Program : **B.Tech**

Subject Name: **Manufacturing Technology**

Subject Code: **ME-405**

Semester: **4th**

Unit-III
Plastics & Manufacturing of Plastics

Introduction

Plastics are commonly known as synthetic resins or polymers. In Greek terminology, the term polymer comprises 'poly' means 'many' and 'mers' means 'parts'. Thus, the term, polymer represents a substance built up of several repeating units, each unit being known as a monomer. Thousands of such units or monomers join together in a polymerization reaction to form a 'polymer'. Some natural polymers like starch, resins, shellac, cellulose, proteins, etc are vary common in today's use. Synthetic polymers possess a number of large applications in engineering work. Therefore plastic materials are fairly hard and rigid and can be readily molded into different shapes by heating or pressure or both. Various useful articles can be produced from them rapidly, accurately and with very good surface quality. They can be easily produced in different colors or as transparent. They are recognized by their extreme lightness, good corrosion resistance and high dielectric strength. Plastics are synthetic resins characterized as a group by plastic deformation under stress. These materials generally are organic high polymers (i.e. consisting of large chain like molecules containing carbon) which are formed in a plastic state either during or after their transition from a low molecular weight chemical to a high molecular weight solid material. These materials are very attractive organic engineering materials and find extensive applications in industrial and commercial work such as electrical appliances, automotive parts, communication products bodies (Telephone, Radio, TV), and those making household goods. They possess a combination of properties which make them preferable to other materials existing in universe.

Properties of plastics

The properties of plastics are given as under.

1. Plastics are light in weight and at the same time they possess good toughness strength and rigidity.
2. They are less brittle than glass, yet they can be made equally transparent and smooth.
3. Their high dielectric strength makes them suitable for electric insulation.
4. They resist corrosion and the action of chemicals.
5. The ease with which they can be mass-produced contributes greatly to their popularity as wrappers and bags.
6. They possess the property of low moisture absorption.
7. They can be easily molded to desired shapes.
8. They can easily be made colored.
9. They are bad conductance of heat.
10. They are hard, rigid and heat resistance.
11. They possess good deformability, good resistance against weather conditions, good color ability, good damping characteristics and good resistance to peeling.

Plastics are broadly classified into thermo plastics and thermo-setting plastics.

Thermo Plastics

Those plastics which can be easily softened again and again by heating are called thermoplastic. They can be reprocessed safely. They retain their plasticity at high temperature, i.e. they preserve an ability to be repeatedly formed by heat and pressure. Therefore, they can be heated and reshaped by pressing many times. On cooling they become hard. They are sometimes also called as cold-setting plastics. They can be very easily shaped into tubes, sheets, films, and many other shapes as per the need.

Types of Thermo Plastics

(A) Amorphous

1 Polystyrene
2 Acrylonitrite-butadiene-styrene
3 Mrthacrylate
4 P.V.C (Polyvinyl chloride)
5 Polychloroacetal
6 Auorinated polymers,
7 Polycarbonate etc.

(B) Crystalline

1 Polyethylene
2 Polyamides
3 Polyacetal

4 Polypropylene

The reason for the re-softening of thermoplastic resins with heat is that they are composed of linear or long chain molecules. Application of heat weakens the intermolecular bonds by increasing thermal agitation of the molecules, and the material softens and thus plastic can be easily molded and remolded without damage.

Thermo-Setting Plastics

Those plastics which are hardened by heat, effecting a non-reversible chemical change, are called thermo-setting. Alternatively these plastics materials acquire a permanent shape when heated and pressed and thus cannot be easily softened by reheating. They are commonly known as heat-setting or thermosets.

Thermosetting resins

(*i*) Phenol-formaldehyde resins
(*ii*) Urea-formaldehyde resins
(*iii*) Melamine-formaldehyde resins
(*iv*) Polyester resins
(*v*) Epoxy resins
(*vi*) Silicone resins

Comparison between Thermo Plastic and Thermosetting Plastic

S.No	Thermo Plastic	Thermosetting Plastic
1	They can be repeatedly softened by heat and hardened by cooling.	Once hardened and set, they do not soften with the application of heat.
2	They are comparatively softer and less strong.	They are more stronger and harder than thermoplastic resins
3	Objects made by thermoplastic resins cannot be used at comparatively higher temperature as they will tend to soften under heat.	Objects made by thermosetting resins can be used at comparatively higher temperature without damage
4	They are usually supplied as granular material	They are usually supplied in monomeric or partially polymerized material form in which they are either liquids or partially thermoplastic solids.
5	Applications. Toys, combs, toilet goods, photographic films, insulating tapes, hoses, electric insulation, etc.	Applications. Telephone receivers, electric plugs, radio and T.V. cabinets, camera bodies automobile parts, tapes, hoses, circuit breaker switch panels, etc.

Fabricating of Plastics

(*a*) Themo-plastics can be formed by

(*i*) Injection molding.
(*ii*) Extrusion.
(*iii*) Blow molding.
(*iv*) Calendaring
(*v*) Thermo-forming.
(*vi*) Casting.

(*b*) Thermosetting plastics can be formed by

(*i*) Compression or transfer molding.
(ii) Casting

Thermoplastics can be joined with the help of

(*i*) Solvent cements.
(*ii*) Adhesive bonding
(*iii*) Welding
(*iv*) Mechanical fasteners

Thermosetting plastics can be joined with the help of

(*i*) Adhesive bonding
(*ii*) Mechanical fasteners.

Composition and Structure of Plastics

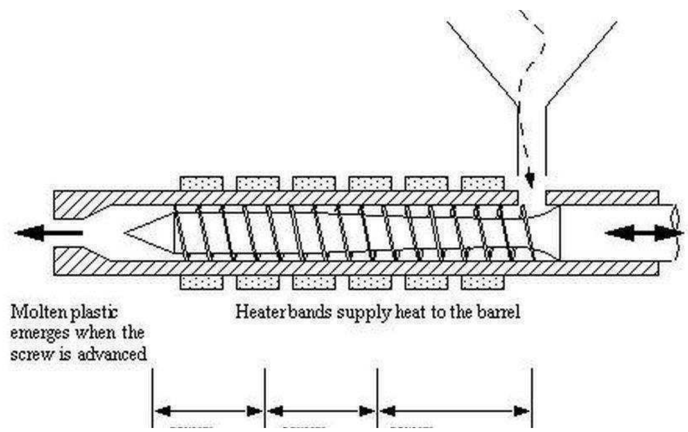
Plastics are mostly carbon-based atoms. Silicones are an exception since they based on the silicon atom. The carbon atom is capable of linking to other atoms with up to four chemical bonds. In plastics, the carbon atoms also link to hydrogen, oxygen, nitrogen, chlorine, or sulfur. When the linking of these atoms results in long chains, like pearls on a string of pearls, the polymer is termed as 'Thermoplastic'. Thermoplastics are meltable. All thermoplastics have repeating units, i.e. the smallest identical section of the chain. About vast majority of plastics are 92% thermoplastics.

To make unit cells a group of atoms is used called 'Monomers'. Upon the combination of monomers, we get polymers or plastics. All the monomers contain double bonds between carbon atoms such that the carbon atoms can subsequently react to form polymers.

The plastic behavior of polymers is influenced by their arrangement of molecules on a large scale. In other words, polymers are either amorphous or crystalline. The arrangement of molecules in the amorphous state is random and are intertwined. In crystalline state, the arrangement of molecules is in a closely identifiable manner. On the other hand, semicrystalline materials exhibit crystalline regions, called crystallites, within an amorphous matrix.

The chemical structure of the plastics can change, with the use of copolymers, and the chemical binding of different elements and compounds and on the other hand, the use of crystallizability can change the processing, aesthetic, and performance properties of plastics. Alteration of plastics can also happen by adding additives.

