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Rubber technology

CONTENT

INTRODUCTION

Rubbers are described as materials which show “elastic” properties. Such materials are generally long chain molecules known as “polymers” and the combination of elastic and polymers has led to the alternative name of “elastomers”. Rubbers and elastomers will be considered to be synonymous in this work.

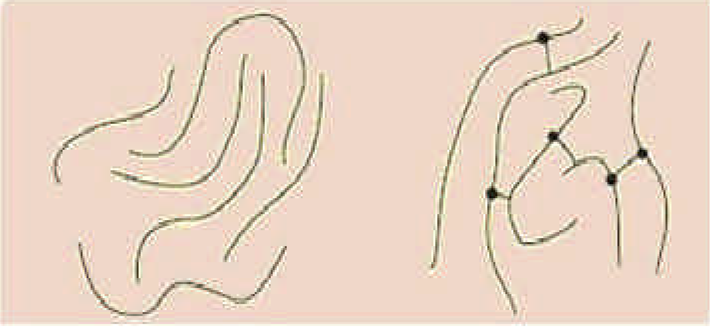
Products made from rubber have a flexible and stable 3–dimensional chemical structure and are able to withstand under force large deformations. For example the material can be stretched repeatedly to at least twice its original length and, upon immediate release of the stress, will return with force to approximately its original length.

Under load the product should not show creep or relaxation. Besides these properties the modulus of rubber is from hundred to ten thousand times lower compared to other solid materials like steel, plastics and ceramics. This combination of unique properties gives rubber its specific applications like seals, shock absorbers and tyres.

Rubber is used as a name for 3 categories:

Raw or base polymers	These determine the main characteristics of the final product.
Semi-manufactured product	The addition to raw rubber of various chemicals, to impart desirable properties, is termed compounding. This semi-finished material is getting its rubber properties after vulcanization.
Final product	After moulding the rubber compounds gets its elastic properties after a vulcanisation process.

Modern rubber materials consist of approximately 60 percent of synthetic polymers. The other part consists of vulcanisation agents, softeners, accelerators, anti aging agents and other chemicals. These additions are necessary to achieve the desired properties of the final product.



non vulcanised phase *vulcanised phase*

Bonded flexible chains

Polymers have a backbone of hydrocarbons. The hydrogen atom is often replaced by other atoms or molecules (like CH_3, Cl or F) and thus create another type of elastomer. These chains are chemically bonded together by sulphur, peroxides or bisphenol. An exception is silicone. Silicone contain very flexible siloxane backbones (Si-O) and can be cured with peroxide or platinum-catalyst curing.

RUBBER MATERIALS

The most common elastomers are:

Ethylene Propylene Rubber (EPDM/EPM)

EPM is a copolymer of ethylene and propylene. This type can only be crosslinked with peroxides. If during the copolymerization of ethylene and propylene, a third monomer, a diene, is added the resulting rubber will have unsaturation and it can then be vulcanized with sulphur. These rubbers are the so-called EPDM's.

The main properties of EPDM are its outstanding heat, ozone and weather resistance. The resistance to polar substances and steam are also good. It has excellent electrical insulating properties. The EPDM copolymer can be filled with more than 200 percent of its own weight with non re-inforcing fillers, resulting in reduction of costprice but also in physical properties. For these reasons this rubber is widely applied in many applications.

Nitrile rubber (NBR)

NBR is a family of unsaturated copolymers of acrylonnitrile (CAN) and butadiene monomers. Although its physical and chemical properties vary depending on the polymer's composition of nitrile (the more nitrile within the polymer, the higher the resistance to oils but the lower the flexibility of the material), this form of synthetic rubber is generally resistant to oil, fuel, and other chemicals. It is used in the automotive industry to make fuel and oil handling hoses, seals, and grommets.

NBR's ability to withstand a range of temperatures from -40 °C to +108 °C makes it an ideal material for automotive applications. Nitrile rubber is more resistant than natural rubber to oils and acids, but has less strength and flexibility. Nitrile rubber is generally resistant to aliphatic hydrocarbons. Nitrile, like natural rubber, can be attacked by ozone, aromatic hydrocarbons, ketones, esters and aldehydes.

Natural Rubber (NR)

Natural rubber has a very high elasticity, high tensile strength and a very good abrasion resistance. The material is obtained by coagulation of latex derived from the rubber tree. The rubber is not resistant to aging and oil. For these reasons NR is rarely used as a seal for technical applications, but is mixed with other elastomere compounds like EPDM to improve rubber properties.

Styrene - Butadien Rubber (SBR)

SBR is a synthetic rubber copolymer consisting of styrene and butadiene. It has good abrasion resistance and good aging stability when protected by additives, and is widely used in car tyres, where it is blended with natural rubber.

Chloroprene rubber (CR)

Commonly known under the trade name Neoprene® of Dupont. CR is not characterised by one outstanding property, but its balance of properties is unique among the synthetic elastomers. It has good mechanical strength, high ozone and weather resistance, good aging resistance, low flammability, good resistance toward chemicals and moderate oil and fuel resistance.

