

### Formation of Macromolecules

There are three separate types of formation reactions for macromolecules. In polymerisation, the polymers merge in lines and form macromolecules without any kind of by-product being produced. This has already been illustrated in Figure 2.2. The number of monomers contained in a macromolecule is also referred to as the degree of polymerisation. If the macromolecules are made up of only one type of monomer, they are called homopolymers, one example being standard polystyrene. If different monomers form part of the structure of a macromolecule, then they are called copolymers (mixed polymers). Thus, for example, SB consists of styrene and butadiene monomers. ABS comprises three different types of monomers: acrylonitrile, butadiene and styrene.

**In polycondensation** macromolecules are formed from monomers under the splitting action of another substance, usually water. If polymerisation takes place at a temperature of over 100 °C, steam is formed.

The macromolecules generated by polycondensation can be made up of one type of monomer, (e.g., PA 6), or 2 different monomers, (e.g., PA 66), depending on the shape of the monomers. Further examples of polycondensates are polycarbonate (PC) and linear polyesters such as polyethylene terephthalate (PET).

**In polyaddition** macromolecules are formed from monomers, without the generation of any cleavage products. Two different monomers are always required for polyaddition. The monomers undergo slight changes during this process. A few atoms change places between the different monomers. Examples are polyurethane (PU) and epoxy resins (EP).

### Introduction to Injection Moulding

Injection moulding is one of the most common processes used to produce plastic parts. It is a cyclic process of rapid mould filling followed by cooling and ejection. A variety of materials both plastic and non-plastic can be used as feedstock. However, the machine must be configured for the type of material used.

The material, which is generally available as grains or powder, is plasticised in an injection unit and injected into a clamped mould under high pressure (500-1500 bar). The main advantage of injection moulding is that it is a very economical method of mass production. Ready parts with tight tolerances can be produced in one step, often completely automatically. In general after-processing is not necessary. It is also possible to integrate different functions into one part to avoid the formation of different components that would be more expensive, e.g., the base of a typewriter with integrated guidance and fixing elements, the springy components of a printer element, a lens with integrated prisma to stop down a beam of light.

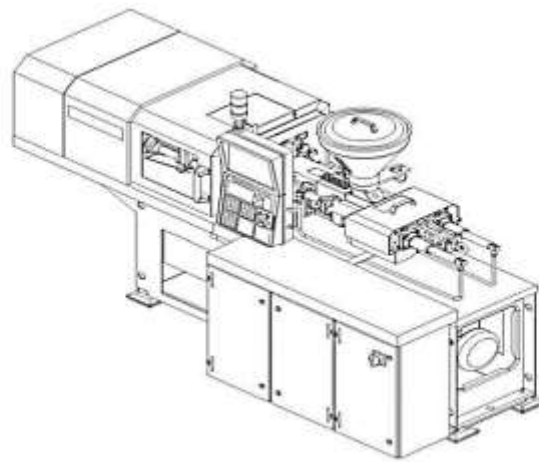
To guarantee a high quality in the injection moulded parts the following points have to be considered:

- The material has to be plasticised and injected carefully to avoid negative effects on the material properties.

### General Injection Molding

- The process settings (such as pressures and temperatures) concerning the machine and mould have to remain constant with regard to time and space.
- Basic parts of an injection moulding machine.

An example of a commercially available injection moulding machine is shown in Figure 1.1. The basic parts that make up a machine are shown in below.

