Practical Guide to Blow Moulding

by Norman Lee

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Preface

Blow moulding has evolved from the ancient art of glass blowing and it is used to advantage with plastic materials specifically because these materials can be engineered to provide a variety of properties. These properties have been developed over a period of time beginning with celluloid, which was first used to blow mould baby rattles and novelties in the 1930s. Linear low-density polyethylene was used in the 1940s for high production bottles; polyethylene terephthalate (PET) was used to make soda bottles by the injection blow moulded stretch method, to the highly sophisticated multilayered containers and automotive fuel tanks in the last decade, and complicated twisted shapes by the three dimensional blow moulding method in the last few years.

The plastic industry as a whole, blow moulding in particular, is driven to take advantage of material development and computer technology with microprocessors, the latter enabling process programming of machines and robots. The machine and mould builders responded by developing robust sophisticated equipment.

The author has been personally involved in the development of the industry since the early 1960s. During the 1980s he recognised the need for individuals in the industry to keep up with new developments and advances in materials, processes and equipment, and he developed a series of blow moulding seminars, which were held by the Society of Plastic Engineers. Key experts from the industry (listed below) were selected to present the latest and greatest advances in materials, equipment and processes.

Each of these has influenced the content of this book – *Practical Guide to Blow Moulding*. It is presented in simple language describing the basics of blow moulding as well as latest state-of-the-art and science of the industry.

A key feature is the approach of discussing the ‘basics’ then taking the reader through the entire process from design development through to final production.

Finally I wish to acknowledge the hard work of the Blow Moulding Quality Engineer, Loretta Lee from WhiteRidge Plastics in assisting me with the manuscript and diagram production without which this work would not have been possible.

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1 What is Blow Moulding?

1.1 Introduction

1.1.1 Definition

Blow moulding is a process of producing hollow or double wall objects from thermoplastic materials [1] (See **Figure 1.1**).

1.1.2 Basic Process

The basic process is common to all variations of the blow moulding method, which consists of three stages [2]:

1. *Melting and Plasticising* – This is accomplished with either extrusion and/or injection moulding machine to produce the melt.

2. *Plastic Formation* – Through head and die or in an injection mould.

3. *Blowing and Moulding* – An auxiliary compressor provides air pressure and a clamp unit, which closes over a split mould that is operated with an hydraulic system.

The first step involves the production of a hot tube, known as a parison, a term derived from the glass industry. This may be produced, as indicated, by one of two methods, extrusion or injection. In the injection case it is referred to as preform.

The heated parison or preform is placed between two halves of the blowing mould, which closes and clamps around it. The heated tube is blown against the cavity wall and the molten plastic or resin takes the shape of the mould while being cooled. This is illustrated in **Figure 1.2**. After the cooling stage the part is ejected from the mould. In the case of an extruded part it is necessary to remove the flash (excess plastic around the part) for further finishing.

Drilling, labelling or printing may be required in both methods. Moulding for high volume production parts often uses robots.

Figure 1.1 Array blow moulded products

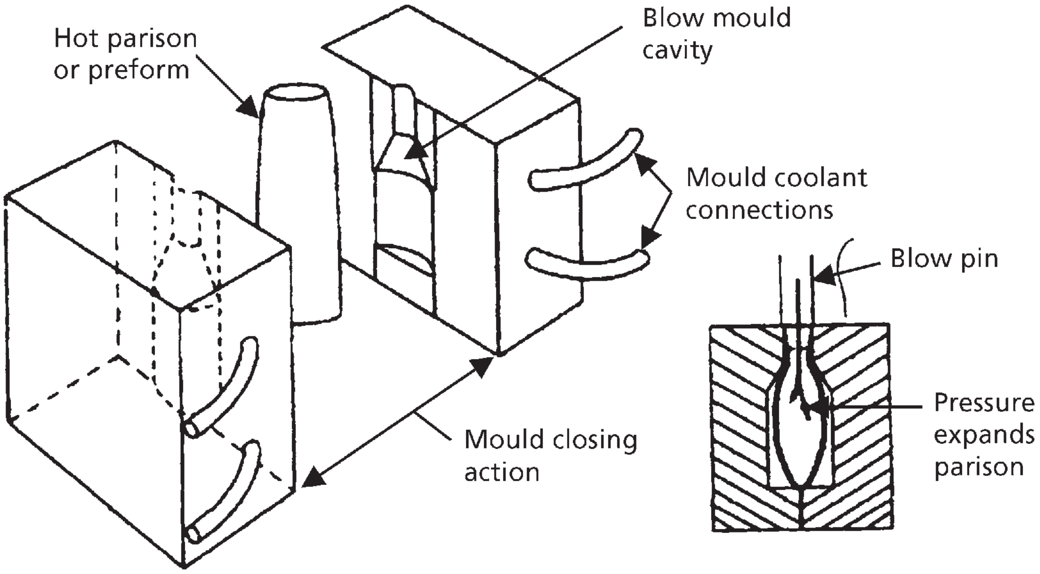


Figure 1.2 Basic blow moulding process

1.1.3 History and Development

The process of using air to blow hot material was first used by the Syrians well before the birth of Christ. This involved placing a long tube, into a receptacle, which is located in a blast furnace containing liquid glass, and removing a blob of white hot liquid glass and spinning it and then blowing into a mouthpiece on the other end of the tube.

This process was refined in Europe during the Middle Ages because of the demand for bottles to contain and ship products such as wine. The English developed a system to blow the hot blob of glass into a split mould to mass produce these bottles. An original primitive factory showing this method may still exist in the Marina Grande, Portugal.

Plastic material covers a large range of properties and applications. They have to meet the demands of modern society. The first known record of plastic material is Parkesine, named after Alexander Parkers, which was first exhibited at the Great International Exhibition held in London in 1862 [3]. This material was the forerunner of Celluloid, from which a number of products were made, including billiard balls, as a lower cost alternative to ivory. This typified the application of the development of plastic materials, which replaced higher cost natural materials. During the twentieth century (and even now), plastic material was engineered for specific purposes. Two examples are: high impact plastics used for construction workers' hard hats and flexible soft material used for heat valves.

The application of blow moulding began with the use of 'Celluloid' and celluloid nitrate, which is highly flammable, and had a limited use [3]. Later celluloid acetate was used for novelties and toys. The commercialisation came with the use of the first automatic blow moulding machine by Plax Corporation in the 1930s, see **Figure 1.3**. By 1939 they had machinery, which could produce 25,000 bottles per day.

In the mid-1930s ICI (Imperial Chemical Industries) developed low-density polyethylene (LDPE), which was commercialised in 1939. This material was a factor in the winning of the Battle of Britain since it was used for radar co-axial cable. Plax Corporation perfected the use of LDPE squeeze bottles

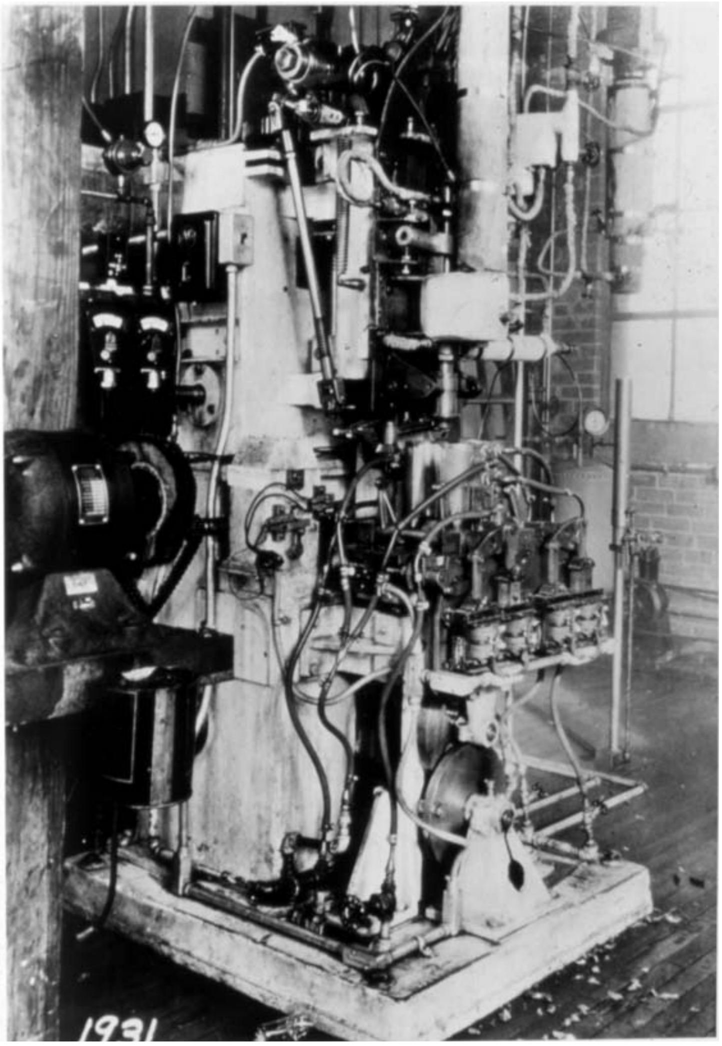


Figure 1.3 First automatic blow moulder

in 1945. Meantime the Plax Corporation also developed an injection blow moulder along with Owens-Illinois Glass Company. Continental Can purchased a continuous extrusion horizontal wheel technology from EE Mills. The American Can Company also acquired vertical wheel technology from CC Coates of the Royal Manufacturing Company in this same time period.

In 1953 high-density polyethylene (HDPE) [4] was discovered by both Paul Hogan of the Phillips Petroleum Company in the United States and Professor Zieglar in Germany. Later Professor Natta, of Italy, went further and polymerised both propylene and butylenes [5]. With the appearance of HDPE in the market place a virtual explosion of blow moulded products occurred in both Europe and North America. The one limitation of HDPE is its opaqueness. Thus, when clarity is required polyvinyl chloride is used.

In the 1960s European equipment became available in the United States for items other than bottles. Then in the 1970s biaxially oriented polyethylene terephthalate (PET) was developed with the introduction of the two-step process in which the preform and bottles are produced on separate machines by Cincinnati Milacron, USA. In 1977 Nisser, ASB Company (Japan), began to offer biaxial orientation of PET using blow moulding equipment based on a one-step process.

Multilayer blow moulding came to the USA with the introduction of the ketchup (tomato sauce) squeeze bottle.

With the introduction and application of microprocessor resins, a wide range of material properties became available. Also the availability of larger more robust equipment and microprocessor technology led to the production of a range of industrial products such as automotive fuel tanks, arm rests air conditioners. Then from Japan and Germany complex shapes and irregular contours were possible with the introduction of 3-D blow moulding.

1.2 Types of Blow Moulding

1.2.1 Introduction

As indicated earlier blow moulding may use either extrusion or injection methods for processing. **Figure 1.4** shows the breakdown of the subsidiary methods in each case and where they crossover in application.

1.2.1.1 Injection Blow Moulding

Injection blow moulding produces a parison with bottle neck and threads already formed to final dimensions. This process is used primarily for small pharmaceutical and personal product containers. The economics for such containers dictate multiple (up to ten) cavities - one set each for injection moulding and blow moulding.

When tolerances in the neck and closure thread area are critical, injection blow moulding is applicable to larger bottles. An example is pressurised carbonated beverage containers up to 2 litres. Another

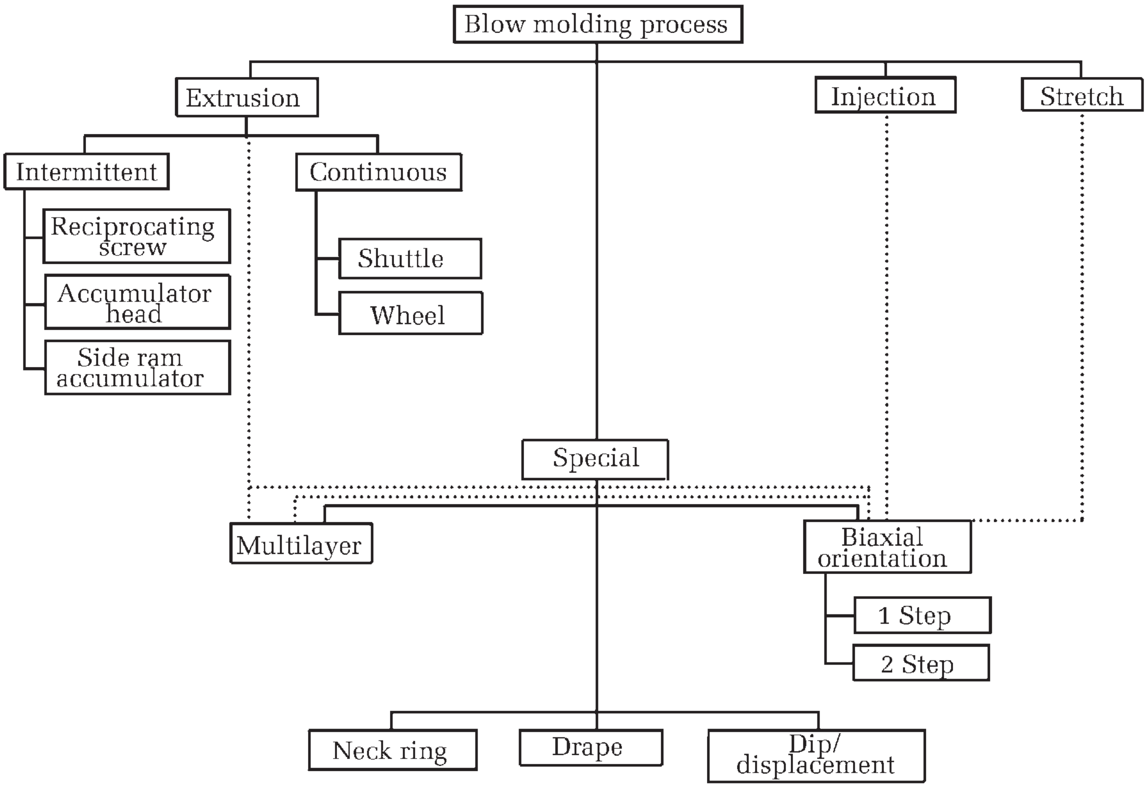


Figure 1.4 Breakdown of subsidiary methods

application is aerosol spray bottles, in which neck tolerances must provide sufficient thickness and taper to meet top load stresses from pressurised filling line equipment, and the closure thread (or lip) must conform to the twist cap (or valve seal).

There is essentially no plastic waste or trim generated with the latest injection blow moulding machines, only improperly formed containers from start-up and occasional 'off-spec' parts from production are candidates for regrind.

1.2.1.2 Injection Blow Moulding Process

The injection moulding process produces a moulded parison called a preform. This method is preferred over extrusion blow moulding for making small parts that require high production volumes and closer quality dimensions. Injection blow moulding consists of injecting a thermoplastic material into a cavity and around a core rod producing a hollow test tube like shape (preform). The moulded preform still on the core rod is transferred to the blow mould. The mould is clamped around the preform and air is blown to shape of the cavity. The preform is injected onto a support pin or core, which forms a neck with threads to their required dimensions. The preform is then blown against the cavity wall to its final shape. See **Figure 1.5**.

1.2.1.3 Reciprocating Screw Machine

This is a combination of an injection and a plasticising unit in which an extrusion device with a reciprocating screw is used to plasticise the material. Injection of material into a mould can take place by direct extrusion into the mould, or by using the reciprocating screw as an injection plunger, or by a combination of the two. When the screw serves as an injection plunger, this unit acts as a holding, measuring, and injection chamber (see **Figure 1.6**).

1.2.1.4 Advantages and Disadvantages of Injection Blow Moulding

Advantages of injection blow moulding are:

- No scrap or flash to trim and reclaim
- High quality neck finish and details
- No process weight variation
- Offers lowest part cost for high-volume bottles 37 grams (12 oz) or less.

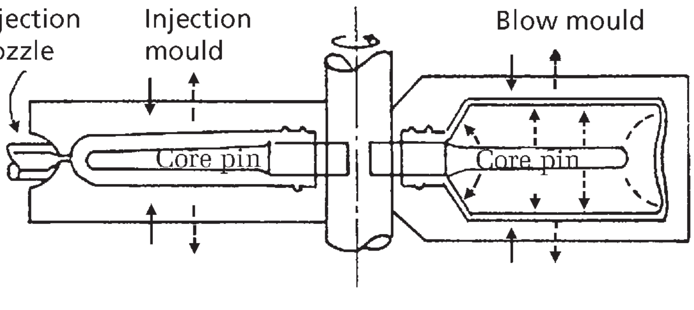


Figure 1.5 Basic diagram of the injection blow moulding

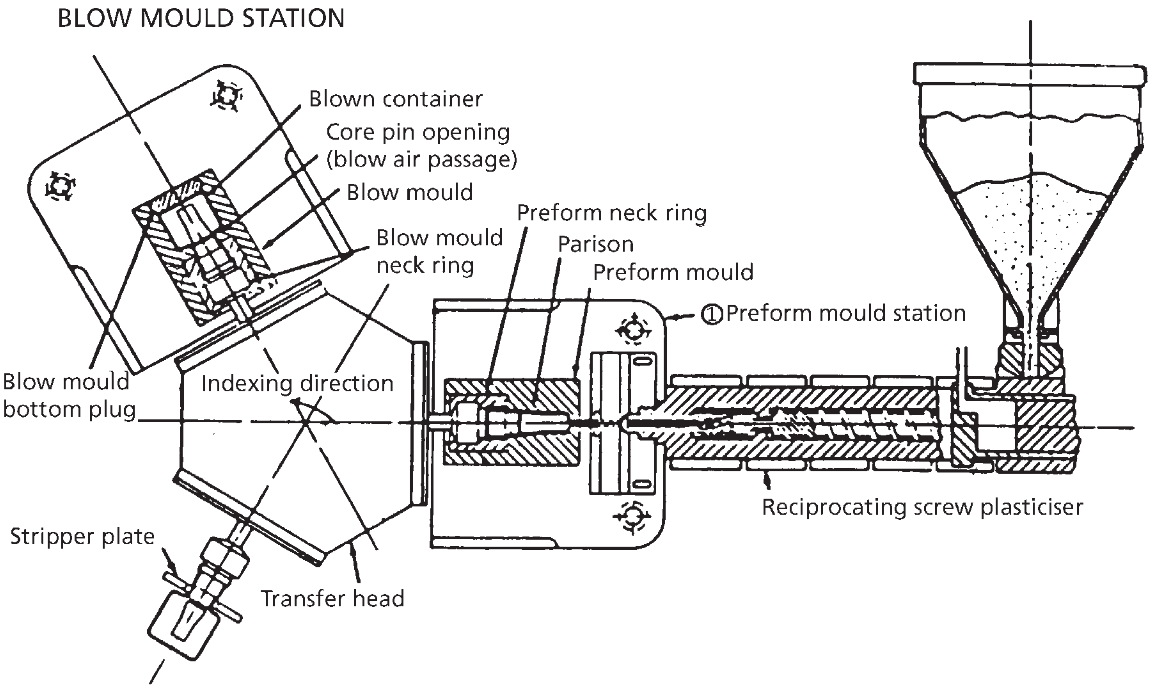


Figure 1.6 Injection reciprocating machine

Disadvantages of injection blow moulding are:

- Tooling costs are higher than extrusion blow moulding
- Bottle sizes and shapes are limited to an ovality ratio of 2:1 and a blow-up ratio of no greater than 3:1
- Offset necks are possible but not handles.

1.2.2 Stretch Blow Moulding

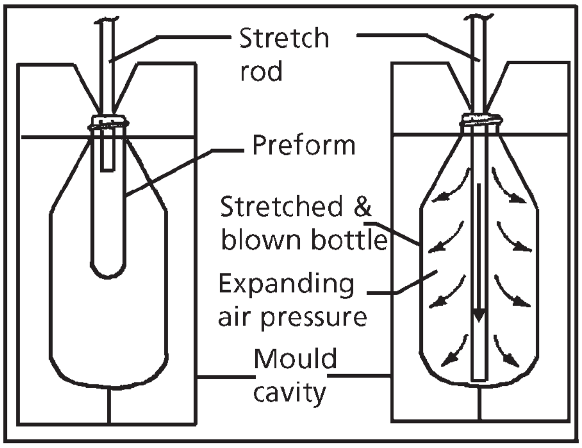
Stretch blow moulding became known in the blow moulding industry with the introduction of the soft drink bottle.

Bi-axial stretch blow moulding applies to the method of producing a plastic container from a preform that is stretched in the hoop direction and the axial direction when the preform is blown into its final shape.

Stretch blow moulding consists of conditioning (heating) a moulded and cooled preform to a specific temperature. The preform is closed in the blowing mould and is stretched in length and diameter (see **Figure 1.7**).

1.2.2.1 Two Step Method

Usually in this method two steps are used whereby the injection moulded perform is made and stored until delivered to the forming machine and equilibrated in a reheat station.



A temperature conditioned preform is inserted into the blowmould cavity, then is rapidly stretched. Often a rod is used to stretch the preform in the axial direction with air pressure to stretch the preform in the radial direction.

Figure 1.7 Stretch blow moulding

1.2.3 Extrusion Blow Moulding

In contrast to injection blow moulding, all areas of the extruded (free) parison, with the exception of the pinch off, undergo forming during the blowing step. This includes the closure threads on bottles and, in some cases, handles and support lugs. Containers produced by extrusion blow moulding must meet minimum stiffness requirements to undergo filling on automated lines and to avoid, or limit, unsightly bulging under weight of their contents, both alone or when stacked. They must also withstand normal impacts of handling, transport and accidental dropping. Such impact must be absorbed by container walls, weld lines (pinch-off and handle areas), and screw cap closure threads, often under extremes of temperature.

HDPE provides most of the requirements noted previously at low cost, and is also chemically inert to many fluids used in personal products, food products, and household and industrial chemicals (see **Figure 1.8**).

1.2.3.1 Extrusion Blow Moulding Process

Extrusion is the process of applying heat and pressure to melt the resin and force it through an accurately dimensioned die to produce the desired shape. For blowing purposes this is a shape from which the parison is cut. There are several main parts to an extrusion blow moulding machine, which are: screw, barrel, hopper, feed section, compression section, metering section, screen pack, breaker plates, adapter, die head, core, mandrel, and die tip.

In the various sections the resin is melted, plasticised, and delivered to a die or dies at the proper temperature at a uniform rate (see **Figure 1.9**).

1.2.3.2 Co-Extrusion Blow Moulding

This term refers to products made with several layers in their wall structure and to the method of making them. These layers may be different materials, coloured or not coloured, recycled or virgin.

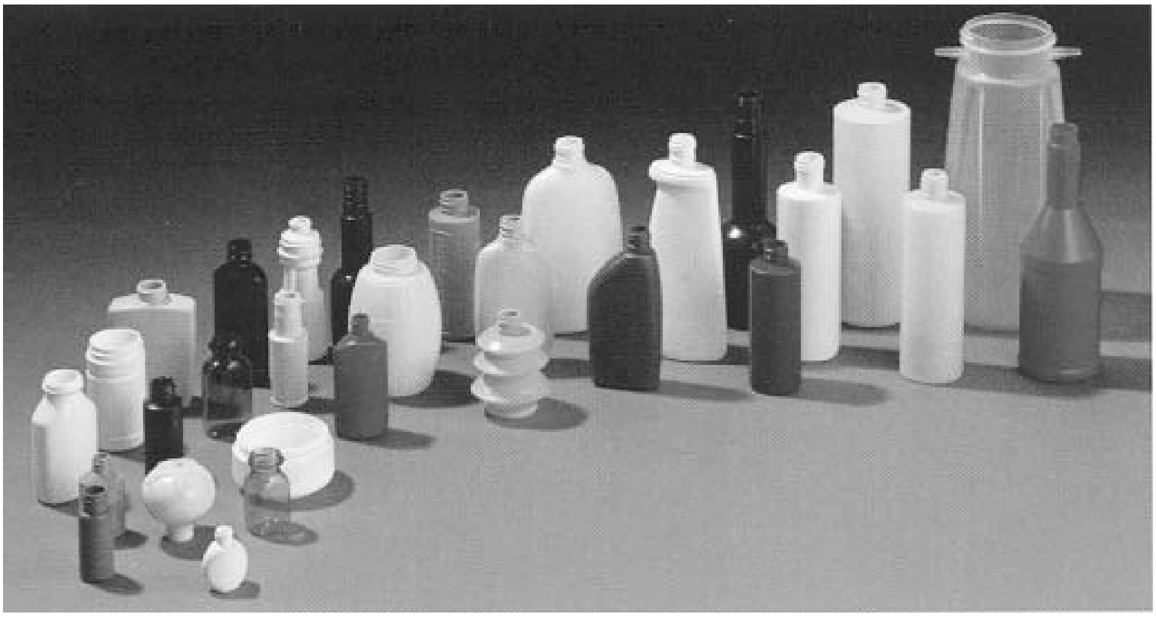


Figure 1.8 Array of blow moulded bottles

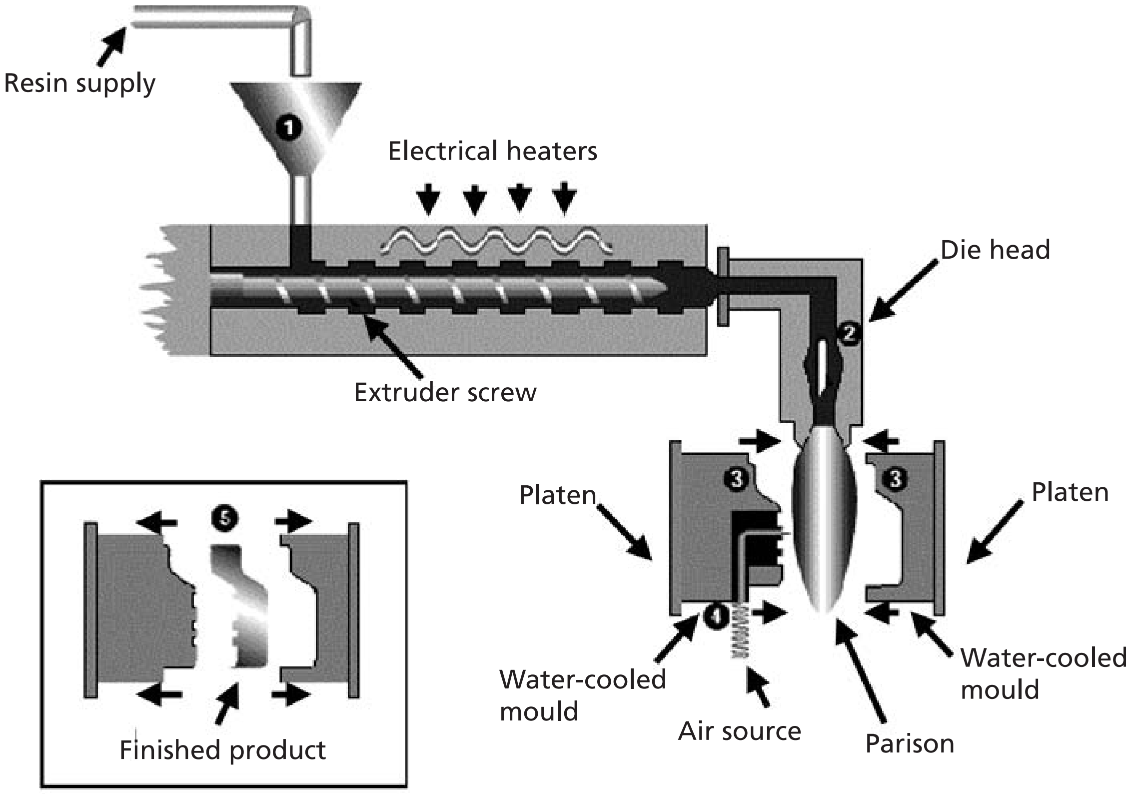


Figure 1.9 Cross section through extrusion blow mould machine

This process makes it possible to combine materials of various properties to create a final product to meet the requirements of a particular application.

The first commercial application of this process was a Heinz Ketchup (tomato sauce) bottle by the American Can Company in 1983. Currently, the automotive fuel tank is a typical application of this method (**Figure 1.10**).

Combining layers in the die before finally extruding a parison creates the multilayered structure of co-extruded products. See multi-layered head - **Figure 1.11**.