Silicone (VMQ/MVQ/HTV)

Silicones differ from other polymers in that their backbones consist of Si-O-Si units unlike many other polymers that contain carbon backbones.

Silicone rubber offers good resistance to extreme temperatures, being able to operate normally from -55 °C to +230 °C. At the extreme temperatures, the tensile strength, elongation, tear strength and compression set can be far superior to conventional rubbers although still low relative to other materials. Organic rubber has a carbon to carbon backbone which can leave them susceptible to ozone, UV, heat and other ageing factors that silicone rubber can withstand well. This makes it one of the elastomers of choice in many extreme environments.

Compared to organic rubbers, however, the tensile strength of standard silicone rubber is lower. For this reason, care is needed in designing products to withstand low imposed loads. Nowadays also silicone compounds with improved tensile strength are available.

Acrylic rubber (ACM)

Acrylic rubber, known by the chemical name alkyl acrylate copolymer (ACM), is a type of rubber that has outstanding resistance to hot oil and oxidation. It has a continuous working temperature of 150 °C and an intermittent limit of 180 °C. Disadvantages are its low resistance to moisture, acids, and bases. It should not be used in temperatures below -10 °C. It is commonly used in automotive transmissions and hoses.

Hydrogenated Nitrile Butadiene Rubber (HNBR)

The properties of hydrogenated nitrile rubber depend on the acrylonitrile (ACN) content, and on the degree of hydrogenation. They can be ‘tailored’ to particular applications, but have the general advantage over standard nitrile rubber of having higher temperature resistance and higher strength.

HNBR’s also have good high temperature oil and chemical resistance and are resistant to amines. They are suitable for use in methanol and methanol/hydrocarbon mixtures if the correct ACN level is selected. They have good resistance to hot water and steam. They can have excellent mechanical properties including strength, elongation, tear resistance, abrasion resistance and compression set. For the best properties peroxide curing is used, unless low hysteresis is required. They are reported to be satisfactory up to temperatures around 180 °C in oil. Fully saturated grades have excellent ozone resistance. They have poor resistance to some oxygenated solvents and aromatic hydrocarbons.

Fluoro rubber (FKM)

Fluoroelastomers are a class of synthetic rubber which provide extraordinary levels of resistance to chemicals, oil and heat, while providing useful service life above 204°C. The outstanding heat stability and excellent oil resistance of these materials are due to the high ratio of fluorine to hydrogen, the strength of the carbon-fluorine bond, and the absence of unsaturation.

The original fluoroelastomer was a copolymer of hexafluoropropylene (HFP) and vinylidene fluoride (VF2). It was developed by the DuPont Company in 1957 in response to high performance sealing needs in the aerospace industry. To provide even greater thermal stability and solvent resistance, tetrafluoroethylene (TFE) containing fluoroelastomer terpolymers were introduced in 1959 and in the mid to late 1960’s lower viscosity versions of FKMs were introduced A breakthrough in cross linking occurred with the introduction of the bisphenol cure system in the 1970’s. This bisphenol cure system offered much improved heat and compression set resistance with better scorch safety and faster cure speed. In the late 70’s and early 80’s fluoroelastomers with improved low temperature flexibility were introduced by using perfluoromethylvinyl ether (PMVE) in place of HFP.

Fluoroelastomers are a family of fluoropolymer rubbers, not a single entity. Fluoroelastomers can be classified by their fluorine content, 66%, 68% and 70% respectively. Fluoroelastomers having higher fluorine content have increasing fluids resistance derived from increasing fluorine levels. Peroxide cured fluoroelastomers have inherently better water, steam, and acid resistance.

Fluoroelastomers are used in a wide variety of high-performance applications. FKM provides premium, long-term reliability even in harsh environments. A partial listing of current end use applications (industries like aerospace and automotive) include: O-ring seals in fuels, lubricants and hydraulic systems, shaft seals, valve stem seals, fuel injector O-rings, diaphragms, lathe cut gaskets and cut gaskets.

The following table provides a summary of the various elastomer groups and their names according the ISO 1629 standard.

Designation	**Trade name**	**Abbreviation ISO 1629**
Acrylonitrile Butadiene rubber	Perbunan® Buna-N ®	NBR
Hydrogenated Acrylonitrile Butadiene rubber	Therban® Zetpol®	HNBR
Butyl rubber	Esso Butyl®	IIR
Chloroprene rubber	Neoprene® Baypren®	CR
Ethylene Propylene Diene Rubber	Dutral ® Keltan®	EPDM
Fluorocarbon rubber	Viton® Fluorel® Tecnoflon®	FKM
Silicone rubber	Elastosil® Rhodorsil® Silopren®	MVQ
Fluorosilicone rubber	Silastic®	FMVQ
Perfluoro rubber	Kalrez® Chemraz®	FFKM
Tetrafluorethylene-Propylene Copolymeer	Aflas®	FEPM
Polyester Urethane	Adiprene®	AU
Polyether Urethane	Pellethan® Desmopan®	EU

RUBBER PROPERTIES

Elastomers and rubber materials provide a variety of properties. Important specifications for elastomers and rubber materials include mechanical, thermal, electrical, optical, processing, and physical properties.