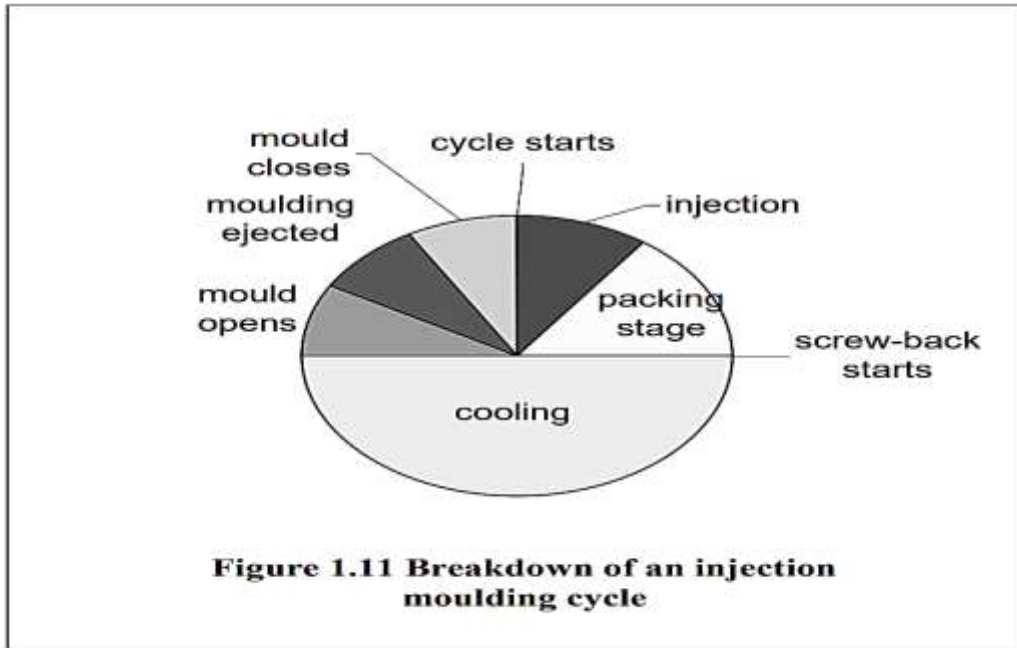


### The Injection Moulding Process

In injection moulding the mould and the plasticising area are separated from each other. The plasticising area, i.e., the plasticising cylinder temperature, is kept at the level of the processing temperature. The mould on the other hand, is kept cold enough for demoulding of the injection moulded part (thermoplastics) or warm enough for crosslinking (thermosets). The plasticised material is injected into the clamped mould. In an injection moulding machine, the clamping unit which contains the mould and the injection unit are integrated. Completely automated production is possible if the mould is installed with a vertical parting line. This enables the parts to fall down and out of the mould after demoulding.

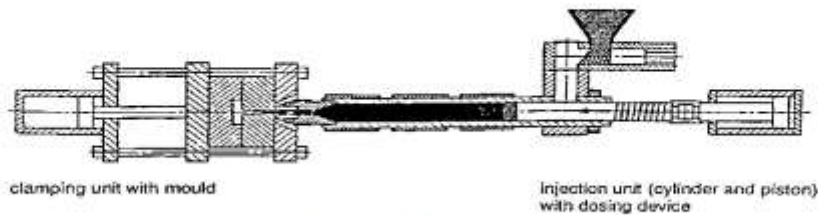
**Injection moulding** machines are typically used for the processing of thermoplastics. There are two types of injection unit available: a piston injection unit and a screw piston injection unit (reciprocating).

The reciprocating screw method is the most common. For the processing of thermosets only screw piston machines can be used. This is because without the screw, the dwell time would be too long and the risk of early crosslinking would be too high. The injection sequence for both types of machine now follows.



**Piston Injection Unit**

- Injection sequence:
1. Injection starts (clamped mould, start of piston movement) (Figure 1.3)
  2. Injection and dosage
  3. Holding pressure (to balance the solidification shrinkage) (Figure 1.4)
  4. Ejection (Figure 1.5)



**Figure 1.3 Piston injection unit (1)**



**Figure 1.4 Piston injection unit (2)**

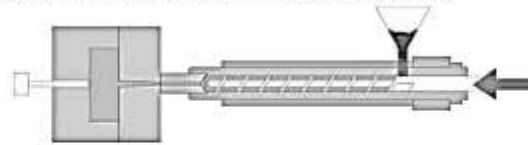


**Figure 1.5 Piston injection unit (3)**

**Reciprocating Screw Machine**

For a reciprocating screw machine the process cycle can be split into five stages:

1. In stage one, as shown in Figure 1.6, material is injected into the tool.



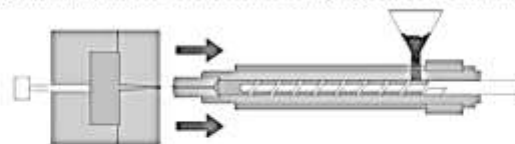
**Figure 1.6 Injection moulding: injection**

2. In stage 2 (Figure 1.7), the screw begins to turn and retract, metering a specified weight of molten material for the next shot. The previous shot is now cooling in the closed tool.