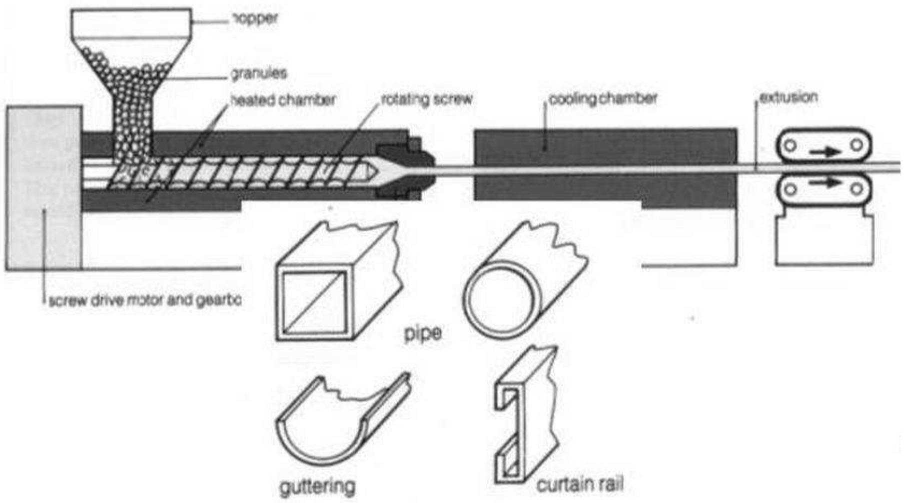
Plastic Injection Molding Process



Injection molding is one of the main methods by which parts are manufactured from plastic. The first step in the injection molding process is to feed plastic pellets into the hopper, which then feeds the pellets into the barrel. The barrel is heated and contains a reciprocating screw or a ram injector. A reciprocating screw is typically found in machines that produce smaller parts. The reciprocating screw crushes the pellets, making it easier for the plastic to be liquefied. Toward the front of the barrel, the reciprocating screw propels the liquefied plastic forward, thereby injecting the plastic through a nozzle and into the empty mold. Unlike the barrel, the mold is kept cool to harden the plastic into the correct shape. The mold plates are held closed by a large plate (referred to as a movable platen). The movable platen is attached to a hydraulic piston, which puts pressure on the mold. Clamping the mold shut prevents plastic from leaking out, which would create deformities in the finished pieces.

Plastic Extrusion Molding Process

Extrusion molding is another method of manufacturing plastic components. Extrusion molding is very similar to injection molding and is used to make pipes, tubes, straws, hoses and other hollow pieces. Plastic resin is fed into a barrel where it is liquefied. A rotating screw propels the liquefied plastic into a mold, which contains a tube-shaped orifice. The size and shape of the tube determines the size and shape of the plastic piece. The liquefied plastic then cools and is fed through an extruder, which flattens the plastic and forms the piece into its final shape.



Some common extrusions

Transfer Molding

Transfer molding process combines the principle of compression and transfer of the polymer charge. In the transfer molding, polymer charge is transferred from the transfer pot to the mold. The mold is cooled and molded part is ejected. The schematic of transfer molding process is shown in figure1.

In this process, the required amount of polymer charge is weighted and inserted into the transfer pot before the molding process. The transfer pot is heated by the heating element above the melting temperature of the polymer charge. The liquid charge is gravity filled through the sprue to the mold cavity. A "piston and cylinder" arrangement is built in the transfer pot so that the resin is squirted into the mold cavity through a sprue. The plunger is also preheated in the transfer pot. The plunger is used to push the liquid polymer charge from the transfer pot into the mold cavity under pressure. The mold cavity remains closed as the polymer charge is inserted. The mold cavity is held closed until the resin gets cured. The mold cavity is opened and the molded part can be removed once it has hardened with the help of ejector pin. The sprue and gate attached to the molded part have to be trimmed after the process has been completed.

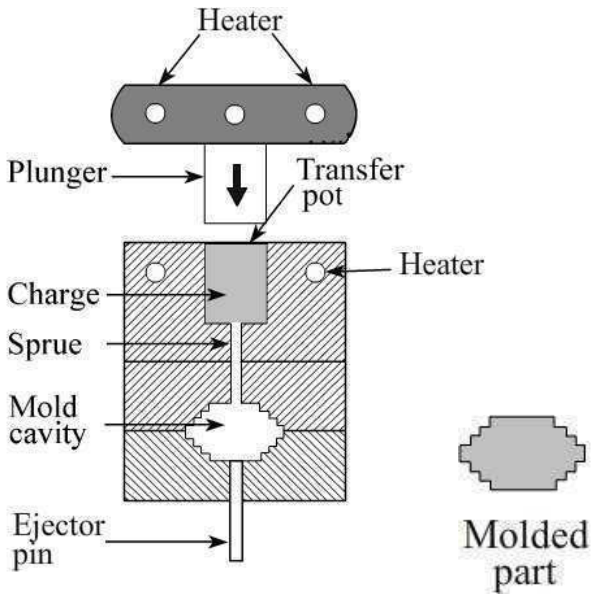


Figure Transfer molding process

This is used for mass production. It has short production cycle and smaller tolerances and more intricate parts can be achieved. It produces more waste material; therefore it is the more expensive process. The mold cavity can be made from metals such as aluminum or steel for larger production.

Process Parameters

- Heating time
- Melting temperature of the charge
- Applied pressure
- Cooling time

Materials Used

Generally, thermoset plastics (such as epoxy, polyester, phenol-formaldehyde, vinyl ester, silicone) are processed by transfer molding process, but certain thermoplastic materials can also be processed.

Applications

This process is widely used to encapsulate items such as integrated circuits, plugs, connectors, pins, coils, and studs. It is suitable for molding with ceramic or metallic inserts which are placed in the mold cavity. When the heated polymer fills the mold it forms bonding with the insert surface. Transfer molding is also used for manufacturing radio and television cabinets and car body shells.

Advantages

- Fast setup time and lower setup costs
- Low maintenance cost
- Plastic parts with metal inserts can be made
- Design flexibility
- Dimensionally stable
- Uniform thickness of parts
- Large production rate

Disadvantage:

- Wastage of material
- Production rate lower than injection molding
- Air can be trapped in the mold

Compression Molding

Compression molding process is one of the low cost molding methods as compared to injection molding and transfer molding. It is a high pressure forming process in which the molten plastic material is squeezed directly into a mould cavity by the application of heat and pressure to conform to the shape of the mold. The schematic of compression molding process is shown in figure.

Working Principle

In this process, the predetermined amount of charge of plastic material is placed in the lower half of a heated mold cavity. The plastic material is preheated before inserting into the mold cavity to reduce the temperature difference between the material and the mold cavity. The mold cavity is closed with upper movable half mold and pressure is applied to compress the material in to the mold cavity. This causes the raw material to be squeezed out to take the shape of the mold cavity. The application of the heat and pressure increases the polymerization process. Hence, plastic material is cured. The temperature of the mold cavity is usually in the range of 130- 200°C. Generally, the hydraulic pressure is required in the range of 7-25 MPa to squeeze the plastic material. The mold cavity is then cooled for sometimes so that molded plastic part gets solidified. The mould cavity is then opened and the final product is taken out with the help of ejector pin. The molded part may require the finishing operation.

In compression molding, the charge of plastic material may be inserted into the mold cavity either as a powder, granules or as a preformed. The manufacturing cycle time (heating, cooling, and part ejection) may be long (about 1-6 minutes). For high production rate, it is desirable to have multi cavity molds. Compression mold cavity can also be available in a wide variety of shapes and sizes; therefore plastic products can be manufactured into different shapes and sizes. There are four important factors to be considered before compression molding process:

- Amount of plastic material (charge)
- Heating time and melting temperature of plastic material
- Pressure required to squeeze the material in to the mold cavity
- Cooling time

Two different types of molding compounds i.e. bulk molding compound (BMC) and sheet molding compound (SMC) are commonly used in compression molding process.
In bulk molding compound, the plastic materials are blended with fillers and short fibers and placed into the mold cavity. In SMC, the long fiber sheet is usually cut according to the mold cavity and placed into the mold surface. The resin is placed on the fiber sheet. It is a layer by layer making process. The process is completed until desired thickness is obtained. The long fiber sheet results in better mechanical properties as compared with the bulk molding compound products. In both the molding compounds (BMC and SMC), the plastic materials are conformed to the mold cavity, with the application of heat and pressure.