Mechanical properties include tear strength (TS), ultimate tensile strength (UTS), tensile modulus or modulus of elasticity, elongation, and impact toughness as measured with an Izod test and a notched sample.

Thermal properties include maximum use temperature, glass transition temperature, thermal conductivity, and coefficient of thermal expansion (CTE).

Electrical and optical properties include electrical resistivity, dielectric strength, dielectric constant or relative permittivity, index of refraction, and light transmission. Processing and physical properties include bulk or apparent density, water absorption, viscosity, process temperature, and melt flow index (MFI).

To make it possible to compare the different material characteristics several tests have been standardized. The material datasheets provide the results of these tests. Below the most important properties are explained in more detail.

Specific gravity

This property is fully defined by the composition of the material. Any other value will indicate another material or composition is on hand. The specific gravity is the mass per unit volume and is measured by weighing the sample in air and in water.

Specific gravity = weight in air / (weight in air – weight in water)

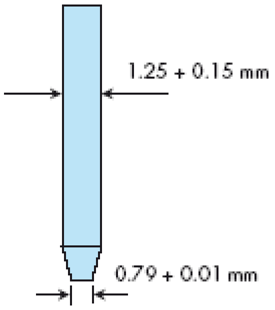
Standards: ISO 2871, ASTM D 1817

Hardness

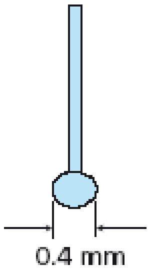
Hardness represents the elasticity of the material. The lower the hardness the more elastic the material is. Two scales are normally used: Shore-A and micro-IRHD. They are roughly the same. The instruments used for the measurement are:

Durometer: a pointed conical indentor when pressed against a sample, is pushed back into the case of the tester against a spring and this motion is translated into movement of the pointer on the dial. The harder the sample the farther it will push back the indentor point and the higher will be the numerical reading on the scale. The unit is Shore-A.

IRHD tester: a dead-load is applied to the indentor for a specific time and the hardness is obtained from the depth of the indentation.



Shore-A



micro IRHD

Standards: ISO 48, ISO 1400, ISO 1818, ASTM D 2240, ASTM D 1415

Tensile strength, elongation

Tensile strength is the maximum tensile stress reached in stretching a test piece, usually a flat dumb-bell shape, to its breaking point. By convention, the force required is expressed as force per unit area of the original cross section of the test length.

Elongation, or strain, is the extension between bench marks produced by a tensile force applied to the test piece and is expressed as a percentage of the original distance between the marks. Elongation at break, or ultimate elongation, is the elongation at the moment of rupture.

Standards: ISO 37, ASTM D 412

Compression set

Rubbers deform under load and rarely return completely to their original dimensions when the load is removed. The difference between the original and final dimensions is known as compression set. Small cylindrical disks of 13 mm diameter and a thickness of 6 mm or 29 mm diameter and a thickness of 12.5 mm are being used to perform the tests.

The disks are compressed in such a way that the compression is 25 percent of the original height. This at a known temperature, often at 23°C (or between 70 and 250°C) with a duration of 24 or 72 hours.

At the end of the specified time, the test pieces are removed from the test jig and allowed to recover at 23°C for 30 minutes before the thickness is re-measured. The compression set is the difference between the original thickness of the test piece and that after recovery, expressed as a percentage of the initially applied compression.

As formula:
Compression set = (Original thickness – Thickness of the piece after recovery) / (Original thickness – Height of the compression)

Standards: ISO 815, ASTM D 395

Resistance to heat aging

The properties of an elastomer will generally change after prolonged exposure to high temperatures. Tests for heat aging are carried out for two reasons. Firstly, there are tests to establish the changes in physical properties at elevated service temperatures. Secondly, there are accelerated tests at high temperatures which attempt to predict the long-term life at lower temperatures. Tests are carried out in an air oven or an oxygen pressure chamber.

Standards: ISO 188, ASTM D 573

Resistance to weathering
Deterioration in physical properties can occur when elastomers are exposed to the weather. This deterioration can be observed as cracking, peeling, chalking, colour changes and other surface defects. By far the most important cause of deterioration by weathering is the presence of ozone. Less than one pphm of ozone in the atmosphere can severely attack non-resistant rubbers if they are in a slightly strained condition. The result are cracks sheer on the direction of the strain. Sunlight (UV), oxygen, moisture and temperature also affect elastomers.

Standards: 1431/1, ASTM D 1149

Resistance to low temperatures
All elastomers undergo several kinds of change when they are exposed to low temperatures. Some of the changes occur immediately, others after prolonged exposure. All are reversible; the elastomer regaining its original properties when it is returned to room temperature. At low temperatures the material will become brittle and shatter on sudden bending or impact.