**Figure 1.7 Injection moulding: metering**

3. In stage 3, the injection unit moves back from the clamping unit as shown in Figure 1.8.

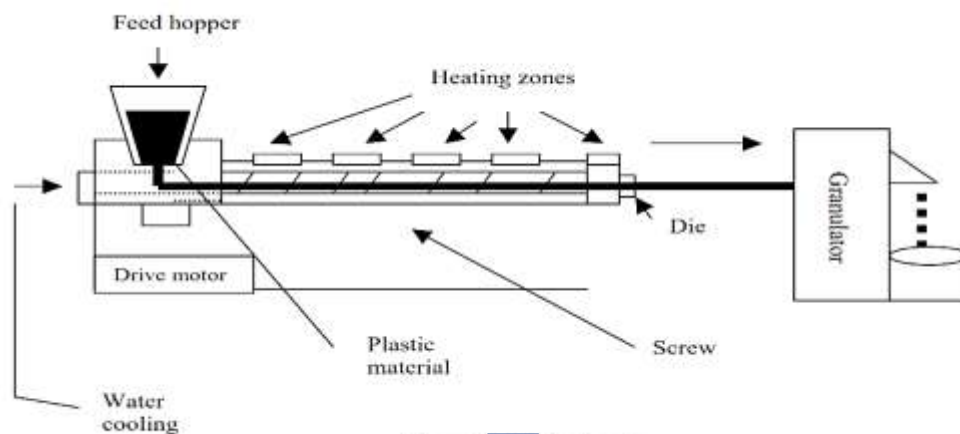


**Figure 1.8 Injection moulding: injection unit retracts**

4. Stage 4 is shown in Figure 1.9. In this stage the tool opens to reveal a cooled injection moulded component.



**Figure 1.9 Injection moulding: mould open**



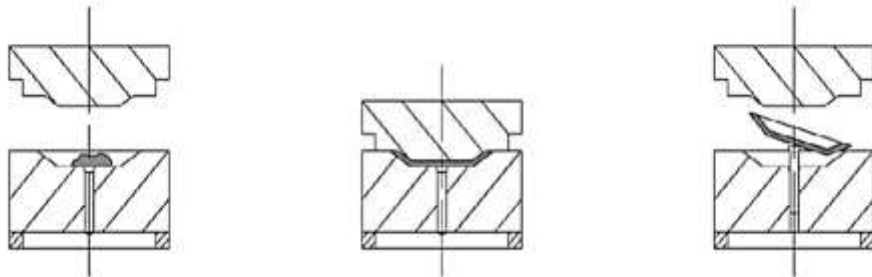
**Figure Extrusion**

**Compression Moulding**

With compression moulding a weighed amount of material is placed in an open mould tool and then compressed (Figure below). During the clamping movement, the material is heated up to its processing temperature by heat transfer from the hot mould allowing it to form to

### General Injection Molding

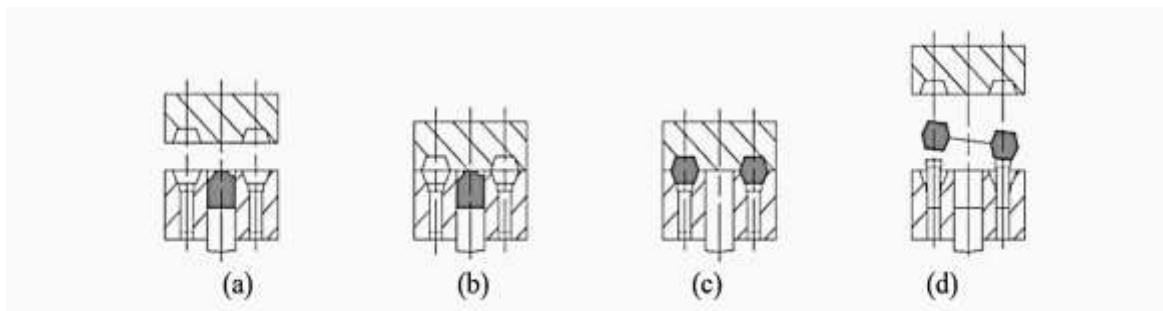
the shape of the tool. After sufficient pressure and temperature has been applied the tool is opened. Thermosets are demoulded from the hot mould when crosslinking is complete. Thermoplastics have to be cooled until the part is rigid enough for demoulding. Therefore the cycle times for thermoplastics are very long (12-20 minutes). In consequence, this method is only used for thick wall parts or for boards.