Figure 1.10 Fuel tank with layered wall

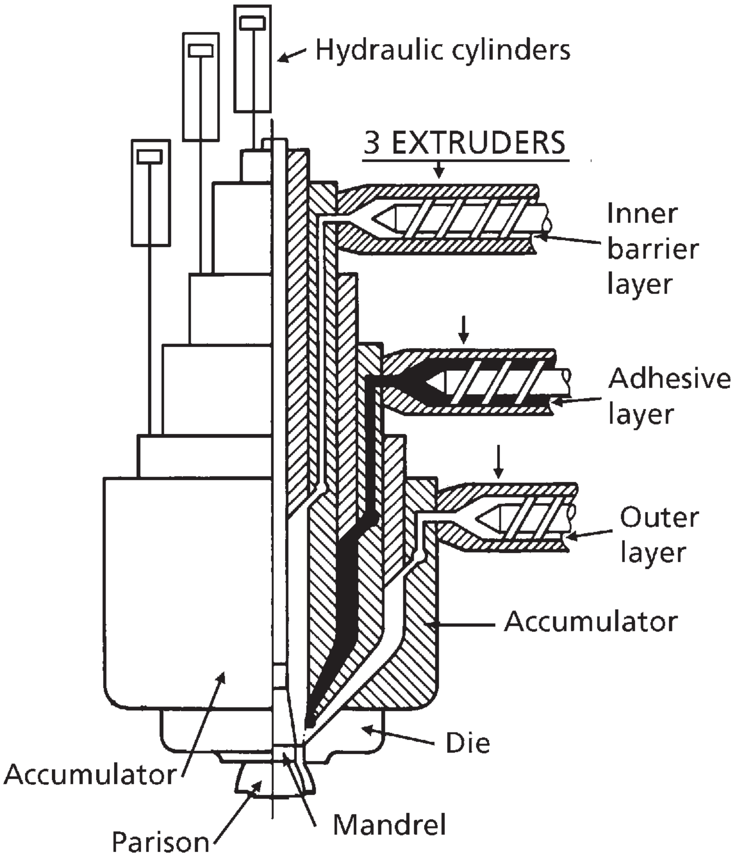


Figure 1.11 Multi layered die head

1.2.3.3 Advantages and Disadvantages of Extrusion Blow Moulding

Advantages of extrusion blow moulding are:

- Natural process for containers and hollow parts
- Preferred process for high volume containers

Disadvantages of extrusion blow moulding are:

- Uneven wall thicknesses
- Close dimensional tolerances are difficult to achieve
- Relatively low accuracy of surface finishing details.

1.3 Material Considerations

1.3.1 Materials Selection

Since each end product calls for particular properties, the selection of the most suitable resin for each application is very important. Resin selection is not an easy job. The problems must be clearly defined beforehand. Careful investigation of the end use properties must be made. Moreover, resin requirements vary with blow moulding procedure and the available equipment.

Extrusion Method – When the parison is extruded from the die it is subject to gravity pull. Thus the material wall will thin out at the top (**Figure 1.12**) this is known as sag, draw down, neck down or stretch out.

Such thinning is overcome by formulating the resin to provide body so that it will not drop to the floor before the mould closes. This factor is indicated by the 'melt index' which is a measure of melt flow. Thinning is further compensated by moving the mandrel in the die, which gradually increases the wall thickness, and is known as programming.

Injection Method – Since the resin is injected through a small orifice the melt flow of the material has to be rapid thus in the plastic state it needs to be liquid. The resin formation is also influenced by gate size, mould filling pattern, wall thickness and dimensional tolerances.

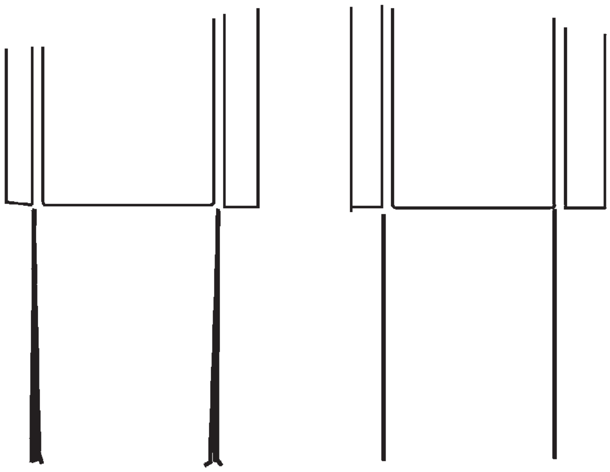


Figure 1.12 Extruded parison with gravity pull

1.3.1.1 Physical Properties

The inherent physical properties of a resin may be modified by altering processing and operating conditions during the fabricating process, starting in the extrusion or injection machine and ending in the blowing mould. The main influences are those exerted by heat (or cooling) and pressure, and the time and duration of these influences is essential.

This is why good knowledge of the equipment and mould and their operation will permit its skilful use to obtain the highest possible output of high quality, uniform items. These are discussed in the following chapters.

1.3.2 Product Properties and Market Usage

1.3.2.1 Blow Moulding - American Market

Quite generally, items requiring stiffness, and hardness such as containers for household detergent or chemicals, should be made of high-density resins. These items represent currently the bulk of the blow moulding in North America market. For squeeze bottles and flexible items such as toys, lower-density polyethylene resins are more suitable. PET is the choice for soda bottles and personal care products [6, 7].

1.3.2.2 Blow Moulding European Market

The European market has been developing rapidly since 1900. Recently the use PET has largely replaced the use of glass in such sectors such as personal care products. PET lead the way with 60% of polymer usage in Central Europe [8]. Chart of percentages of polymer usage by country is shown in **Figure 1.13**.

Note: Materials selection is covered more extensively in Chapter 2 – Design and Engineering.

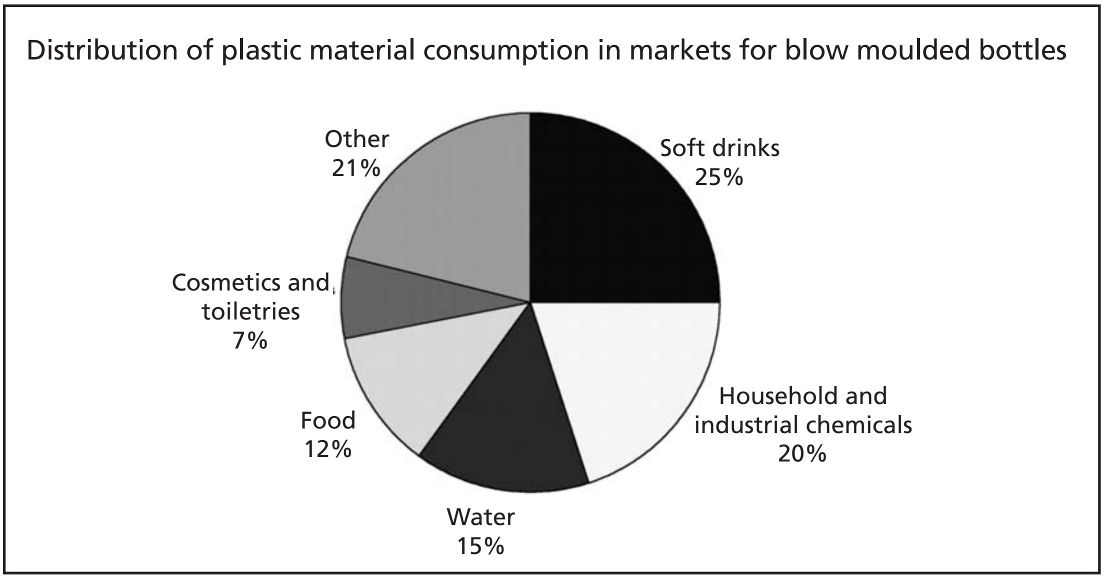


Figure 1.16 Distribution of polymer demand for blow moulding in Europe

Courtesy Plastics Engineering Europe.

Source: Applied Market Information Ltd., Bristol, UK.

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2 Design and Engineering

2.1 Design

For successful design and development of a product all the disciplines involved in the production process need to provide an efficient, effective design, this is particularly true of blow moulding, as the final product is dependent on mould engineering, processing and finishing methods, in addition to the product performance and dependability [1].

The following considerations such as characteristics of materials, processing, assembly and finishing, life cycle and performance of the product all play a part in producing the ultimate product, thus it is important to have a team approach to the product design, engineering and development [2]. A method to facilitate this was developed at Brigham Young University, (UT, USA) with a computer integrated manufacturing (CIM) [3] system, illustrated with a wheel (see **Figure 2.1**).

This was further refined by the Computer and Automated Systems Association (CASA) of the Society of Manufacturing Engineers (SME) and built upon previous work.

The new manufacturing enterprise wheel [3] (**Figure 2.2**) has the customer requirements as its hub, with, the disciplines and functions in an organisation which are working together toward a common goal, as the spokes and the rim.

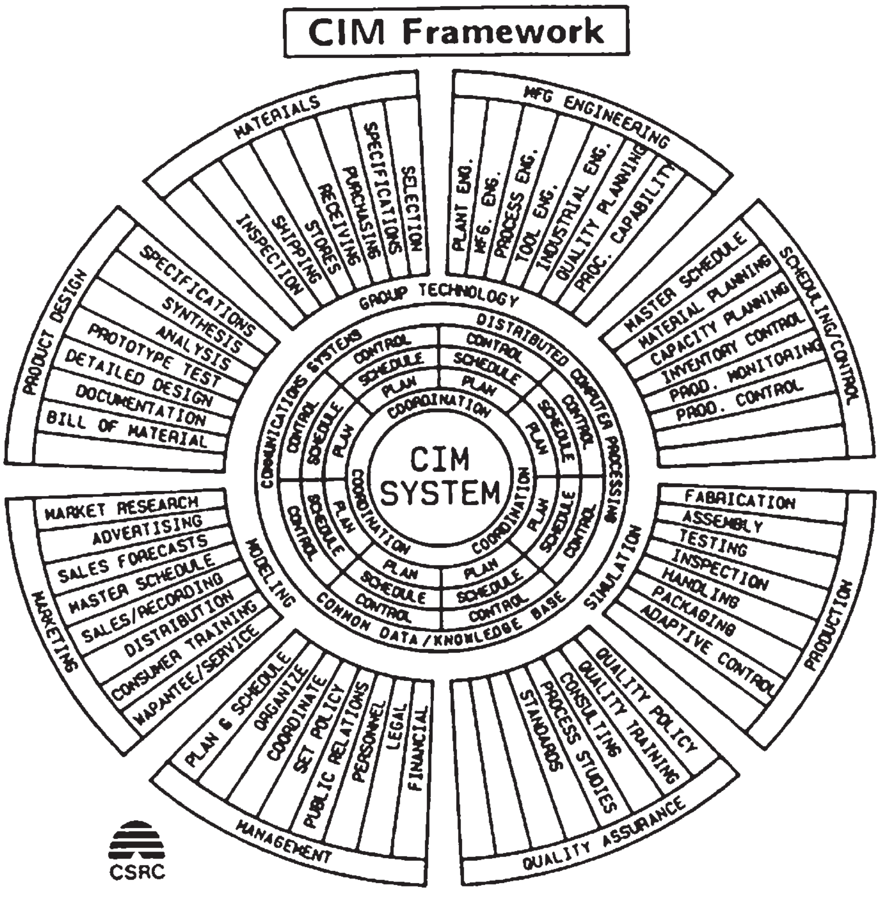

Figure 2.1 Computer Integrated Manufacturing (CIM) wheel

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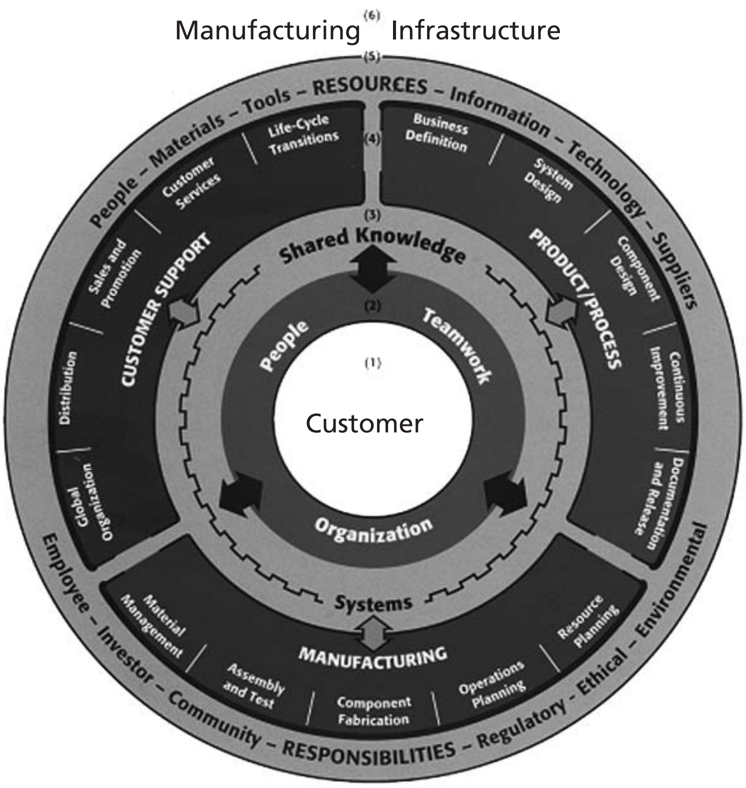


Figure 2.2 Manufacturing infrastructure

Reproduced with permission from the Society of Manufacturing Engineers, USA.

Although one cannot be an expert in all aspects of the design arena, one can have an understanding of how the system should work. When designing for plastic blow moulded parts, one should take into account aesthetics, functional process, capabilities and the manufacturing constraints. The design process should be an organised approach and should go through various phases and milestones and have everybody's input.

2.1.1 Product Design and Development System

A management system for this to occur is a five phase system as illustrated in **Figure 2.3**. Although there are many variations and names given to these five phases they all have to take place and the milestones achieved for the product to happen.

Inherent in the system is the requirement of written objectives, including customer's 'must haves' and 'wants' and 'would like to haves'. The designer's role is to have a clear understanding of these criteria, a team leader or manager (who may be anyone of the team member disciplines), can be responsible for time schedules, cost and monitoring progress reports to the project owner (a representative from top management) who ensures resources are committed and team co-operation takes place.

2.1.2 Process Management Tracking Systems

There are many project management tracking systems approaches to programming, scheduling and contracting which are beyond the scope of this book, including the Program Evaluation and

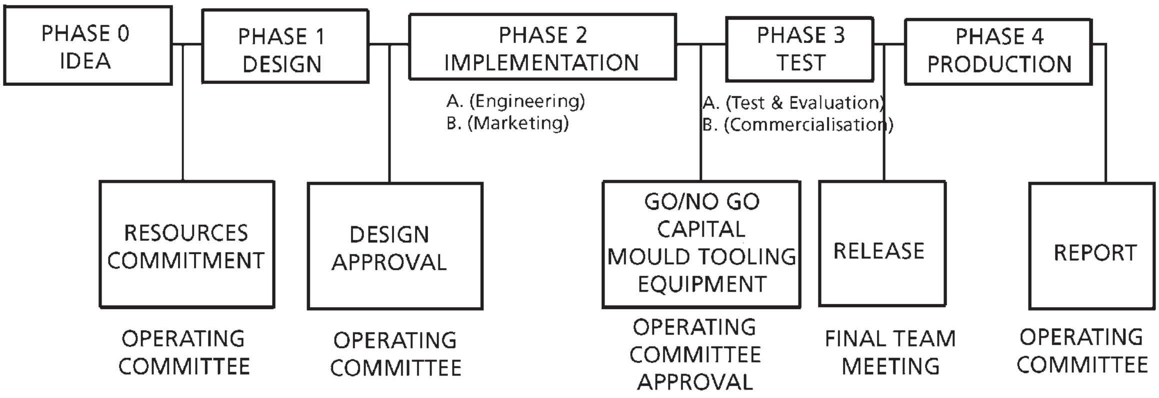


Figure 2.3 Product design and development

Review Technique (PERT), 'Precedence' diagramming and Critical Path Method (CPM). If your organisation does not use one, it is advisable to implement your own.

2.2 Basic Design

It was stated previously that blow moulding is the preferred method of making hollow containers, this requires the designer and engineer to think in different terms. Generally most have been accustomed to thinking in terms of shells because plastic parts are predominantly one-dimensional objects which are injection moulded or thermoformed. Now the consideration is three-dimensional.

The understanding of the blow moulded structure, its advantages and disadvantages and how the configuration can best be utilised is the first step to making a successful part. When looking at a part being considered for the blow moulding process the following considerations are to be made: where the mould separates (part line), allowing for draft of the part (removal from mould), layout, blow ratio, corners, finishing and appearance. The following is a list of these terms with definitions:

1. *Draft of the Part* – all surfaces which are parallel to the direction of the movement of the mould should have taper or draft for easy part removal.

2. *Layout of the Part* – is dependent on its outer shape and configuration.

3. *Blow Ratio* – All parts are shaped by the process of blowing air into the parison. To understand blow ratio one needs to think of a balloon, which when it is blown up, has a much thinner wall.

4. When the parison enlarges it fills the mould space and the wall thins out. The mould therefore determines the outer diameter (OD) of the part. The difference between the diameter of the parison and the diameter of the finished part determines the degree of 'blow up ratio'. This is absolutely true if the parison were blown into a cylindrical shape (**Figure 2.4**). However, when the shape is irregular the 'blow ratio' is determined by examining the cross-sections of the irregular shapes to determine the 'blow ratio' that occurs in these areas (**Figure 2.5**). In other words there are areas of isolated 'blow ratio' in contrast to the overall 'blow up ratio' (The calculation of blow ratio is described later).

5. *Guidelines for Radii* – Shaped edges and corners should be avoided, abrupt changes: should be blended on all surfaces.

6. Strength and stiffness may be gained by moulding geometric configurations such as gussets and grooves to the structure. This will be covered more fully in bottle design (Section 2.2.2.1).

7. *Structural Enhancement* – can also be obtained with welded surfaces, known as 'pinch offs' and 'tack-off'. These are essentially local compression areas in the blow moulded part. This will also be covered in bottle and structural design (Sections 2.2.2.1 and 2.2.3).

8. *Layout of the Part* – is dependent on its outer surface configuration, blow ratios, relationship to parison, and placement of inserts, openings, vent pins, knock-out holes, ejection, lettering and labels.

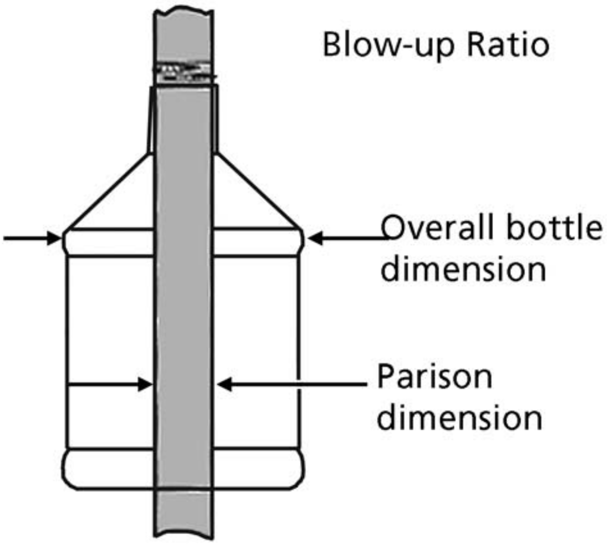


Figure 2.4 Blow up ratio

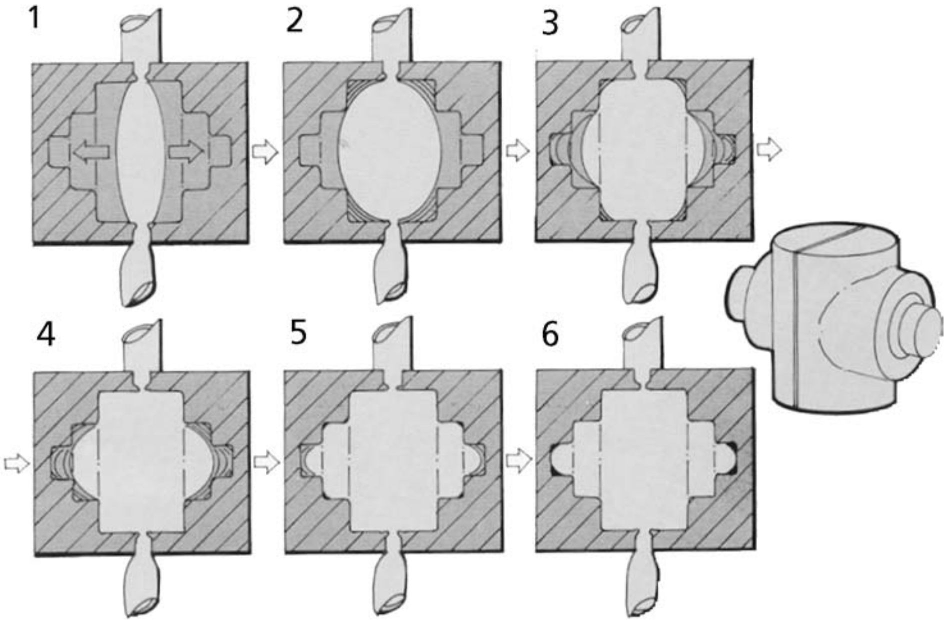


Figure 2.5 Blow ratio – isolated areas

2.2.1 Basic Design Considerations

All these definitions will now be discussed in greater detail.

2.2.1.1 Size Variations

There are times when the 'blow up ratio' is acceptable, the parison may be encapsulated inside the mould cavity and blown out to the cavity sidewalls (**Figure 2.6**).

At other times, it is best to have a parison larger than the mould cavity itself and therefore the mould pinch-off of the part of that parison that will be blown into the mould cavity configuration (**Figure 2.7**).

2.2.1.2 Part Line and Draft of the Part

Selection of the part line and subsequently the draft of the part is the first step, in most parts, where the part line is to be located it is obvious, and selection of the draft therefore becomes a simple matter (**Figure 2.8**). Some parts may require the part line not to be symmetrical (not the ideal) in which case the consequences - uneven wall thicknesses, must be expected. An extreme case of a part with an edge part line is shown in **Figure 2.9**. For an irregular part, such as a figurine, the part line will also need to be irregular and more complex (**Figure 2.10**).

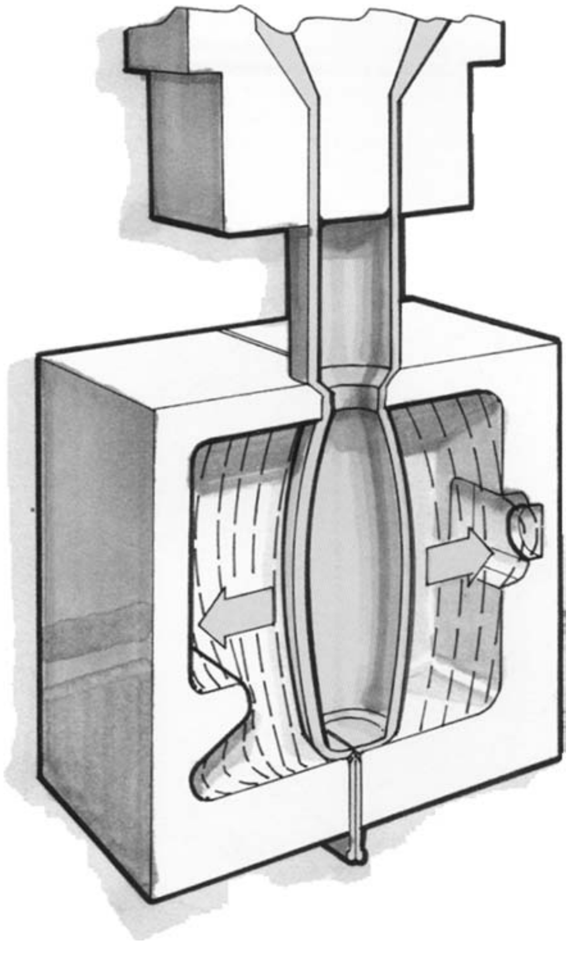


Figure 2.6 Encapsulated part

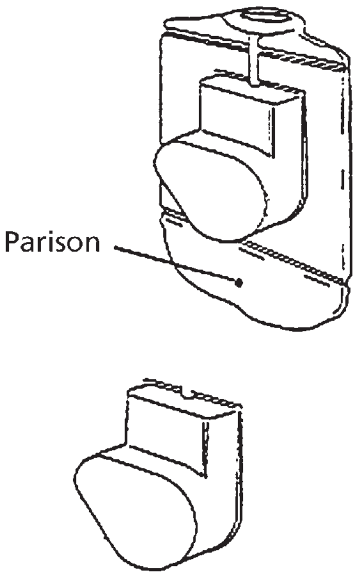


Figure 2.7 Part larger than cavity

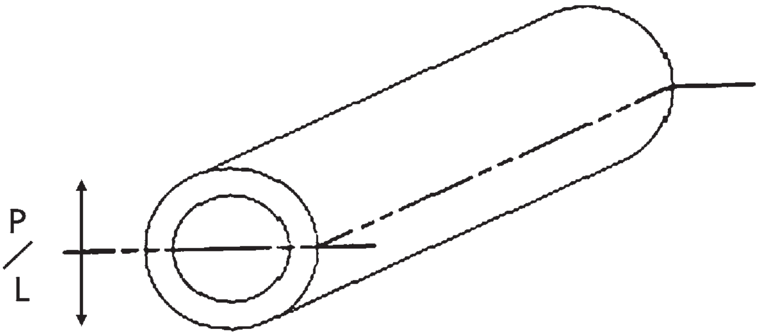


Figure 2.8 Simple part line

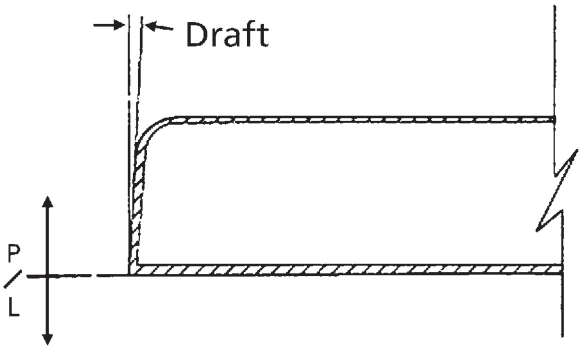


Figure 2.9 Edge part line

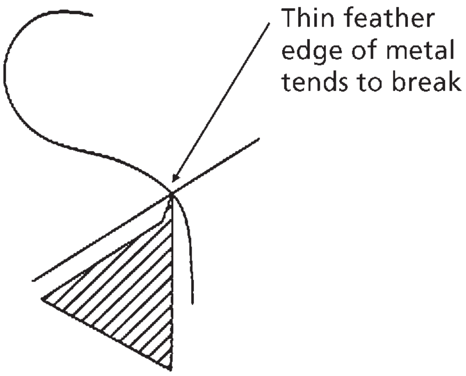


Figure 2.10 Irregular part line

The following are rules for draft:

Minimum draft – 1 degree/side
Recommended draft – 2 degrees/side
With texture – 1 additional degree per 0.0254 mm depth.

2.2.1.3 Blow Ratio and Draft Configurations

Blow ratio, as indicated earlier, is perhaps one of the most important considerations in the design of the blow moulding process. This term is used to describe various conditions that may arise when the parison is inflated in the mould cavities. First the term can apply to the initial inflation of the parison upon mould closing. If the mould has a 1:1 blow ratio, the depth of half the cavity is equal to half its smallest width. At this point it must be thick enough without blowing a hole in the parison ('blow out'), but it still provides the desired wall thickness in the part at that location. It is possible that a part may have several points with blow ratio conditions.

The theoretical blow ratio, if ignoring stretch, is where the inflation of the surface area of the parison is less than the total surface area of the cavity it is blown into. Therefore as the surface area of the cavity increases, the part wall thickness must decrease.

Referring to **Figure 2.11**, if the area (length x width) is 10 square units and stretches into a cavity of 50 units in surface area and if the initial wall thickness was 0.1 units, then the average formed thickness is 0.020 units. This simplistic illusion does not represent the real world, since the actual part does not stretch evenly and thus the final wall thickness depends on the geometric conditions of the part.

The factor that is most critical is the width and length dimensions relative to the depth. As a general rule, the depth should not exceed the smallest width by more than a ratio of 1:2 when a minimum of 2 degrees draft, and radii of twice the wall thickness are used.

A consideration that would allow a greater depth would be a generous radius, top and bottom, and the draft angle (see **Figure 2.12**).

Another factor to consider would be the shape of the opening. Four case applications of blow radii guidelines are shown in **Figure 2.13**.

NOTE: An optimum blow ratio may be influenced by materials and the process used. Injection blow moulding of polyethylene terephthalate (PET) will have a different optimum than extrusion blow moulding of high-density polyethylene (HDPE).

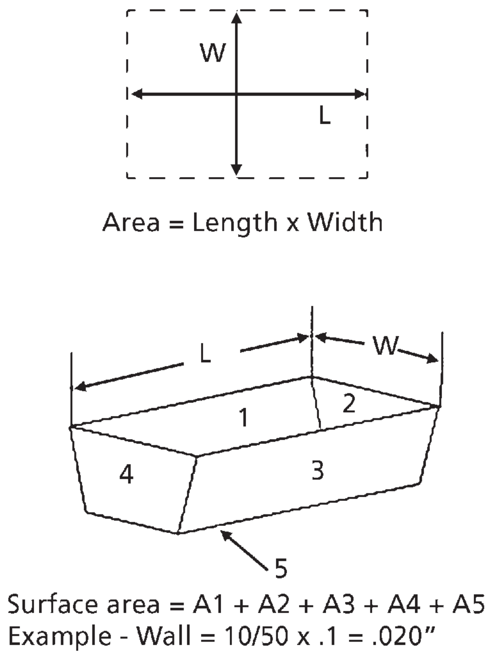


Figure 2.11 Theoretical blow ratio

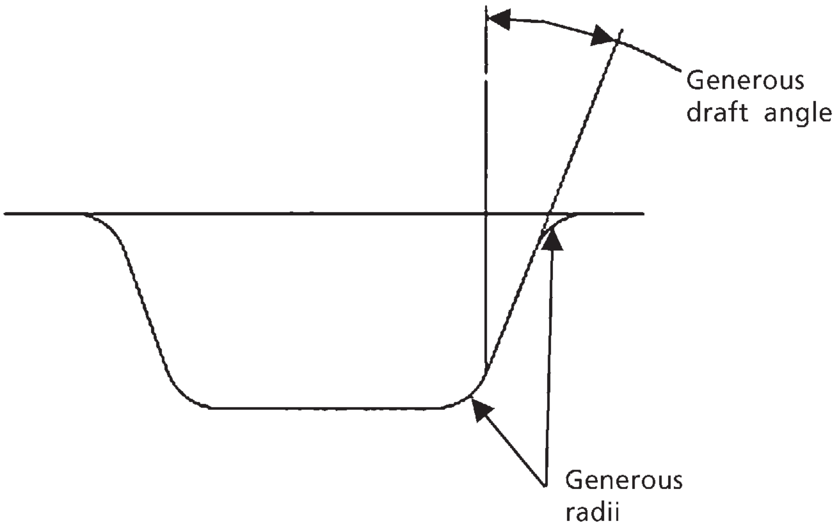


Figure 2.12 Generous draft angle and radii

As a general rule the blow ratio = H (maximum depth of cavity or height of protrusion *versus* depth of cavity/W (smallest dimension at opening of cavity or smallest dimension at base protrusion).

$$\text{Blow Ratio} = \frac{\text{Maximum depth of cavity or height of projection}}{\text{Smallest dimension at opening of cavity or smallest dimension at base of projection}} \qquad \frac{H}{D}$$

2.2.1.4 Draft and Radii of the Part

The draft is to allow for the ejection of the part from the mould cavity, also, as just as seen from the blow ratio discussion, it can assist the reduction of wall thickness thinning by making the draft and the radii as generous as possible, within the design requirements allowed (See **Figure 2.14**).