The temperature at which this occurs, when determined under certain prescribed testing conditions, is called the brittle point. Another test, to measure the modulus of the material, is the material retraction test. Generally known as the TR test.

Standards: ISO R 812, ISO 2921, ASTM D 2137, ADTM D 1053, ASTM D 1329

Abrasion resistance
A test piece is pressed against a rotating drum covered with an abrasive cloth. The loss in weight (volume) is measured after a certain number of revolutions and gives an indication of the abrasion resistance.

Standards: ISO 4649, ASTM D 394

Resistance to liquids
The action of liquids on elastomers may result in the absorption of liquid by the elastomer, extraction of soluble constituents from the elastomer or chemical reaction with the elastomer. Absorption is usually greater than extraction and there is a net increase in volume, generally known as swelling. For some products a decrease in volume or dimensions could be more serious than swelling and if there is a significant chemical reaction a low swelling may hide a large deterioration in physical properties. Consequently, although degree of swelling provides a good general indication of resistance it is also important to measure the change in other properties. In general the following guide lines can be used:

0-5% swell; recommended, no or minor effect
5-10% swell; seal can be used in most cases, less to moderate effect.
10-20% swell; Seals only in static applications to be used, moderate to severe effect
> 20% swell; not recommended

Standards: ISO 1817, ASTM D 1817

Of course, many more properties can be tested. Depending on the application the most appropriate tests can be selected and carried out to give the best results to predict the life time of a product.

RUBBER INGREDIENTS

A rubber compound is obtained by mixing a base polymer or crude mixture with a series of additives. The choice of the base polymer and the additives is closely linked to the type of properties to be achieved. The resulting product is a non vulcanized compound. The quantity of additives used varies for 20 to 130 percent as a percentage on the weight. The most common additives are:

Fillers

There are two types of fillers, reinforcing and non reinforcing fillers. Carbon black is commonly used as reinforcing filler. This is also the reason why most rubbers are black. Calcium carbonate is an example of a non reinforcing filler.

Plasticizers

Besides fillers, plasticizers play the biggest quantitative role in building a rubber compound. The reasons for the use of plasticizers are: improvement of flow of the rubber during processing, improved filler dispersion, influence on the physical properties of the vulcanizate at low temperatures. Mineral oils and paraffins are widely used as a plasticizer.

Vulcanization chemicals

Vulcanization is the conversion of rubber molecules into a network by formation of crosslinks. Vulcanizing agents are necessary for the crosslink formation. These vulcanizing agents are mostly sulphur or peroxide and sometimes other special vulcanizing agents or high energy radiation. Since vulcanization is the process of converting the gum-elastic raw material into the rubber-elastic end product, the ultimate properties like hardness and elasticity depend on the course of the vulcanization.

Accelerators

Accelerating agents increase the rate of the cross linking reaction and lower the sulphur content necessary to achieve optimum vulcanizate properties.

Activators

Like zinc-oxide and stearic acid. They activate the vulcanisation process and help the accelerators to achieve their full potential.

Anti degrading agents

These agents increase the resistance to attacks of ozone, UV light and oxygen.

Process aids

Chemicals that improve the processability.

Pigments

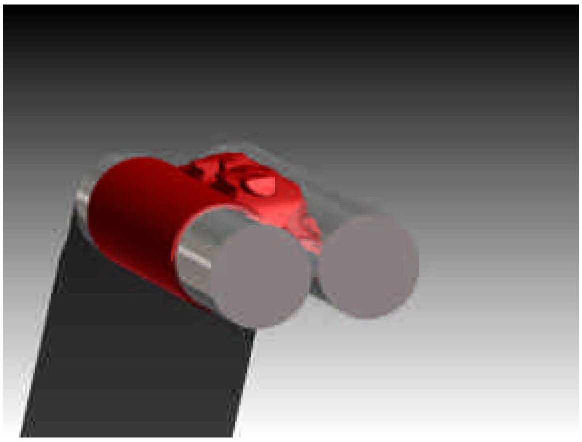
Organic and inorganic pigments are used to colour rubber compounds. The colour pigments are also considered inactive fillers. Only silica’s have a reinforcing effect. Silicone can be coloured easily without loss of properties.

RUBBER COMPOUNDING

Compounding is the operation of bringing together all the ingredients required to mix a batch of rubber compound. Each component has a different mix of ingredients according to the properties required for that component. Rubber compounding is generally carried out on open mills or internal mixers.

Open mill

An open mill consists of twin counter-rotating rolls, one serrated, that provide additional mechanical working to the rubber. The rolls can be heated or cooled as necessary. The rubber is placed on the rolls and mixing is achieved by the shearing action induced at the “nip” between the rolls. Additives are added in carefully weighed quantities during the mixing process. After the mixing operation is complete, the compound is removed from the mill in the form of sheet.



