBR.

Butyl: A copolymer of isobutylene and isoprene.

C

CAD: Abbreviation for computer-aided design.

Calender: A machine with two, three or four parallel, counter-rotating rolls. Often used to form rubber sheeting where the thickness needs to be accurately controlled.

CAM: Abbreviation for computer-aided manufacture.

Carbon black: A black pigment and reinforcement filler used in rubbers. Carbon black is a form of amorphous carbon that has a high surface-area-to-volume ratio. The degree of reinforcement increases with decreasing particle size.

Catalyst: A chemical, usually added to a mix in small quantities relative to the reactants, that modifies and increases the rate of a reaction without being consumed in the process.

Cavitation: A condition in which vapour or gas bubbles occur, normally in an area where there is a temperature change or reduction in pressure, which results in a collapse of the bubble and high local impact pressures. This can lead to both equipment wear and reduced seal life.

Cellular rubber: A generic term for rubbers containing either open, closed or both types of cells dispersed throughout the material. These cells are formed by blowing agents during the processing of the rubber.

Cement: An adhesive that is either a liquid dispersion or a solution of raw or compounded rubber, or both, usually dissolved in solvent, and used to bond rubbers to other rubber or non-rubber products.

Chalking: The formation of a residue on the surface of a rubber which is commonly as a result of UV damaging the surface of the material.

Checking: Shallow, short cracks on the surface of a rubber, which is usually as a result of environmental attack.

CO: Epichlorohydrin homopolymer.

Coagent: An ingredient added to a rubber compound, usually in small amounts to increase the cross-linking efficiency of non-sulphur vulcanising systems, such as organic peroxides.

Coated fabric: A product constructed by coating a fabric with a rubber, resulting in a flexible material which can be moulded into products or used in conjunction with rubbers to provide higher rigidity and improved extrusion resistance.

Coefficient of thermal expansion: The average expansion per degree over a stated temperature range, expressed as a fraction of the initial dimension.

Cold flexibility: Flexibility of the elastomer following exposure to a specified low temperature for a specified period of time.

Cold flow (also called **Creep**): A slow deformation, under gravitational force for example, at or below room temperature.

Cold resistant: The ability of an elastomer to function at low temperatures.

Compound: A term applied to a mixture of polymers, reinforcements, curatives and other ingredients to produce a rubber material. The compound is prepared according to a prescribed formula and mixing process.

Compression moulding: A moulding process in which an uncured rubber blank is placed directly in the mould cavity and compressed to its final shape by closing the mould. This process normally results in excess material in the form of flash.

Compression set: The amount a rubber specimen fails to return to its original shape after being released from a constant compressive load. This testing normally takes place at an elevated temperature and helps to develop an understanding of the reduction in sealing force which may be encountered in service.

Conductive rubber: A rubber which has been produced such that it is capable of conducting electricity.

Glossary of terms

Copolymer: A polymer composed from two different monomers, for example an NBR composed of polybutadiene and acrylonitrile.

CR: Abbreviation for chloroprene rubbers.

Corrosion: Progressive wearing away of a surface because of a chemical reaction.

Cracking: Axial cracks on elastomeric seals on the lip contact surface.

Crazing: The formation of shallow cracks on the surface of a rubber. This can be as a result of exposure to UV light or certain chemicals. Although they look similar, crazing differs from ozone cracking, as it does not depend on the presence of an externally applied strain.

Creep: The time-dependent part of a strain resulting from stress.
Also see **Cold flow**.

Cross-section: A section formed by a plane cutting through an object, usually at right angles to an axis.

Cross-linking (see also vulcanising): The formation of chemical bonds between polymer chains to give a three-dimensional network structure.

Cross-link density: A measure for the relative number of cross-links in a given volume of elastomer.

Crumb rubber: Vulcanised waste or scrap rubber which has been ground down to a known mesh size and can then be added to new compound as a filler.

Crystallinity: The orientation of the disordered long-chain molecules of a polymer into repeating ordered patterns. Many rubber materials have a degree of crystallinity, and some will tend to crystallise under certain conditions. The degree of crystallinity affects stiffness, hardness, low temperature flexibility and heat resistance.

Curatives: The collective term for the chemicals involved in curing the rubber material. These include, for example, accelerators, vulcanising chemicals such as sulphur, and activators.

Cure: Another term for 'vulcanisation'. This process results in the cross-linking of polymer chains.

Cure time: The required amount of time needed to complete the curing process to a pre-determined level. The time taken to cure is dependent on the temperature, material type and section of the rubber profile.