### Transfer Moulding

In a transfer mould, there is a special plasticising area (cylinder) as well as cavities.

With an open mould a weighed amount of material is placed into the plasticising area (Figure below a). After mould clamping (Figure below b), the material is pressed through the sprue channels into the cavities by the piston (Figure below c). The material is warmed by heat transfer from a hot mould. Frictional heat also warms the material, which occurs in the tool but especially when it passes through the sprue channels.



### Blow Moulding

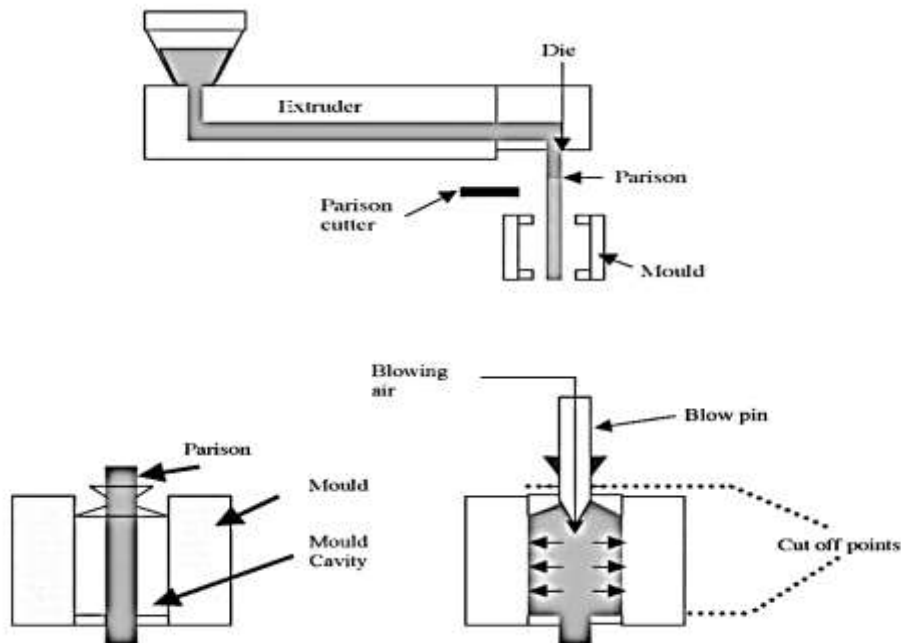
Blow moulding is the third most commercially important process for plastics production after extrusion and injection moulding. It is used to produce a range of hollow articles for example bottles, fuel tanks and other large containers. There are two main variations, injection blow moulding and extrusion blow moulding. The process sequence for both is the same.

- The material is either extruded or injected to produce a tube like preform.
- The preform is blown out to the shape of the mould and then cooled.

Injection blow moulding is most commonly employed for the production of transparent soft drinks containers. However, extrusion blow moulding is the one most commonly employed for mouldings such as shampoos and detergent containers, plastic drums and milk bottles and is described below.

## General Injection Molding

The material is fed through a transfer screw (which is very similar to an extruder), into a die head where the material is melted and passes out through a die as a tube like extrudate termed a parison as shown in Figure below . This process can be either continuous or with larger articles intermittent. The parison extrudes down vertically and relies on the hot strength of the plastic to hold the parison weight in shape. For these reason blow moulding uses far more viscous materials than would normally be employed for the injection moulding process. A low viscosity material would simply pour out of the die onto the floor or split off before the parison had formed.