Internal mixer

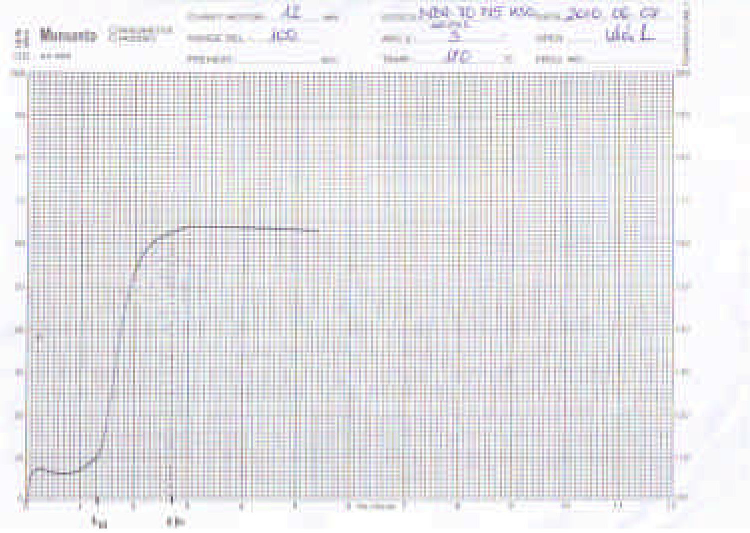
Internal mixers are often equipped with two counter-rotating rotors in a large housing that shear the rubber charge along with the additives. The mixing can be done in three or four stages to incorporate the ingredients in the desired order. The shearing action generates considerable heat, so both rotors and housing are water-cooled to maintain a temperature low enough to assure that vulcanization does not begin.

Compound control

The properties of the final product are mainly determined by the properties of the compound. Before starting the production of the final products the compound is tested to guarantee the correct properties. This is a common applied and standard procedure in rubber compounding. A rheometer test is carried out on every single batch of compound.

The rheometer describes precisely and quickly curing and processing characteristics of vulcanizable rubber compounds. It works on a very simple principle. A test piece of rubber compound is contained in a sealed test cavity under positive pressure and maintained at a specified elevated temperature. A rotor is embedded in the test piece and is oscillated through a small specified rotary amplitude. This action exerts a shear strain on the test piece and the torque (force) required to oscillate the disc depends upon the stiffness of the rubber compound. The stiffness of the specimen compound increases when cross links are formed during cure. A plot of this torque (force) value against time gives a typical graph called rheometer curve.

The cure curve obtained with rheometer is a finger print of compound's vulcanization and processing character.



Of course hardness and tensile strength are also checked for every batch. When all values are within allowed parameters the compound is released for production.

RUBBER MOULDING

Moulded rubber parts can be produced by different manufacturing methods. Major techniques are:

Compression moulding

Compression moulding is a process in which a compound is squeezed into a preheated mould taking a shape of the mould cavity and performing curing due to heat and pressure applied to the material. The method uses a split mould mounted in a hydraulic press

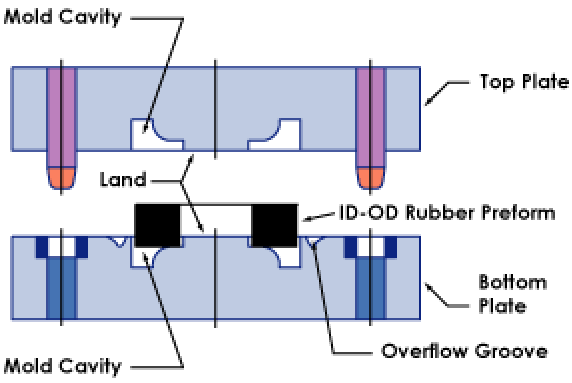
Compression moulding process involves the following steps:

1. A pre-weighed amount of the compound is placed into the lower half of the mould. The compound may be in form of putty-like masses or pre-formed blanks.

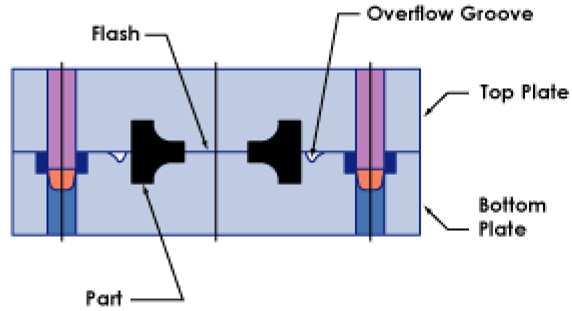
2. The upper half of the mould moves downwards, pressing on the compound and forcing it to fill the mould cavity. The mould, equipped with a heating system, provides curing (cross-linking) of the compound

3. The mould is opened and the part is removed for necessary secondary operations

Compression Molding



Compression Mold - Open



Compression Mold - Closed

Injection moulding

Injection moulding is a process in which the compound is forced under high pressure into a mould cavity through an opening (sprue).

The rubber material in form of strips is fed into an injection moulding machine. The material is then conveyed forward by a feeding screw and forced into a split mould, filling its cavity through a feeding system with sprue gate and runners.