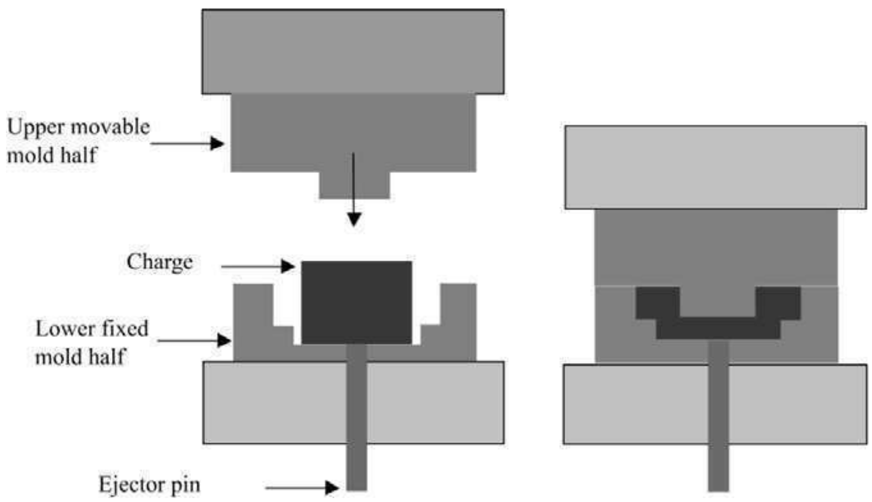


Figure Compression molding setup

Materials Used

Different types of thermosets and thermoplastics materials can be used for compression molding process. For example: Epoxies, Urea formaldehyde (UF), Melamine formaldehyde (MF), Phenolics (PF), Polyester, Polyamide (PI), Polyamide-imide (PAI), Polyphenylene sulfide (PPS), Polyetheretherketone (PEEK), Torlon, and Vespel.

Applications

Compression molding process is used for manufacturing electrical and electronic equipments (electrical wall receptacles, circuit breakers, television cabinets, radio cases, electric plugs and sockets, electrical switch, fuse box, electricity meter housing), brush and mirror handles, trays, cookware knobs, clothes dryer blower fan blade, cooking utensils, milling machine adjustment wheel, water testing equipment buttons, dinnerware, appliance housings, aircraft main power terminal housing, pot handles, dinnerware plates, automotive parts (such as hoods, fenders, scoops, spoilers, gears), flatware, buttons, buckles, and large container. Compression molding is also suitable for heavy molding applications.

Advantages

The advantages of the compression molding process are as following:

- Low initial setup costs and fast setup time
- Heavy plastic parts can be molded
- Complex intricate parts can be made
- Good surface finish of the molded parts
- Wastes relatively little material as compared with other methods
- The molding process is cheaper as compared to injection molding

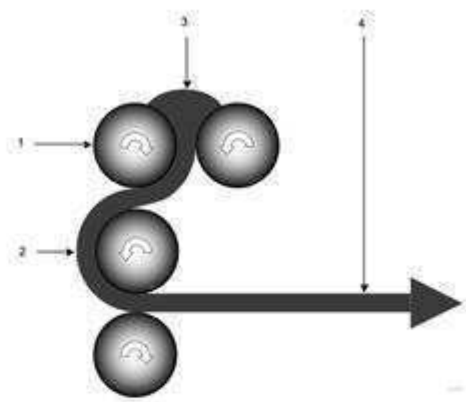
Disadvantages

The disadvantages of the compression molding process are as following:

- Low production rate
- Limited largely to flat or moderately curved parts with no undercuts

Calendering Process

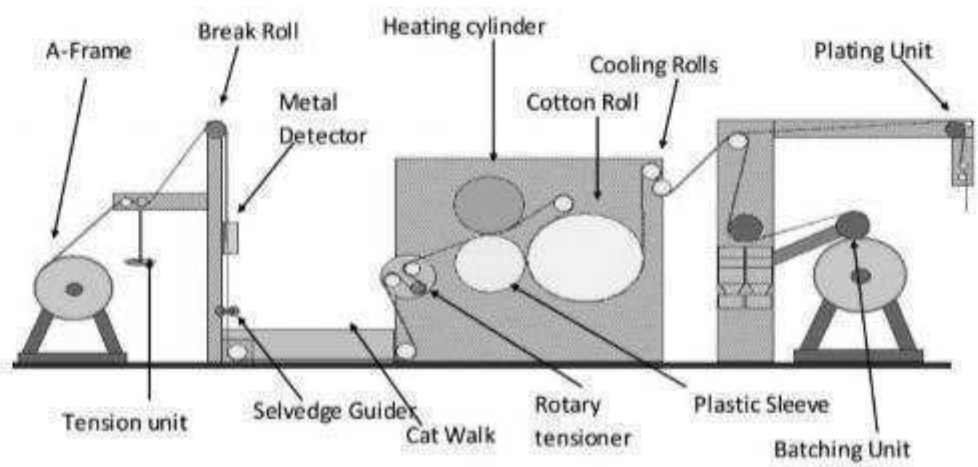
Calendering is a finishing process applied to textiles and plastic. During Calendering rolls of the material are passed between several pairs of heated rollers, to give a shiny surface. Extruded PVC sheeting is produced in this manner as well other plastics. Calendering is a final process in which heat and pressure are applied to a fabric by passing it between heated rollers, imparting a flat, glossy, smooth surface. Luster increases when the degree of heat and pressure is increased. Calendering is applied to fabrics in which a smooth, flat surface is desirable, such as most cotton, many linens and silks, and various man-made fabrics.



The molten material is fed to the calender rolls from a Banbury mixer and two-roll mill system, or from a large extruder. The major plastic material that is calendered is PVC. Products range from wall covering and upholstery fabrics to reservoir linings and agricultural mulching materials. Owing to the large separating forces developed in the calender gap, the rolls tend to bend. This may result in undesirable thickness variations in the finished product. Compensations for roll deflections are provided by using crowned rolls having a larger diameter in the middle than at the ends or by roll bending or roll skewing.

Calender installations require large initial capital investment. Film and sheet extrusion are competitive processes because the capital investment for an extruder is only a fraction of the cost of a calender. However, the high quality and volume capabilities of Calendering lines make them far superior for many products. Calendering in principle is similar to the hot rolling of steel into sheets. It is interesting to note that strip casting of semi-solid alloys can be modeled with the help of the hydrodynamic lubrication approximation for a power-law viscosity model, just like plastics calendering. The process of Calendering is also used extensively in the paper industry.

Passage of a Modern calendar machine:



Inlet unit: it contains tension device and break roll for even and proper feeding of fabric to the machine.
Metal detector: to detect metal particles in the fabric for avoiding damage to calenders rolls and fabric.
Cat walk: to avoid dust and dirt particle coming in contact with the fabric.
Calendering unit: this contains one steel roll, plastic coated roll and one cotton roll. Steel roll is heated with thermic fluid. Hydraulic oil is supplied in the plastic roll to give enough pressure on the steel roll. Cotton roll is used to increase the weight of the fabric.
Cooling rollers: are used to cool fabric after passing from calendar unit.
Batching / Plaiting device: is used to wind fabric or plaiting of the fabric in the trolley.

Advantages

- Improved appearance – Luster, Whiteness etc.,
- Improved Feel which depends on the handle of the fabric and its Softness, Suppleness, Fullness etc.,
- It improves the wearing qualities – Nonsoiling, Anti-crease.
- It gives special properties required for particular uses – Water proofing, Flame proofing etc.,
- It covers the faults of the original cloth.
- It increases the weight of the fabric.
- It increases the sale value of the material.
- It improves the natural attractiveness of the fabric.
- It improves the serviceability of the fabric.