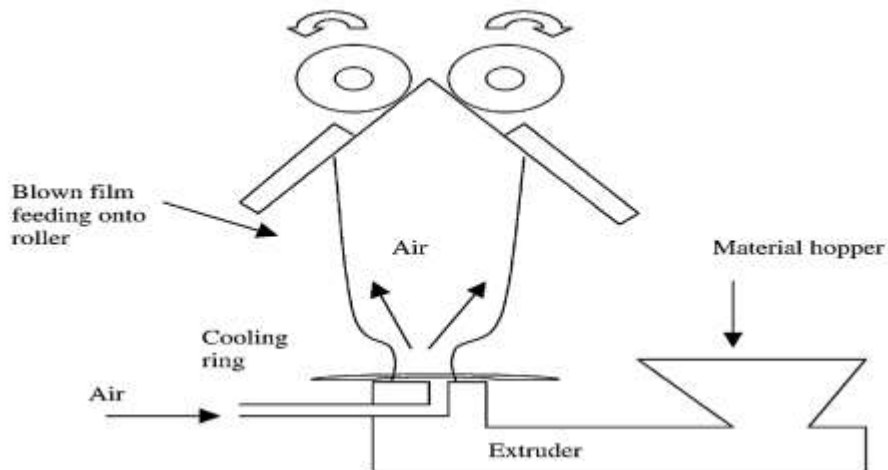
The criteria for a blow moulding material are quite specific:

- High melt strength
- Suitable viscosity
- Be extendable when inflating (this is often given as an inflation ratio for the material)
- Be able to seal at the base of the moulding.

During inflation the material expands at a constant rate to give a constant wall thickness across the body of the moulding.

## Film Blowing

In film blowing the plastic material is fed through an extruder to an annular die opening. The cylindrical molten tube is inflated from the inside by blowing air, creating a bubble of material that can be fed and collected onto rollers. Cooling is achieved by blowing air through a cooling ring above the die. The process is shown in Figure below.



**Molecular Weight**

A polymeric material may have many macromolecular chains, all of various lengths or repeat units. The molecular weight distribution is used to describe this variation and the average size of these chains determines the polymer molecular weight. As well as the backbone, polymers may also have side chains of varying lengths. This branching from the main chain also affects the properties of the polymer. Branching restricts the ability of the polymer chains to pack together. Therefore branching affects the density of a polymer. For example with high density polyethylene there is very little branching hence giving the term high density, low density polyethylene in contrast has many branches. An illustration of this effect on both density and melting point can be seen in Table below .

Influence of branching on properties of polyethylenes				
Polyethylene	Melting point (°C)	Density (g/cm <sup>3</sup> )	Tensile strength (MPa)	Number/type of branches
LDPE	110-120	0.91-0.93	17-26	Long branches
LLDPE	122-124	0.92	13-27	10-35 short branches (per 1000 carbon atoms)
HDPE	130-135	0.94-0.97	21-38	4-10 short branches (per 1000 carbon atoms)

**Thermosets**

Thermoset injection moulding compounds change their structure when injected. Before injection moulding, they still consist of thread-shaped molecules similar to thermoplastics. However, during a process termed 'curing' the molecules crosslink forming a highly dense network of bonds. This makes the material stiff and brittle and the thermoset moulded parts can then no longer be melted. Thermoset materials decompose before they can melt, therefore, they cannot be reprocessed in the same way as thermoplastics. The differences in the arrangement of molecules between thermoplastics and thermosets can be seen in Figure . Thermosets are often used where their strength and durability can be utilised, some common thermosets are shown in Table below.

Common thermoset materials	
Thermoset polymer	Application
Epoxy	Adhesives, electrical insulation
Melamine	Heat resistant laminate surfaces, i.e., kitchen worktops
Phenolics	Heat resistant handles for pans, irons, toasters
Polyurethane (PU)	Rigid or flexible foams for upholstery and insulation
Unsaturated polyesters	Partitions, toaster sides, satellite dishes

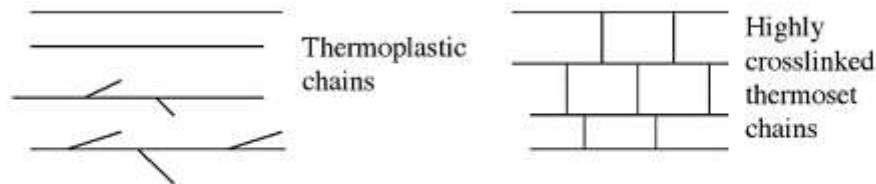


Figure 1 Arrangements of thermoplastic and thermoset molecular chains

**Important issue is heat and heat transfer**

A thermoplastic cannot flow when it is in its solid state. To enable it to flow it needs to be heated to either

- Above its melting point ( $T_m$ ), if it is a crystalline material or
- To its glass transition temperature ( $T_g$ ), if it is an amorphous thermoplastic.