This becomes extremely important as the 'blow ratio' goes over 1:1.

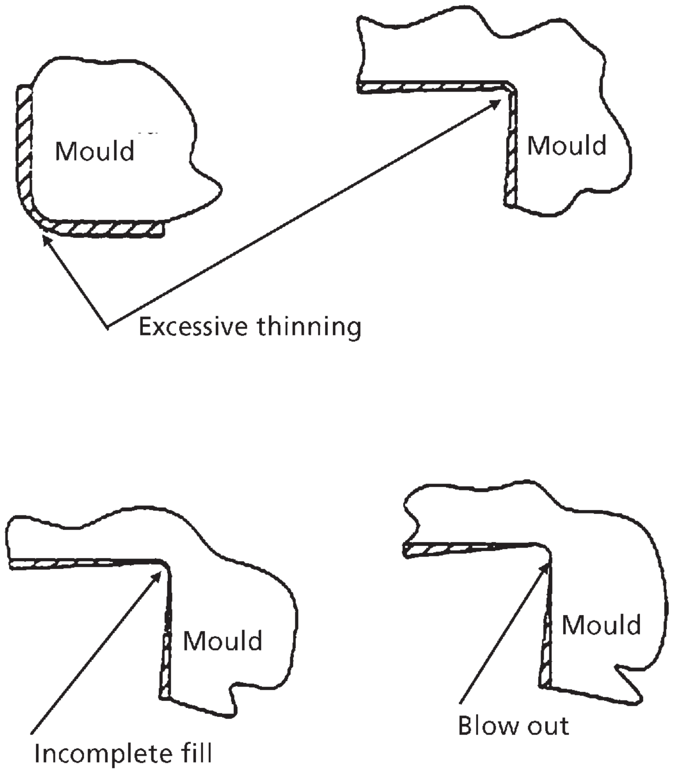


Figure 2.13 Guidelines for blow radii

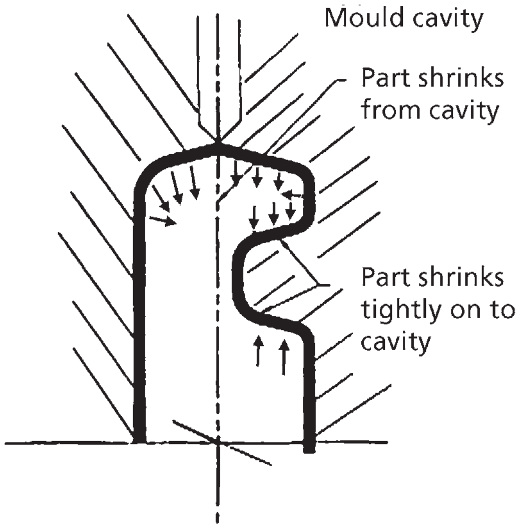


Figure 2.14 Case application of blow ratio

Part shrinkage direction is also a consideration, when considering internal shapes of the part. In **Figure 2.15** it can be seen that the part will shrink away from the outer walls to a plug and shrinks onto the plug. A further consideration is the parison inflation, that the hot parison sticks to the cold surface of the mould first and is then blown into the cavity.

2.2.2 Bottle and Container Design

In most cases a bottle or container is conveying a product to the consumer. Therefore it has to be functional, durable and low cost and at the same time in today's world, it also has to be attractive since it also has to sell. Usually the quantity produced is large thus high productivity, while maintaining quality assurance, is required to provide optimum value.

The blow moulding process is often the choice for producing low cost packages without sacrificing, indeed sometimes enhancing, the marketing requirements. The single most important cost element is the weight of the resin, but processing machine productivity, and container performance are all factors to be considered in the equation to produce a functional cost-effective part.

Both the extrusion and injection blow moulding methods, and all the variations within those methods are used for producing containers [4].

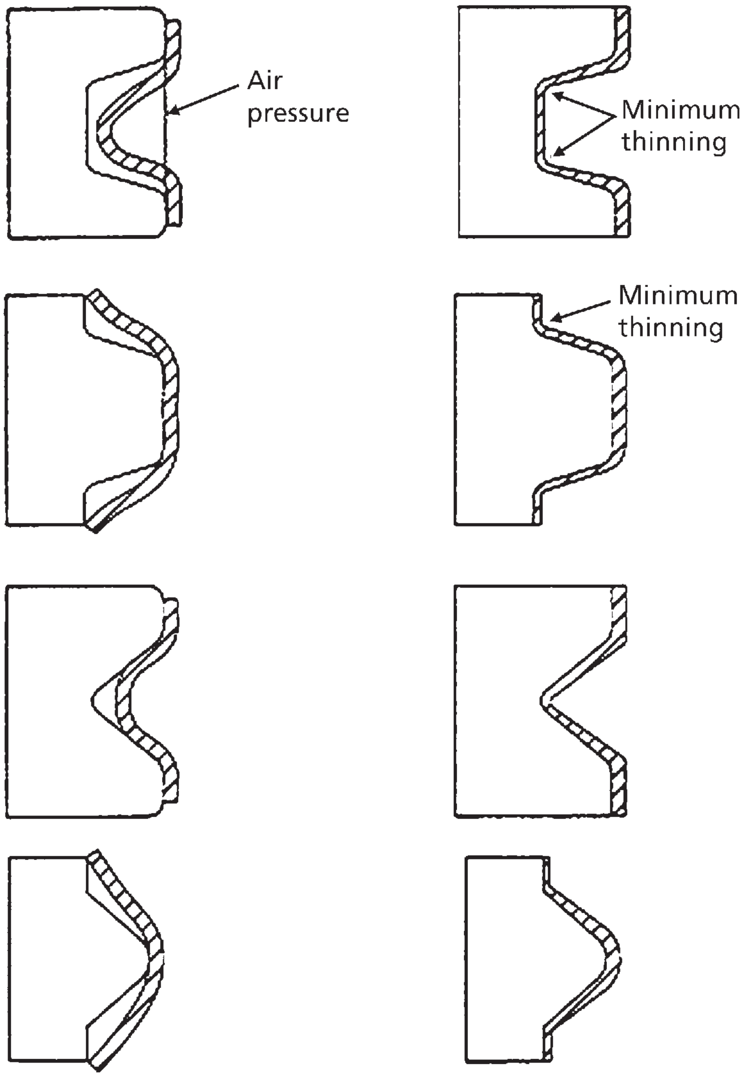


Figure 2.15 Part shrinkage direction

2.2.2.1 Basic Types

Optimising the container design requires consideration be given to these basic types:

1. *Circular tube* –An injection moulded ‘preform’ which is a ‘test’ tube like part with a rounded closed bottom.

2. ‘*Toothpaste*’ *tube* – extrusion blow moulding where the parison falls inside a centrally located neck. For bottles that are oval at the bottom and round at the top (see **Figure 2.16**).

3. *Flat ‘pillow’* – extrusion blow moulding, where the parison is outside the neck (see **Figure 2.17**).

   Ideal for moulding in handles such as milk bottles

4. *Rib design*

As a general rule with a round container use horizontal ribs to the improve hoop stiffness, but pay attention to the cross section so as not to create an accordion condition. For compression stiffness use vertical ribs (see **Figure 2.18**).

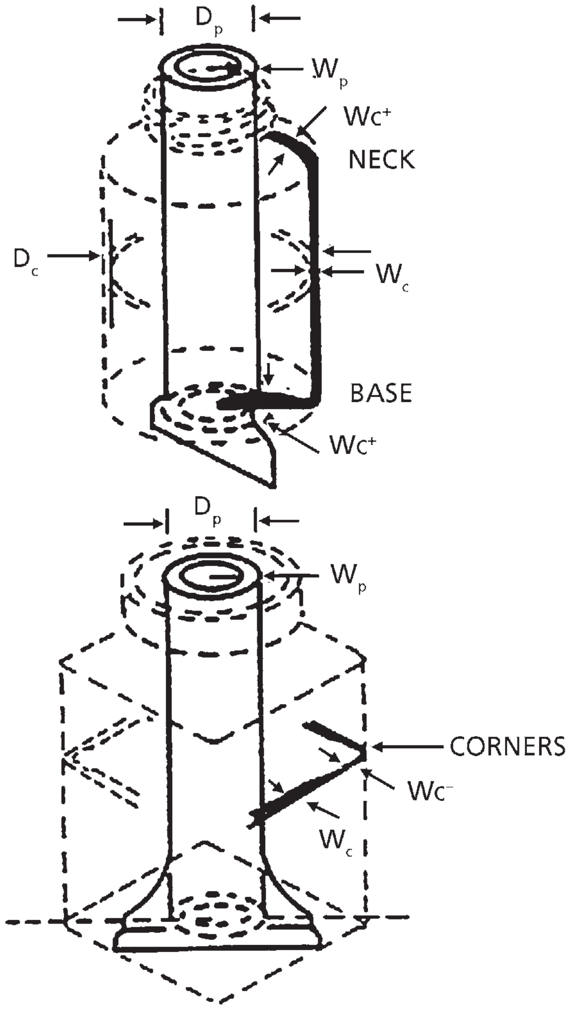


Figure 2.16 Toothpaste tube. D_p = Parison diameter; W_p = Parison wall thickness; Wc^+ = Wall thickness at neck/base; Wc^- = Wall thickness at corners; W_c = Wall thickness of container; D_c = Diameter of container

It is noted that square containers actually reduce stiffness, thus losing both top load strength and bulge resistance as well. See oversquare containers (**Figure 2.19**) and truss groove (**Figure 2.20**).

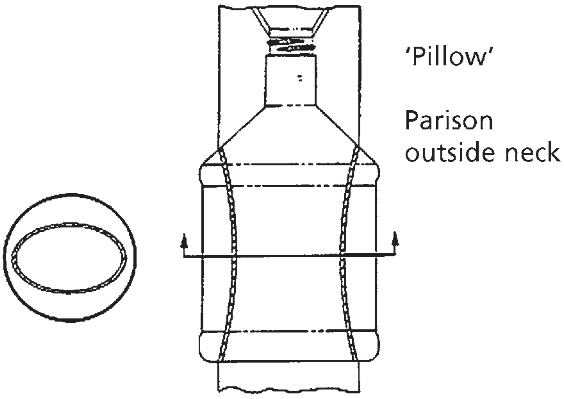
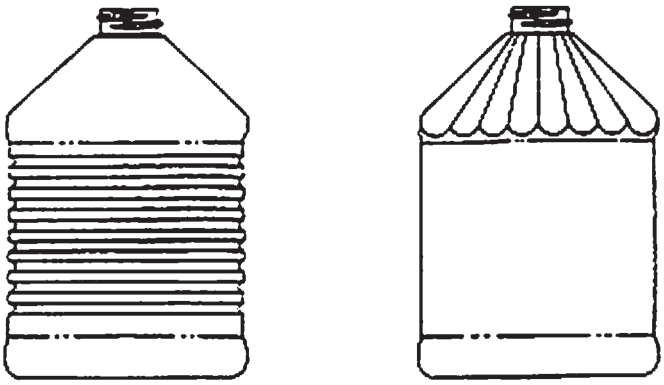


Figure 2. 17 Flat pillow


Horizontal ribs

Vertical ribs

Figure 2.18 Horizontal and vertical ribs

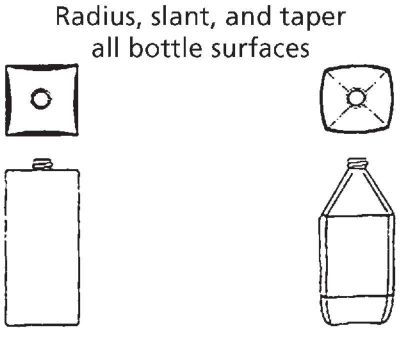


Figure 2.19 Over square containers

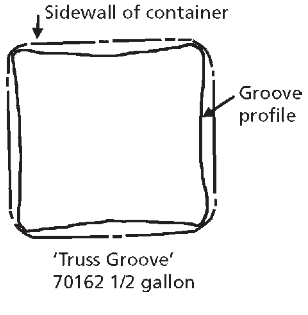


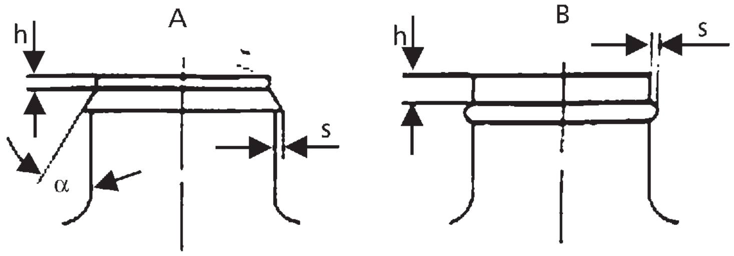
Figure 2.20 Truss groove

2.2.2.2 Cross Sections

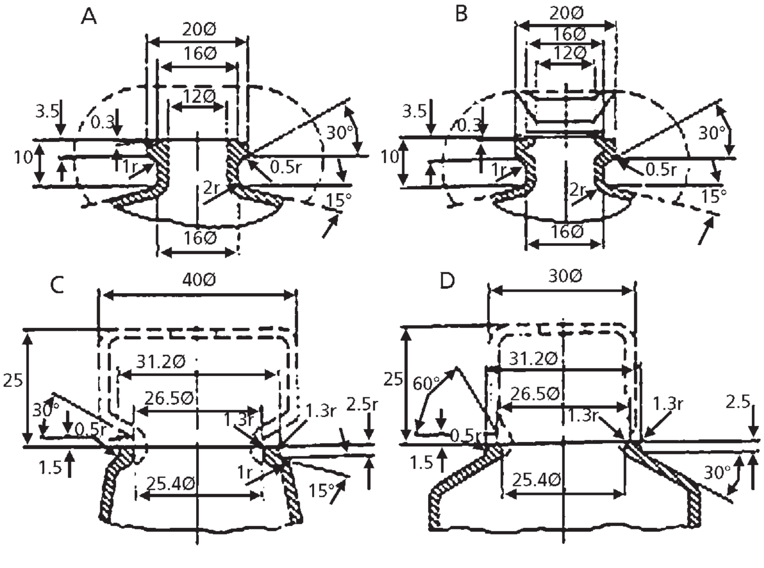
Establish the part line so that the part has an acceptable blow ratio, and the cavity geometry is not ‘over square’ (sections that are deeper than wide), a problem that is often seen in the handle and occasionally with engraved lettering.

2.2.2.3 Bottle Neck, Threads and Openings

The blowing process generally uses a blow pin with a channel to emit air into the parison - this creates a natural opening for bottles and containers. There are exceptions to this method of blowing air, which are discussed elsewhere (Section 3.8.2). In this neck section, the thickness can be controlled to a greater degree than the rest of the part with the careful matching of the blow pin and neck cavity dimensions. Actually this area may be treated as compression moulding. Of course some types of plug or cap must be used to fill the hole when the container and contents are to be stored or transported. Since the majority of blow moulded containers are used for packaging, it is important to have standards for threaded openings, which are to be closed with a cap. The Plastic Bottle Division of the Society of the Plastic Industry (SPI) has established recommended voluntary guidelines for the dimensions (See **Figure 2.21**). Two main shapes, L and M are shown in **Figure 2.22**. The ‘L’ shape is similar to those found on glass bottles, while ‘M’ is typical of plastic containers. A complete listing and explanation of terms used in the following figures and tables can be obtained from the Plastic Bottle Institute [4]. An example of SPI charts is shown in **Table 2.1**.



Pouring neck with click stop for snap closure. A: Design with conical tortus. h = 1-3 mm, α = 30-45°, s = 1-2 mm. B: Design with annular torus, dimensions as in A.



Design recommendations for the top of an aerosol container.
A: Internally calibrated glass bottle type top. B: Externally calibrated glass bottle type top. C: Top for 2.5 cm lift valve on slimline aerosol container. D: Top of 2.5 cm lift valve on aerosol shouldered container.

Figure 2.21 Neck examples

Table 2.1 SPI Bottle thread charts - example

mm	T		E		H		L	S		T	W	HELIX ANGLE β	CUTTER DIA.	THD'S PER INCH
	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MIN	MAX			
13	0.514	0.502	0.454	0.442	0.467	0.437	0.306	0.052	0.022	0.218	0.045	3° 11′	0.375	12
15	0.581	0.569	0.521	0.509	0.572	0.542	0.348	0.052	0.022	0.258	0.045	2° 48′	0.375	12
18	0.704	0.688	0.620	0.604	0.632	0.602	0.429	0.052	0.022	0.325	0.084	3° 30′	0.375	8
20	0.783	0.767	0.699	0.683	0.757	0.727	0.456	0.052	0.022	0.404	0.084	3° 7′	0.375	8
22	0.862	0.846	0.778	0.762	0.852	0.822	0.546	0.052	0.022	0.483	0.084	2° 49′	0.375	8
24	0.940	0.924	0.856	0.840	0.972	0.942	0.561	0.061	0.031	0.516	0.084	2° 34′	0.375	8
28	1.088	1.068	0.994	0.994	1.097	1.067	0.655	0.061	0.031	0.614	0.094	2° 57′	0.500	6

SP – 415 FINISH

mm	T		E		H		L	S		T	W	HELIX ANGLE β	CUTTER DIA.	THD'S PER INCH
	MAX	MIN	MAX	MIN	MAX	MIN	MIN	MAX	MIN	MIN	MAX			
18	0.704	0.688	0.620	0.604	0.538	0.508	0.361	0.052	0.022	0.325	0.084	3° 30′	0.375	8
20	0.783	0.767	0.699	0.683	0.569	0.539	0.361	0.052	0.022	0.404	0.084	3° 7′	0.375	8
22	0.862	0.846	0.778	0.762	0.600	0.570	0.376	0.052	0.022	0.483	0.084	2° 49′	0.375	8
24	0.940	0.924	0.856	0.840	0.661	0.631	0.437	0.061	0.031	0.516	0.084	2° 34′	0.375	8
28	1.088	1.068	0.994	0.974	0.723	0.693	0.421	0.061	0.031	0.614	0.094	2° 57′	0.500	6

SP – 410 FINISH

1.Dimension 'H' is measured from the top of the finish to the point where diameter 'T', extended parallel to the centreline, intersects the top of the shoulder.

2. A minimum of 11/2 - full turns of thread shall be maintained.

3. Use of bead is optional. If bead is used, bead dia. And 'L' minimum must be maintained.

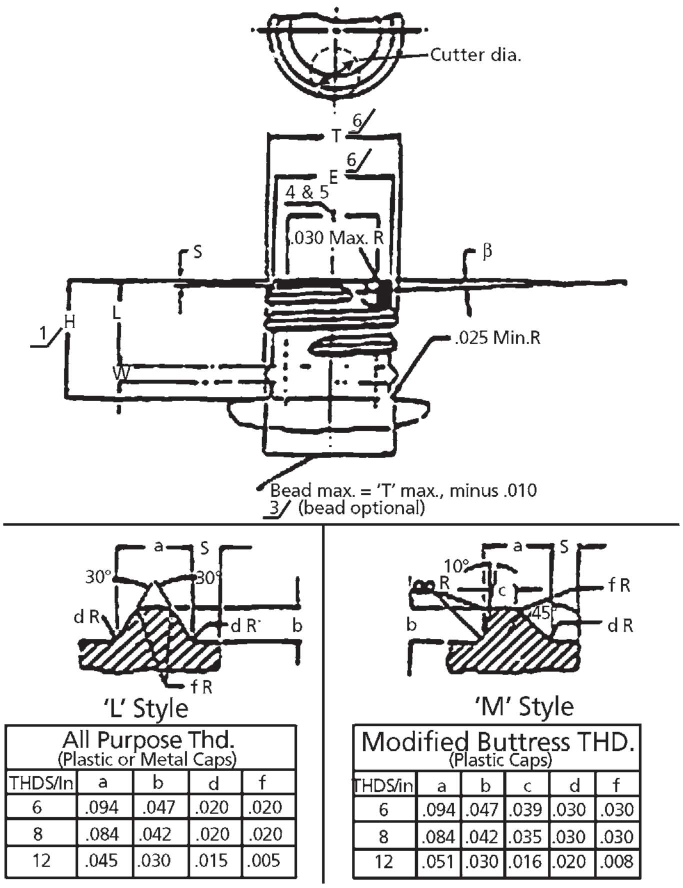
4. Hole diameter 'I' to be measured through full length of finish unless otherwise specified.

5. Concentricity of 'I' min. with respect to diameters 'T' and 'E' is not included. 'I' min. is specified for filler tube only.

6. 'T' and 'E' dimensions are the average of two measurements taken 90° apart. The limits of ovality will be determined by the container supplier and container customer, as necessary.

7. All dimensions are in inches unless otherwise indicated.

To the best of our knowledge the information contained herein is accurate. However, The Society of the Plastics Inc., assumes no liability whatsoever for the accuracy or completeness of the information contained herein. Final determination of the suitability of any information or material for the use contemplated, the manner of use and whether there is any infringement of patents is the sole responsibility of the user.



All Purpose Thd. (Plastic or Metal Caps)				
THDS/In	a	b	d	f
6	.094	.047	.020	.020
8	.084	.042	.020	.020
12	.045	.030	.015	.005

Modified Buttress THD. (Plastic Caps)					
THDS/in	a	b	c	d	f
6	.094	.047	.039	.030	.030
8	.084	.042	.035	.030	.030
12	.051	.030	.016	.020	.008

THREAD CROSS SECTIONS

Example thread nomenclature:
'L' Style: L22SP415
'M' Style: M22SP415

Figure 2.22 L and M necks

Other neck openings are designed for caps, or spray attachments. Typical designs are shown for these types of neck configurations in **Figure 2.23**.

2.2.3 Structural Design

Although the initial growth for blow moulded products has been with the packaging industry, and still has the greater share of the blow mould market place, structural blow moulded parts have had a significant impact in the automotive industry, large storage containers, transport packaging and other industry uses. Resins used have not only been traditional polyethylene (PE) but also a wide range of engineered plastics, such as polycarbonate and acrylonitrile-butadiene-styrene (ABS). Products from a pencil size tube to 380 litre containers have been made commercially.

The blow moulding process is ideal for making complex double walled parts in a single moulding process. With the proper use of 'pinch-offs', moulded in stiffeners and structural ribs - high stiffness to weight ratios can be obtained as well as a good moment of inertia for a given volume of resin. High production parts such as tank, pressure vessels, air ducts and cable channels, protective double wall cases and municipal refuse carts, provides the highest moment of inertia for a given volume of resin as compared with other processes such as single shelled injection moulded or reaction injection moulded parts.

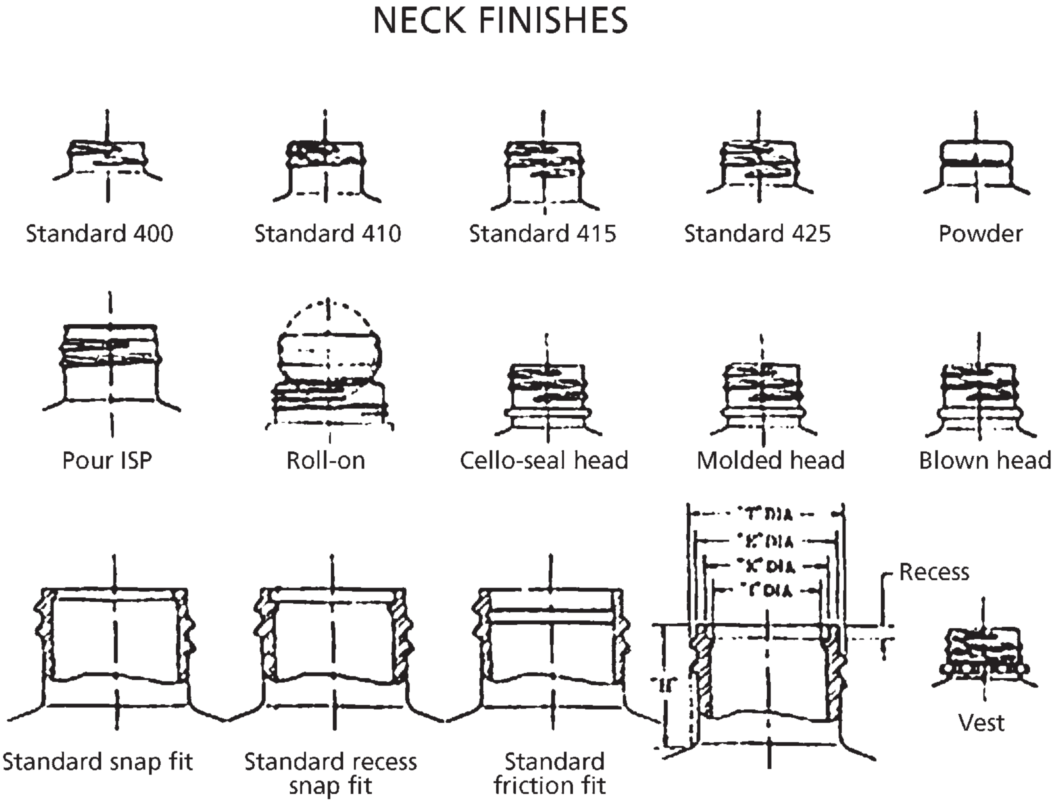


Figure 2.23 Examples of neck configuration

A hollow blow moulded part can also serve as an outside skin of a composite structure. In such a part it can be filled with a polyurethane (PU) foam, or even expanded beads of polystyrene (PS) foam (see **Figure 2.24**), which form the core of the composite and add structural rigidity, insulation and/or buoyancy to the finished part.

The availability of engineering resins allows blow moulded hollow parts to meet more demanding requirements, such as being exposed to high heat, internal pressures, heavy loading and severe impact.

The following are examples that illustrate the points made:

Kinetic energy dissipation – construction of the ideal blow moulded part with a double wall will absorb and dissipate mechanical energy, generally from impact.

Deformation (of skin in an area of impact) – because of the nature of the part it deforms into itself at the point of impact and recovers to its original shape.

A sealed hollow part – the pressure is distributed and the energy is absorbed due to its decrease in volume. By properly sizing the orifice (a small hole) the part will be vented and this will control the amount of damping.

Foam filled, blow moulded parts may be designed to dissipate considerable mechanical energy when the interior is filled with a foamed material - if it is rigid it will cause nonrecoverable deformation, if filled with a flexible material then it will absorb the impact energy. This technique is used for bumpers in the automotive and transport industry

Figure 2.24 Formed part

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2.2.4 Design Details

One of the major advantages with plastic processes is the ability to add function by in-mould bosses, snap-fits, inserts and gussets as previously mentioned. Blow moulding is no exception but the approach is slightly different as the following examples show.

Mould-in inserts or components – blow moulded parts have few restrictions due to the size, shape, material and support during moulding process and the low pressure required during blowing as well as being able to eject parts from the mould cavity. When irregular shapes are used the inflated parison forms around an inserted part. If the insert is a plastic material in order for it to bond it must be the same grade of resin.

Interlocking systems – this technique requires an interference fit between male and female configuration of an interlock. The locking detail (or detent) prevents accidental disassembly. It is used to create snap together assemblies and panel systems. When constructing the mould cavity for this type of assembly the cavity should be 'cut metal safe' (it is easier to cut metal to make the part larger) so parts fit together to the desired interference. Metal is removed from the cavity to tighten the interlock/snap-fit. After sampling, repeat several times until desired fit is obtained.

Snap-fits – Open top container with lids (such as waste or trash bins) may be moulded with the lid and container in one piece and cut apart in a post moulding operation. It can be seen from **Figure 2.25** that when cut apart the lid will snap fit to the container.

Multiple/Combination Cavities – to improve the economics of producing an open top product making two parts from the same parison may be considered. In '2-up' or siamese moulding the mould is built with open ends together with the moulded part cut in half. A short transition between the two halves is desired so that the parison may be blown through a hollow needle (see mould next chapter, Section 3.8.2) which pierces and blows through this area leaving no hole in the part. Two cuts are made separating the moulding into two containers leaving the transition which is later reground. The same technique may be used for the container and lid in the previous example.