Curing temperature: The temperature at which vulcanisation takes place.

D

Damping: The property of a material or system that causes it to convert mechanical energy to heat when subjected to deflection. In rubber, the property is caused by hysteresis.

Deflashing: The process of removing excess material from the flash-line resulting from the moulding process. Various methods exist, including buffing and cryogenic trimming.

Degassing: The passing of a gas out of a rubber, normally generated by the volatile ingredients in the rubber mix which are activated at elevated temperatures.

Delamination: The separation of layers of rubber (normally in a plied format) or the rubber separating from a surface to which it is bonded.

Demoulding: The operation of removing a vulcanised rubber product from the mould in which it has been cured. This can be done carefully by hand, but in some cases pins or brushes can be incorporated into the mould or press to perform this function automatically.

Density: The weight per unit volume of a substance.

Desiccant: A rubber compounding ingredient used to absorb moisture irreversibly, particularly for the purpose of minimising the risk of porosity and/or blisters during vulcanisation.

Diametral clearance gap: The difference in diameters between two mating surfaces.

Die: The shaped plate fitted in the head of an extruder designed to create a profile suitable for the moulding process.

Die swell: The change in dimensions of an extruded rubber section as it exits the die. This swell is mainly due to the elastic recovery of the material.

Differential pressure: The difference in pressure between the high-pressure and low-pressure side of a sealing system.

Dimensional stability: The ability of the elastomer to retain its original shape and size having been exposed to a combination of stresses and temperatures.

DIN: Abbreviation for Deutsches Institut für Normung – German Institute for standardisation.

Dipping: A method of manufacturing rubber articles by dipping a former of the shape required into a rubber solution.

Dispersion: The distribution of particles throughout a medium. For rubbers this often refers to the distribution of compounding ingredients in rubber mix.

Dough: Rubber compounded and swollen in solvent and worked on a 'wet' mill until it reaches the consistency of dough. It is then applied behind the doctor blade of a spreading machine through which the fabric to be coated is passing. Self-curing doughs are used in the repair of rubber products (tyre tread cut-filling) and the splicing of belting.

Durometer: An instrument for measuring the relative hardness of rubber.

Dynamic properties: The response in an elastomer to forces applied to them.

Dynamic seal: A seal used in an environment that is subjected to any type of movement relative to its position and that of the contact / sealing surface.

E

Ebonite: 'Hard rubbers' which are formed when they are cured with high levels of vulcanising agents.

ECO: Epichlorohydrin copolymer with ethylene oxide.

Efficient vulcanisation: A term applied to vulcanisation systems in which sulphur or a sulphur donor is used very efficiently for cross-linking the rubber.

Elasticity: The rapid recovery of a material to its initial shape after deformation and release of an applied force.

Glossary of terms

Elastomer (also known as rubber):

A general term used to describe both natural and synthetic polymers possessing the ability to return to their original shape after the deforming force is removed.

Elongation, per cent: The extension of a specimen as a result of an applied tensile stress, expressed as a percentage of the original length.

Elongation at break: The elongation measured at the point of rupture. A high value is important if substantial stretching is required during fitting of the product.

EPM: Abbreviation for ethylene-propylene rubber.

EPR: Abbreviation for ethylene-propylene rubber.

EU: Abbreviation for polyether urethane.

Explosive decompression:
See **Rapid gas decompression**.

Extender: A material added to a rubber compound which is designed to reduce the cost of the compound without imparting any enhanced physical properties.

Extensometer: A device used to determine the elongation of a specimen as it is strained under testing conditions. Often these machines can also record the tensile strength and modulus values of a given material.

Extrudate (also referred to as extrusion): The profiled material which results from the extrusion process.

Extruder: A machine designed to create a profiled rubber shape by forcing the rubber through a die which has a shape similar to that of the required profile. The two most common types are screw and ram.

Extrusion (seal): The distortion, under pressure, of some of the sealing element into the clearance between mating parts.

F

Fatigue: The weakening of an elastomer during repeated deformation, strain or compression.

Fatigue life: The number of deformations required to produce a specified state of fatigue in a test specimen.

FDA: Food and Drug Administration (USA).

FEA: Abbreviation for finite element analysis.

FEPDM: Abbreviation for tetrafluoroethylene/propylene dipolymers.

FFKM: Abbreviation for perfluoroelastomers.

Filler: A compounding ingredient which is added to a rubber usually in finely divided form. There are into two main categories of filler: reinforcing which adds strength to the elastomer (see **Reinforcing fillers**) and extending, which has the function of cheapening the elastomer (see **Extender**).