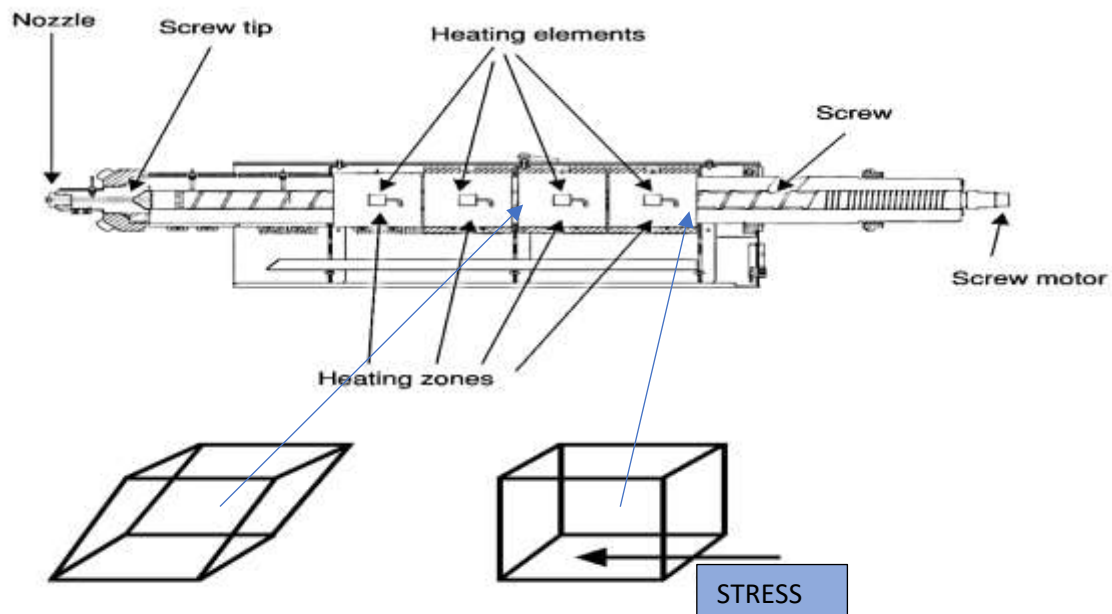
Some melting points of common polymers are shown in Table below. The melt temperature is also sometimes referred to as a flow temperature or a crystalline melting point for amorphous and crystalline polymers respectively. Amorphous materials do not have a clearly defined melting point like crystalline materials, but tend to soften and flow instead. At the melt temperature, which may be a fairly sharp point or a range, the polymer behaves as a viscous liquid and flows as the molecules are free to slide over one another. Highly crosslinked polymers do not have a melting temperature. The chemical bonds between the chain form a rigid structure.

Melting points of common polymers	
Polymer	$T_m$ (°C)
Polyethylene (PE)	135
Polypropylene (PP)	170
Polyethylene terephthalate (PET)	245
Polyamide 6 (PA6)	233

From these examples, a wide range of melting points can be clearly seen. Once above the melting point the viscosity will decrease as the temperature increases. The rate of this change varies, according to the particular type of material. Eventually the polymers will reach a point where they become thermally unstable and start to degrade. Generally, this shows itself as a discolouration of **the melt turning yellow or brown**. On excessive heating, polymers burn or decompose.

### The Injection Cylinder

Once the material has passed through the hopper, it enters the injection barrel. The barrel will consist of a number of separately controlled heating zones as can be seen in Figure below. The heat is generated from conduction of heat from the cylinder and also the heat generated by the shearing action of the screw on the material feedstock. Polymers are not particularly good conductors of heat; therefore the polymer thickness in any section of the screw tends to be kept low. The amount of shear is material dependent, mainly viscosity related and controlled by the machine screw back and back pressure.