Tack-off's – Stiffening ribs may be added to a blow moulded part buy allowing the inflated parison to compress, in local areas see examples in **Figure 2.26**.

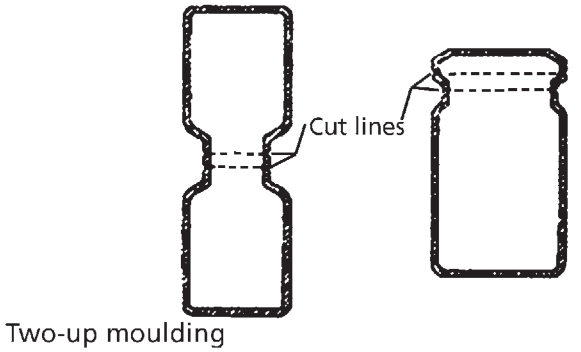


Figure 2.25 Container with lid

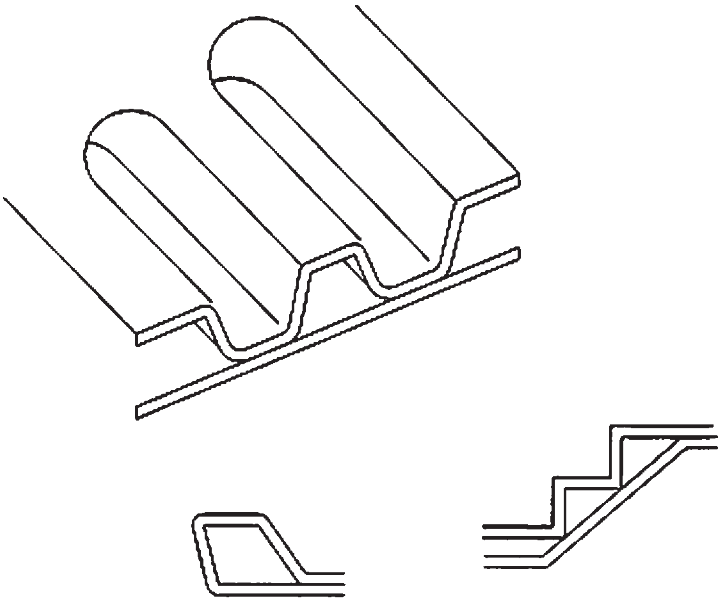


Figure 2.26 Tack-off ribs

Container configuration – consideration of the effect of warpage for square and rectangular shapes for containers (even more so with open top containers) is essential, as was discussed in bottle design. Flat sides tend to warp - this warpage is made exaggerated after the part is cut due to stress set up by shrinkage and wall thickness variations (see die shaping in Chapter 4.11.9 where wall thickness variations can be compensated). As with bottles a shallow curvature is recommended. Warpage is experienced when the container is cut to create the opening. This is because the lip tends to fold inward - to avoid this phenomenon a corrugated or cross-section design must be considered (**Figure 2.27**). Care must be taken not to violate the 'blow ratio'.

Nesting and stacking – for economy of storage and shipment the container part should nest to provide maximum stacking (See **Figure 2.28**).

The lip must clear the ledge of upper part. The nesting is a function of wall thickness and angle of sidewall.

Example: with a stacking angle of 1 degree and a wall thickness of 0.0175 units, the stacking height would equal 1 unit.

Cutting containers apart - to obtain a clean cut it is recommended that a knife blade be used (see Chapter 10). The groove configuration to guide the blade should be as shown in **Figure 2.29**.

Vertical and horizontal rib is recommended for the structural strength required as in bottle design.

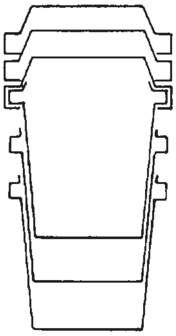


Figure 2.27 Corrugated cross section

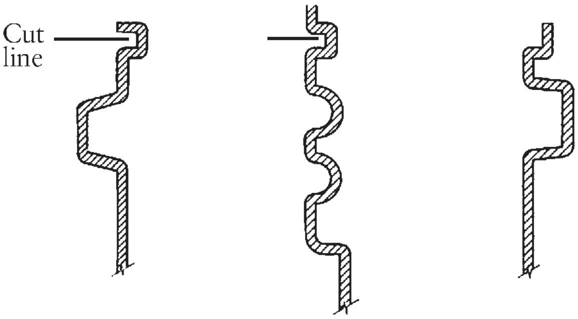


Figure 2.28 Nesting and stacking

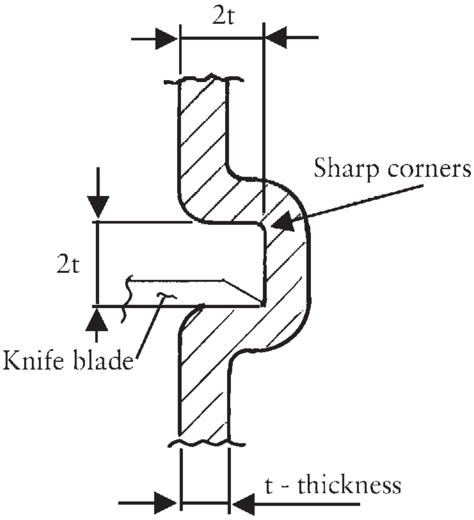


Figure 2.29 Grooved for cutting

2.3 Selection of Materials

Since each end product calls for particular properties, the selection of the most suitable resin for each application is very important. Resin selection is not an easy job. The problems must be clearly defined beforehand. Careful investigation of the end-use properties must be made. Moreover, resin requirements vary with the blow moulding procedure and the equipment available.

Quite generally, items requiring stiffness, high strength, hardness, such as containers for household detergents or chemicals, should be made of HDPE resins (these items currently represent the bulk of the blow moulding market). For squeeze bottles and flexible items such as toys, low-density polyethylene (LDPE) resins are more suitable.

The inherent physical properties of a resin may be modified by altering processing and operating conditions during the fabricating process, starting in the extrusion or injection machine and ending in the blowing mould. The main influences are those exerted by heat (or cooling) and pressure, and the time and duration of these influences are essential.

2.3.1 Polymer Principles [4]

The term polymer is a combination of the prefix poly, meaning many and the suffix mer, which means ‘unit’. The combination, loosely translates to: many units.

The term plastic is derived from the description of a type of mechanical deformation under a load. More properly, it would be said ‘plastic’ is a term applied to a material that will undergo plastic deformation.

Since many polymers will plastically deform, the term plastic was applied and stuck. Many polymers do not, plastically deform. Examples are rubber, certain silicones, thermoplastic rubbers, and many urethanes to name a few.

These mechanical properties result from the structure and building blocks, monomers (single units), utilised in a particular polymer’s composition.

A few useful terms at this point include:

Monomer – single unit or basic building block
Dimer – two or double unit building block
Trimer – three or triple unit building block
Polymer – multiple unit building block.

Connection of repeated monomers is referred to as polymerisation or making of the plastic. By this, many different combinations of the monomers can be linked by varying degrees to each other or to a different monomer or combination of them.

2.3.2 Types of Polymers (see also Chapter 1)

The most common division of polymers is by processing chemistry. These are commonly referred to as: thermosets and thermoplastics.

Thermosets are the class of polymers that undergo a chemical change when pressure and heat is exerted on them resulting in a unique structure which is different from the monomer and/polymer combinations of which it is composed.

Thermoplastics are the class of polymers that do not undergo a chemical change and can be cycled through pressure and temperature cycles to give different shapes which they retain upon cooling and at ambient conditions.

The classes of thermoplastics and thermosets have ‘grey’ areas where they overlap. An example of this is crosslinked PE. Another example is polysiloxanes or silicone resins which also are called elastomers.

Thermoplastics show the most promise for processing by blow moulding.

Thermoplastics are made from monomers that create long chains of the monomer linked together much like box cars on a train.

Homopolymers are a special case when only one monomer is used. Today, true homopolymers are becoming the exceptions, whereas only a decade ago they were predominant in terms of commercial volume. The trend today is to utilise catalysts to put together engineered versions of a polymer.

The development of olefins or oil formers as PE, polypropylene (PP) and polybutene were originally known has drastically changed since the 1970s. Originally the work by the German chemist Ziegler and the Italian chemist Guilio Natta commercialised the manufacture of olefins by the use of catalysts. These are referred to as Ziegler-Natta stereospecific catalysts.

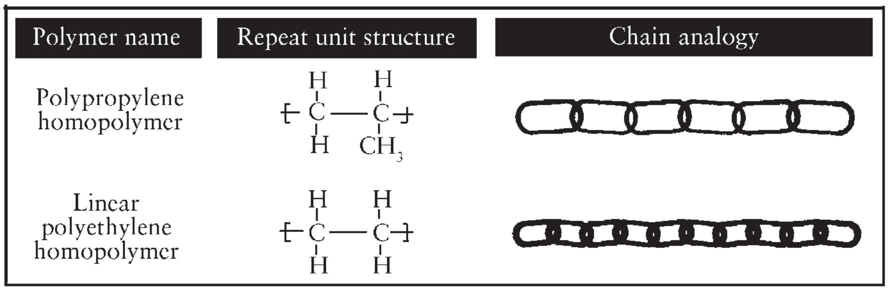
These small, molecular particles were coated onto beds of non reactive larger particles and gases such as ethylene, propylene and butylenes were heated and introduced to the catalysts. This process opened the chemical bonds and formed them into polymers with length and structure to order (see **Figure 2.31**).

Polymerisation is achieved by breaking the double bond of the ethylene (or other monomer) and linking it to other chains by a free radical process. The result is a continuous chain or linking of thousands of these monomer units into a giant polymer. The catalyst allowed control of the process and ultimate length of the PE (**Figure 2.32**).

$H_2–C = C – H_2$ -> $H_2 – C – C – H_2$

Ethylene monomer Free radical form

Figure 2.31 Polymerisation



Both the degree of polymerisation (chain length/molecular weight) and the repeat unit structure of a plastic material influence the material’s end use properties. Two materials with the same chain length, but different repeat unit structures, will have different properties.

Figure 2.32 Chain analogy

Three types of polymer configurations were identified by Ziegler, Natta and other scientists. These are atactic, isotactic and syndiotactic. These names indicate the amount of 'order' present in a polymer and represent the first attempt to classify this important characteristic of plastics:

Atactic: very random arrangement, disorderly. Atactic PP is cheeselike.
Isotactic: regular alternation or order.
Syndiotactic: controlled or specific alternation.

2.3.3 Amorphous and Crystalline

Thermoplastics can also be grouped into two structural categories, amorphous and crystalline. In an amorphous resin the molecules exist in a random coiled up state. These long chains are also intertwined with each other forming a glassy mass. In general, amorphous resins have less shrinkage when cooled. Processing is generally easier because of a forgiving melt temperature range, which helps to minimise the amount of stress moulded into a product. Products made from these resins can range from rigid with lower impact strength (for example PS or acrylic), or they can have excellent impact and clarity (as found in PC).

In a crystalline polymer, molecules are oriented in a more ordered fashion. The polymer chains essentially lie side by side in an orderly fashion. Crystalline polymers are usually tougher, softer and have high shrink rates when cooled. The melt ranges of these types of materials are usually narrow. Examples of crystalline resins are PE and Nylon. PP can be of either type or a blend (**Figure 2.33**).

2.3.4 Fundamental Properties

The physical performance of polymers can be characterised by using a series of tests. An understanding will then be developed on how materials are classified (grade) by testing and using this information an optimal material for a particular application can be picked. Throughout this section the designer needs to ask the following three questions:

A. What are the characteristics or properties of this material?

B. What role will these characteristics play in how the parts are moulded?

C. Will these characteristics make the material suitable for the application?

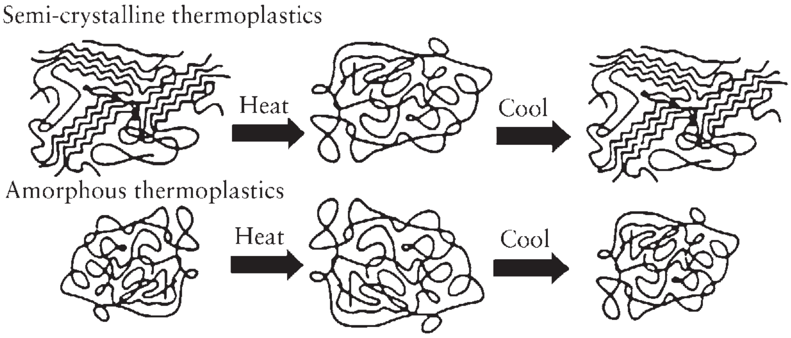


Figure 2.33 Amorphous and crystalline

The designer should also keep in mind four fundamental material concepts from which problems could occur. This will allow the performance difference or variance to be traced:

1. Average molecular weight

2. Morphology

3. Chain linking

4. Additives

2.3.4.1 Average Molecular Weight

Plastic materials are chain-like molecules made up of a repeating link or 'mer'. The number of links that make up the chain (i.e., the chain length or molecular weight) can vary considerably from one grade to another. Most materials are available in a wide variety of molecular weights, or more correctly, average molecular weights. Unlike most other materials, plastic material grades do not have a fixed molecular weight, but rather have a distribution of variable chain lengths leading to an average molecular weight as indicated in **Figure 2.34**.

The material grades with the higher average molecular weights tend to have better performance properties (creep resistance, chemical resistance, impact strength and so on) due to an increase in chain (molecular) entanglement and intermolecular attraction (i.e., the attractive forces between adjacent polymer chains). Those with lower molecular weights tend to offer improved processibility or lower melt viscosity, but somewhat lower material performance. In practice, plastic engineers and designers commonly refer to melt flow rate or melt index (MI).

2.3.4.2 Chain Linking

As stated previously, plastic materials are chain-like molecules made up of repeating links or mers as shown in **Figure 2.35**. Like molecular weight, the chemical structure of the repeating unit or link will influence the properties of a material. Both the degree of polymerisation (chain length/molecular weight) and the repeating unit structure of a plastic material influence the material's end use properties. Two materials with the same average chain length, but different repeating unit structures, will typically have different properties.

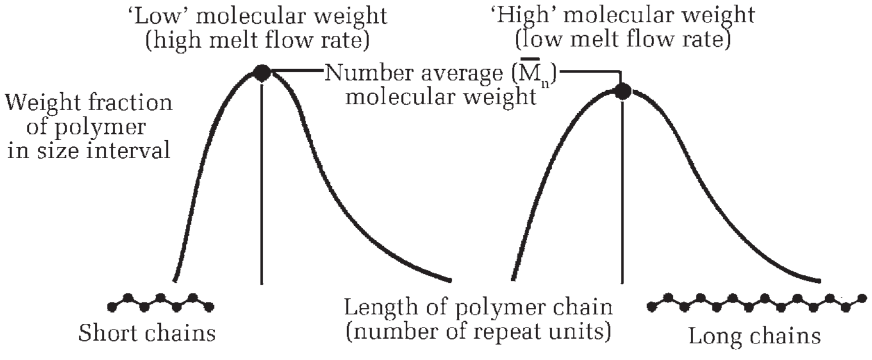


Figure 2.34 Molecular weight distribution

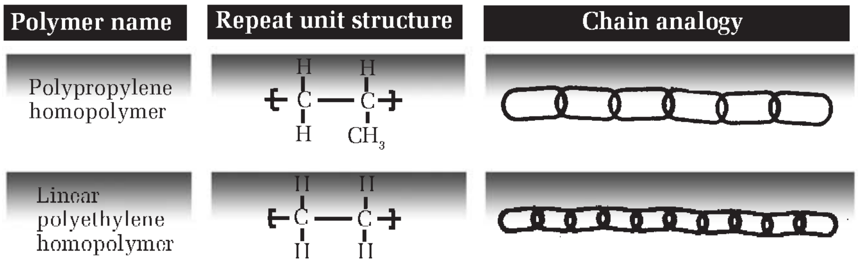


Figure 2.35 Chain linking

2.3.4.3 Morphology

Morphology is the way that the chains arrange themselves relative to one another. The most common chain arrangements associated with thermoplastics are random (amorphous) and semi-crystalline. The molecules of amorphous polymers, such as PS, are in theory random coils with no particular orientation. The materials soften when heated due to a reduction in intermolecular bonding, and gradually regain their strength as they cool in the mould. However, in practice, it is likely that there is at least some degree of 'frozen-in' orientation associated with the injection of hot melts into relatively cold moulds.

2.3.4.4 Additives

Almost all commercial plastic materials contain additives. Like medication, additives are beneficial in some respects, but can have negative side effects as well. This is particularly true when the additives are used at higher concentrations.

As an example, glass fibres are commonly used to enhance the stiffness, strength and dimensional stability of plastic materials. However, the side effects associated with the use of glass fibres include factors such as increased abrasion during processing and deterioration in the surface finish achievable.

A general understanding of these material factors will enhance the designer's ability to establish a suitable design, and avoid unanticipated processing or performance related problems. As a simple example, consider the embrittlement of a moulded thermoplastic part operating in a high temperature environment that is subject to intermittent loading (e.g., a latch mechanism). Initially, the part functions properly, but over time becomes brittle and fails under load. There are a number of possible causes of such ageing related failure, including: a possible change in structure or molecular weight due to oxidation, hydrolysis and/or UV light; a change in morphology (particularly for a semi-crystalline material; or a change in additive concentration (migration/evaporation of volatiles such as a plasticiser or even water). While there are many similar examples, the key point is to keep each of these four plastic material fundamentals in mind when making design related decisions or when diagnosing problems.

2.3.4.5 Physical Properties

The physical properties of polymers determine their selection for use in a particular product. Among the properties tested for in resins are average molecular weight, hardness, flexibility, tensile strength, flow, moisture content, and impact resistance. To gain a better understanding as to why a material is chosen for a specific job, the following properties are taken into account:

• *Specific Gravity*

By simply dropping a plastic sample in water we can gain an idea of its type and its specific gravity. Specific gravity is defined as the ratio of the weight of a given volume of a substance to that of an equal volume of another substance, usually water. In simpler terms we are comparing the difference in weight between resins when suspended in water.

If the sample material floats in water it may be PE or PP. These materials have a specific gravity less than water. Water is always referred to as 1. PE and PP are in the 0.90 - 0.96 range. If the sample material sinks in water it may be any of the materials that has specific gravity greater than water.

By using the specific gravity of a material, and then multiplying it by the accumulator capacity of PE (cubic units), one can calculate that head's capacity in the new resin.

For example: Specific gravity of PC is 1.20
Head Capacity x 35 units
Head Capacity in PC = 1.20 x 35 = 42 units of PE

Specific gravity can also explain why parts moulded of one resin may vary in weight when compared to the same part moulded in another material. For a list of specific gravities see **Table 2.2**.

Table 2.2 Specific gravity listing of materials

Phillips HMX-50100 HDPE	0.950
Allied BA50100 HDPE	0.950
Soltex K-50-10 HDPE	0.950
Phillips HGX-010 polpro	0.904
General Electric Cycolac ABS	1.020
General Electric Noryl PPO	1.100
General Electric Lexan PC	1.200
General Electric Prevex PPO	1.100
General Electric GTX PPO	1.100
General Electric Geloy 901	1.060
Dow Magnum 941 ABS	1.050
PPO: Polyphenylene oxide	

• *Melt Flow Rate (Melt Index)*

The MI of a resin describes the flow behaviour that can be expected during processing. The flow behaviour will vary with the molecular weight of the material. The test is measured in the number of grams of resin forced through a 2.95 mm orifice (die) when subjected to 2160 grams of force in 10 minutes at 190 °C. If the MI of a resin is high, the melt flow resistance during the process is low.

If a material is purchased in large quantities it is important to test them according to their criteria to ensure quality. If material is displaying poor hang strength or unusually low motor current, it signals the need for a MI check.

• *Moisture*

The absorption of moisture in the resin is an important factor that must be considered before processing. High moisture or 'wet' resins can cause blistering, weakened melt strength and poor part integrity. With many plastics, moisture must be kept below 0.2% by weight. This number is determined by the level of how much water is absorbed in 24 hours at room temperature, if greater than 0.1%, drying is required.

Resins that absorb moisture are called hygroscopic. A popular method for drying materials is the hot air desiccant process. Air is passed over and through a bed of moisture absorbing desiccant. This removes the water in the air and lowers the Dew Point. This makes the air very dry and causes it to pull moisture from the resin. A hopper drier can be mounted on the machine to keep material dry after it has left the primary unit. These units utilise hot air only.

• *Hardness*

Hardness is an important factor in the selection of a polymer for a given product. In general, hardness refers to scratch and abrasion resistance. Hardness is often associated with other properties to characterise materials. Material can be described as hard and tough, hard and brittle, or hard and strong.

The test for hardness is usually made by the indentation of a pin into the plastic surface. Measurements are made by 'Rockwell' hardness testers or 'Shore' durometers. Refer to **Table 2.3** for a comparison of hardness values based on the Rockwell Hardness Scale.

Table 2.3 Comparison of hardness values

Softer Materials		**Harder Materials**	
Material	**Rockwell hardness**	**Material**	**Rockwell hardness**
PC	130	HDPE	140
PPO/Noryl	120	Phenolic	130
	110		120
	100		110
PP (homopolymer)	90	Polyester	110
	80		90
	70	Polyvinyl chloride, acetal	80
	60		70
PU (flexible)	50		60
	40		50
HDPE	20		

• *Tensile Strength*

Tensile strength refers to the resistance of a plastic part to be pulled apart. The tensile strength of plastic materials range from 13.8 – 207 MPa. Tensile properties (see **Table 2.4**) are one of the most important single indications of a plastic's strength. A tensile testing machine can reveal a polymer's 'yield strength' or the point at which nonreturnable stretch begins. 'Ultimate elongation' or the maximum length a material can stretch before breaking is also measured. Associated with tensile strength is the term 'toughness'. This is defined as the total energy that is needed to break the sample. The tougher the material the more difficult it is to break. High tensile materials with good elongation such as PC and ABS are used in applications where impact is important. High tensile materials such as PS that have low elongation are too brittle for some applications unless they are rubber modified.

Table 2.4 Tensile strength of plastics

Plastic	Tensile strength, MPa	Tensile strength, psi
HDPE	24.12	3500
PP	26.2	3800
ABS	37.92	5500
PC	55.16	8000
Nylon	103.42	15,000

- *Creep*

Creep refers to the slow dimensional change of a plastic material when it is placed under load for a long period of time. Creep resistance is an important property for products that carry heavy loads which must be stacked. Temperature resistance is an important factor in creep.

2.4 Characteristics For Blow Moulding

2.4.1 HDPE

Characteristics of HDPE, which make it acceptable for blow moulding are:

a. High impact strength

b. Low temperature toughness

c. Excellent resistance to chemicals

d. Good electrical insulating properties

e. Poor ultraviolet resistance

Drying required: No
Melt temperature range: 188 - 232 °C

A recommended temperature profile is given in **Table 2.5**.

Table 2.5 Temperature profile for HDPE

Feed	187-193 °C	370-390 °F
Transition	193-204 °C	380-400 °F
Metering	193-204 °C	380-400 °F
Head	193-221 °C	380-430 °F

Regrind Ratio: Up to 100% can be used for two generations without it affecting the physical properties.

Pellet type: Virgin has a spherical shape.

Die Swell: 2 or 3:1 depending on die design and push out rates.

Blow up rate: 3:1 safely, 4:1 is possible depending on a part design.

Hang Strength: Very good when at proper processing temperatures.

Shrinkage: 0.38-1.02 mm/mm or 1.5-4.0%

Material Identification: Material in natural state is milky white. Burns easily with the smell of candle wax. Has a melting point of 130-135 °C. It can be cut easily with a knife or scratched with a fingernail.

Residence Time: In the absence of air, it remains stable for up to four hours.

Temperature consideration: Try to hold melt temperature at the lower end of the range. Temperatures that fall below this range can result in non-melt and/or have a rough finish. Temperatures above this range may result in high gloss streaking.

Mould cooling: Requires temperatures of 7.2-29 °C to provide optimum cooling cycle.

Cycle Times: Often restricted by the shrinkage of the part.

2.4.2 Acrylonitrile Butadiene Styrene (ABS)

Characteristics of ABS, which make it acceptable for blow moulding are:

a. A hard, tough material

b. Good impact resistance

c. Good electrical insulation properties

d. Versatile additive acceptance

Drying required: ABS is hygroscopic, that is, it will absorb moisture from the atmosphere. A dryer is recommended. Drying should be a minimum of four hours at 77-82 °C. Maximum drying time is twelve hours.

Melt temperature range: 199-227 °C.

A recommended temperature profile is given in **Table 2.6**.

Table 2.6 Temperature profile for ABS

Feed	187-193 °C	370-380 °F
Transition	193-221 °C	380-430 °F
Metering	193-221 °C	380-430 °F
Head	193-221 °C	380-430 °F

Regrind ratio: Up to 100% can be used but care must be taken that the physical properties of the part are not affected. Regrind may need to be dried if not used right away.

Pellet type: Virgin pellets are cylindrical in shape.

Die swell: 1.5:1 - Dependent on extrusion rate and head tool design.

Blow up rate: 1.5 or 2:1 - Dependent on part design.

Hang strength: Good compared to most engineered resins. Dependent upon melt temperature, parison weight distribution and additive package.

Shrinkage: 0.127-0.203 mm or 0.5-0.8%.

Material identification: Material will sink in water. Begins to melt at approximately the temperature of PE. Has a sweet styrene smell when dried.

Residence time: At high temperatures fumes can be a problem. It remains stable for only a short period of time. If an extended delay occurs, then lower heat to 121 °C. Contamination can be reduced if shot weight is at least 80% of head capacity.

Temperature consideration: Mould temperatures range from 24-85 °C. The higher the temperature the better the texture reproduction and parting line weld strength. Part design may require that mould halves be maintained at different temperatures.

2.4.3 Polycarbonate (PC)

Characteristics of PC, which make it acceptable for blow moulding are:

a. Excellent resistance to heat

b. Hard, tough material

c. Good impact resistance

Drying required: PC is hygroscopic and will readily pull moisture from the atmosphere. Drying temperatures are 93-105 °C for a minimum of six hours. Maximum drying times are eighteen hours.

Melt temp range: 254-271 °C.

A recommended temperature profile is given in **Table 2.7**.

Table 2.7 Temperature profile for PC

Feed	248-260 °C	480-500 °F
Transition	254-271 °C	490-520 °F
Metering	254–271 °C	490-520 °F
Head	254–271 °C	490-520 °F

Regrind ratio: Avoid using ratios above 50%. Regrind has a negative effect on hang strength of a parison after extrusion. Regrind material must be dried before use.

Pellet type: Virgin material has a cylindrical shape.

Die swell: 0.8 - 1:1 – This resin has no die swell. Will require larger head tooling than other resins.

Blow up rate: Typically 1:1 – part design is an important factor here. Quick set up rate of this material also plays an important role.

Hang strength: Poor stiffness at melt temperature. Parison support is critical. Top pinch bar may be required: 0.8 - 0.88%.

Shrinkage: 0.203-2.23 mm/mm.

Material identification: Pellets will sink in water. Material softens at 148 °C and melts at 221 °C.

Residence time: Material will degrade quickly if flow is stopped. Keep material moving. Degradation will occur at some point even if melt flow has not been stopped. This can be seen by the appearance of yellow and brown streaking. Purging with ABS may increase degradation.

Temperature considerations: Suggested mould temperatures are 35-98 °C. High mould temperatures produce texture reproduction and improve dimensional stability of the part. Pinch edge weld is also improved.

Start up: Start up temperatures should be -7 °C higher than normal operating temperatures, to reduce high screw load caused by cold material feed. Temperatures can then be lowered when a proper parison is produced.

Shutdown: Run machine completely dry. Purge with a high molecular weight material. Purging with ABS may increase degradation. As temperatures are brought down, the cooling PC will pull contamination off the interior walls of the extruder and head. Head tear down may be necessary after long runs with PC.

Cycle time: Because of the quick set up properties of PC cycle times are faster than many other materials.

2.4.4 Polypropylene

Characteristics of PP which make it, acceptable for blow moulding are:

a. Good impact strength

b. Good chemical resistance

c. High abrasion resistance

d. High melt strength

Drying required: None.

Melt temperature range: 191–232 °C.

A recommended temperature profile is given in **Table 2.8**.

Table 2.8 Temperature profile for PP

Feed	187-199 °C	370-390 °F
Transition	198-227 °C	390-440 °F
Metering	198-227 °C	390-440 °F
Head	198-227 °C	390-440 °F

Regrind ratio: Up to 100% re-grind can be used for two generations. In PP that is loaded with white pigment, yellow streaking may appear when re-grind is used. Lowering temperatures by 10-20 °C may help.

Pellet type: Virgin pellets are spherical in shape.

Die swell: 2 or 3:1 depending on die design and extrusion rate.

Blow up ratio: A maximum of 3:1 for the best moulding performance. Mould design may decrease this ratio.

Hang strength: Very good at proper melt temperatures.

Shrinkage: 0.304-330 mm/mm.

Material identification: Virgin material is milky in colour. Pellets will float in water. Pellets have hard, dry feel. They have a candle like smell when burned. It will begin to melt at 170 °C.

Residence time: Similar to PE but will degrade more readily. If melt flow must be stopped be sure to fill and purge the head every twenty minutes.

Temperature considerations: Mould temperatures must be in the 10-24 °C range to provide the quickest cycle. Mould texture will reproduce at these temperatures.