Applications

Calendering is used for manufacturing sheet rubber in various thicknesses, for plasticizing and heating rubber stock, and for rubberizing fabric.
In textile manufacturing, Calendering is used for packing cotton, linen, and jute fabrics, adding luster to them, and applying embossed patterns.

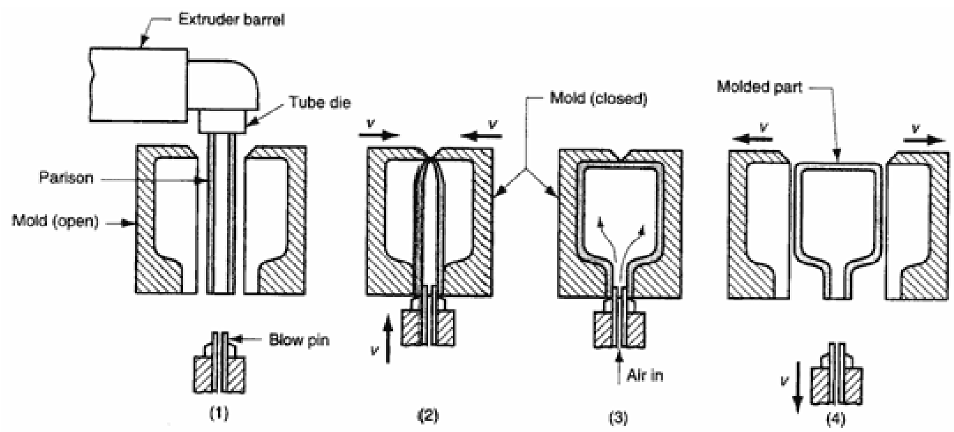
Blow Molding

Blow molding is a process in which manufacturers use air pressure to inflate soft plastic into a mold cavity. It's a critical industrial process for making one-piece hollow plastic parts with thin walls, such as bottles and containers. Because

many blow molded items are used for mass marketed consumer beverages, blow molding manufacturers typically organize production with high quantities in mind. Manufacturers borrowed the molding technique from the glass industry, making them a competitor in the disposable and recyclable bottle market.
Blow molding consists of two steps:
Step 1: Fabricating a starting tube made of molten plastic called a parison (the same term used in glass blowing)
Step 2: Inflating the parison into the desired final shape

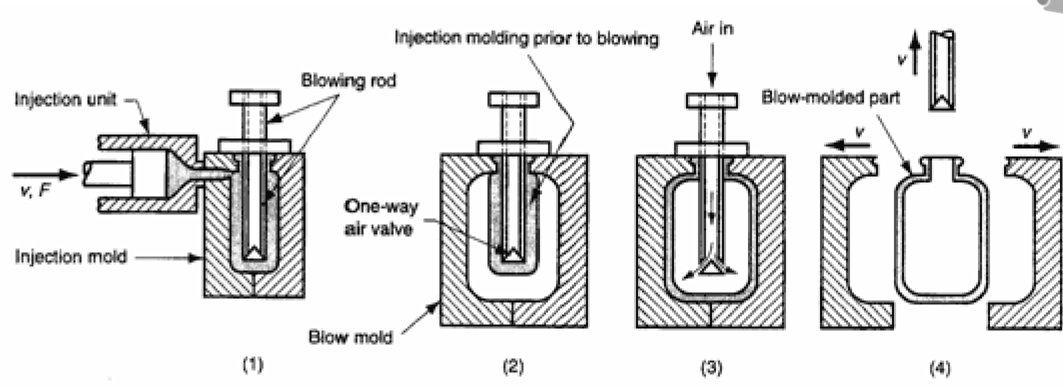
Extrusion Blow Molding
Custom injection molding companies use extrusion blow molding in high-production operations for making plastic bottles. The sequence is automated and is usually integrated with downstream operations, such as bottle filling and labeling. In general, blown containers must be rigid. A container's rigidity depends on several factors, such as wall thickness.
The extrusion blow molding cycle illustration below outlines the steps blow molding manufacturers take during the molding process:

- Extrude the parison
- Pinch the parison at the top and seal it at the bottom around a metal blow pin as the two halves of the mold come together
- Inflate the plastic tube so it takes the mold cavity's shape
- Open the mold and remove the solidified part



Injection Blow Molding
In the injection blow molding process, custom mold and design manufacturers inject-mold the starting parison instead of extrude it. Compared to its extrusion-based counterpart, the injection blow molding process has a lower production rate. Therefore, it isn't as widely used.
The injection blow molding process involves:

- Injection-mold the parison around a blowing rod
- Open the injection mold and transfer the parison to a blow mold
- Inflate a soft polymer to conform to a blow mold
- Open the blow mold and remove the blown product



Injection blow molding: (1) parison is injection molded around a blowing rod; (2) injection mold is opened and parison is transferred to a blow mold; (3) soft polymer is inflated to conform to a blow mold; and (4) blow mold is opened and blown product is removed.

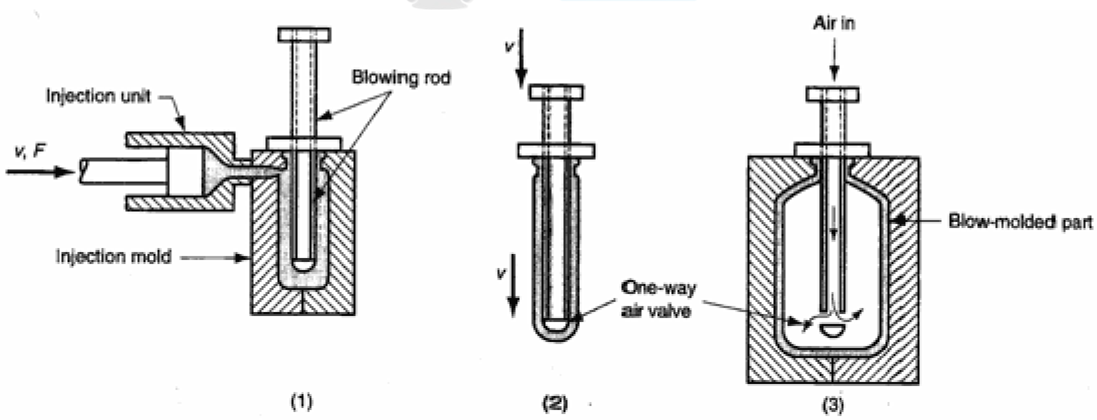
Stretch Blow Molding

Custom injection molding companies use a variation of injection blow molding called stretch blow molding. The technique involves extending a blowing rod downward into the injection molded parison (see step 2). This stretches the soft plastic and creates a more favorable stressing of the polymer than conventional injection blow molding or extrusion blow molding. As a result, the structure is more rigid, has higher transparency, and is more impact-resistant.

For this type of custom plastic injection molding, polyethylene terephthalate (PET) is the most popular material used. PET is polyester with low permeability. The stretch-blow-molding process strengthens it. The combination of PET's properties makes it ideal for making containers for carbonated beverages.

Stretch blow molding steps include:

- Injection molding the parison
- Stretching
- Blowing



Stretch blow molding: (1) injection molding of the parison; (2) stretching; and (3) blowing.

Blow Molding Materials and Products

Blow molding manufacturers are limited to thermoplastics. Polyethylene (PE) is the polymer of choice for blow molding because of its high density (HDPE) and high molecular weight polyethylene (HMWPE).

When comparing the properties of HDPE and HMWPE with a more affordable low-density PE in regard to the stiffness-related requirements of the final product, it's more economical to use the more expensive materials because it's possible to make a container's walls thinner.