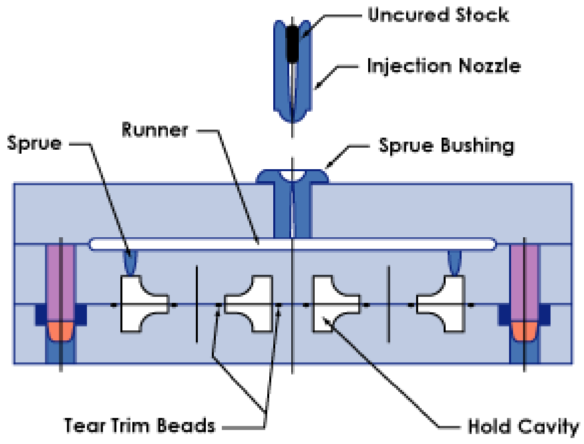
An injection moulding machine is similar to an extruder. The main difference between the two machines is in screw operation. In the extruder type the screw rotates continuously providing output of continuous long product (pipe, rod, sheet).The screw of the injection moulding machine is called a reciprocating screw since it not only rotates but also moves forward and backward according to the steps of the moulding cycle.

It acts as a ram in the filling step when the compound is injected into the mould and then it retracts backward in the moulding step. The mould is equipped with a heating system providing controlled heating and vulcanization of the material.

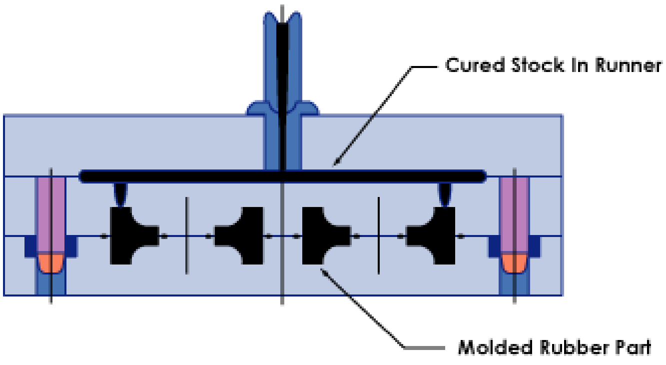
The compound is held in the mould until the vulcanization has completed and then the mould opens and the part is removed from the mould.

Injection moulding is a highly productive method providing high accuracy and control of shape of the manufactured parts. The method is profitable in mass production of large number of identical parts. A principal scheme of an injection moulding machine is shown here.

Injection Molding



Injection Mold - Before Shot



Injection Mold - Filled

Transfer moulding

Transfer moulding is a process in which a pre-weighed amount of a compound is preheated in a separate chamber (transfer pot) and then forced into a preheated mould through a sprue, taking a shape of the mould cavity and performing curing due to heat and pressure applied to the material. The picture below illustrates the transfer moulding process.

The method uses a split mould and a third plate equipped with a plunger mounted in a hydraulic press. The method combines features of both compression moulding (hydraulic pressing) and injection moulding (ram-plunger and filling the mould through a sprue).

The transfer moulding process involves the following steps:

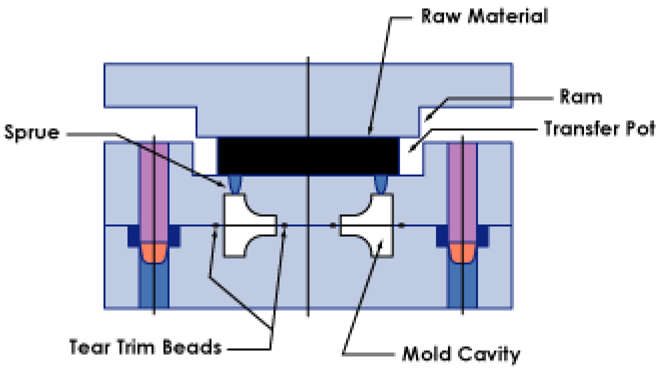
1. A pre-weighed amount of a compound is placed into the transfer pot. The compound form putty-like masses or pre-formed blanks. The compound is heated in the pot where the material softens.

2. The plunger, mounted on the top plate, moves downwards, pressing on the material and forcing it to fill the mould cavity through the sprue. The mould, equipped with a heating system, provides curing (cross-linking) of the compound.

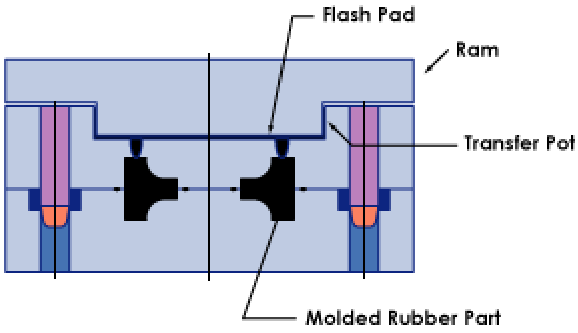
3. The mould is opened and the parts are removed for necessary secondary operations

The scrap left on the pot bottom (cull), in the sprue and in the channels is removed. Scrap of vulcanized rubber is not recyclable.