Cycle times: Like most materials with high shrink rates, parts made of PP are often cycle restricted. Use the lowest mould temperatures possible that will still provide the desired surface finish.

2.4.5. Polyphenylene Oxide

Characteristics of polyphenylene oxide that make it good for blow moulding are:

a. Good flame retardancy

b. Good chemical resistance

c. Good impact resistance

d. Retains mechanical properties in high heat environments

Drying required: Dry for a minimum of four hours at 82 °C Maximum drying time is eighteen hours. Re-grind will need to be dried if not used within an hour.

Melt temperature range: 204-227 °C.

A recommended temperature profile is shown in **Table 2.9**.

Table 2.9 Temperature profile for PPO

Feed	199-210 °C	390-410 °F
Transition	204-221 °C	400-430 °F
Metering	204-221 °C	400-430 °F
Head	204-221 °C	400-430 °F

Regrind ratio: Up to 100% regrind may be used in some applications. If possible, it should be kept below 50% for the best melt strength.

Pellet type: Virgin pellets are cylindrical in shape. Pellets often come pre-coloured.

Die swell: 0.9 - 1:1 – Die swell marginally better than with PC. May require larger head tooling than most resins. Diverging tooling will be required in most cases.

Blow up ratio: 1 or 1.2:1 – depending on part design.

Hang strength: Marginally better than PC. Staying on the low end of the melt range will provide best stiffness. Parison support is required in most cases.

Shrinkage: 0.152-0.229 mm/mm or 0.6-0.9%.

Material identification: Pellets will sink in water. Material has a strong styrene smell when processed. Smoking may be a problem when melt temperatures are too high.

Residence time: Material will begin to degrade in 1-2 hours if melt flow is stopped. Purge each half-hour to avoid degradation.

Temperature considerations: Mould temperatures can range from 21–85 °C. Higher mould temperatures provide better reproducibility and weld strength.

Cycle times: This material sets up quickly and provides for fast cycle times. Wall thicknesses above 2.27 mm will require longer cycles.

2.5 Colouring Plastic Materials

Thermoplastic materials, in general, can be moulded in a wide range of colours. The colour can be provided in a pre-coloured base plastic or by adding solid or liquid colour concentrates at the machine just prior to plasticisation.

Colour concentrates are high pigment content dispersions of colorants in carrier resins. The concentrate supplier matches the desired colour with a blend of colorants. The supplier then compounds a concentration formula, typically 20-60%, in a carrier resin. Additives such as antioxidants, stabilisers and anti-blocking agents are often co-blended at this point. A recommendation is then made as to the amount of concentrate required to blend with the base resin to obtain the desired colour. This is referred to as the let down ratio.

Example: if 45 kg of resin is mixed with 0.45 kg of concentrate the ratio is 100:1

Generally, the lower the ratio (25:1, 30:1) the easier it is to disperse the colour accurately. Factors such as screw L/D ratio and screw speed may also require different percentages of pigment to those originally suggested. The reason for this is the pigments need to be mixed in the screw, the less time it spends in the screw, the less mixing takes place.

The carrier resin is preferably the same as the let down resin for good compatibility. The melt flow of the carrier resin should be high enough that it will mix readily and uniformly throughout the let down resin.

The important quality check for colour concentrates is the colour match. The colour chip must match when compared to the moulded part and colour references.

It is important that the type of light under which a match is checked be specified. Ultraviolet, fluorescent and sunlight are common choices. Colours may match under one source of light but not another. This is known as metamerism.

Colour concentrates are heat sensitive and may reduce available residence times. Generally, reds are the most heat stable while yellows and oranges work in the moderate range. Darker colours work in the low heat tolerance range.

Colour concentrates which have a hygroscopic base resin may need to be blended first then dried. They may require re-drying prior to mixing in an extruder to ensure that good parts are obtained.

2.6 Regrind

Blow moulding by its nature will generate a certain amount of flash. In some parts flash can be up to 100% of the total part weight. It is an economic must that this flash be recovered as regrind.

In order for this regrind to be used for finished product it must be kept clean. Foreign material can harm surface appearance and degrade the properties of the part or resin. Foreign material may also hang up in the head and cause additional foreign material build-up. All material should be covered and all material handling equipment (grinders, boxes, loader) should be clean.

The amount re-grind used in a given product is determined by several factors.

2.6.1 Re-grind Specifications

Many times testing of physical properties is required to determine a maximum or optimal amount of re-grind in the finished product. Reprocessing material tends to reduce these values.

2.6.2 Process Performance

For some materials, re-grind levels above 50% can have a negative affect on hang strength and die swell. Parison length consistency will also be a problem.

2.6.3 Physical Properties

Some resins will lose important physical characteristics at high re-grind levels. Most resin suppliers recommend that a re-grind have no more that three heat histories. Parts, which need to withstand impact or repeated stress, should be produced with precisely controlled levels of re-grind.

Quantities of flash can be reduced by keeping the mould as close to the head as possible and by using the proper size head tool for the job.

Regrind with a high degree of dust or ‘fines’ may require feed zone temperatures to be reduced -12 to -7 °C. This will help prevent premature melting of the plastic.

Regrind percentages may affect colour loading ratios or the processors’ ability to match a specified colour. This relates to the fact that many colours are heat sensitive and will change shades after being reprocessed.

Regrind material will be conveyed differently to virgin pellets, because of the irregular shape of the reground pellets. Materials which are ‘rubbery’ in feel will tend to stick together. PP materials have a tendency to bridge due to pellet shape.

2.7 Post Consumer and Industrial Recycled Materials

The majority of the factors to be considered in processing are the same for recycled HDPE and virgin HDPE. Other materials are not blow moulded in volumes that are finding their way into the recycling stream. HDPE in a variety of grades, especially for blow moulding is the largest volume plastic available. The items to be considered most in handling the recycled material is that chips or flakes will flow differently to pellets. This will cause a problem in both the initial feed area due to more chance of bridging at the extruder inlet. The presence of fines in the flake increases this situation. Determination of the amount of fines is often a very important specification to have in order to evaluate the potential for this type of problem.

The problem of optimising the concentration level of the recycled HDPE to the virgin HDPE in a given application centres on the long-term property requirements, as well as, the short term properties. Exposure of test bars of the material to accelerated or natural UV radiation is necessary to establish the long-term toughness of the material and compare it to the initial value for the HDPE. This will ensure the selected material ratio will meet the short-term and long-term requirements for the product.

The same procedure would be duplicated for any recycled plastic material. Blending virgin and recycled material together requires a determination of which blend will meet the specifications that are normally applied to virgin materials. The feed streams for HDPE and other plastics will give different characteristics. Staying with HDPE for example, milk jugs are at one end of the spectrum with fractional melt indices. This is good for blow moulding, bad for injection moulding where high flow (MI of 20-30) is necessary. Detergent bottles of mixed colours, where melt indices of fractional to 5 or so are common - once again, this is good for extrusion and blow moulding, less attractive for injection moulding. Films (trash bags, pallet wrap, and so on) are also poor for injection moulding but good for extrusion or blown film applications. The point being, testing must be done when a given stream of recycled material is being considered. This will ensure that the proper recycled material gets into the proper production part or product.

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3 Mould Design and Engineering

3.1 Main Characteristics of the Mould

The mould determines the shape of the end product with all its details. It helps provide an end product with the essential physical properties and the desired appearance. Usually, the mould maker builds the blowing mould according to the holder's or his customer's specifications. But frequently, minor adjustments or improvements, which would not justify its being returned to the mould maker, can be made with equipment and knowledge available in the blow moulding shop.

The blowing mould may have a number of parts, counting its various inserts, but it usually consists of two halves. When closed, these halves will form one or more cavities which will enclose one or more parisons for blowing. The two mould halves are usually alike. There are usually no male and female sections.

Pinch-off edges are generally provided at both ends of the mould halves. A blowing pin may have the additional function of shaping and finishing the neck inside.

Both mould halves must have built-in channels for the cooling water. Sets of guide pins and bushings or side plates in both mould halves ensure perfect cavity alignment and mould closing. Accurate guiding devices in both mould halves reduce setup time. **Figure 3.1** shows the two halves of a blowing mould for small bottles. **Figure 3.2** shows basic features and the location of the cooling-water channels.

On some blowing presses, mould closing is carried out in two steps, first at high speed, with lower pressure to say, 6.5 to 13 mm 'daylight'. The second step is slower with higher pressure to protect the mould from tools or anything else that might have fallen between the halves (which, however, should never happen in a well-kept shop) and for operator safety.

Moulds are not necessarily positioned vertically, that is, in line with the parison. They may occasionally be tilted (**Figure 3.3**). This will result in a non-uniform distribution of resin which may be helpful, for example instance when such irregular pieces as a pitcher with a handle are being blown. It may also result in some saving in parison length.

3.2 Basic Design and Construction Considerations

The chart in **Table 3.1** shows the things that need to be considered when determining what type of mould to build.

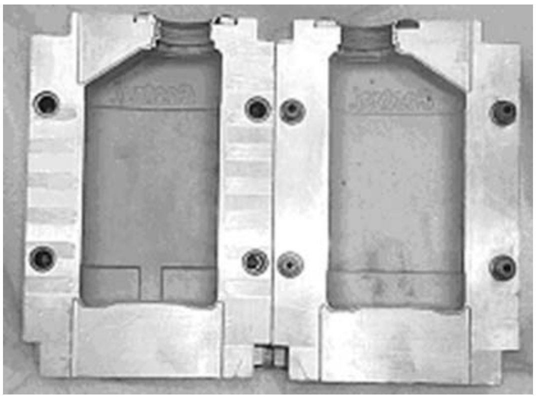

Figure 3.1 Mould halves

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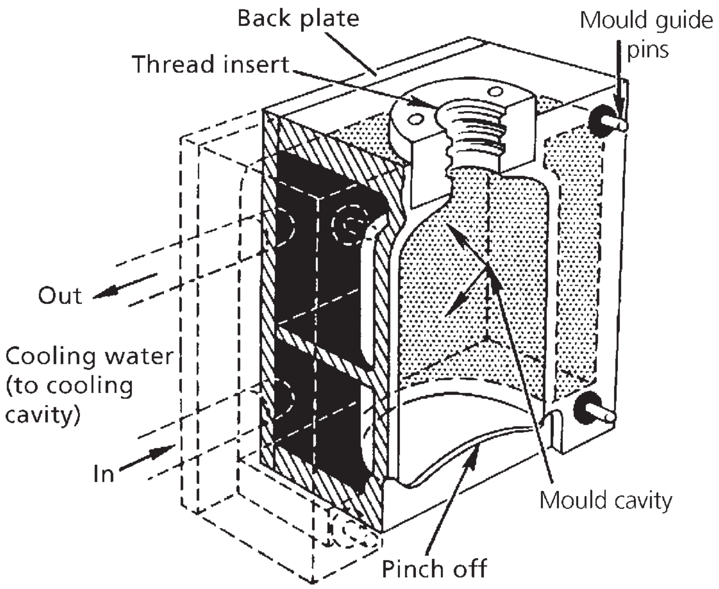

Figure 3.2 Basic features

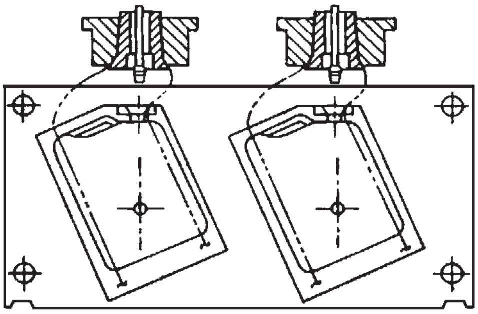

Figure 3.3 Tilted mould

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Table 3.1 Basic mould design criteria

Property	Criteria
Select the right mould material	Strength, heat transfer, cost
Proper mould cooling	Turbulent flow, fastest cycle
Venting of the cavity	Correct part shape, less scrap
Correct pinch-off design	Good weld line, leak proof

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3.2.1 Mould Materials

Because of the comparatively low clamping and blowing pressures, the blow mould need not be made of a high tensile strength material, with the possible exception of moulds for very long production runs, say, hundreds of thousands or millions, which are sometimes made of steel. The predominant raw materials used for blow moulds are machined from aluminium billet, cast aluminium alloys, zinc alloys such as Kirksite, and occasionally, bronze. Beryllium-copper because of expense and difficulty to machine is usually reserved for pinch inserts or cores where fast heat transfer is needed. All these alloys are excellent materials for blow moulds (**Table 3.2**).

Table 3.2 Mould alloys

Product	Thermal Conductivity (W/m °C)	Rockwell Hardness	Charpy V-notch Impact Strength (J)	Compressive Yield Strength (MPa)	Tensile Strength (ksi)	Elongation (%)	Coefficient of Thermal Expansion (10^{-6}/F)
Stainless steel 420	22	HRC 50	16	1482	1758	10	6.1
Tool steel H-13	26	HRC 45	19	1275	1448	15	7.1
*Moldmax® high hardness	104	HRC 40	5	1069	1275	6	9.7
*Moldmax® low hardness	130	HRC 30	16	965	1172	10	9.7
Tool steel P-20	29	HRC 30	34	758	965	20	7.1
*Protherm®	251	HRB 96	68	621	793	18	9.8
Alloy 940	207	HRB 94	47	517	689	12	9.7
Alumec 89	164	HRB 88	41	517	552	7	12.9
Aluminium QC7	138	HRB 80	41	448	538	7	12.8

**Brush Wellman certifies hardness value only, upon request*
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Aluminium is the softest of the mould materials in use and is most easily damaged in the shop. Furthermore, aluminium moulds wear easily. On the other hand, they are easiest to machine. Aluminium and beryllium-copper cast moulds may be slightly porous, and occasionally, blow moulders have experienced some permeability of such moulds to the viscous resin. This may affect the appearance of the blown part. The remedy is coating the inside of the mould halves with a sealer (such as radiator sealer). This will not affect the heat transfer between the resin blown against the mould and the mould walls.

Steel moulds are heavier, more expensive and more difficult to machine than those made of non-ferrous alloys. Higher weight will mean more setup time in the moulding shop. Moreover, the heat conductivity of steel is inferior to that of the three non-ferrous mould materials. This results in a slower cooling rate and a correspondingly longer cooling cycle and consequently, a lower production rate for steel moulds.

3.2.2 Selection of Materials

The selection of the material from which the mould is to be constructed not only depends upon the properties previously mentioned but how the part to be moulded is configured, which in turn determines the method of manufacture and the cooling requirements.

Table 3.3 gives the characteristics for each method of mould manufacture.

Table 3.3 Selection of materials

Property	Criteria
As-cast aluminium moulds	Intricate shapes, prototypes, short run, low cost
Cast to shape moulds and cut to size	Good part accuracy *versus* mould price
Cut from billet moulds	High accuracy parts, long runs, superior metal qualities

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3.2.3 Characteristics of Mould Materials

3.2.3.1 Aluminium Alloys

QC Mould Plate: This is a high-strength aluminium alloy which, is fully heat-treated and stress relieved. This alloy has outstanding thermal conductivity along with high strength and surface hardness and as such is suitable for polishing and texturing. All gauge tolerances are on the plus side of nominal. This alloy is suited for use in production injection moulds, blow moulds, structural foam moulds, reaction injection moulding (RIM) moulds, and aluminium die sets. It is weldable and highly machinable.

2024, T351/7075, T651: These are general purpose, high-strength aluminium alloys suitable for blow moulds and structural foam moulds.

ALUMOLO ONE: This high-strength alloy is heat-treated and stress relieved. It is ideally suited for large blow moulds, injection moulds, and other high-pressure mould applications. It is also suitable for use in aluminium die sets. It exhibits very high strength and surface hardness with excellent thermal conductivity. It is weldable and highly machinable.

ALUMOLO TWO: This is a high-strength aluminium alloy suitable for blow moulds, structural foam moulds and injection moulds, which currently use alloy 7075. It has higher strength and surface hardness than 7075 even when thicker than 8.9 cm. There is no copper in the alloy giving it greater resistance to corrosion. It can be heat-treated and stress relieved. This alloy is not quench sensitive like the alloy 7075 is and, therefore holds its high strength even at a thickness greater than 8.9 cm.

6013 and T651: This alloy combines the high corrosion resistance, thermal conductivity and weldability of 6061 with the high Brinell hardness of 2024. It machines with the same feeds and speeds, creates similar chip sizes and has a surface finish that is found in 7075 or 2024 alloys. The material is heat-treated, aged to peak strength, and stress relieved. It is suitable for many 6061 or 2024 applications.

6061-T6, T651, T652, Aluminium Heavy Plate: These alloys which are heat-treated (and stress relieved in the case of T651 and T652) are generally suited for low-pressure applications including large blow moulds, prototype injection moulds, compression moulds, vacuum form moulds, RIM moulds, and structural foam moulds. These alloys have excellent thermal conductivity but exhibit relatively low strength and surface hardness. Therefore, these alloys are not recommended for applications requiring high surface hardness.

6061- T6511 VSQT: This extruded aluminium plate is heat-treated and stress relieved and is suitable for use in vacuum-form moulds and investment-cast moulds. It is also suitable for use as back plates on blow moulds and structural foam moulds. This alloy's hardness and thermal conductivity are the same as 6061 mould plate.

MIC-se: This direct, chill-cast alloy exhibits very low internal stress and therefore machines relatively stress free. Its high degree of surface finish, typically 0.635 µm, eliminates costly additional surface machining. This alloy is suitable for low-strength mould applications such as vacuum form moulds.

ALCA MAXe: This cast alloy gets its unique properties from a proprietary thermal treatment. This product is thermally stable with 0.127 mm maximum deviation upon machining. It exhibits uniformly consistent machinability and polishability throughout the thickness of the plate. This alloy is suitable for use in large blow moulds, prototype injection moulds, structural foam moulds, and investment cast moulds. It is weldable and is virtually residual stress free.

3.2.3.2 Copper Alloys

Moldmax: These high-strength beryllium-copper alloys are suitable for mould applications requiring high thermal conductivity, high surface hardness, and high strength. The alloys are supplied as 40 RC and 30 RC and are already heat-treated. They offer good corrosion resistance, excellent polishability, good wear resistance and excellent weldability. They can be used for entire moulds or inserts in steel and aluminium moulds.

Protherm: This very high thermal conductivity beryllium-copper alloy is suitable for mould applications requiring more rapid removal of heat than can be attained in steel or aluminium moulds. It offers excellent corrosion resistance, good polishability, excellent weldability, and resistance to high temperatures. It is also suitable for gates and nozzle tips.

NOTE: for machining beryllium-copper alloys contact your supplier.

Ampco 940: This nickel-silicon-chromium-copper alloy features superior thermal conductivity, the ability to accept high surface finishes, inherent corrosion resistance, welding compatibility with other copper alloys, and is readily machined.

Telmax - Tellurium-Copper: This is a highly machinable, tellurium-copper alloy suitable for manufacturing electrodes for the electrical discharge machining (EDM) industry. It combines low cost, mirror finishes, high strength, high resistance to DC arcing, with no dust generation. It is recommended for use in limited-flushing applications.

3.2.3.3 Stainless Steel

440C: This is a high carbon stainless steel that has maximum hardness with other good stainless steel properties. It has excellent corrosion resistance, polishability, and resistance to wear. These characteristics make it suitable for injection moulds.

3.3 Cut Mould *versus* Cast Moulds

3.3.1 Cast Aluminium Moulds

The following figures show typical examples of cast moulds and parts made from cast moulds. Basically they have detailed texture of design such as feathers or irregular part lines, see **Figures 3.4**, **3.5**, and **3.6**.

Also, fuel tanks because of their irregular shape are often cast moulds (**Figure 3.10**).

Figure 3.4 Examples of objects made using cast aluminium moulds

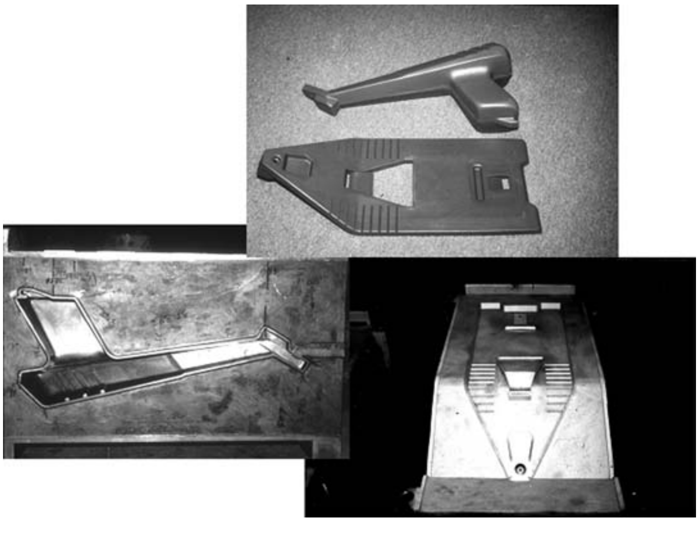

Figure 3.5 Examples of objects made using cast aluminium moulds

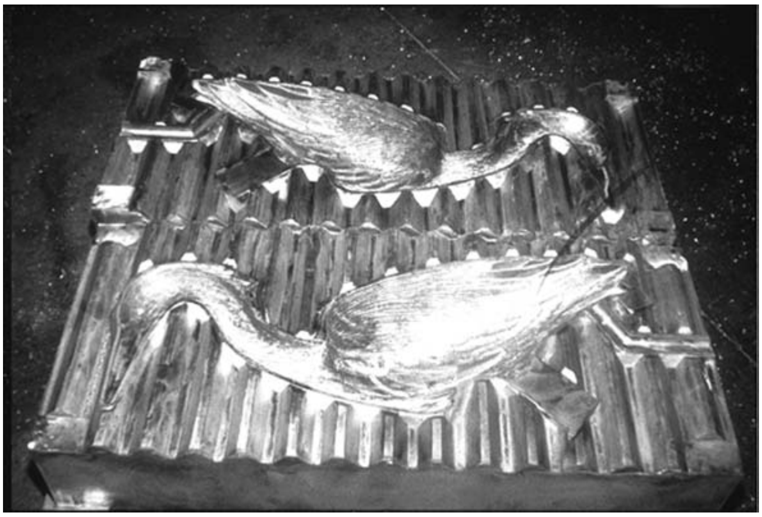

Figure 3.6 Objects made using cast aluminium moulds

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3.3.2 Cut Moulds

When dimension control is required, machined moulding is the method of choice. With computer numerically controlled (CNC) machines common in today's machine shops the cost has come within range of a cast mould. CNC machines are shown in **Figures 3.7** and **3.8**.

3.3.3 Cast and Cut Moulds

For some large parts it is preferable to cast the shape. Since aluminium billets have a limitation on thickness, moulds would need to be fabricated, but because some dimensions are critical they have to be machined. Examples are shown in **Figure 3.9** and **Figure 3.10**.

3.4 Importance of Fast Mould Cooling

3.4.1 Fast Heat Transfer Material Considerations

Fast heat transfer of the material of which the mould is made is of utmost importance because the cooling step controls the length of the blow moulding cycle (cooling takes up roughly two-thirds of the entire blowing cycle). Good heat transfer means faster cooling, and faster cooling means more items blown per hour, that is, less expensive production. This is the main reason why, for blowing moulds, the previously mentioned alloys are generally preferred to, the usually, more durable steel.

3.4.1.1 Heat Transfer Considerations

Considering only their heat transfer rate, the principal blowing mould materials follow each other in this order: beryllium-copper, aluminium, Kirksite, and steel.

Occasionally, several different alloys are used in the same mould to obtain the desired strength and special cooling conditions. However, as these mould materials have different heat transfer rates, a blow mould, with the exception of the steel pinch-off inserts (see 'Pinch Off' - Section 3.5) should really be made of only one material. Different materials with consequently different heat conductivity at various points in the mould will result in non-uniform cooling. This, in turn, might set up areas of stress in the finished piece, which are susceptible to splitting in use.

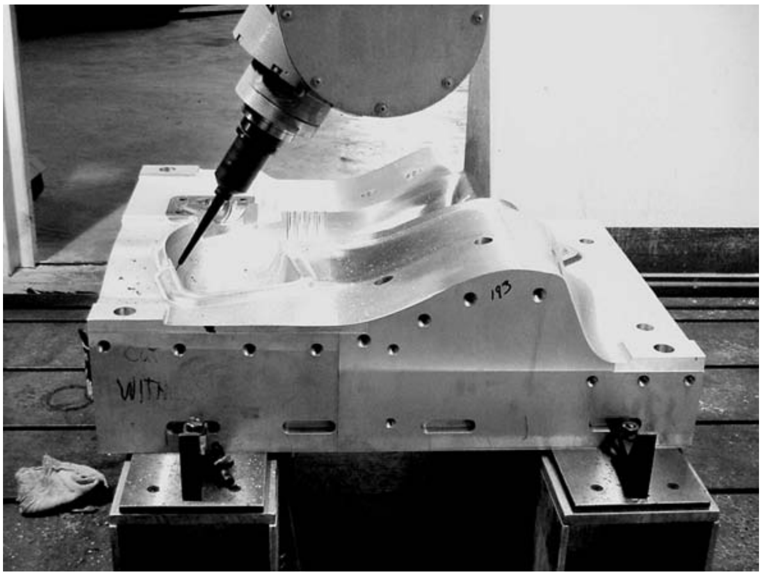

Figure 3.7 CNC machine

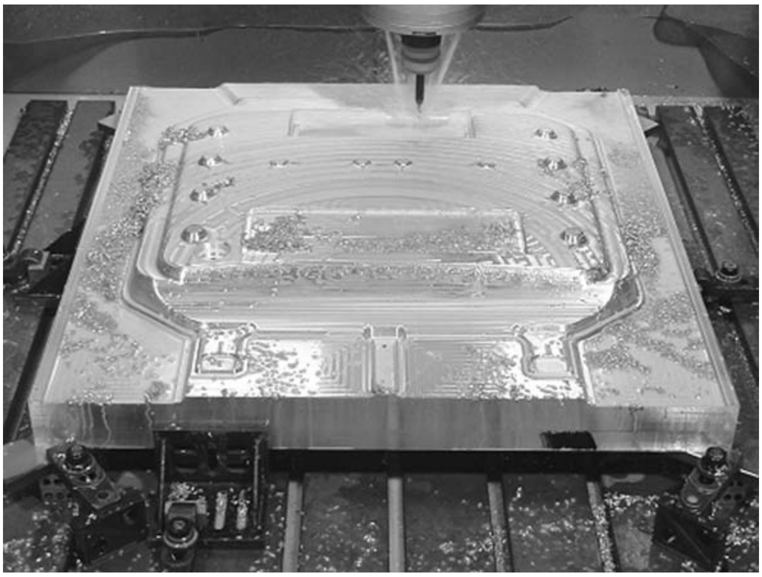

Figure 3.8 CNC machine

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3.4.1.2 Mould Halves

The blow mould halves must always be adequately cooled to solidify the part quickly, immediately after the parison has been blown out against the mould walls.