Finite element analysis: A mathematical technique developed to predict the stress-strain behaviour of objects which do not lend themselves to simple analysis.

Fire retardant: An additive used in rubber compounding to reduce the fire hazard.

FKM: Abbreviation for fluorocarbon rubber.

Flame resistance: The resistance to burning of a rubber material.

Flash: The excess material resulting from the moulding operation found at the mould split lines.

Flex cracking: Repeated flexing of a rubber resulting in the material cracking.

Flex life: The number of cycles required to produce a specified state of failure in a rubber specimen. The test uses a prescribed method of flexing, such as shear or bending.

Flexural strength: Ability of an elastomer to flex without permanent distortion or damage.

Flow marks: Marks present on the surface of a moulding caused by insufficient or improper flow of the material in the moulding cavity.

FMQ: Abbreviation for fluoro methyl silicone.

Formula: A list of the ingredients and their amounts used in the preparation of a compound.

FPM: Abbreviation for fluorocarbon rubber.

FSA: Food Standards Agency (UK).

FVMQ: Abbreviation for fluoro vinyl methyl silicone.

G

Gate: The point through which a rubber is injected into the moulding cavity in both transfer and injection moulding techniques.

Gate mark: A witness mark left on the moulding as a result of injecting rubber through the gate. This can be either a raised or sunken mark on the surface of the moulding.

Glass transition temperature (T_g): The point at which the material loses its flexibility at low temperature. This point is affected by system pressure and varies for different polymers.

Green strength: The strength of a rubber in the uncured state.

Groove: The machined glandular recess into which an 'O' ring is fitted.

Gough-Joule effect: When rubber is stretched adiabatically (without heat entering or leaving the system) heat is generated by the material. The effect was originally discovered by Gough in 1805 and re-discovered by Joule in 1859.

H

Hardness: Measurement of the resistance to indentation. The most common units are Shore A and IRHD. See **IRHD** and **Shore A**.

Heat ageing: A test for the reduction in physical properties of an elastomer as a result of exposure to temperature.

Heat history: The total heat which has been received by the rubber compound (mixing, milling, extruding, calendering), particularly the temperatures reached by the rubber and the time it has been held at these temperatures.

Heat resistance: A rubber's ability to undergo exposure to some specified level of elevated temperature and retain a high level of its original properties.

Heteropolymer: A polymer composed of differing monomers.

HNBR: Abbreviation for hydrogenated nitrile rubber.

Homopolymer: A polymer formed from a single monomer.

Glossary of terms

Hooke's law: Within the limits of elasticity of a material, tension is proportional to elongation, or strain is proportional to the stress producing it.

Hysteresis: The difference between the energy input and output under elastic deformation in a rubber is known as hysteresis. The loss of energy results in heat build-up.

Hysteresis loss: The loss of mechanical energy due to hysteresis.

I

ID: Inside diameter.

Immediate set: The deformation found by measuring immediately after removal of the force causing deformation.

Impact resistance: The resistance to fracture under a quickly applied load.

Impact strength: A measure of the toughness of the material to rapidly applied loads. It is often represented as the energy required to break a specimen with a single swinging blow.

Inhibitor: A compounding ingredient which is added to a mix to suppress a chemical reaction such as the curing of a rubber material.

Injection moulding: Moulding process where preheated rubber is injected under pressure through a series of runners and into a closed mould cavity.

Insert: Normally a metal or plastic component to which rubber is chemically and/or physically bonded during the moulding process.

Internally lubricated rubber: A rubber containing lubricating additives designed to reduce the material's coefficient of friction.

IRHD: Abbreviation for International Rubber Hardness Degrees. This is a method of measuring rubber hardness. IRHD is similar to Shore A durometer units, but uses different test method and apparatus.

ISO: International Organisation for Standardisation.

K

Knit line (also known as weld line): A line present in a moulding as a result of opposing flow fronts during the forming of the rubber material in a mould not knitting together. A knit line is an area weakness in the moulding.

L

Latex: A stable dispersion of a polymeric substance in an aqueous medium.

Leaching: See *Bleeding*.

Leakage rate: The rate at which a fluid passes through or around a seal.

Life test: A test of the amount and duration of a product's resistance to destructive forces.

Liquid silicone rubber: High purity platinum cured silicone with low compression set, great stability and ability to resist extreme temperatures of heat and cold.

Low temperature flexibility: The ability of an elastomeric product to be flexed at low temperatures without cracking.