Transfer Molding



Transfer Mold - Open

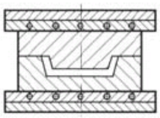
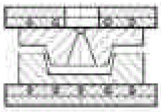
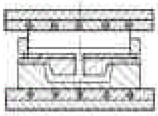
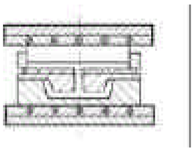
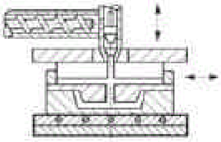
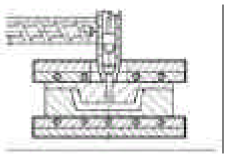
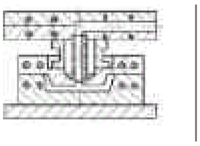
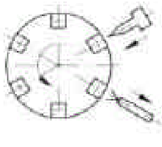


Transfer Mold - Closed

The transfer moulding cycle time is shorter than compression moulding cycle but longer than the injection moulding cycle. The method is capable to produce more complicated shapes than compression moulding but not as complicated as injection moulding.

Transfer moulding is suitable for moulding with ceramic or metallic inserts which are placed in the mould cavity. When the heated compound fills the mould it forms bonding with the insert surface.

More In detail, available production techniques are summarized in the next table.

	Technique	Symbol	Characteristics	Applications
Press	Compression moulding (CM)		o Pressing pre-shaped rubber compound in tool + Tool costs - Manufacturing costs	o Small series, large parts o Prototypes o Samples
	Injection compression moulding (ICM)		o Pressing pre-plastified rubber compound + Compound division without canals - Tool know-how	o Large surface membranes and sealings o Small precision parts o High number tool parts
Transfer press	Transfer press (TM)		o Transfer of rubber compound to cavities + Tolerances - Compound waste	o Complex precision parts o No secondary finishing (flash less)
	Transfer press with cold runner (TM-K)		o Transfer of pre-heated rubber compound + Less compound waste - Complexity	o Complex precision parts o No secondary finishing (flash less)
	Transfer injection press (ITM / TM-K)		o Transfer of pre-plastified rubber compound + Constant flow stream - Tool costs	o Large series of small parts, also in rubber-metal o No secondary finishing (flash less)
Injection moulding	Injection moulding (IM)		o Injection of pre-plastified material + Manufacturing costs - Tool costs	o Medium-large series of parts o Rubber-metal parts o Automated manufacturing
	Injection moulding with cold runner (IM-K)		o Injection of pre-mixed material through cooled runners + Material waste - Tool costs, RM costs	o Large series of small parts o No secondary finishing (flash less)
	Multicomponent injection moulding		o Injection of multiple materials during a cycle + Manufacturing costs large series - Tool costs, investment costs	o Very large series o Automated production o No secondary finishing

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Secondary finishing

Depending on the requirements and production process, some secondary finishing steps might be necessary or required:

Aftervulcanisation
Some rubber types require a process of aftervulcanisation (heating) for some hours. HNBR and FKM rubber is aftervulcanised to give the rubber its optimal mechanical properties after moulding.

Postcuring
Silicones parts applied in food or medical applications are mostly post cured after moulding. Post-curing is one of the principal tools to mitigate outgassing. Post-cure is a process that removes the volatiles from the cross-linked silicone rubber by diffusion and evaporation and is carried out at a temperature greater than the service temperature for the part. Post-curing also helps to improve the compression set.

Cryogene finishing
Cryogene deflashing and deburring is a step that is meant to remove excess imperfections on moulded parts such as fleece or flash lines. The process uses liquid nitrogen, high speed rotation and media (shot blast) in varying combinations to remove the flash in a highly precise and expedient manner.

RUBBER EXTRUSION

In the extrusion process of rubber, the compound including polymers, various types of additives and fills like curing agents, antioxidants, pigments are fed into the extruder. The extruder typically consists of a rotating screw inside a closely fitted heated barrel. The primary purpose of the extruder is to do three things, a) soften, b) mix, c) pressurize the rubber as it is fed continuously to the die at the extruder exit.

The die is a sort of metal disk that has a machined opening in the desired shape of the part that needs to be extruded. The rubber already softened by heating is then forced by the rotating screw through the die opening into the shape of the profile cut in the die. A typical phenomenon called die swell takes place as the rubber shape leaves the die. Because of this the part cross-section becomes larger than the die cross-section. The part cross-section depending on the material may rise up to several folds over the die.

Subsequently the processes of vulcanization or curing takes place as the last step in the extrusion process. This aids the rubber extruded profiles to maintain its shape and acquire necessary physical properties. Typical examples of extruded rubber parts are profiles, hoses, strips and cords.

DIMENSIONAL TOLERANCES

Rubber products are subject to changes in their dimensions after processing and vulcanisation. This may due to a variety of factors, such as mould shrinkage or relaxation of die swell. These changes should be determined and allowed for when designing such items as moulds and dies used in the manufacture of a given product.