The cooling water may be tap water. If it has a high content of minerals, which may settle in the narrow, cooling channels, a closed system for circulating purified water should be used. Unless the water is cold enough (as for example, in winter), it should be chilled by a heat exchanger to 4 to 20 °C. Such low temperatures may, however cause water condensation on the outside mould walls. Some moulders, though, use non-cooled tap water. Usually, the cooling water is recirculated, that is, reused time and again for a long period. Sometimes, it is partly recirculated and mixed with

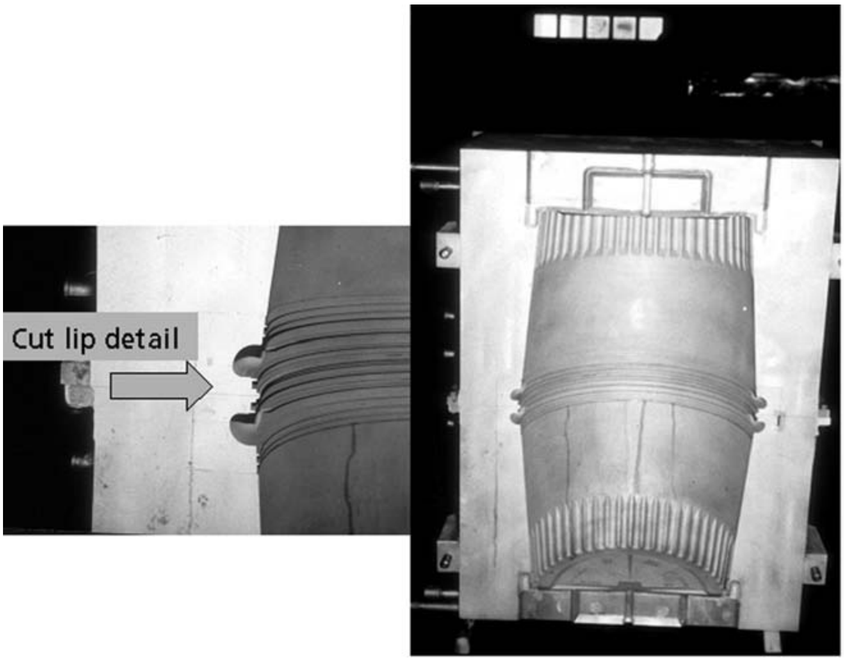

Figure 3.9 Cast and cut moulds

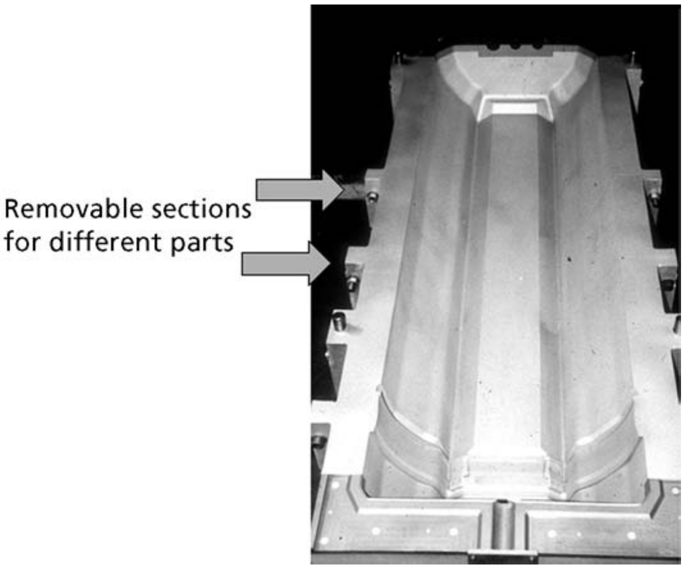

Figure 3.10 Cast and cut moulds

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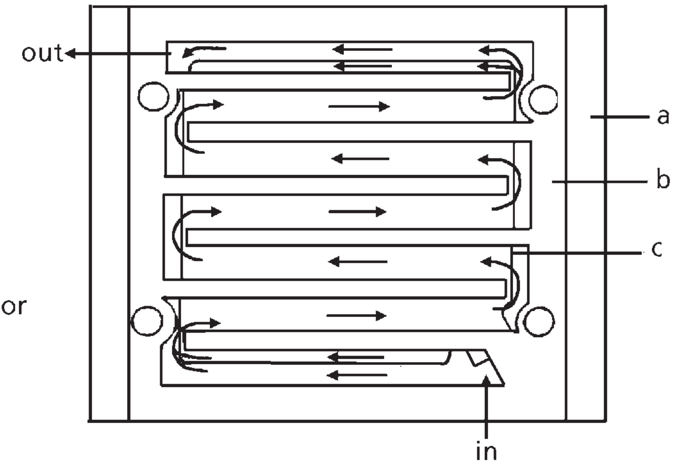
fresh tap water, to maintain the desired temperature and to economise. Conduit flow is determined by Reynold's number:

$$Re = \frac{pVd}{n} \qquad (3.1)$$

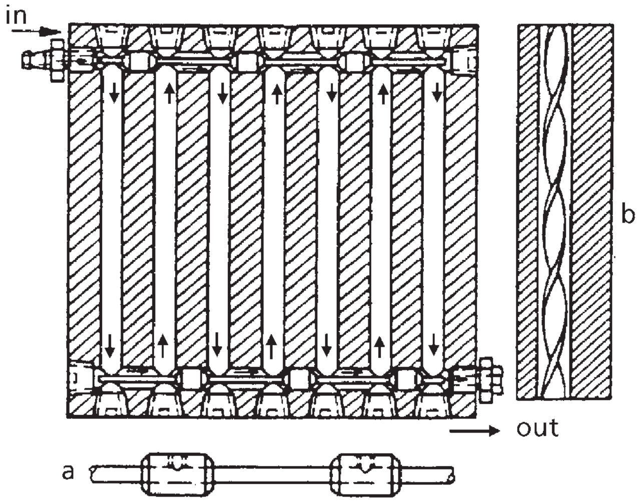
where: p = fluid density
V = mean (av.) flow velocity
d = diameter of the channel
n = viscosity of fluid

3.4.1.3 Water Circulation

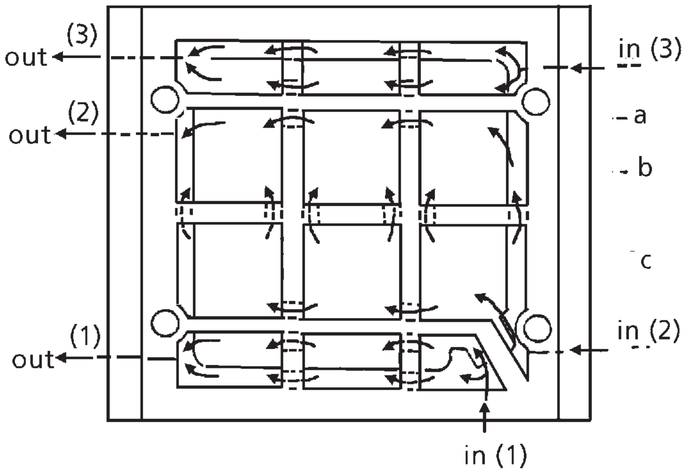
The water usually circulates through the hollow mould halves. Sometimes, a copper tubing system is cast into the mould. However, to create the most useful flow, water channels are machined into the mould halves (See **Figure 3.11**). Well-placed channels will ensure that the cooling water comes as close to the mould cavity as is feasible (see **Figures 3.12**, **3.13** and **3.14**).



Channel system with labyrinth-type water flow produced by baffles.
(a) Mounting plate
(b) Blow mould
(c) Visible contours of mould cavity for a canister with fillers connections at one corner



Cooling channels with labyrinth-type water flow.
(a) Continuous rod with stoppers
(b) Inserted copper spiral



Cooling a blow mould by means of three cooling circuits and cooling chambers.
(a) Mounting plate
(b) Blow mould
(c) Visible contours of mould cavity for a canister with a filler connection at one corner

Figure 3.11a, b, c Cooling channels

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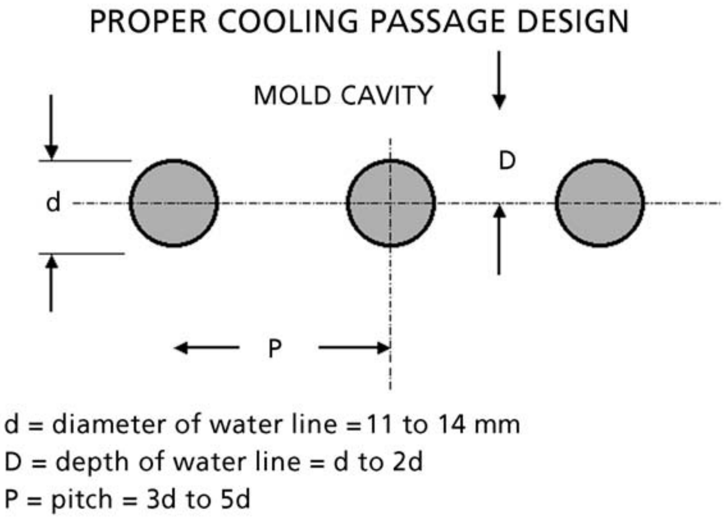

Figure 3.12 Cooling water lines spacing

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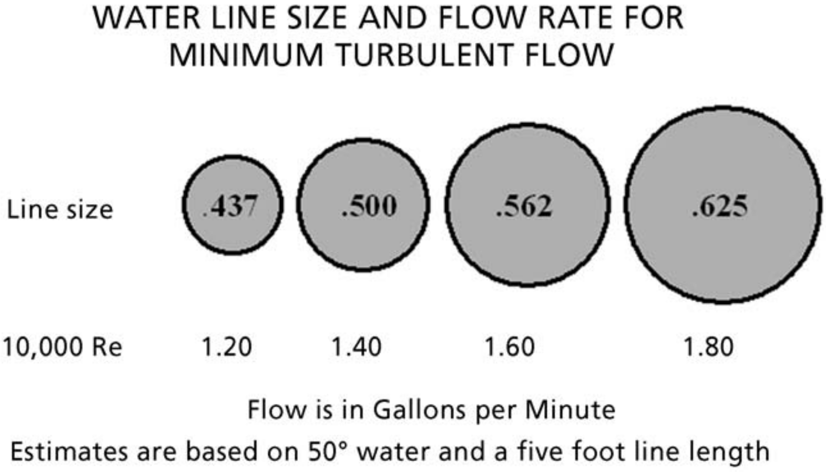

Figure 3.13 Cooling water lines sizes

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Note: Drilled holes are tapped sizes for National Pipe Thread Standards for inlet and outlet threaded holes. For metric use appropriate equivalent

For proper cooling passage design, the use of 'plug baffles' (borrowed from injection moulding) are recommended for deep cores (see **Figure 3.15**). Pictures of a mould half showing an in and out cooling channel is shown in **Figure 3.16**.

Larger moulds may be equipped with several - up to three or more - independent cooling zones. Generally, in the top or bottom areas, that is, around a bottleneck or the bottom pinch-off, or both, greater masses of resin are needed than along the other areas. Such areas as well as thicker wall sections, therefore, often require additional cooling. Otherwise, these sections would still be viscous while the thinner wall sections have solidified when the piece is ejected. This may result in a deformed piece or one with non-uniform shrinkage and resulting warpage, which the customer will reject. That is why frequently even a simple mould has two or more cooling systems for each half.

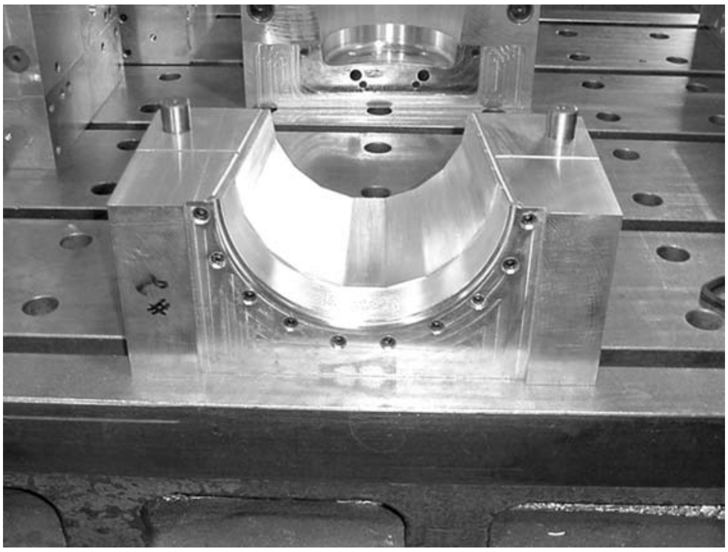

Figure 3.14 Cooling channels in and out

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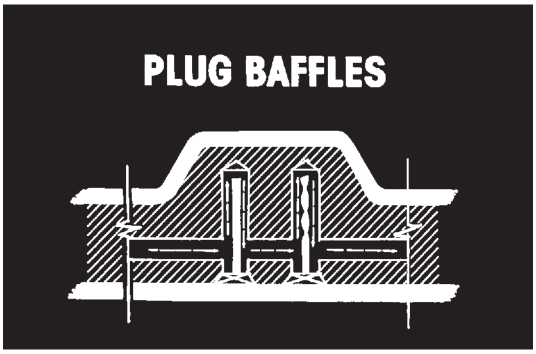

Figure 3.15 Plug baffles

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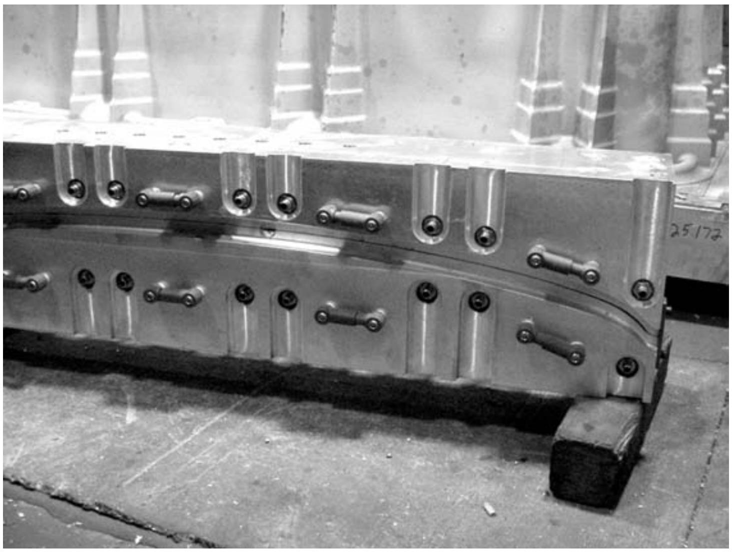

Figure 3.16 Cooling channels in and out

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3.4.2 Manifolds

The following is the proper way to manifold a mould, or cooling plate, for fast cycles. Any mould run for a year (for around 800 to 1,000 pieces total) will pay for itself in faster cooling cycles and better parts.

No cooling channels or tubing should be more than three or four metres long without going into a manifold. High turbulence in the cooling fluid is essential for fast cycles. Every molecule of the controlled temperature fluid needs to bounce off the side walls. The nature of conduit flow (laminar or turbulent) is determined by the value of the Reynolds number (Re) (Equation 3.1).

3.4.2.1 Turbulent Flow

In the movement of a fluid through a flow channel, turbulent flow will occur when turbulence is above the critical Reynolds number, which is about 2,100. Below the critical number, laminar flow occurs - this is referred to as streamline flow. The greater the Reynolds number is above 2,100, the more efficient the cooling regardless of how the mould temperature drops, or if the internal stresses in the formed part increase.

Increasing the flow rate from a Reynolds number of 2,000 to a Reynolds number of 10,000 increases the heat transfer coefficient by about nine times. In other words, the more turbulence, the better the cooling rate.

When copper tubing is swaged into machine channels, the tubing should have an outer diameter of 12.7 mm and again, no tubing should run more than three or four metres before going into a manifold.

The use of a manifold with ‘in’ and ‘out’ openings (use quick disconnect) is recommended to obtain more even cooling of mould cooling plate (cavity) and thus the part (see **Figure 3.17**).

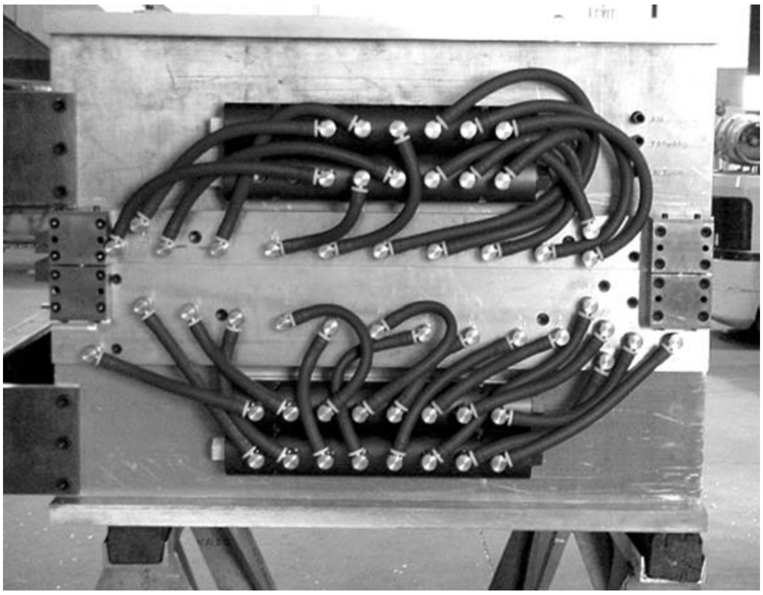

Figure 3.17 Manifold in and out

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3.4.2.2 Blowing Pin Cooling

Occasionally, the blowing pin is also cooled. Sometimes, air cooling from the outside is provided for the pinched 'tail' of the parison sticking out of the mould bottom. The 'tail' is much thicker than the wall and cools correspondingly slower. Air may be circulated inside the blown part to speed up its cooling.

Cooling time is strongly affected by the extrusion melt temperature of the blow moulding cycle. It has been found that an increase, or decrease, of 6 °C in melt temperature can extend, or shorten, the cooling cycle by as much as one second.

See *Further Reading* at the end of the chapter.

3.4.3 Control of Flash

3.4.3.1 Flash Control Ability

The ability to control the adverse effects of flash is critical to success in extrusion blow moulding.

Flash generation imposes limits on blow moulding efficiency. Economics dictate that flash materials be recaptured in a closed-loop operation. Flash removal also calls for a post-moulding trim step, which requires special equipment and poses a risk of increased levels of defective parts. Further, flash has the potential for significantly extending the blow moulding cycle, primarily by increasing the time needed to cool a blow moulding.

3.4.3.2 Impacts On Cooling Cycle

Flash is created at the pinch points, which means that flash thickness is typically double that of the part's maximum wall thickness. Further, since flash is integral to the moulding and remains in the tool during cooling, it typically doubles the time required to fully cool the moulding.

In practice, most blow moulders minimise this cooling time penalty by ejecting the part before the flash is fully cooled. That approach, however, means that flash is still soft and pliable when ejected, which in turn can create other problems. One is a tendency for flash to fold over on itself and adhere to adjoining parts following ejection of the moulding (**Figure 3.18**).

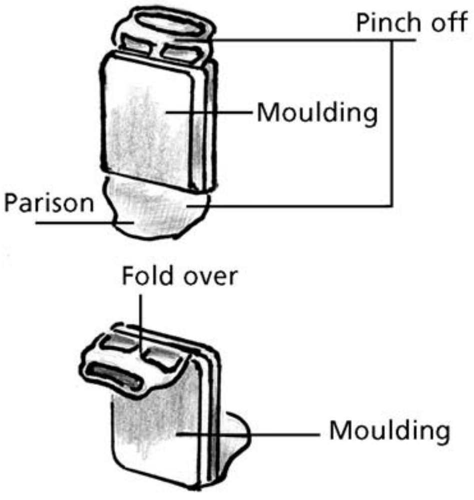


Figure 3.18 Flash fold over

Flash is also considerably more difficult to handle and trim when the moulding is ejected while hot. In either case, the resultant penalty may be a significant increase in the part reject rate.

In theory, the solution to this dilemma is to reduce to the greatest possible extent, the change between the different cooling times for the flash and the part. To achieve that calls for an understanding of the forces at work in the cooling of an extrusion blow mould, and transfer of that know-how into design or modification of tools.

3.4.4 Rate of Cooling

Factors that affect the rate of cooling of a blow moulded part include the inherent thermal properties of the resin involved and the processing parameters used. In addition, the cooling time is influenced by the rate at which heat is removed from the mould, which in turn can be optimised through skilful design of air, water or oil cooling channels machined into the mould. The most widely used cooling medium in extrusion blow moulding is water.

The nature of flow patterns that are induced in a water-cooled mould channel (and the cooling rates associated with these patterns), is defined by the Reynolds Number (Re). The underlying equation determining the Reynolds number is:

$$Re = \frac{pVd}{N}$$

where: p = fluid density,

V = average flow velocity,

d = channel diameter and

N = viscosity of the fluid.

Typically, a Reynolds Number of around 2,100 or lower results in laminar (or streamline) flow in the water lines, which is relatively inefficient flow behaviour for removing energy. In contrast, a Reynolds number that exceeds 2,100 tends to create one of several types of turbulent flow patterns, which in turn are more efficient in the removal of heat. Clearly, a key consideration in designing the cooling channels for blow moulding tools is to induce or modify turbulent flow patterns. In some cases, as in some injection moulding tools, a mechanical device, (e.g., a spiral rod) can help to induce turbulent flow in the cooling channel.

A different option would be to operate the mould at a lower temperature in order to accelerate the cooling rate and reduce cooling time. In practice, that approach fails as a solution for two reasons, one being that a build-up of internal stresses in the parts tends to occur. The other flaw is that running the mould at a temperature lower than that of the surrounding ambient air leads to ‘mould sweating’, i.e., the formation of droplets in the mould that creates watermarks, causing surface defects on parts called the ‘orange peel effect.’ This serious source of part defects has to be avoided. General industry practice is to run tools with some margin of safety in the 7 to 13 °C temperature range.

3.4.5 Remedies for Flash

Several possible ways to reduce the extent to which flash extends the cooling time of blow mouldings arise from the preceding analysis. In the vast majority of blow moulding tools, it is fortuitous that the zone at which flash takes place is already designed as a separate insert. That is because the flash zone is typically the area where pinch-off occurs, which traditionally has required the design of a special metal insert (e.g., QC-7 aluminium) better able to resist wear and increase the heat transfer efficiency.

That being so, it becomes relatively easy for a tool-builder to design the insert (or redesign an existing one) as a separate cooling zone, making an improvement in insert cooling efficiency possible. Retrofit of inserts to include cooling is often feasible.

Meanwhile, the cross-section of the insert's parting line in a conventional blow mould would have traditionally taken the form of a horizontal line (i.e., a flat plane), one reason being that it is easier and less costly for a tool-builder to machine in straight lines. However, a cross-section that is trapezoidal would considerably expand the surface area in contact with the flash, thereby providing for more efficient heat removal (**Figure 3.19**).

Also, see **Figure 3.8** - bird mould. In addition, a trapezoidal cross-section in the insert increases the stiffness of flash, making the 'hot tails' more resistant to folding over when sticky and hot.

For a four litre, 63 g weight bottle programme, the two remedies described previously, were combined with great effect. Design of the insert as a separate cooling zone, in unison with trapezoidal machining of the insert cross-section, reduced the cooling time by 4 seconds, so that cycle time was reduced from 13 to 9 seconds, or by 31%. This more than justified any additional costs incurred.

3.5 The Pinch Off

3.5.1 Importance

Because of the comparatively high pressure and mechanical stress exerted on the mould bottom when (in the closing step) it pinches one end of the parison together, the pinch-off in a nonferrous-metal mould is frequently an insert made of hard, tough steel. The effect on the blown part always shows in the so-called weld line.

The pinch-off section does not cut off the excess parison 'tail' (see **Figure 3.20**).

Its protruding edges are cut nearly through, creating an airtight closure by pinching the parison along a straight line which makes it easy later to break off or otherwise remove the excess 'tail'

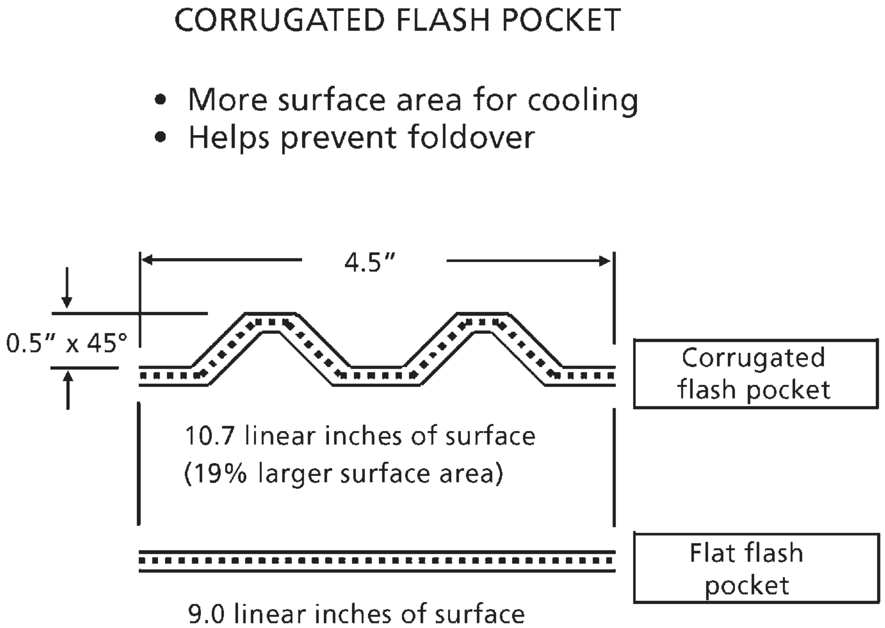


Figure 3.19 Trapezoidal flash cross section

piece. A high quality pinch-off of a thick-walled parison is more difficult to obtain than that of a thin-walled parison. However, much depends on the construction of the pinch-off insert.

3.5.1.1 Bottles and Thin Parts

The pinch-off should not be knife-edged, but, according to some moulders, should be formed by lands about 0.1 to 0.5 mm long. The total angle outward from the pinch-off should be acute, up to 15° (**Figure 3.21**).

These two features combine to create a welding line, which is rather smooth on the outside and forms a float elevated line or a low bead inside, not a groove. A groove, which weakens the bottom along the seam, may be formed when these two features of the pinch-off are missing on thick walled parts (2.54 mm and over).

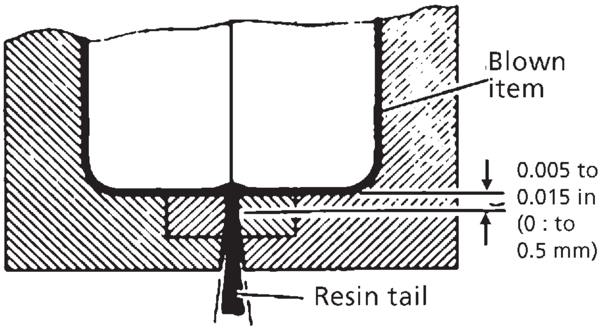


Figure 3.20 Excess 'tail'

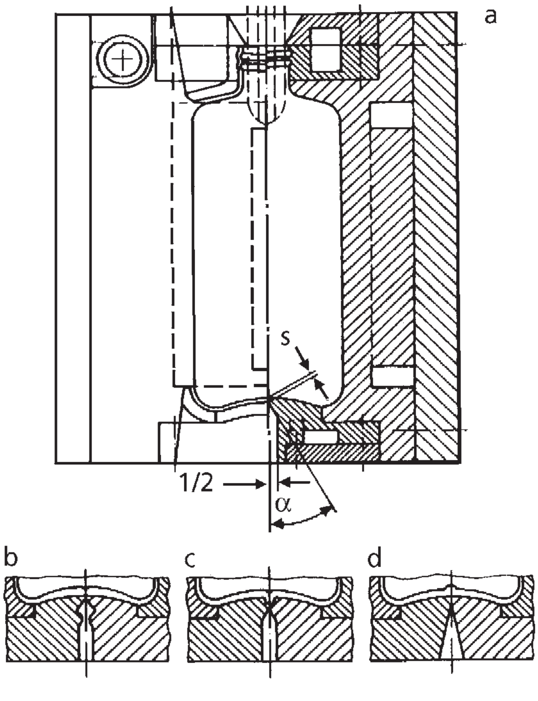


Figure 3.21 Pinch-off angle showing styles of pinch-off pockets and welding edges. s = edge width; a = opening angle of pinch-off pocket; t = width of pinch-off pocket

Reproduced with permission from Hoechst AG.

3.5.1.2 Heavy Walled Parts

One method of obtaining more uniform weld lines is to build ‘dams’ into the mould halves at the parison pinch-off areas. These ‘dams’ force some of the molten resin back into the mould cavities to produce strong, even weld lines (**Figure 3.22** and **3.23**).

Figure 3.24 shows a cross-section through a container bottom with a good shape and one through a bottom with a poor shape due to an incorrectly constructed pinch-off insert and one which would be adequate.

3.6 High Quality, Undamaged Mould Cavity Finish

3.6.1 Mould Cavity Finish

High quality mould cavity finish and undamaged inside surfaces are essential in polyethylene (PP) blow moulding to avert surface imperfections in the end product. If the highest possible gloss of the

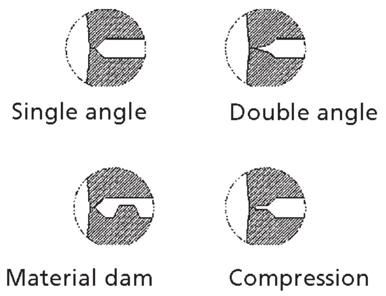


Figure 3.22 Pinch-off dams

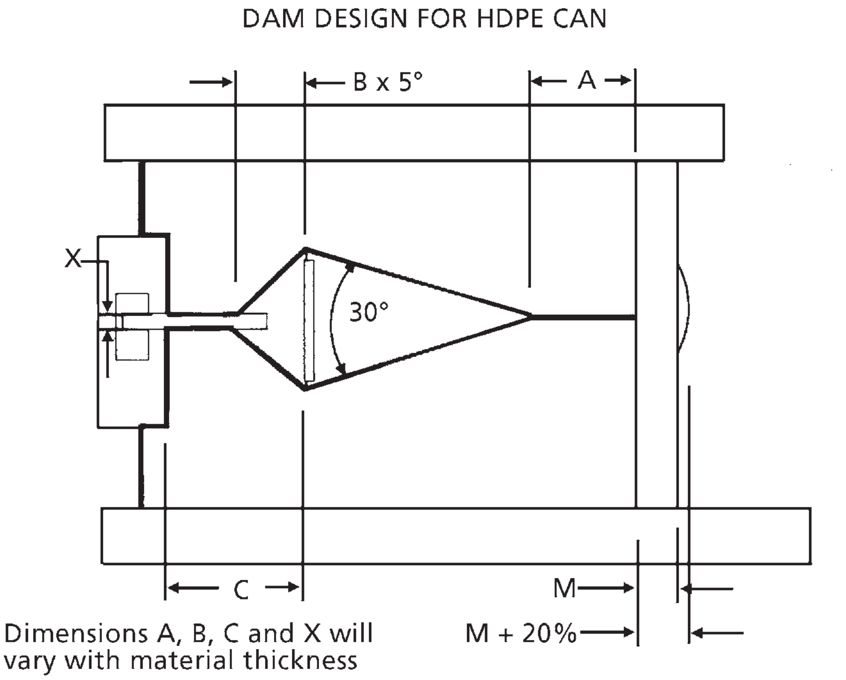


Figure 3.23 Pinch-off dam

end product is desired, the mould cavity should be sand blasted with 100-grit flint sand and have vacuum assists for removal of entrapped air. If other end-product finishes are desired, the mould cavity should be finished accordingly.