Litharge: Lead monoxide, PbO, formerly used as an inorganic accelerator but now mainly used as a vulcanising agent in some polychloroprene rubbers.

M

Make-up: Uncured elastomer that is cut to a profile, weight and/or length prior to placing in a mould.

Master batch: A homogeneous mixture of polymer and one or more materials in known proportions.

Mastication: The breakdown or softening of raw rubber by the combined action of mechanical work (shear). This can be accelerated by the use of a peptiser.

Memory: Ability of a rubber to return to its original shape after deformation.

Microwave curing: Vulcanisation of rubbers by heat produced by high frequency radiation.

Mill: A machine with two counter-rotating rolls used for rubber mastication, mixing or sheeting.

Mineral oils: Petroleum and other hydrocarbons oils obtained from mineral sources. In rubber compounds they act as softeners and extenders.

Mixer: A machine with a closed chamber in which specially shaped rotors masticate the rubber and incorporate compounding materials through the action of mechanical work (shear) with the aim of creating a homogenised finished material.

Modulus: In elastomer technology this is defined as the stress at a particular strain or elongation. Modulus tends to increase with hardness, with higher modulus materials, in the main, being more resistant to deformation and extrusion.

Modulus of elasticity: The ratio of stress to strain in an elastic material.

Molecular weight: The weight of a molecule of a substance.

Mould cavity: Profiled shape cut into a mould within which the rubber is cured to produce the product.

Mould marks: An imperfection transferred to a moulded product from corresponding marks present on the mould surface.

Mould release: A substance applied to the surface of a mould cavity to aid the release of the rubber product after curing.

Mould shrinkage: Dimensional loss in a moulded rubber product that occurs during cooling after it has been removed from the mould.

N

NBR: Abbreviation for nitrile-butadiene rubber.

Nerve: The toughness and elasticity of unvulcanised, unmasticated rubber.

Nibbling: Normally observed when pressure cycling occurs. When system pressure is applied the housing lifts or dilates, causing the clearance to increase. A nub of rubber extrudes into this clearance and is subsequently 'nibbled' off when the pressure is dropped and the clearance is reduced.

Nip: The radial distance between the rolls on a mill or calender, measured at the line of centres.

Non-fill: A defect in a rubber product caused by the rubber failing to completely fill the mould.

Glossary of terms

Non-sulphur vulcanisation: The process of vulcanisation without the use of sulphur.

NR: Abbreviation for natural rubber.

O

OD: Outside diameter

Oil resistant: The ability of vulcanised rubber to resist swelling and other effects which reduce the performance of the material whilst exposed to oils.

Oil swell: The change in volume of a rubber due to the absorption of oil.

Optimum cure: The state of vulcanisation at which a desired property value or combination of property values is obtained. In some materials this may require post-curing or autoclaving to produce this desired level of cure.

Orange peel: Pitted or uneven surface on a moulded part, resembling the surface of an orange.

'O' ring: Solid elastomer seal of circular cross-section.

Outgassing: The release of vapours or gases from a rubber compound.

Overcure: A degree of cure greater than the optimum. In some cases this can lead to a loss of elongation and an increase in hardness. In the case of natural rubber this can lead to reversion.

Oxidation: The reaction between oxygen and a rubber which can lead to a detrimental change in physical properties.

Ozone resistance: The ability to withstand the deteriorating effect of ozone.

P

Parting line: The line on the surface of a moulded part where the separate mould parts meet and create a small clearance gap.

PB: Abbreviation for polybutadiene.

PCP: Abbreviation for polychloroprene.

Peptiser: A compounding material used to accelerate, by chemical action, the softening of rubber under the influence of mechanical action or heat (or both).

Permanent set: Amount of deformation in a rubber after the distorting load has been removed.

Permeability: Measure of the ease with which a liquid or gas can pass through a rubber material.

Peroxide: One of the ingredients which can be used for vulcanising rubbers.

Pig: Roll of rubber cut from a mill.

Pigment: A material used to impart colour to a rubber compound.

Plasticiser: A substance, usually a heavy liquid or oil, which is added to an elastomer to decrease stiffness, improve low temperature properties, reduce cost and/or improve processing.

Poisson's ratio: The measure of the simultaneous change in elongation and in cross-sectional area within the elastic range during a tensile or compressive test. For thermosetting elastomers, typical values of 0.48 to 0.50 are achieved which is why elastomers can be successfully used for sealing applications.

Polymer: Literally means 'many units' and is a large molecule constructed from many smaller monomers.