With this in mind, good thermal stability is a requirement for most polymer processing operations, as the combined action of heat and shear can produce degradation. The effect of this is chain breakage. The length of the chain is related to the molecular weight, the molecular weight to the properties. Therefore any change in chain length will affect:

- Molecular weight and viscosity
- Tensile and impact properties.

Combined heat and shear can also result in:

- Change in colour (yellow or brown discolouration)
- Reduced fibre length in glass filled materials.

### The Formulation of Plastics

It was stated earlier in the chapter that plastics are mixtures of polymers and other materials. There are many additives commercially available that can be mixed with polymers. For example, glass or carbon fibre reinforcement gives increased strength. Flame retardants can be added for flame resistance. They can be coloured with pigments for aesthetic or technical purposes, or they can be made more heat and light resistant by the use of stabiliser additives. Those are just a few examples of the numerous possibilities. In addition, the levels of each of

these additives can also be varied. It is easy to see how so many grades of plastic have come to exist. It is also hopefully now apparent how they have been able to compete so successfully with other materials as diverse as glass, metal and wood. A list of some of the more common plastic additives is given in Table below. Plastics, which incorporate reinforcing materials such as glass fibre or clay, are called polymer composites. Composites can be made from both thermoplastic and thermoset polymers, with materials such as glass and carbon fibres, which increase the tensile stiffness and strength of the resultant materials. Polymer composites are widely used for a variety of applications where their high strength to weight ratio can be utilised. The automotive industry especially has taken advantage of these properties to make weight savings over metal components to improve fuel efficiency.

Common additives for plastics	
Additive	Purpose
Reinforcement, e.g., glass fibre	Increased strength and stiffness
Extenders, e.g., calcium carbonate	Cost reduction: much cheaper than polymer
Conductive fillers, e.g., aluminium powder	Improved thermal and electrical conductivity
Flame retardant	Increased fire resistance
Light stabilisers	Increased resistance to degradation from daylight
Heat stabilisers	Increased resistance to degradation from elevated temperature exposure
Pigments	Give colour, improved aesthetic properties
Plasticisers	Improved flow properties and increased flexibility
Coupling agents	Improved interface bonding between the polymer and a reinforcing agent
Foaming agents	Lightness and stiffness
Mould release agents	Processing aids
Antistatic additives	Prevent dust build up on consumer items

The following benefits are achieved through the application of **injection process** regulation:

- Significant reduction in start-up cycles. The required consistency in quality characteristics is achieved after just a few cycles.
- Better reproducibility of the parts. The deviation spread of the dimensions lies significantly below that of a non-regulated machine.
- Cycle-time reduction. By the ability to visualise the internal pressure signal, the sealing point can be determined much more easily and accurately.
- Re-starts. If the same internal pressure curve is applied at a re-start, the resulting parts are exactly alike.
- Improved quality of the parts through effective speed and pressure profiles. Internal pressure profiles without spikes make possible the production of parts with low residual stresses. Switch over as a function of internal pressure prevents over-injection of the part, regardless of the selected dosage stroke.

### Injection Moulding Machines for Rubber Compounds

Standard machines can be prepared for the processing of elastomeric materials. The machines must, however, have the following equipment:

- Cylinder for elastomeric material
- Mould blow unit
- Dosage delay
- Special control for cleaning and brushing devices in the mould (to remove bloom).

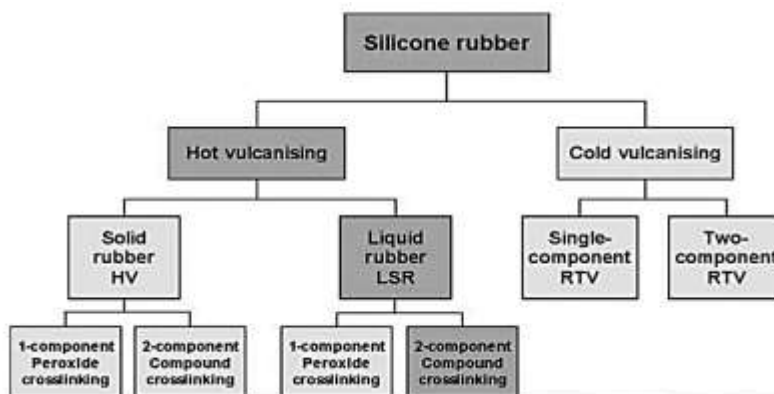
### Silicone Elastomers – Liquid Silicone Rubber (LSR) Systems

Increasing expenses for machines, staff and especially raw materials forced manufactures of plastic materials and custom moulders to look for new solutions. Thus liquid silicone rubber was introduced by the chemical industry in 1978. The base material is quartzite or quartz powder (SiO<sub>2</sub>), making it independent of crude oil (in contrast with synthetic rubber).