Other materials used for blow molding include:

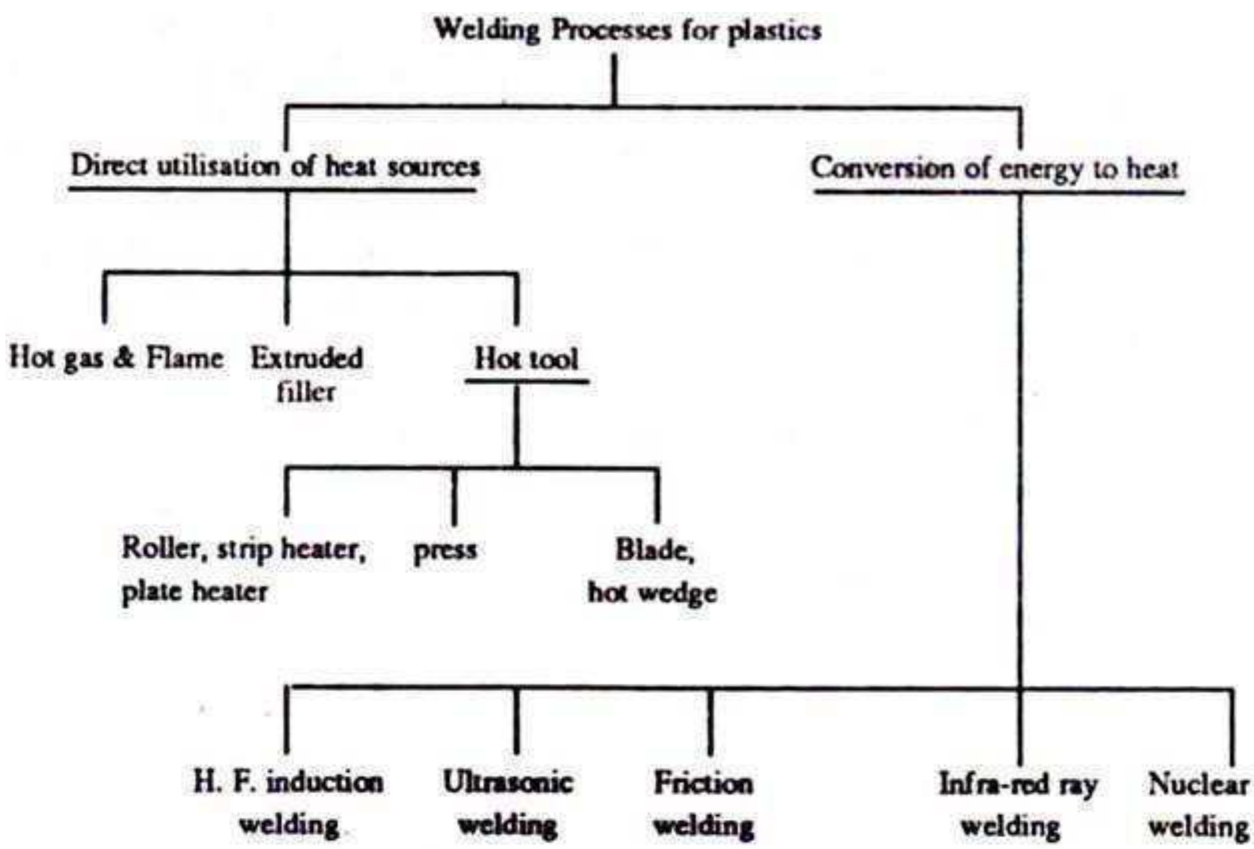
- Polypropylene (PP)
- Polyvinylchloride (PVC)
- Polyethylene terephthalate

Disposable containers for packaging liquid consumer goods make up the bulk of products made using blow molding. Custom injection molding companies use the technique to make other products, too, such as:

- 55-gallon shipping drums for liquids and powders
- 2,000-gallon storage tanks
- Automotive gasoline tanks
- Toys
- Sailboard and small boat hulls
- Small boat hulls are made using a single blow molding and cutting the finished product into two open hulls

Welding Process for Plastics

Welding of plastics is widely used in a number of industries particularly for joining of thermoplastic films and sheets. All welding processes employed at present involve the application of heat to the area of contact. According to the source of heat employed the welding process for plastics may be divided into two broad classes as shown in Fig.



A. Direct Utilisation of Heat Sources:

One class of welding processes utilises heat from an extraneous source such as a stream of hot gas, a hot extruded filler material, or a hot tool. In all these processes heat is transferred to the surfaces being welded by conduction, convection, and radiation.

The second group includes processes in which heat is generated within the workpiece through conversion of some other form of energy such as high frequency current, ultrasonic waves, friction, infra-red light, chemical reactions, or neutron irradiation.

The mechanism of welding of plastics is considered to be the phenomenon of auto-cohesion by which welding is accomplished by the diffusion of some molecular chains from one piece into another to form a strong macro-molecular bond between the two pieces.

Welding of plastics is done in the viscous fluidic state under the application of pressure. Better weld ability is shown by thermoplastics which have a wider softening range rather than a sharp melting point. Because the coefficient of thermal expansion of plastics is several times that of metals, residual stresses may develop in the weldment resulting in reduced joint strength.

The factors affecting process selection for welding of plastics include workpiece thickness, physio-chemical properties of the plastic, design of the article, and the number of components to be produced. The filler material used in welding plastics should be as close in mechanical properties to the parent material as possible.

1. Hot Gas Welding:

In this process a jet of hot gas which may be air, nitrogen, argon, products of combustion of some fuel gas (for example, acetylene, hydrogen, LPG) is played on the edges to be joined as shown in Fig. Fuel gas cannot be used directly to weld plastics because the flame has a very high temperature.

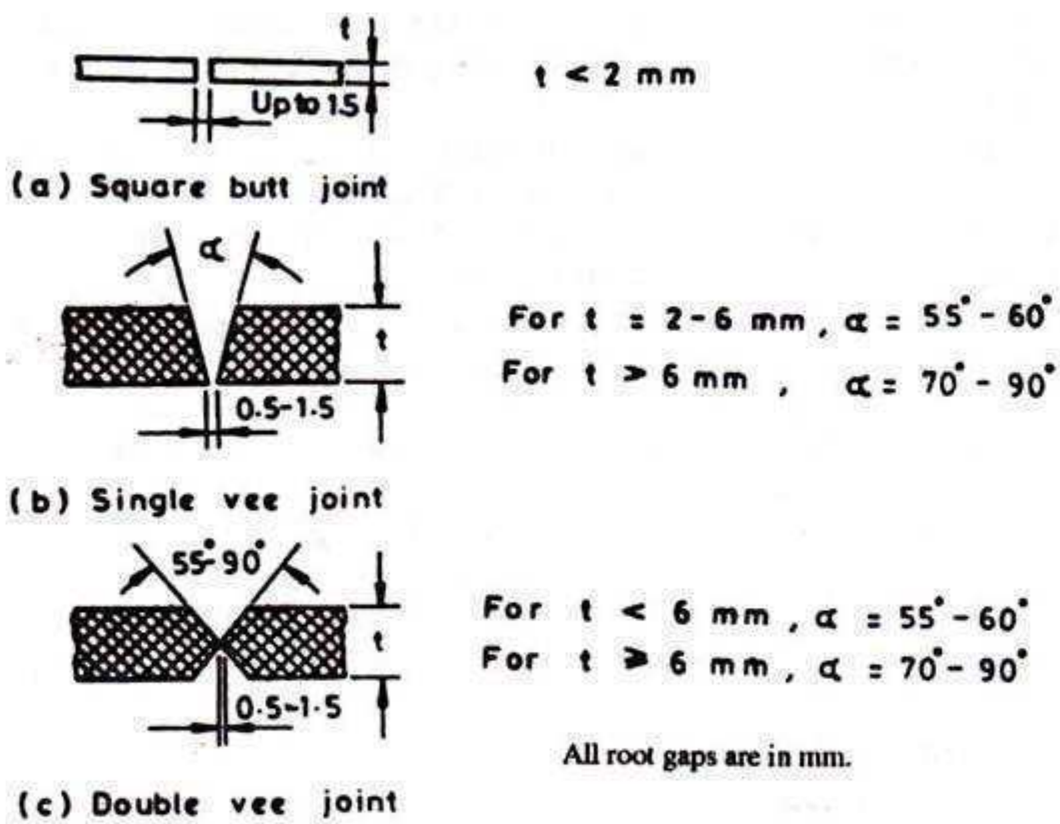
That is why special torches have been developed for the hot gas welding of plastics. The welding gas may be heated by electricity or by flame. Air temperature can be adjusted by varying its flow rate and the resistance of the electric element.