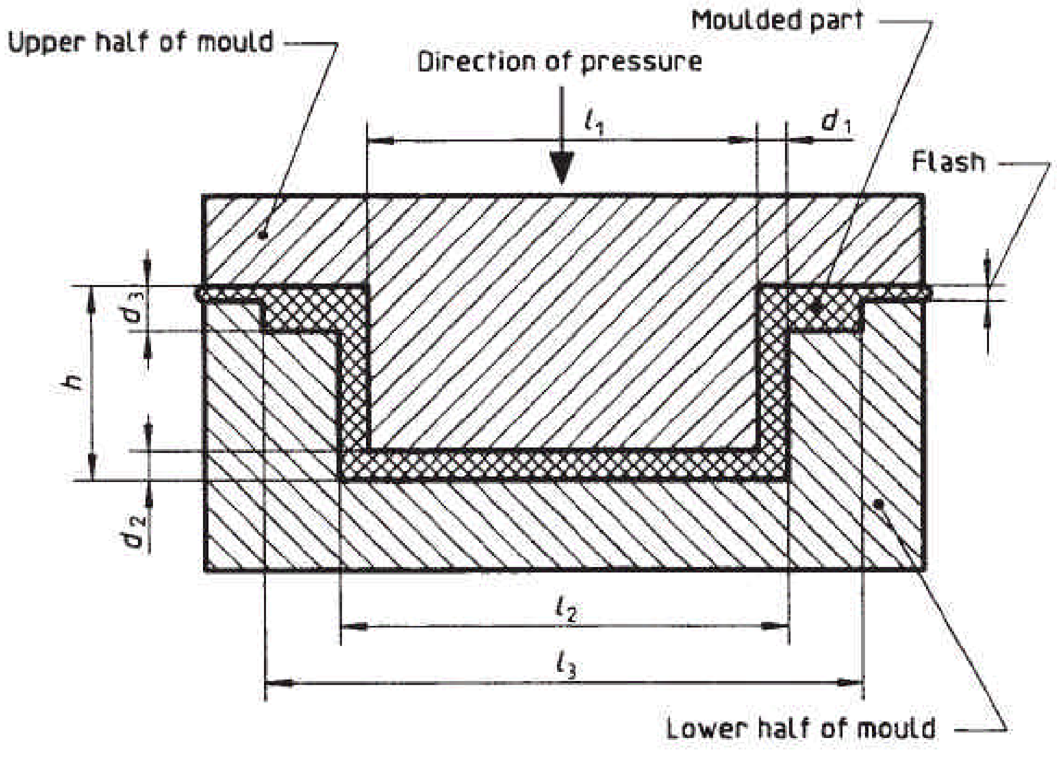
All rubbers show some shrinkage when cooled after moulding, and allowance for this is made in the mould design. The amount of shrinkage is dependent on the rubber compound and the mix used, but also varies from batch to batch of the same compound. Also moulds are made in various ways depending on the type of product and accuracy demanded.

In general, the product can be no more accurate than the mould, and the greater the degree of accuracy demanded, the more expensive become the moulds and their maintenance.

A commonly applied standard for dimensional tolerances for rubber mouldings is described in ISO 3302-1. In this standard two sets of tolerances, F and C, are given and defined. F (fixed) dimensions are dimensions which are not affected by deforming influences like flash thickness or lateral displacement of different mould parts (see l1, l2 and l3).

C (closure) dimensions are dimensions which can be altered by variation in the flash thickness or lateral displacement of different mould parts (see d1, d2, d3 and h).

The standard established four classes of tolerances for fixed and closure dimensions, varying from M1 (high precision mouldings) to M4 (non-critial dimensional control). The tolerances to be applied shall be chosen, by agreement between interested parties from the classes F and C.



Nominal Dimension		**Class M1**		**Class M2**		**Class M3**		**Class M4**
above	up to and including	F	C	F	C	F	C	F and C
		±	±	±	±	±	±	±
0	4.0	0.08	0.08	0.10	0.15	0.25	0.40	0.50
4.0	6.3	0.10	0.12	0.15	0.20	0.25	0.40	0.50
6.3	10.0	0.10	0.15	0.20	0.20	0.30	0.50	0.70
10.0	16.0	0.15	0.20	0.20	0.25	0.40	0.60	0.80
16.0	25.0	0.20	0.20	0.25	0.35	0.50	0.80	1.00
25.0	40.0	0.20	0.25	0.35	0.40	0.60	1.00	1.30
40.0	63.0	0.25	0.35	0.40	0.50	0.80	1.30	1.60
63.0	100.0	0.35	0.40	0.50	0.70	1.00	1.60	2.00
100.0	160.0	0.40	0.50	0.70	0.80	1.30	2.00	2.50
160.0		0.3 %	0.4 %	0.5 %	0.7 %	0.8 %	1.3 %	1.5 %

Tolerances for mouldings (values in mm)