Post cure: The application of heat to a thermosetting rubber after curing to enhance one or more properties.

Pre-form: See *Blank*.

Processability: The relative ease with which raw or compounded rubber can be processed. This can relate to all aspects of manufacturing.

Processing aid: A compounding ingredient that is added to the mix with the aim of improving the material's ability to be processed.

PU: Abbreviation for polyurethane.

R

Radial seal: Seal having compression applied to its outside and inside diameters.

Radial squeeze: Compression on a seal's outside and inside diameters.

Rapid gas decompression (RGD): Also known as explosive decompression (ED). The rapid release of applied system pressure, causing dissolved gases in

the rubber to rapidly expand. If the force of the expanding gas is greater than the strength of the material then cracks, blisters and catastrophic material failures can occur.

Recovery: The degree to which a rubber product returns to its original dimensions.

Reinforcement: The act of increasing the mechanical strength of a rubber.

Reinforcing filler: A compounding ingredient added to the rubber to increase the resistance of the material to mechanical forces.

Resilience: The ratio of energy output to energy input in a rapid full recovery of a deformed rubber specimen.

Retarder: A compounding ingredient which is added to the mix and is designed to reduce the tendency of a rubber compound to vulcanise prematurely.

Reversion: The deterioration of vulcanisate properties that may occur when vulcanisation time is extended beyond the optimum. Usually shown by reduced tensile strength and modulus, increased elongation at break and tackiness. This is a particular problem in natural rubbers.

Rheology: The science of the deformation and flow of matter.

Rheometer: An instrument for the study of the rheological properties of elastomers.

RTV: Abbreviation for room temperature vulcanisation.

S

Saturation: Saturated chemical compounds are those whose constituent molecules contain no double or triple valency bonds; such compounds do not form addition compounds.

SBR: Abbreviation for styrene-butadiene rubber.

Scission: Breaking of chemical bonds.

Scorching: The premature vulcanisation of a rubber compound.

Secondary accelerator: An accelerator used in smaller concentrations, when compared to the primary accelerator, to achieve a faster rate of vulcanisation.

Glossary of terms

Shelf-life: Length of time a moulded compound can be stored without suffering significant loss of physical properties.

Shore hardness: The relative hardness of an elastomer measured on a Shore durometer instrument.

Shrinkage: The reduction in size upon cooling of a moulded rubber part.

Solubility: The degree to which one substance will dissolve in another.

Sponge rubber: One type of cellular rubber. Conventional sponge rubber has a porous structure, the cells being open and intercommunicating; it shows very high absorption of water.

Spreading: Coating, normally a fabric, with rubber.

Sprue: Channel through which the elastomer enters the mould cavity; also the cured elastomer remaining in this channel.

Squeeze: The amount of radial or axial compression of a seal between two surfaces when installed.

Stabiliser: A substance added to a rubber to maintain properties at or near their initial values during its production, processing and storage.

Staining: Change of colour of a rubber when exposed to light or change of colour in a material in contact with, or adjacent to, a rubber.

State of cure: The degree of vulcanisation of a rubber compound.

Static seal: A seal between parts that have no relative motion.

Sulphur: An agent responsible for the vulcanisation of some rubbers.

T

Tack: The property that causes contacting surfaces of unvulcanised rubbers to stick to each other.

Tackifier: A compounding material that enhances the ability of vulcanised rubber to adhere to itself or another material.

Tear resistance: Resistance to the growth of a nick or cut in a rubber specimen when tension is applied.

Tear strength: The maximum force required to tear a specified test specimen.

Tensile strength: A measure of the stress required to rupture a standard test piece.

Terpolymer: A polymer formed from three monomer species.

Thermal degradation: An irreversible change in the properties of a material due to exposure to heat.

Thermal expansion: Linear or volumetric expansion caused by temperature increase.

Thermoplastic: Applied to high polymers which soften by the application of heat and which may be resoftened by heating, provided chemical decomposition does not take place.

Thermoplastic elastomer (TPE): A diverse family of rubber-like materials that, unlike conventional vulcanised rubbers, can be processed and recycled like thermoplastic materials.

Transfer moulding: The process of moulding a material by forcing rubber from a reservoir chamber through a gate into the moulding cavity of a closed mould.

Thermoset: Materials that undergo chemical cross-linking of their molecules when processed, and cannot be softened and reshaped following further application of heat.

TR-10: A measure of the low-temperature capability of an elastomer. It is the temperature at which a stretched and frozen specimen has retracted 10% of the stretched amount. TR stands for 'temperature retraction'.