The flow rate is set anywhere between 25 and 30 m/sec with a valve, and the resistance of the circuit with a rheostat. Air temperature can be checked by placing the tip of the torch within 5 mm of the bulb of a mercury thermometer. If the thermometer reads the required temperature in 10 to 15 second the operator may proceed with welding.

For operator safety, electrically heated torches operate on voltage not exceeding 36 volt. The efficiency of electrically heated torches is 60 percent. Such torches are simple to make and there is no open flame therefore these may be used in room holding inflammable materials. However, these torches are heavy and, thus, rather unwieldy for use in places difficult of access or in awkward positions.

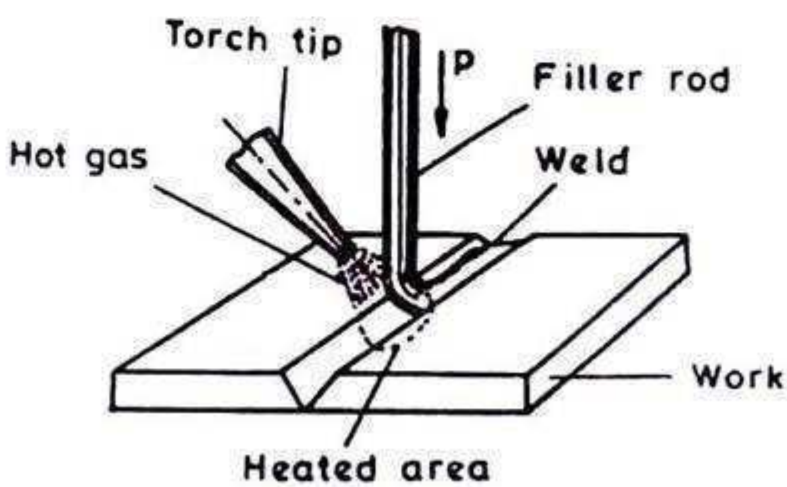
Gas torches may be either directly or indirectly heated. In directly heated gas torches the welding gas is mixed with the products of combustion of fuel gas while in indirectly heated gas torches the products of combustion transfer their heat to the welding gas through the wall. The fuel gas (C_2H_2, H_2 LPG, etc.) is used under a pressure of 0.5 to 10 N/cm^2.

In comparison with electrically heated torches gas torches can weld at a higher rate, are lighter in weight and more durable. When used eight hours a day, the service life of a gas torch is 1.5 to 2 years. A major drawback of gas torches is that the gases used are inflammable and explosive.



Usually butt joints are preferred because lap, tee, and fillet joints are more difficult to make. Depending upon the work thickness, square edge, single vee, and double vee edge preparations are employed for butt joint preparation as shown in Fig. 22.16. The standard edge preparation for butt welds requires a root gap but no root face.
Double vee joints are usually stronger than single vee joints and the groove angle has a decisive effect on joint strength. As a rule joint strength increases as the groove angle is increased because better penetration is obtained at the root; however the production rate is lowered.

Welding Procedure:
The fusion faces are carefully cleaned and de- greased,-say with acetone; the glossy spots are removed with emery paper or scraper. Before welding torch is switched on or fired the welding gas is turned on and its flow rate adjusted. The gas is then fired in case of a gas torch or electric current switched on for an electric torch.
Filler rods used come in diameters of 2, 3, 4, ± 0.5 mm and other shapes like triangular and trapzoidal of different sizes. The filler rods are fabricated from the same material as the work material but may be of different colour and usually contain higher percentage of plasticizer to lower down its softening point.
The filler rods may either be cut to lengths of at least 0.5 m and tied up in bundles or uncut and supplied in coils of 3 to 4 kg. The size of filler rod is chosen to suit the work thickness, type of edge preparation and the strength desired. Thicker rods usually result in reduced joint strength.
The torch tip size is selected depending upon work thickness, and edge preparation. Tips with orifice diameter of 1-5 – 2 mm are used to weld sheets 3 to 5 mm thick while tips with diameter of 3-5 – 4 mm are used for sheets 16 to 20 mm thick. As a rule the orifice diameter of a tip should be equal to the diameter of filler rod used. Otherwise the rod will not be heated adequately and the strength of the joint will be impaired.
The torch-to-work angle is chosen in relation to material thickness. For sheet under 5 mm this angle should preferably be 20°-25° and for sheets in the range of 10—20 mm, it should be 30°- 45°. The torch tip-to-work distance should be kept constant between 5-8 mm. To produce a good bond between the filler and the work the rod should be heated and fused at the start of the weld so that its end extends 3—5 mm beyond the end of the work.
The hot gas stream must not be directed in any one position, instead it should be moved continuously over a short length of the welding rod and the surface being welded so as to heat both uniformly. The joint edges and the filler rod are rapidly heated at the surface because plastics are poor conductors of heat.
However, it is essential to heat the rod throughout its bulk so that it can be thoroughly softened at the center and properly placed in the groove. That is why thicker rods cannot be used and welding is slow by hot gas process particularly with filler rod technique. If the pressure is not applied properly the softened rod is compressed in the direction opposite to its motion which produces waviness in it.
The filler rod should be fed square to the weld so as to exert proper control of pressure. As the filler rod is forced down by hand it welds to the softened edges and forms a weld, as shown in Fig.



Hot gas welding without filler rod accelerates the process and enhances the mechanical properties of the joint. A simple setup for this technique is shown is Fig. (c). In this method the sheet edges are scarfed and fitted before being uniformly heated by hot gas.

The hot gas jet is followed by cold rollers which exert the required pressure to complete the weld. Welding rate with this technique may be 12 to 20 m per hour, depending upon sheet thickness. The strength of the joint is 80 to 90 percent that of the parent material and the impact strength remains the same. Hot gas welding without filler material is most often applied to make lap joints in films.
For critical joints it is better to seal the weld root to improve the joint strength and quality.
After welding the joint is allowed to cool. Artificial cooling particularly in material thicker than 10 mm may lead to cracking.
The strength of butt welds in plastics is 65% that of the parent material in shear, 75% in tension, 85% in compression, and 65% in bending while that of fillet weld is 65% in tension. The impact strength of the weld material is usually very low.
Apart from low strength of the joint hot gas welding also results in reduced plasticity in the weld and near-weld area, low production rate especially in thick sheets, danger of overheating and dependence on the operator skill. Inspite of these limitations hot gas welding is widely used for welding PVC, polyethylene, acrylics, and polyamide.
For welding PVC, hot gas welding process is most often used. PVC has no sharp melting point. At a temperature of over 80°C it softens. At 180°C it begins to flow, and at 200 – 220°C it passes into viscous fluidic state; if pressure is then applied it will weld. The welding temperature must be kept below the critical point at which the material begins to decompose.
To obtain an optimal temperature of 200 – 220 °C for hot air in the welding zone, it should be heated to 230 – 270°C in the torch. The effect of air temperature on welding rate and joint strength are presented in table.

Air temperature (°C).	Welding rate for single run (m/h)	U.T.S. for double vee joint (N/mm²)	Joint efficiency (%)	Remarks
210	4.8	14	25	Indirectly heated gas torch.
230	8.4	34	25	Air pressure 0.6 atmosphere.
250	11.4	32	58	Tip diameter, 2.5 mm.
270	13.8	35	63	Rod diameter, 2.5mm.
300	15.0	17	30	
320	Material	decomposes.		