**LSR is vulcanised into silicone rubber** in the mould. Preforms made from LSR, in spite of the high material prices, are often considerably more cost-effective than those made from conventional types of rubber, because the processing costs are considerably lower. Among the variety of plastics and elastomers, the silicones occupy a special position. Their significant difference from other plastics lies in their chemistry. Most plastics have a backbone of carbon-carbon bonds. In contrast to this, the silicones are distinguished by alternating silicon and oxygen atoms. Since there are very many different possibilities for varying organic groups within the molecule chains, there are many different products in the silicone marketplace with widely differing properties.

### Classification

Silicone rubbers may be classified by crosslinking method, viscosity and vulcanisation temperature. Differentiation can be made between hot and cold (room temperature vulcanisation (RTV) rubber types. Within each of these two groups are found single-component and two-component systems, grouped by viscosity range. The viscosity of the rubber (fluid-mouldable, pasty, plastic-firm) determines the processing method and influences the characteristics of the vulcanised material. Figure below depicts the classification of silicones.



## General Injection Molding

### Specific Properties

- High heat resistance up to constant temperatures of 180 °C
- Good low-temperature resistance and cold flexibility to –50 °C
- Good tensile strength and tear strength
- High resistance to weathering and ageing
- High electrical insulating properties as well as resistance to shock
- Constant mechanical and electrical properties within a wide temperature range
- High resistance to alcohol, polar solvents and weak acids
- Anti-adhesive and hydrophobic characteristics
- Excellent physiological properties.

**Liquid silicone rubber (LSR)** for the production of elastic parts in injection moulding technology is gaining an ever increasing significance in the processing of elastomers. The characteristic for liquid silicone rubber is the low viscosity in comparison to solid silicone rubber and other elastomers. The LSR raw-material producers provide a number of differing types of material in order to cover as broad a spectrum of applications as possible. The following typical commercial products are available at this time:

- Standard types with Shore hardness of 20 to 70 Shore A
- Electrical conducting types
- Oil-sweating, self-lubricating types
- Flame-retarding products
- Types for medical technology, physiologically harmless

### Machine Technology

Injection moulding machines for the processing of LSR are differentiated by a few process-relevant peculiarities from machines that process other materials, and especially through a special injection unit. A standard injection unit can be converted relatively quickly and easily for LSR processing by the installation of an LSR cylinder module. Since LSR technology places great demands on the machine in order to ensure problem-free operation, the following points should be kept in mind during the selection of a suitable injection moulding machine.

- The machine control unit must be structured simply and flexibly in order to make the hook-up of different peripheral machines possible. In addition, secondary equipment and mould heating must be operated and monitored directly through the machine control unit.
- The most important motion process phases of the machine should be controlled to ensure the highest possible reproducibility of parts.
- A screw with position regulation allows, among other things, the absolutely precise maintenance of the defined stroke and pressure profile at injection.

### *General Injection Molding*

- Ramp-controlled mould sealing provides for positioning on the clamping platen which is accurate to the millimetre, providing problem-free operation of the handling devices.
- Mould sealing, which is characterised by high rigidity and parallelism of the mould platen, as well as fast opening and closing speeds enable a rapid injection cycle. Due to the fast vulcanisation time of LSR, 4 to 5 second cycles are not rare.

### *In General Injection Molding*

Tooling costs will be key to future developments in this , due to the prohibitive costs often involved in tooling for multiple materials. Developments in both the mouldability and adhesion characteristics of both thermoset and thermoplastic materials, and machinery enhancements in terms of improved speeds and control are likely to further enhance processing and material combination options. With such possibility inherent in these processes it is likely that the future limitations on this technology may extend only to the limits of designer imagination.