Even a first-class machining job inside the mould cavity cannot prevent the occurrence of die lines, especially if the blown item has a very thin wall (**Figure 3.25**).

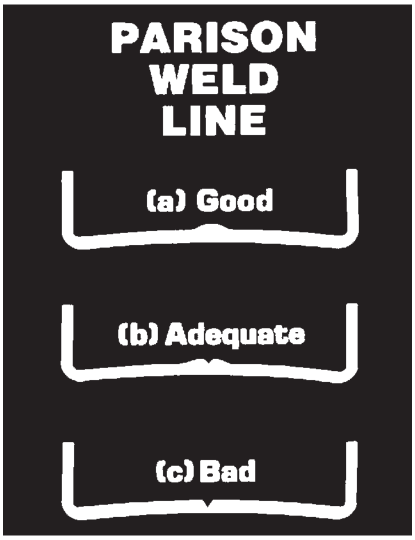


Figure 3.24 Good/bad 'pinch-off'

Figure 3.25 Die lines

Reproduced with permission from Krupp, England, Germany, Japan and USA.

3.7 Effects of Air and Moisture Trapped in the Mould

3.7.1 Polished Moulds

In highly polished moulds, air may be trapped between the mould walls and the hot, still soft piece, marring the surface of the piece. This will happen especially when thick-walled, large pieces are blown. In such cases, the mould must be vented by either sandblasting (resulting in a matte outer surface of the piece) or by putting grooves in the separation lines or, in extreme cases, by putting valves in the mould.

Generally, about one-half of the parting line periphery is vented to a depth of 0.05-0.102 mm. In venting difficult areas, such as handles or thread inserts, holes are usually drilled into these areas so that they vent to the atmosphere. The vent holes are normally about 0.204-0.254 mm in diameter. Particular care must be taken when drilling these holes so that the mould cooling cavity is not pierced (**Figure 3.26**).

3.7.2 Moisture

Moisture in the blowing air may result in marks on the inside of the blown part. This may result in high reject rates, especially if the part is transparent or translucent. Moisture in the blowing air can be removed by means of a heat exchanger, which cools the compressed air, or by traps and separators in the pipelines.

3.8 Injection of the Blowing Air

3.8.1 Injection Blowing Air

Injection of blowing air can be done by various means, such as downward through the core, or through a blowing needle inserted sideways through the mould wall, or from below through a

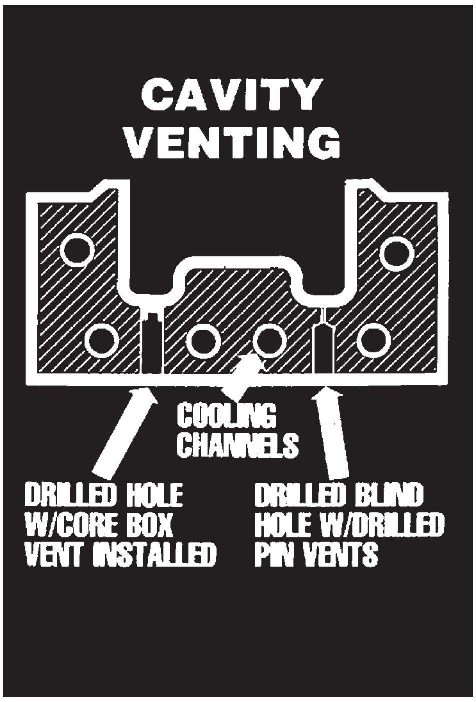


Figure 3.26 Vent hole drilling

Reproduced with permission from Portage Casting and Mould Inc.

blowing pin moved up into that end of the parison which will become the (frequently threaded) neck of a bottle (**Figure 3.27**).

3.8.2 Blowing Devices

Sometimes, different blowing devices are used in combination. As with every step in the blow moulding cycle, blowing time and duration must be well coordinated with all other parts of the cycle. As explained before, compared with the cooling time, blowing time is very short.

To obtain rapid inflation of the hollow piece, the volume of injected blowing air should be as large as possible. The opening through which the air enters the mould must, of course, be adequate.

The thinner the wall thickness and the lower the melt and mould temperature, the faster the blowing rate should be and the higher the blowing pressure, up to about 10.5 kg/cm^2 for very cold moulds and thin-walled parts (compressed air injected into a cold mould may lose some pressure because a cooling gas contracts). High blowing pressure requires a correspondingly high clamp pressure to keep the mould tightly closed during the blowing step.

3.9 Ejection of the Piece from the Mould

3.9.1 Ejection Methods

Ejection of the blown piece can be effected forward between the mould halves or downward, provided the press is built in such a way that a free fall from between the open mould halves is possible. Many machines have an automatic ejector, or stripper, assembly. Ejector, knockout pins or plates push the piece out with a rapid motion, preferably hitting it on a trim area so that the piece itself will not be distorted. Ejection of the blown piece is part of the automatic blowing cycle. If the piece is not too large, it can be blown forward out of the mould by an air jet from behind.

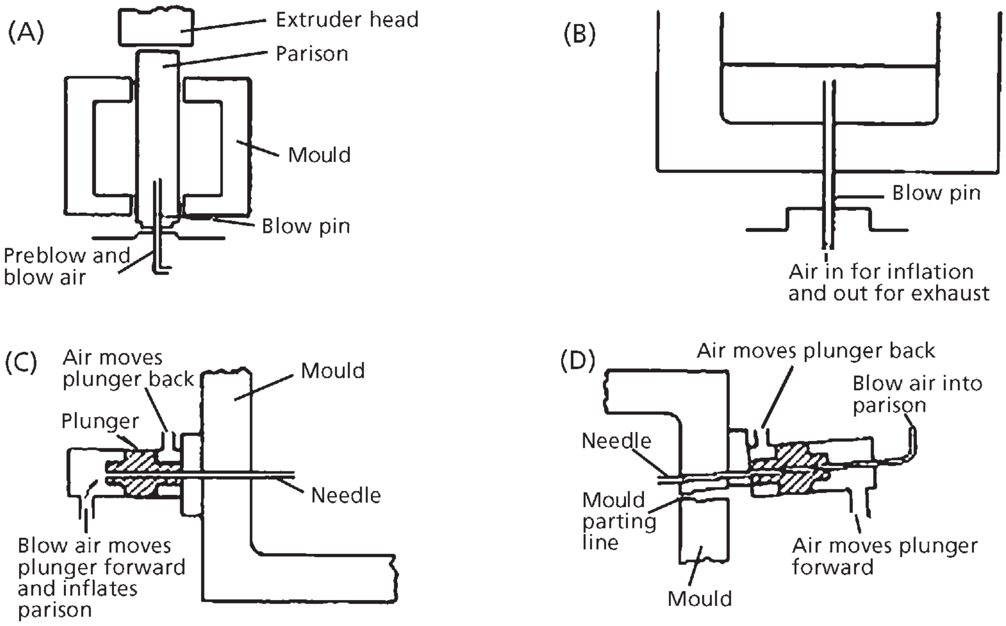


Figure 3.27 Blowing needle location. (A) = Pre-blow air into parison before inflation; (B) = Blowing air into part top or neck area; (C) = Needle location at back of mould for air blowing into back of part; (D) = Needle location above part line for air blowing into wall of part.
Reproduced with permission from General Electric Corporation.

3.9.2 Manual Ejection

The operator sometimes manually removes very large pieces from the mould. To reach it, the operator must first push the protective gate or shield aside, which automatically stops every mould or platen movement so that the operator's hands are in no danger of being hurt between the mould halves.

3.9.3 Automatic Ejection

Automatic stripping, being a very fast operation, requires a pneumatic (air) pressure system, just as in the blowing proper, as with the cut-off at the die, and the operation of automatic valves in the die head. Because so many moving parts are actuated by air, it is sometimes recommended that the air in the pneumatic system be lightly oiled.

3.9.4 Hydraulic Systems

Hydraulic (always oil) systems are generally used for clamping and moving the moulds, the platens on which they are mounted, and other heavy parts of the moulding equipment (such as rams), which are used in some moulding procedures.

3.10 Pre-Pinch Bars

3.10.1 Top Pinch

In industrial blow moulding products it is sometimes necessary for a parison to be pinched closed to retain the low pressure air inside, making it like a pillow. This may be for a flat shaped part, e.g., a panel or a double wall case and prevents the parison from collapsing.

This can be accomplished by pre-pinching the parison at the top, before parison drop, or at the bottom when the parison has reached the correct length. At the top, this is achieved with pinch bars mounted just below the die head, which are activated by a quick action air cylinder, and when withdrawn leaves a sealed parison that proceeds to extrude between the open mould.

3.10.2 Bottom Pinch

The alternative is to pinch the parison when it has reached the desired length. Two bars may be mounted each on a mould half with a spring mechanism, and as the mould closes and the bars close on the parison first, the spring compresses as the mould continues to close. When the mould retracts, the parison (as a blown part), is held by the bars, which assists in stripping them from the cavity.

This latter method may also be accomplished with air or hydraulic activated cylinders.

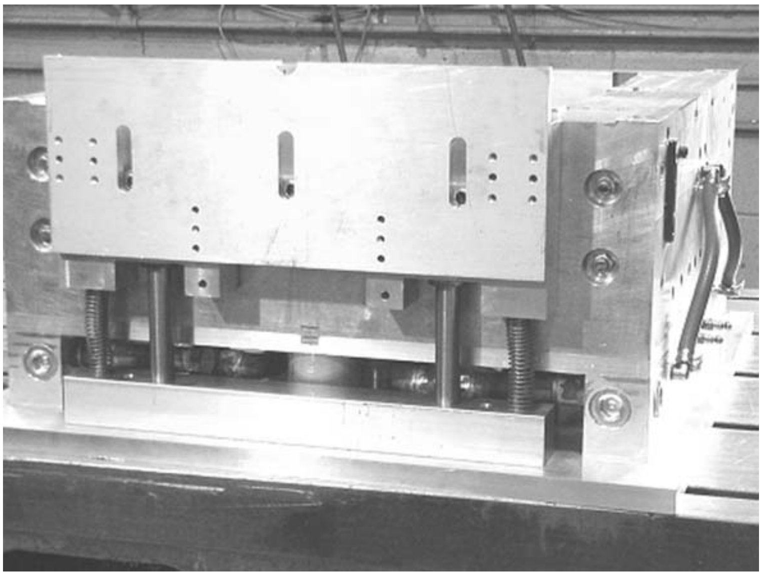
These lower pinch bars also need to have a water-cooled channel since the bars will get hot. **Figure 3.28** gives an example of a mould mounted with spring loaded pre-pinch bars.

3.11 Bottle Moulds

3.11.1 Neck Ring and Blow Pin Design (Figures 3.29-3.34)

The neck ring and blow pin work together to form the container's finish. The neck opening, usually being a thread form - this is the finished area of the container where the closure will be applied, and provides the relationship of the threads to the top sealing surface and the shoulder of the container.

(a)



(b)

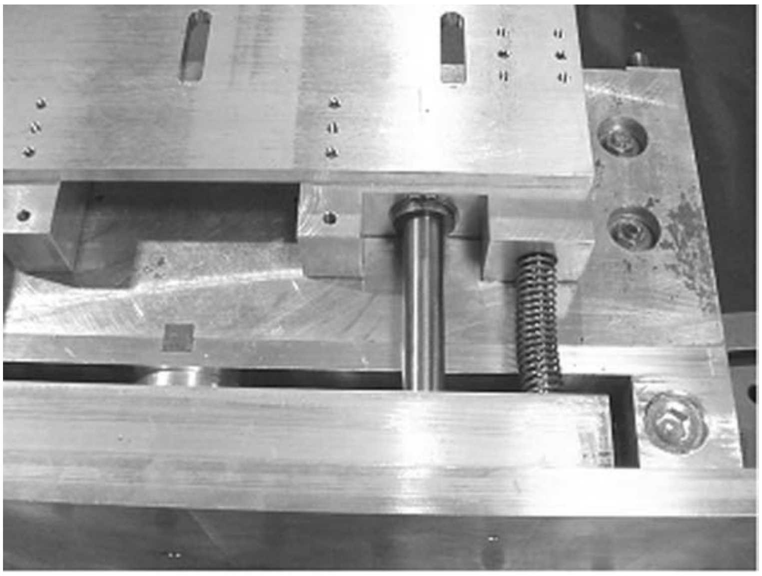


Figure 3.28 Spring loaded pre-pinch bars

Reproduced with permission from Portage Casting and Mould Inc.

The neck ring is an aluminium block mounted on the top of the main body. Within the limits of the container design, any of several styles of finish can be interchanged. For proper cooling, water lines in the neck ring interconnect with water lines in the mould body.

With the exception of cam and ratchet locks used on some special closures, most of the finish in the neck is cut on a lathe. The shrinkage applied to the neck ring is carefully calculated, based on the finishing technique and product wall thickness. The shrinkage rates are often different from that applied to the cavity. This is because the shrinkage of the thick wall section of the neck area is greater than the thin wall of the body.

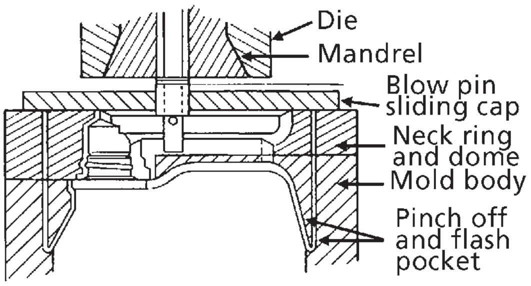


Figure 3.29 Guillotine method

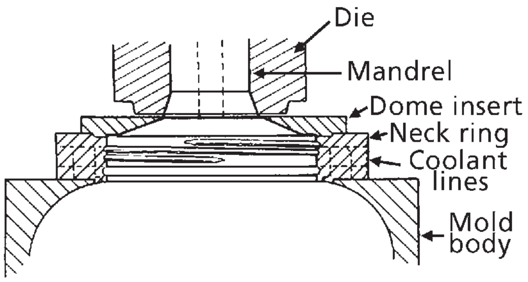


Figure 3.30 Moulded Dome-Fly cut post-moulded part

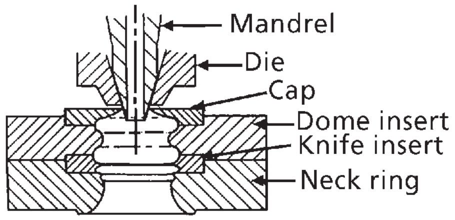


Figure 3.31 Spin-off method

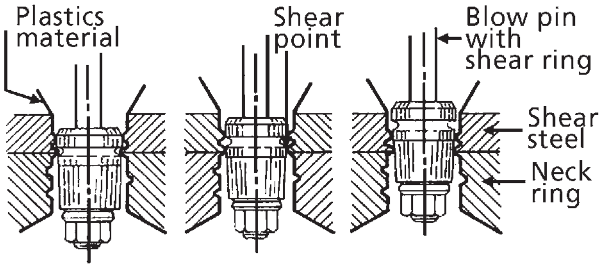


Figure 3.32 Pull-up method

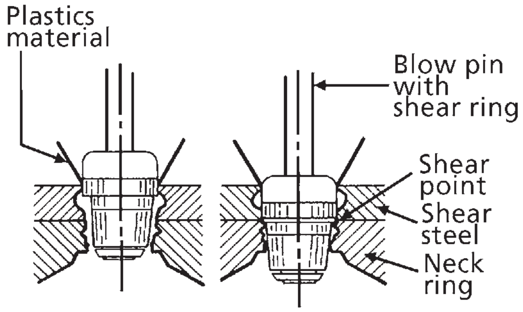


Figure 3.33 Push down method

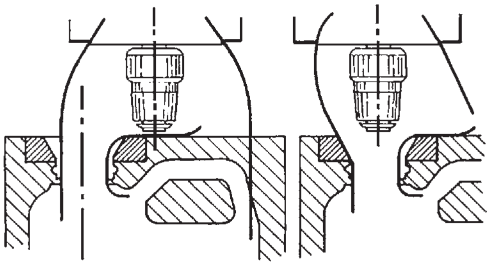


Figure 3.34 Push down method with sliding mould

Figures 3.29 - 3.34 Neck finishes

Reproduced with permission from Johnson Controls Inc.

3.12 Dome Systems

3.12.1 Dome Blow Pin

In dome systems, the blow pin is not as critical, and in some applications it is not required. In pre-finished systems, the blow pin has an important role in moulding the finish. With the dome system, the neck ring forms only the threads of the finish. The blow pin, if required, is used to seal and channel air inside the parison. After moulding, the dome top is cut off and the container sized and trimmed to specification.

3.12.2 Trimming Types

Three basic types of dome neck rings can be chosen, depending on the type of container and the type of trimming equipment. The guillotine-and-face method requires a blow pin and is used for handles and flat oval containers requiring the parison to flash outside the neck. After moulding, the trimmer will guillotine the dome top from the container, the pour lip and the inside diameter of the finished part would be facing the cutter.

The fly-cut method is used for wide mouthed containers - where the parison will fall inside the neck, a blow pin is not required. The parison is sealed against the mould, against the die of the head cooling. The dome is removed when the fly-cutter sizes the inside diameter of the finish.

The spin off method is used for any container where the parison will fall inside the neck. A blow pin is not necessary. A special dome, shaped like a pulley is moulded above the finish. After part trimming, a V-belt fits into the dome, spinning the container against a stationary knife blade that cuts through the dome top in the sharp groove at the top of the finish. Spin-off technology was patented by Johnson Controls, Manchester, MI, USA.

3.13 Pre-Finished System

3.13.1 Pre-Finished Neck Rings

With the pre-finished system, the neck ring and blow pin work together to mould and size the finish to the required specification before the container is removed from the mould cavity. Some pre-finished neck rings require the parison to be extruded over the blow pin and the flash must be outside the neck. Choice of the pull-up or ram-down method is dependent upon the type of closure used.

3.13.1.1 Pull-up Method

The pull-up method (patented) is used primarily on dairy container closures, which usually seal on the inside diameter of the finish. With the pull-up system, the blow pin moves upwards just prior to the mould opening, shearing the plastic material to form the finish inside diameter. The diameter of the hardened shear steel mounted on the top of the neck ring and the hardened shear ring mounted to the blow pin are held to a very close tolerance. This ensures the finished inside diameter will be accurate, smooth, and free of burrs.

3.13.1.2 Ram Down Method

The ram down method (patented) is used in containers with closures requiring a flat, smooth, top sealing surface on the finish. Immediately after mould closing, the blow pin moves downward, pushing material into the finish. The stroke of the blow pin is adjusted so that the shear ring mounted on the blow pin contracts the shear steel mounted in the neck ring without interference, pressure, or stress. The diameters of the hardened shear steel and shear ring are also held to very close tolerances, which ensures that the container finish is held within specification. Containers with off-centre necks, with the finish offset from the centre line, can also use this pre-finish method. The sequence of operation is the same except that the mould side shifts to the upright position, after it closes and before the blow pin down stroke.

3.14 Unusual Problems

3.14.1 Special Features

Several special features have been developed by mould makers to deal with unusual problems - side cores for deep undercuts, needle blow pins for container/cover combinations, and provisions for sealed blowing where the container is sealed before the mould is opened to maintain sterile conditions inside.

Two other special feature developments are the ‘rotating mould’ and the ‘sliding bottom’ (both patented).

3.14.1.1 Rotating Mould

The rotating mould was developed for container designs that have finish centre lines at some angle to the container centre line. The system also permits use of the ram down prefinish method, previously mentioned in **Figure 3.3**.

The sliding bottom is a feature that pre-pinches and seals the bottom of the parison, permitting it to be puffed up like a balloon. The device allows use of a smaller diameter parison than normal. The smaller parison pinch, which results at the bottom, is of value on certain containers filled with a stress-crack agent.

The most common feature is the ‘quick-change’ volume insert. Rigid volume control is a must for dairy containers. Unfortunately, high-density polyethylene (HDPE) containers shrink slowly and change size for many hours after moulding. Because of production volumes and control, many dairies have switched to fill containers moulded several days earlier. Volume-control inserts, which displace the difference in size, are added to mould to ensure that volume and fill levels are the same in both containers at the time of filling. The device works because shrinking is reduced to virtually zero for the life of the HDPE container when it is filled with milk or juice and stored at cold temperatures.

3.14.2 Irregular Shaped Parts

The ability to mould uniquely shaped parts is accomplished by using moving mould sections. An example of a lid with an integral moulded handle is shown in **Figure 3.35** with a mould cross-section with the slides closed. The mould consists of two basic mould halves – one half to form the top and outside skirt and the other to form the internally threaded inside wall of the lid. The top half of this mould differs considerably from the first lid mould. This top mould half splits into two horizontally movable, quarter mould sections to form the handle as shown in the upper part of the figure.

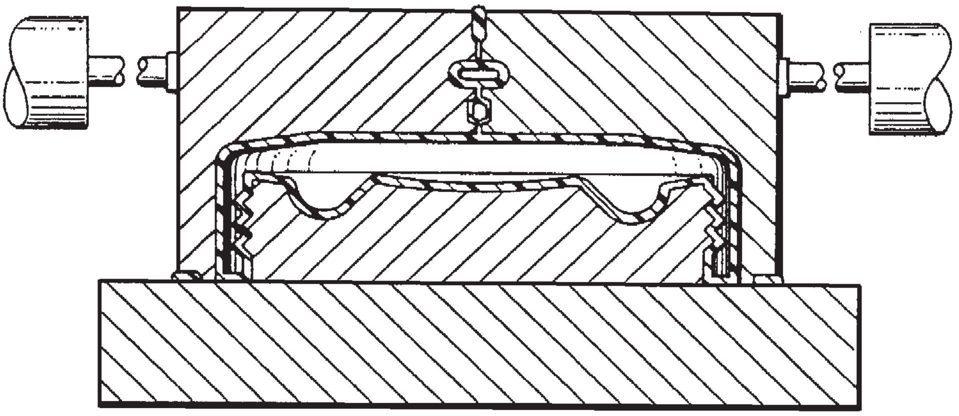


Figure 3.35 Quarter mould sections closed on threaded forming core half

Reproduced with permission from Phillips 66 Corporation, USA.

3.15 Computer Aided Design and Engineering for Mould Making

3.15.1 Application in Mould Making

The mould making industry now operates in a highly competitive market. The companies that survive in this environment will be those that offer exceptional service at a reasonable price to their customers. The United States and Europe in particular, with their high wages and living standards, can best compete on the basis of superior technology, service and quality.

In the previous chapters, it has been shown that this emerging technology analytically eliminates ‘the art of design’ of the part to be moulded, and this technology will emerge as the preferred design system. This is not to say that designs developed through these methods are not artistic, but rather the techniques used are based upon the advanced capabilities of computers, as extensions of the human mind. The high speed of computers allows complex calculations to be made, opening new vistas to the designer/engineer. Those who take advantage of these developing technologies will create better designs, and meet predicted performance criteria. Art and experience are not replaced but enhanced and augmented. Guesswork, although based on experience and rules of thumb, is eliminated. Overall the resulting design is vastly improved [1].

3.15.1.1 Advantages of Computer Aided Design

The advantages of using computer aided design include:

- Full documentation of complex shapes
- Volumetric analysis without building solid models
- Material flow and rigidity
- Images of models for marketing presentation and approval

Databases may be used for programming CNC machine tools and/or speed the design through modular or parametric construction. The purpose of mentioning it here is to show how the mould maker may use this information to input into the computer numerical control (CNC) system to achieve a competitive edge.

3.15.2 Systems and Methods [1]

3.15.2.1 Analytical Personal Computer

The personal computer has brought computer aided design (CAD) and computer aided engineering to the desktop. A decade ago, investment in computer technology meant purchase of expensive mainframe and minicomputers, and hiring a specialist to maintain them. Improvements in the ‘friendliness’ of user interface, processing power, speed, and above all cost has brought computers within economic grasp of even the smallest of shops. Systems developed for IBM PC-AT and compatible machines were responsible for weaning designers from the drafting board forever.

3.15.2.1.1 Minicomputers

The minicomputer workstation is the next step-up. These stations usually start with fast 32-bit, or higher microprocessors. The Unix operating systems with high-resolution, 50 cm colour monitors have the capability to display thousands of colours simultaneously. They function as general purpose computers, which perform the primary task such as computer aided design and drafting and evaluation exercises (such as finite element analysis and flow analysis discussed in previous chapters). They may be purchased as a complete package from several vendors as individual units. Specific units can be developed by the user to perform tasks that are proprietary to an organisation. An important advantage of individual stations is that they can be networked (interconnected), so that printing, plotting, scanning, libraries, and mass storage facilities can be utilised by a large number of employees in the organisation.

3.15.2.1.2 Network Station Approach

Large companies with several ongoing projects may install many workstations and have a central server that supports all workstations. These computers support powerful software programs with a fast response. For this reason, many organisations are choosing the network workstation approach for their computer aided design/computer aided manufacturing (CAD/CAM) resources. Additional PC can be added to the network at relatively low cost and this does not affect the productivity of the other workstations.

3.15.2.2 Utilising CAD/CAM in a Mould Making Organisation

To be effective in the utilisation of the computer, the mould making company, department, or group should be organised in all phases from the quotation, placement of the order to the completed job.

Organisations ideally have three major departments: Business, Engineering, and Manufacturing. This combination of departments creates the internal context for jobs in the manufacturing environment. The coordination of these departments utilising the latest technology provides a competitive edge. The ultimate success of the organisation demands a thorough knowledge of the technology and a high degree of communication between the various departments and individuals involved, including the customer.

As a manufacturer of custom products, every order constitutes a job. Every job requires a series of pre-manufactured parts that are assembled to produce the finished product(s). Finished parts consist of several categories:

- Purchased parts used for direct assembly,
- Purchased parts needing additional manufacturing before assembly, and
- Raw materials converted into finished parts needed to complete manufacturing for assembly.

Manufacturing activities can be accomplished either internally or externally as a subcontracted process. Assembling the components is the final activity that converts the raw materials into finished products. From a business perspective, every job has certain revenues and expenses (costs). For a job to be profitable, the total revenue must be greater that the total cost (**Figures 3.36** and **3.37**).

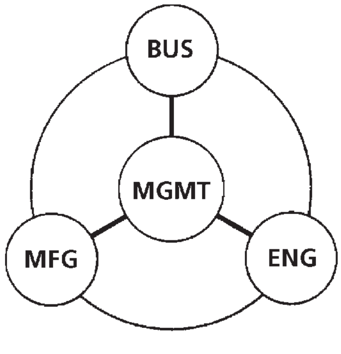


Figure 3.36 BUS = Business; MFG = Manufacturing; ENG = Engineering and MGMT = Management

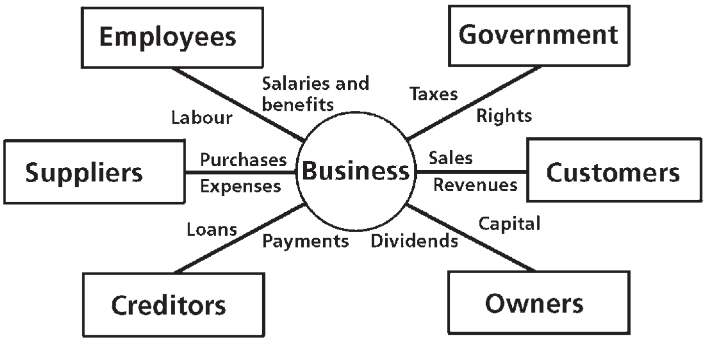


Figure 3.37 Internal context of departmental organisation

3.15.2.3 Engineering Activities

Whenever a job becomes activated, the engineering department becomes responsible for that job. The engineering department must specify all the information needed to properly complete a job. Every job requires the purchase and manufacture of exact quantities and types of components, which must be manufactured and assembled into the finished products. A complete engineering package for a job includes the following items:

- *Part drawings*: The part drawings provide a graphical representation of every part requiring manufacturing and/or assembly. This includes all relevant numeric dimensions, tolerances, manufacturing notes, revisions, and bill of materials identification. All parts must be manufactured to the part drawing specifications.

- *Bill of materials*: The bill of materials provides a complete list of all the raw and purchased materials needed for a job. Using the bill of materials, all necessary materials acquisition and preparation can be tracked and managed. Tracking information should include items such as vendors, date ordered, who ordered, date received, who received, and current status/location.

- *Production plan*: The production plan provides a list of operations. Each list specifies the necessary operations to manufacture a given piece of raw material into a finished part. The type of operation, manual or CNC, is also specified. Using the production plan, raw materials can be efficiently routed, scheduled, and tracked through the various manufacturing operations.

- *Inspection data*: The inspection data may take several forms: a list, notes on the part drawing, or a computer mould maintenance (CMM) programme generated directly from the CAD system. In general, inspection data specify certain dimensions and tolerances, which must be checked before a part is approved. This is determined with the customer during part design.