If a correct welding temperature has been chosen, a dull spot appears on the PVC sheet 2 or 3 seconds after the jet of hot air has been played on it.
Weld quality in PVC depends upon the rate at which the filler rod is fed into the joint, the angle at which it is fed into the joint, the force applied to press the heated rod into the joint, the distance of the torch tip from the work surface, the position and direction of the torch during welding. A filler rod 3 mm in diameter should be fed to the joint at a rate of 12 to 15 m per hour.
Welds made in PVC by hot gas filler rod technique show a low impact strength. PVC is sensitive to stress concentration to such an extent that even when a rod is welded to a tube the impact strength of the joint is just about 10% of the impact strength of the parent material.
The welding of PVC by hot gas welding is a slow process. For example to weld one metre of PVC, 18—20 mm thick, with V edge preparation it is necessary to lay 30 to 35 rods, 3 mm in diameter, requiring about 2 hours to accomplish the job. The welding speed can be increased by raising the gas temperature to 300°C and by preheating the filler rod but this requires careful monitoring of the process otherwise the higher temperature may lead to the decomposition of the material.
Acrylics are welded with a jet of air of 200 – 220 °C. Time taken for welding acrylic sheet is almost double that required for PVC sheet of the same thickness, and the welding rate is therefore nearly halved. The filler rods used are cut from acrylic sheet and have a cross-sectional area of 7—12 mm^2. Acrylics can also be welded satisfactorily by using PVC filler

rods. To achieve quality welds in acrylics it is best to degrease the surfaces to be welded with acetone or dichloromethane prior to welding. The tensile strength of welded joints in acrylics is generally 3P – 45 % that of the parent material.

Polyethylene should preferably be welded with N_2 or CO_2 gas heated to 200— 220 °C, although gas flame torches may also be used.

Hot gas welding is also frequently used to weld vynil plastics, polystyrene, and some other plastic materials.

The major use of hot gas welding is in the production of very large fabrications made from sheet materials, for example, ducting, pipe work and ventilator hoods for chemical plant installations. This method is normally not used for joining small parts.

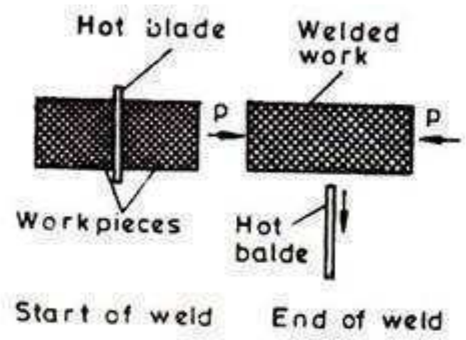
2. Extruded-Filler Welding:

In this method the filler in a viscous fluidic state is fed into the joint. The hot filler material melts the edges of the plastic being joined and a strong bond is formed between the filler and the parent material. In a way this process resembles the hot gas process with filler rod technique. Satisfactory welds can be accomplished by this process both in films and heavy gauge sheets.

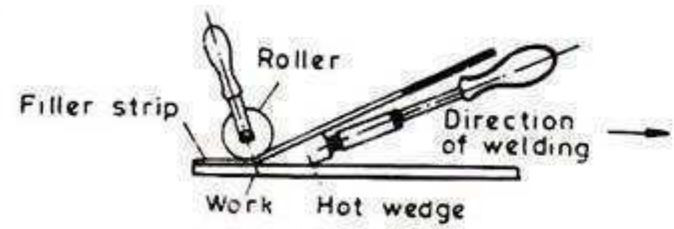
3. Hot Tool Welding:

This process can be performed by several techniques depending upon the type of tool employed which may include hot blade, hot wedge, hot plate, strip heater or a press.

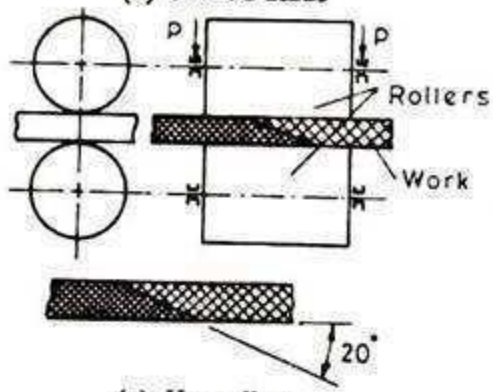
In hot blade welding, the heated blade is placed between the surfaces to be joined as shown in Fig. (a). After the hot blade has softened the surfaces it is rapidly withdrawn and the surfaces are brought in contact under pressure to accomplish the weld. This process can be used to make butt and lap joints over the entire surface of contact at the same time.



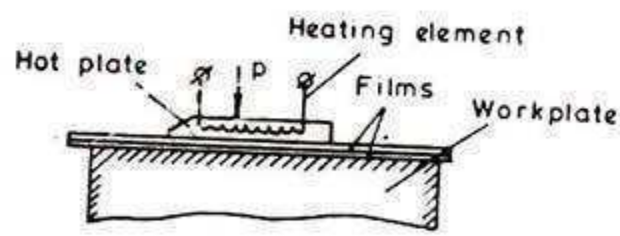
(a) Heated blade



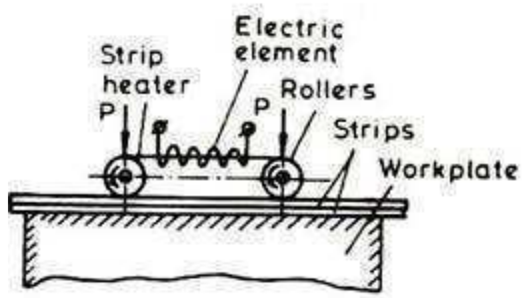
(b) Hot wedge



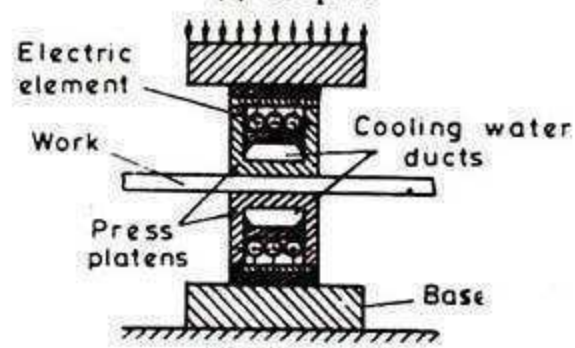
(c) Hot rollers



(d) Hot plate



(e) Hot strip



(f) Press welding

In hot wedge welding shown in Fig. (b) the heated wedge is place between the surfaces to be joined and is moved along the line of welding as the edges are softened. Pressure is applied through a roller to the top strip to weld it to the bottom sheet.

This process is used to weld elastic materials but can also be used to weld thin rigid sheets or straps upto 5 mm to thicker sheets. Precautions are, however, needed in this process to avoid sticking of work material to the hot wedge. Best of all this process can be used for welding films by using pressure rollers arranged above and below the films being joined together as shown in Fig. (c).

Apart from hot wedge method films can also be welded by hot plate, hot strip and thermal impulse methods.

In hot plate welding, resistance heated plate is moved over the films to be lap welded. When the desired welding temperature is reached, pressure is applied to accomplish the weld. The films to be welded are laid out on a work plate as shown in Fig. (d).

In hot strip welding the strip heater, heated by an electric element, is advanced by rollers and is simultaneously forced by pressure P against the films to be lap welded which are laid out on a workplate as shown in Fig. (e). The films can be advanced under the pressure rollers by moving either the welding head or the workplate.

In thermal-impulse process the material (films) is raised to the welding temperature almost instantaneously as a strong current pulse is passed through an electric heater. The heater may be of point, strip, or even an odd shaped type. Because the heat can be accurately metered, overheating at the joint is avoided.

In press welding heat is transferred to the area to be welded by the hot platen of the welding press. The plastic pieces with their edges scarfed are clamped between the resistance heated press platens as shown in Fig. (f). After the workpieces have been raised to the welding temperature, they are kept under the required pressure as the platens are cooled by the water circulated through the ducts.

Presses usually make butt welds. A typical plastics welding press for butt joints develops fairly high pressures, heats the work locally, and compresses the softened zone from all sides. That is why this technique is also referred to as static-jig welding. This technique can butt weld sheets, bars, strips and plates.