U

Ultimate elongation: The percentage a specimen was stretched at the point of rupture.

Under-cure: A condition where rubber has not been cured to its optimum state and will exhibit a reduction in its physical properties.

Unsaturation: In organic compounds the linking of some of the atoms of the molecule by more than one valency bond, ie, double or triple bonds.

UV absorber: A compounding material that retards the deterioration caused by sunlight and other UV light sources.

V

Visco-elasticity: A combination of viscous and elastic properties in a material.

Viscosity: Resistance to flow.

VMQ: Abbreviation for vinyl methyl silicone.

Vulcanisation: Heat induced process whereby the long chains of the rubber molecules become cross-linked by a vulcanising agent to form three dimensional elastic structures.

Vulcanising agent: A compounding material that produces cross-linking in rubbers.

W

Water absorption: The amount of water absorbed by a material under specified test conditions.

Weathering: The tendency of rubbers to surface crack on exposure to atmospheres containing ozone and other pollutants.

Weld line: See *Knit line*.

X

XNBR: Abbreviation for carboxylated nitrile rubber.

About James Walker

About James Walker

James Walker works at the forefront of materials science and fluid sealing technology to create engineered solutions for virtually every industrial sector. We are constantly reviewing material performance and seeking to develop new compounds and variants that will address the operational problems faced by our clients and the industry sectors we serve. Across industries as diverse as aerospace, power generation and bioprocessing, James Walker technical ability and expertise has helped create what are now recognised as class-leading, best practice products and solutions.

High performance elastomers

- Over 300 grades formulated and compounded in-house
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- State-of-the-art facilities for precision compounding
- Rigorous testing and control with full traceability.

With our own, in-house laboratories, testing facilities and research production unit at the James Walker Technology Centre, all processes are under one roof – from compound formulation through to product design, manufacture and testing. This allows us to provide the flexibility of service required to find and produce those bespoke solutions.



Industry leading research

- Rotary and reciprocal application test rigs
- World-leading rapid gas decompression testing facility
- Chemical compatibility testing
- Pilot plant allows batch compounding for product and manufacturing tests
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Elastomer manufacturing

- High precision injection moulding, compression moulding and moulding under vacuum
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- Plastics or metal inserts securely moulded in place
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- Bonding to metals and plastics, plus production of special composites
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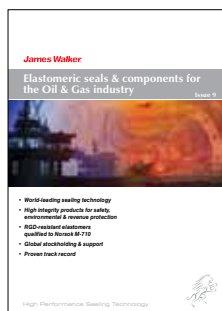
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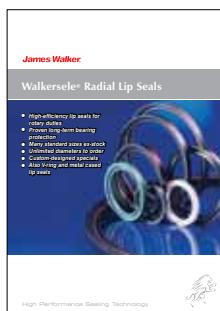
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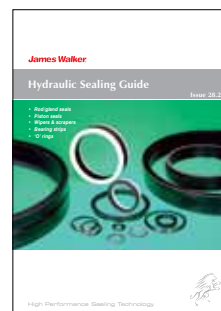
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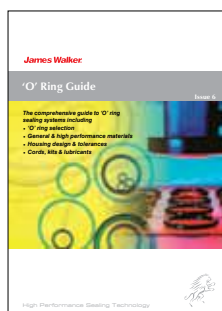
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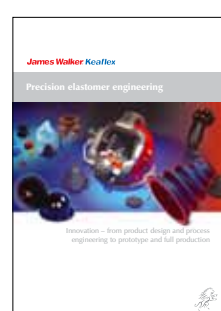
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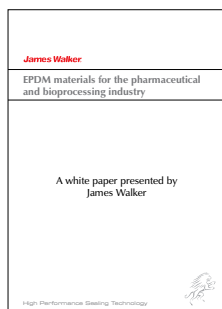
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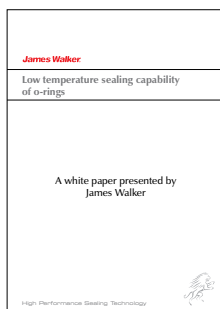
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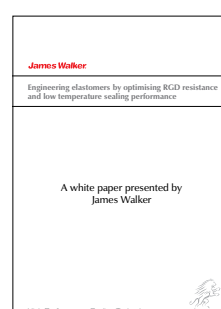
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EPDM materials for the pharmaceutical and bioprocessing industry



Low temperature sealing capability of o-rings



RGD resistance and low temperature sealing performance

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