Stresses may be developed in welding of plastic especially if the sheets to be welded are large in thickness. To relieve these stresses it is a good practice to anneal the welded articles from a temperature 25 to 30°C below the softening point of the material.

Hot tool welding produces strong welds at a high production rate. This process is applicable to plastics which cannot be joined by high frequency induction welding, for example PTFE (polytetrafluorethylene), polyethylene, and polystyrene. Butt, fillet and T-joints can be made by this process. Acrylics joined by hot tool welding retain transparency and clarity at and around the joint it can also be used for welding films for seams of considerable length. When large quantities of welds are required, the hot tool welding method can be easily mechanized.

B. Conversion of Energy into Heat:

1. High Frequency Induction Welding:

In H.F. induction welding the workpiece is placed in a high frequency field set up between two metal electrodes as shown for roller seam welding in Fig. 22.18 (c). Only those plastics which are imperfect dielectric can be welded by this process.

The few free electrons existing in such plastics give rise to conduction current when the material is placed in the H.F. field. The work done to displace the charged particles is converted into heat. Some heat is also generated when the field alternates. To increase the amount of heat generated use is made of very high frequency current in the range of 30 to 40 MHz or even higher. Generally no filler material is used. As all the heat is generated directly in the body of the workpiece being welded, welding speed is high and the electrodes are not overheated.

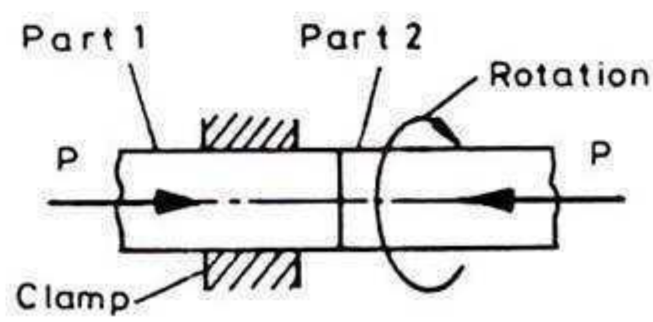
H.F. induction process is used to make spot, static-jig, and scam welds; however butt, fillet, and tee joints are difficult to make. The welds produced are tight and strong. The process can be easily automated to weld films, sheets, and tubes. Lap welds by seam welding machines can be carried out at speeds as high as 27 to 65 m/hr.

Among the merits of high frequency welding are high production rate, economy, and satisfactory joints. It can weld materials upto 5mm thick. However, materials with low dielectric dissipation factor like PTFE, polyethylene, and polystyrene are not possible to weld by H.F. induction welding.

But polyethylene can be welded by this process by placing a strip of PVC in the joint. PVC being an imperfect dielectric gets heated up under the action of H.F. current and transfers the heat to polyethylene to accomplish the weld.

2. Friction Welding:

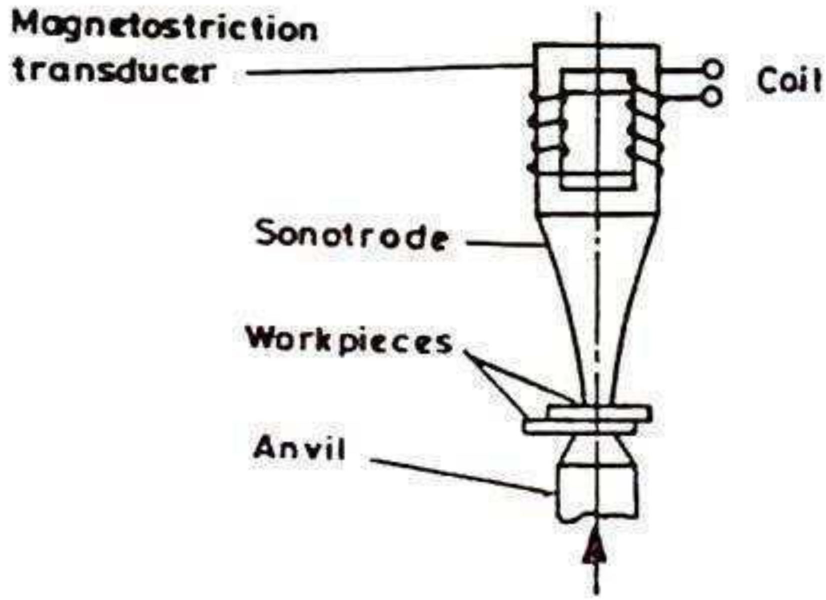
Plastics are friction welded the same way as metals, though normal setup consists of rotating one piece and keeping the other stationary, as shown in Fig, but large pieces can be welded by keeping them stationary and rotating a short insert between them. The quality of the weld depends upon the speed of rotation, the axial force applied, and the amount of plastic deformation involved.



Because the heat is generated at the interface the properties of the adjoining material are not affected and the joint has good mechanical properties. Due to heat produced directly on the surfaces being joined this process has the advantage of high welding rate, adaptability to automatic control and usability under field conditions. However, the process can be

used only if one of the components is cylindrical so that it can be rotated. Also flash formed at the joint means not only the wastage of material but also the additional cost in machining to remove it.
Friction welding of PVC tubes and pipes is well developed. Prior to welding the ends of the tubes are sized by heating the tube ends in oil to 100 °C for 3 toV4 minutes and then clamping the tubes in gauge for 3 minutes followed by water cooling to room temperature. The welding is accomplished by rotating one of the tubes in a chuck.
The speed of rotation depends on tube diameter, for example, 50 mm diameter tube is rotated at 800 rpm while 80 mm diameter tube is rotated at 600 rpm and the spinning time is 1 ± 0.5 minutes. After the desired viscous fluidic temperature of 140 – 160°C is reached the rotation is stopped and a pressure of 20 to 40 N/cm^2 is applied till the weld is cooled to room temperature in about 7 to 10 minutes.
Friction welds in PVC compare in quality with the parent material. Typical joint strength on like materials is about 90 % that of the parent material.

3. Ultrasonic Welding:
For ultrasonic welding of plastics the welding machine has the same features as the one for metals. The main element of the welding machine is a transducer, which converts the H.F. energy supplied by ultrasonic oscillator into vibrations. The vibrations are applied to the work through a sonotrode which is set up on an anvil as shown in Fig.



The mechanical vibrations applied to the work cause the generation of heat in the plastic material. Pressure is applied to the softened material to complete the joint. Welding takes place the same instant as the H.F. voltage is applied to the transducer coil. The frequency used is upto about 20 KHz.

4. Infra-Red Ray (IR) Welding:
In this process welding heat supplied by an infra-red light source such as sylite glower, a chrome-steel resistance element, a quartz rod lamp, etc. To speed up the process, welding is carried out on a black backing plate from a foamed plastic, sponge rubber or thick rubberized fabric. Welding pressure is supplied by the resilience of the backup plate which is held firmly against the workpiece.
Polyethylene film can be joined satisfactorily by IR welding. Work thickness which can be welded depends upon the power of the IR source. For example, a sylite glower with a temperature of 1200°C kept at a distance of 12 to 14 mm off the workpiece with sponge rubber backing can weld a maximum thickness of upto 2 mm. Any plastic film which can pass into viscous fluidic state and requires a low welding pressure can be welded by IR welding process. The welds produced by this process are usually free from undercuts and have high joint strength. Infra-red light can also weld sheets stacked up in a pile.

5. Nuclear Welding:

In this process the workpieces to be welded are irradiated with a stream of neutrons. The surfaces to be welded are given a coat of lithium or boron compound before welding. When such a coated surface is bombarded by neutrons, nuclear reaction takes place resulting in the generation of heat. The heat so produced raises the surfaces to the viscous fluidic state and therefore they can be welded. This process can be used to weld PTFE to polyethylene, polystyrene, quartz, and aluminium.

Nuclear welding has a limitation in that it cannot be applied to materials which become strongly radio-active when irradiated with neutrons.