3.15.2.4 Manufacturing Activities

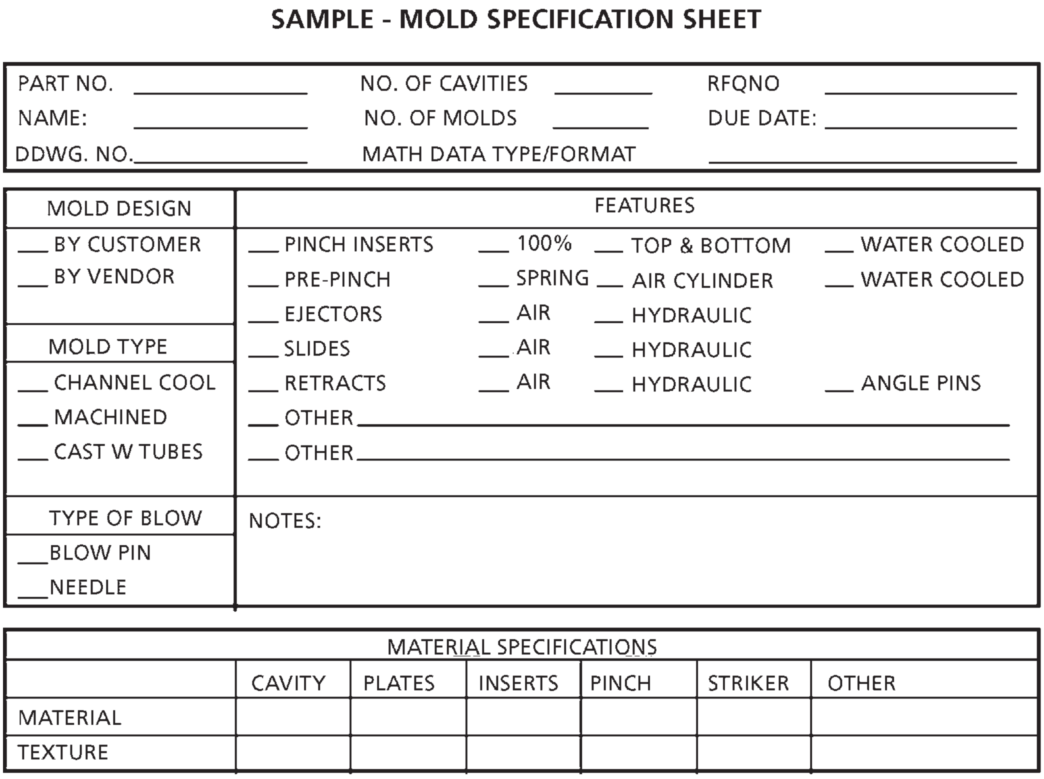
Once the engineering package has been completed and approved, the manufacturing department becomes responsible for producing the necessary components. Utilising the information provided by the engineering department, the raw materials for a job can be efficiently manufactured and assembled into finished products. Before manufacturing operations can take place for a job, the following activities must take place:

- *CNC programmes*: The CNC programmes specify the machine control instructions for every practical operation. Practical operation means that certain operations are best done manually, that is, assembly. The CNC programs generated by engineering should be stored in generic cutter location format (saved for future use). This allows operations to be grouped together and posted to proceed for a particular machine control in a single setup.

- *Part routing*: Part routing determines the order and grouping of operations. An operation group, or one or more operations, is then assigned to a resource. A resource is one or more equivalent man and/or machine combinations. The goal of routing is to determine the least number of setups needed to manufacture a part. This minimises part handling and maximises resources utilisation. Once operations and resources have been determined, the CNC programs can be organised for each setup.

- *Part scheduling*: Part scheduling, in general, determines the most expedient method for manufacturing all the parts needed to deliver jobs on time. Scheduling considers all the jobs active in manufacturing at any given time. The scheduling goal is to complete the necessary operations by assigning the appropriate resource on all parts needed for a job, based on a specific deadline. Job progress can be tracked using the production plan. Manufacturing bottlenecks can be identified by considering the routing queue for a particular resource, estimated time for operation's completion and remaining time until expected or requested delivery (see **Figure 3.38**).

- *Quality assurance*: Quality assurance determines that every part for every job has been manufactured to the degree necessary to satisfy the customer's requirements. Quality assurance is achieved by a system that utilises the inspection data provided by engineering, combined with gauges, manual and automated inspection equipment, and visual methods. Assuming that every part has been manufactured to specification, quality assurance is really quality verification.



SAMPLE - MOLD SPECIFICATION SHEET

PART NO. ______________ NO. OF CAVITIES ________ RFQNO ______________
NAME: ______________ NO. OF MOLDS ________ DUE DATE: ______________
DDWG. NO.______________ MATH DATA TYPE/FORMAT ______________________

MOLD DESIGN
___ BY CUSTOMER
___ BY VENDOR

MOLD TYPE
___ CHANNEL COOL
___ MACHINED
___ CAST W TUBES

TYPE OF BLOW
___BLOW PIN
___NEEDLE

FEATURES
___ PINCH INSERTS ___ 100% ___ TOP & BOTTOM ___ WATER COOLED
___ PRE-PINCH ___ SPRING ___ AIR CYLINDER ___ WATER COOLED
___ EJECTORS ___ AIR ___ HYDRAULIC
___ SLIDES ___ AIR ___ HYDRAULIC
___ RETRACTS ___ AIR ___ HYDRAULIC ___ ANGLE PINS
___ OTHER ______________________________________
___ OTHER ______________________________________

NOTES:

MATERIAL SPECIFICATIONS

	CAVITY	PLATES	INSERTS	PINCH	STRIKER	OTHER
MATERIAL						
TEXTURE						

Figure 3.38 Request for quotation

3.16 General Mould Buying Practices

3.16.1 Mould Procurement

The procurement of moulds for the blow moulding process is developing into a more technical responsibility than it was just a few short years ago. Although it may not take a master mould maker to buy moulds, a good general knowledge of blow mould features and requirements is essential background for making the considerable investment that moulds represent in overall equipment costs.

3.16.2 Request for Quotation

Mould purchase begins with requests to one or more mould makers for price and delivery quotations. The initial request for a quotation maybe the single most important phase of the mould procurement procedure which determines the magnitude of the investment to be made.

Generally speaking, the accuracy of the mould quote in both price and delivery is directly related to the amount of information, or lack of it, given to the mould maker. One of the most reliable methods of providing this information is to develop a standards document that not only spells out the requirements for the particular part, but also incorporates the purchasing company's standard mould requirements.

Because the dimensional envelope of a blow mould is based on the particular part to be moulded, it is very important to address the moulding press specifications of minimum and maximum shut heights and distances between tie bars. Unlike the standardisation one finds on injection moulding presses, blow moulding presses of the same clamp or shot size capacities may vary greatly, depending on the press manufacturer.

The next most important piece of information the mould maker must know is whether a machined mould or a cast mould is required. These were discussed in more detail in Section 3.2, which provided information that will help in making a choice.

In addition to the previous information, the data in the following list of blow mould requirements should be included in an initial request for a quote to help the mould maker provide an accurate price and to assure comparative quotations:

- Blowing provisions: Top blow, bottom blow or needle blow? Determine location.
- Pinch-offs: Top and bottom only, or 100%? Pinch-off plates water-cooled? Pinch-off plate material, if inserts.
- Thread inserts: Material and whether to be water-cooled?
- Logo areas: Artwork availability. Inserted? Interchangeable?
- Sectioned mould: Indicate split(s).
- Pre-pinch device: Approximate stroke.
- Slides: Method of movement.
- Knockout system: Method of actuation; location of pins.
- Texture: Defined area; specific pattern to be quoted for. Sampling prior to texturing?

The accuracy of the quote is related to the information supplied.

The above information is rather general. While it will serve as the basis for a preliminary quotation, the kind of detailed information the mould maker requires to make a final quotation and begin work is shown in **Figure 3.38**.

3.17 Mould Maintenance Program

3.17.1 The Moulds Used to Produce Polyvinyl Chloride (PVC) and Polyethylene Terephthalate

Containers should always have highly polished cavities. It is therefore best to polish them once every two weeks, and certainly before they begin to oxidise. Soft paper tissue and a polishing compound should be used for polishing the cavities. A small amount of the mould polishing compound should be rubbed into each cavity, which should then be polished with a clean tissue until the cavity gives a mirror image. The tissue should be replaced constantly in order to prevent scratching while polishing. If PVC material is used, please note that PVC gas is corrosive and will attack the mould material more aggressively if proper venting is not maintained, thereby causing rapid mould deterioration.

3.17.2 Moulds for PE

The mould cavities used to produce PE containers should always be sandblasted, because sandblasting produces a rough mould surface, which helps proper venting. Sharp lines on the container finish indicate the need to have the cavities sandblasted. When sandblasting, extra care should be taken to protect the pinch-off edges on the parting line. After sandblasting, the mould should be completely disassembled and all cavity split vents and pin vents cleaned, and the parting line vents checked for proper depth and re-machined if necessary. The cavity pin vents or vent plugs should be cleaned every four to five weeks, because of the wax buildup on narrow passages. Improper venting of the mould will result in a poor surface finish, drop test and uneven wall thickness of the end product.

3.17.3 Mould Cooling Lines

Mould cooling lines should be checked for corrosion and any other obstructions that could prevent the flow of the coolant. If any corrosion is detected, the cooling lines should be cleaned immediately. The coolant liquid should also be checked to make sure that the glycol being used is compatible with aluminium, since many of the glycols will cause corrosion when used with aluminium. Reduced cooling would result in poor impact strength, deformation capacity change, and poor surface finish on the containers. In addition, it causes increased cycle time and reduced production.

3.17.4 Guide Pins and Bushings

These should be replaced at least once a year. However, if cycle times are increased, play is detected in mould halves, machine die locks are too loose, or pin and bushing wear is noticeable, the pins and bushings should be changed more frequently. New guide pins and bushings will improve mould life and prevent cavity and bottle mismatch.

3.17.5 Striker Plates and Blow Pin Plates

Striker plates and blow pin plates are vital parts of the mould, and so should be kept in good condition or replaced when necessary. Any uneven wear in the striker-plate cut-off area would produce a poor surface and flash in a neck sealing area, resulting in leaky containers.

3.17.6 Pinch off

Pinch-off edges are designed to cut excessive plastic from the container every time the mould is closed if bottom detabbers are used. However, flash in neck, handle, and shoulder areas remains on the container until its removal as a secondary operation. Worn down pinch-off edges would produce a heavy wall in the pinch-off area, causing deformed containers and difficulty in trimming. Restoring mould pinch-off edges requires specially trained tool-makers, and should therefore be left to the qualified mould maker.

3.17.7 Shut Down

Whenever the operation is shut down for any length of time or the moulds put into storage, all waterlines should be blown out with compressed air and the cavities should be coated with a protective agent to prevent corrosion.

Acknowledgements

The author would like to thank the following for their help with:

Mould cooling and temperature control - Portage Casting and Mold, Inc., Portage, WI, USA.

Computer aided design and engineering - Kennedy Tool and Die, Inc., 225 W. Main Street, Birdsboro, PA, USA.

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Further Reading

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4 The Extrusion Blow Moulding System

4.1 Extruder

This chapter will begin with a basic description of a single-screw extruder machine (it is noted here that there are twin-screw machines mainly used in blow moulding where a powdered resin is used such as polyvinyl chloride (PVC)). Imagine a simple old fashioned mincing machine as used in a kitchen, as shown in **Figure 4.1**.

This consists of a barrel with an arbor (screw), which turns by use of a crank handle. Chunks of meat are fed into the barrel through a hopper; at the end of the barrel is a die through which the meat is extruded. The process causes the meat to move through a forced zone, then a compression or transition zone, on to the metering zone through the spirals on the screw, and then through the holes in the die. All these basic elements are contained in an extrusion machine (see **Figure 4.2**).

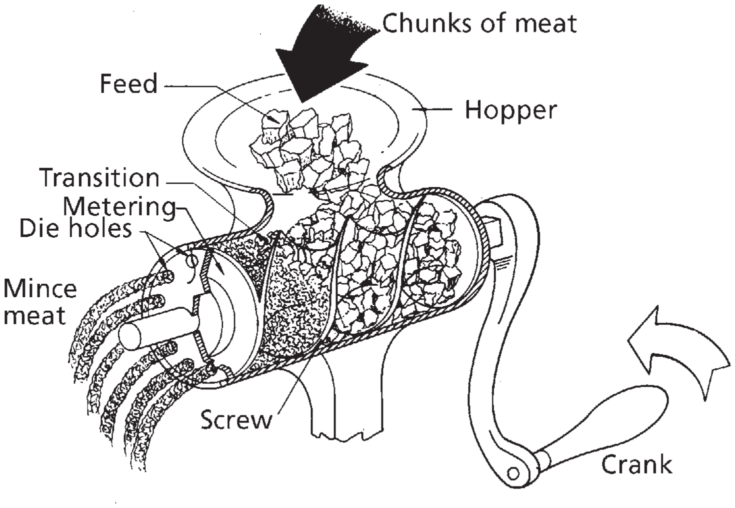

Figure 4.1 Basic extruder-kitchen mincer

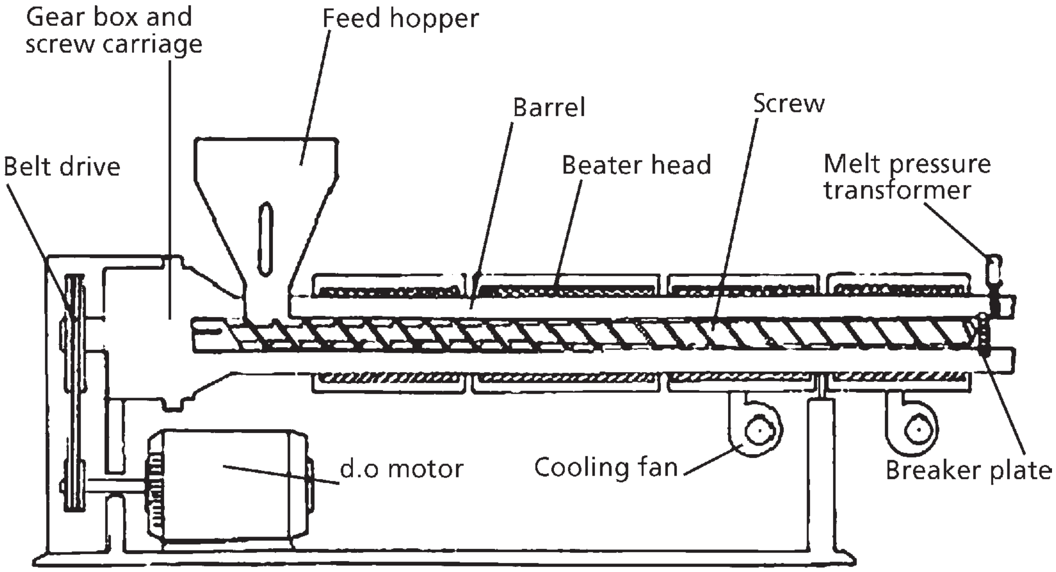

Figure 4.2 Single screw extruder

4.2 Drive

The extruder's drive system consists of a gearbox, screw bearings, and a motor that is linked to the gearbox by gears or belts. The system is designed to support the screw in the barrel and to rotate the screw at a specified speed, this being selected from a range of speeds. Once the speed has been selected, it should remain constant despite changes in the load on the screw or the temperature of the drive system. The turning force (torque) supplied by the drive must overcome the resistance of the screw to turning, even at low speeds. The torque and speed determine the power requirements of the system.

There are two main types of drive motor: direct current (DC) and alternating current (AC). Each has its advantages and disadvantages.

4.2.1 Motors

4.2.1.1 Direct Current Motors

For DC motors, the electrical power supply is AC, which has to be rectified (converted from AC to DC) and controlled through solid-state circuitry. The motor efficiency depends on its size, loading and speed.

Table 4.1 below shows typical efficiencies for DC motors in the power range from 15 - 100 kW.

Table 4.1 Effect of motor speed and load on DC motor efficiency

Speed	Full Load (%)	Half Load (%)
Full	89	87
Half	86	84

4.2.1.2 Variable Frequency AC Drives

The main 60 cycles per second AC power supply is rectified to DC and then converted to a variable frequency waveform using a solid-state switching device. AC voltage is fed to an AC motor whose speed depends on the frequency of its AC supply. Silicon-controlled rectifiers provide a better waveform and can reduce the otherwise considerable power loss in an AC motor. An AC motor costs less than a DC motor but is also less efficient. The extra cost of the solid-state circuitry makes the DC motor more expensive.

The two main advantages of the variable frequency motor are less mechanical maintenance because of the absence of brushes, and a better power factor. In some areas, the cost of electricity is higher for factories with an overall poor power factor.

4.2.1.3 Adjustable Transmission AC Motors

Some extruders use a drive in which the motor turns at a constant speed, with some type of variable-speed transmission used to control the screw rpm. The type of adjustable transmission most often used on an extruder is the design based on eddy currents. A constant speed AC motor drives a steel drum that surrounds a wire-wound rotor fixed to an output shaft. There is no mechanical coupling between the drum and rotor. Eddy currents generated by the rotation of the drum, cause the rotor to turn with the drum, though somewhat more slowly than the drum. If a voltage is applied to the rotor, the electrical linkage between it and the drum can be varied. This permits the speed of the output shaft to be varied, or held constant under a varying load.

4.2.1.4 Motor Power

Table 4.2 shows approximate motor power requirements for different screw diameters, assuming a smooth barrel (without a grooved feed section), no vents, and a length:diameter ratio (L/D) of 24/1. Grooved barrels and vented barrels require extra power.

Table 4.2 Power requirements for different size extruders

Diameter (mm)	Power (kW)	Power (kJ/s)
38	12	11.9
64	40	37.3
89	85	85.8
114	130	130
152	230	231
230	400	395

4.3 Gear Box

Extruder motors deliver constant torque over their speed range. For maximum power, the motor should run near its top rated speed, to match optimum motor speed with maximum screw speed. Because the screw turns more slowly than the motor's optimum speed, a gearbox with a reduction ratio between 10:1 and 20:1 is used. The power transmission capability of the gearbox is matched to the motor's power. When a 'herringbone' type of gear is used, often with two-stage reduction, the efficiency of the gearbox can be as high as 96–98%. Regular gearbox maintenance is essential, to include regular oil level checks and using the correct grade of oil.

Belt drives with some reduction of speed may also be incorporated into the drive system. Belts are more resilient than gears and provide some added safety protection against sudden overload. However, power losses can be as high as 10%.

Note: All belts must be guarded. Never operate an extruder with the guards removed!

4.4 Screw Support Bearings

In addition to supporting the screw at the drive end, the screw support bearings must withstand high thrust loads. A 114 mm diameter screw will experience a backward thrust of 28.5 metric tons if the melt pressure at the die end of the screw is 27.6 MPa. The shank of the screw is fitted into a driving sleeve in the bearing housing. A splined fitting is better than a single keyed fitting for distributing the torque around the shaft and is normally used. Roller bearings are also usually employed since they are better suited to withstand high thrust loads. As with the gearbox, proper lubrication of the screw support bearings is important.

4.4.1 Life of Thrust Bearings

The B-10 life of a thrust bearing is the length of time in hours when 10 out of 100 bearings (10%) are expected to fail if run continuously under the specified screw speed and resulting die head pressure conditions. The B-10 life of a certain thrust bearing assumes that the extruder will run at 100 rpm with 34 MPa head pressure. If the extruder is run faster or with a higher head pressure, there will be a reduction in the expected life of the bearing. **Table 4.3** indicates the B-10 multiplying factor for a range of conditions outside the standard conditions. For example, if a thrust bearing has a predicted life of 100,000 hours at 100 rpm and 34 MPa, its expected life at a screw speed of

125 rpm and head pressure of 48 MPa is only 30,000 hours (0.3 x 100,000). Note: 100,000 hours is about 12 years of continuous operation (see **Table 4.3**).

Table 4.3 Multiplying factor for thrust bearings

Head Pressure (MPa)	Screw Speed (rpm)			
	75	**100**	**125**	**150**
20.3	6.45	4.84	3.87	3.2
27.6	2.72	2.04	1.63	1.36
34.6	1.33	1.00	0.80	0.67
41.4	0.80	0.60	0.48	0.40
48.3	0.51	0.38	0.30	0.25
55.2	0.35	0.26	0.21	0.17

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4.5 Extruder Feed

4.5.1 Feed

To ensure a constant rate of output, materials to be processed must flow smoothly into the extruder. The feed components receive the material, hold it ready for use, and feed it into the extruder.

There are four ways to feed an extruder:

- Flooding,
- Starving (metered),
- Cramming,
- Melting.

4.5.1.1 Flooding

In flood feeding, the materials flow by gravity from a hopper into the extruder, and fill the feed throat and the first few flights of the screw. The extruder conveys the material forward at a rate that is proportional to the depth of the screw channel, the screw rpm, and the screw diameter.

4.5.1.2 Starving

Starve feeding involves metering the amount of material that falls into the feed throat. That amount is usually less than the maximum the extruder could convey, which allows screw rpm and output rate to be independent of each other. Starve feeding is commonly (but not always) used with twin-screw extruders, because single-screw extruders will not operate properly below a certain feed rate.

4.5.1.3 Cramming

In cram feeding, a crammer pushes material into the feed throat with a ram or auger. It is used with hard-to-feed materials that will not flow reliably by gravity.

4.5.1.4 Melting

Melt feeding involves feeding melted material into the feed section instead of solid pellets, granules or regrind. In this application, the extruder is merely a pump. Melt feeding is used when the plastic is prepared in batches or when the melting and mixing device cannot deliver a constant flow against pressure.

4.6 Hopper

The material to be extruded is held in a cylindrical (usually) container with a cone-shaped bottom. In flood fed extruders, the hopper is fastened to the extruder and is kept full. The material in the hopper flows by gravity, which keeps the throat of the extruder full.

Gravity fed systems usually include a hopper with a receiver for loading material. The only action required to operate a gravity fed system is to open or close the slide gates in the system.

The feed throat provides an opening into the extruder to allow the material to enter the barrel.

The feed throat is typically a separate iron casting with a sleeved insert. The insert lines the feed throat and is usually coated with an anti-corrosive layer. This is to protect the surface from exposure to corrosive materials and from rusting that may develop from condensation during shutdown or idle time.

4.6.2 Feed Throat

The top opening of the feed throat should match the hopper opening exactly. Mismatches in the openings can create ledges where pellets can get caught. If the machine often runs different materials or colours, this can be a real problem because it is difficult to remove every trace of the old material. It can also be hazardous if the remaining old material is not compatible, that is, if it reacts violently with the new material. Acetals and PVC are examples of two plastic materials that undergo hazardous depolymerisation if allowed to come in contact with one another at their melt temperatures. The diameter of both the hopper opening and the feed throat should be the same as the diameter of the screw for best feeding. The feed throat casting is made with channels all around the throat. Water flows through them to cool the feed throat surface, which would otherwise become too hot. When the desired temperature of the feed throat has an allowable range of just one or two degrees C, the system may use temperature controlled water instead of tower or ambient temperature water. Materials and processes that require tighter temperature control may need a controller-driven system, in which a thermocouple in the feed throat sends a signal to a controller, which then sends a signal to a valve, adjusting the rate of water flow. Although more complicated, expensive and maintenance intensive, this method gives the best control of feed throat temperature.

4.6.2.1 Temperature Control

The temperature that is maintained in the feed throat must be low enough to keep the plastic material from softening or melting too early, and to keep waxy or soft additives from melting and becoming sticky or oily. In processes that maintain close control of feed throat temperature, it is done because temperature changes can affect how the material flows into the extruder, and small changes in how the material feeds into the extruder can make large changes in the extruder's rate of output.

It is possible to cool the feed throat too much. If the water in the feed throat is significantly cooler than the ambient air, dew (condensation) may form both outside and inside the feed throat. Water in the feed throat can cause feeding problems and lead to defects in the product.

4.7 Single-Screw Extruder

The most popular machine type is the single-screw (twin-screws are usually used for powdered resin). It is the screw within the barrel (extrusion cylinder), which conveys, melts, and generates pressure within the resin. The extruder must deliver a uniformly plasticised material of constant composition that is extruded at a controllable rate. To help this process, the barrel must be made accurately - the total out-of-alignment error must be less than one half of the screw-to-barrel clearance.

4.7.1 Barrel Construction

Barrels must be made to withstand the high pressures generated inside. They are made from thick walled alloy steel tube and are designed to operate at up to 34 MPa with a minimum burst pressure of 69 MPa. Barrels are usually lined with a very hard, wear-resistant material to increase their useful life. In most extruders, the barrel is bolted to the feed throat casting at one end, while a flange is provided at the other end for attaching the adaptor and die head (see **Figure 4.3**).

4.7.2 Zone Heating

The barrel is split into zones or regions for ease of temperature control. Each zone is fitted with its own heating and cooling system. In the case of a zero compression screw, as is used with a grooved feed throat, the first zone (feed) will be water cooled. The smallest machine may have three heating zones, while some larger machines may have 12 or more. A sensor and temperature controller control each zone. Because the barrel surface temperature strongly affects feeding, melting, mixing, and final melt temperature, the barrel temperature is extremely important.

If the processing conditions of a particular material are not known, the resin supplier's recommended process temperatures should be used as a guide. For a given machine, start with the lowest recommended temperature settings for the material, and adjust as necessary. Once the desired melt temperature and melt quality (uniform in colour, well mixed, no unmelted particles) have been achieved, the actual settings and readings should be recorded. The settings needed to achieve the desired melt quality and melt temperature may also depend on screw rotational speed and the amount of back pressure caused by the die restriction at the end of the barrel, so process records must show these as well.

4.7.3 Venting

The extrusion of some materials, on some machines, may require barrel venting. This is to allow gas or volatiles trapped within the resin melt to escape. Often the gas is simply air, but there could also be moisture, or vapour given off by a low-boiling additive in the resin compound. If they are not

Figure 4.3 Extruder barrels

removed, these gaseous materials can be carried to the die, where they may expand and form bubbles in the product. To allow gas and vapour to escape before they reach the die, the melt is decompressed partway along the extruder barrel by decreasing the screw root diameter, directly beneath a vent hole or port in the barrel. After venting, the material is re-compressed and pumped to the die.

4.7.4 Wear Resistant Barrels

Since the screw and barrel assembly operate in a hot, abrasive, and sometimes chemically aggressive environment, severe wear problems can occur. To counteract wear, the barrel may be lined with an alloy such as Xaloy®. There are many lining materials available, to suit the particular applications. The lining may be cast in during barrel manufacture or, especially when repairing a worn barrel, a separate liner may be inserted.

4.7.5 Grooved Barrels

Grooved barrels are considered essential for processing high molecular weight polyethylene (PE) and polypropylene at high throughput rates. Grooved barrels provide constant output even if die head resistance changes, as occurs when parison programming is used. Grooves in the barrel wall at the feed section (see **Figure 4.1**) make conveying more stable, provided that the resin's feed rate, form, and density are consistent. The grooves are nearly always rectangular in cross-section and run longitudinally along the barrel. They are deepest under the feed opening and taper away at about 15°.

The frictional heat developed by the grooves is great. They have to be polished and cooled, as no melt may be allowed to form in this region. If it does, it will clog the grooves, greatly reducing the rate and stability of the feed. A thermal barrier insulates the first heated zone from the water-cooled feed throat section.

4.7.6 Pressure Generation

In order to obtain good quality melt from the extruder, it is important that the material be uniformly heated, melted, and mixed. Proper melting and mixing requires that the correct screw be used and that sufficient pressure is present in the barrel to obtain a melt that is physically and thermally uniform. Screen packs, supported by the breaker plate, are often used to build pressure in a conventional three-zone machine.

4.8 Melt Filtration

The growing use of recycled material increases the need for melt filtration. Contaminants that form small lumps, such as unmelted resin or foreign particles, can block the die or become lodged in the parison causing blowouts (holes in the parison or part). The use of a melt filter that can be changed during machine operation should be considered when running recycled materials.

4.9 The Screw

As stated previously, in blow moulding, the most common type of extrusion machine uses a single-screw. It is the screw within the barrel that conveys the melt and generates pressures within the plastic material. This must be done in a controlled manner so that a uniformly plasticised material of constant composition is produced at a constant and controllable rate.

4.9.1 General Purpose Screw

The most common type of screw is the general purpose screw. With this type, the screw channels are deepest under the hopper and shallowest at the screw tip. This variation in channel depth along the screw means that the screw will compress the material. How much the material is compressed is determined by the screw's compression ratio.

The compression ratio is calculated by dividing the channel depth in the feed section by that in the metering section. For example, if the depth under the hopper is 9.52 mm and 3.175 mm at the tip, the compression ratio is 3:1. The typical general-purpose screw has a compression ratio of 2 or 2.5 to 1 and a L/D of 20:1. See **Figure 4.4** for terms used to describe a screw.

4.9.2 Screw Zones

There are three sections of a general purpose extruder screw:

1. Feed section

2. Compression or transition section

3. Metering section

Feed section – The feed section is the section of the screw nearest the hopper. The channels are deep to accommodate the plastic granules.

Compression section – The compression section is the centre section of the plasticating screw. It is the area where most of the frictional heat is generated in the plastic and where all plastic melting should be completed. The channel depth increases gradually from the end of the feed section to the start of the metering section, where it becomes constant again.

Metering section – The metering section has the shallowest channels (flight depth). It is used to provide additional mixing, a uniform melt temperature, and usually to increase the plastic pressure. The head pressure for the extruder is the plastic pressure at the end of the screw's metering section. The depth of the channels in the metering section has a large effect on the output rate of the extruder. Deeper flights allow higher output but require more power and permit greater variation in output with changes in head pressure.

The feed section is approximately 50% of the length of the screw, the transition section is about 30% and the metering section is about 20% of the screw length.

4.9.3 Dedicated Screws

A general purpose screw, as the name implies, is designed to suit as wide a range of resin materials as possible, which means that it may not be the best design for a specific material. When a machine is dedicated to running one material for a long time, it is well worth considering a specially designed screw, that is, one that has been designed to most efficiently feed, melt, convey, mix, and pump a particular type of material to the die head at a consistent and desired rate.

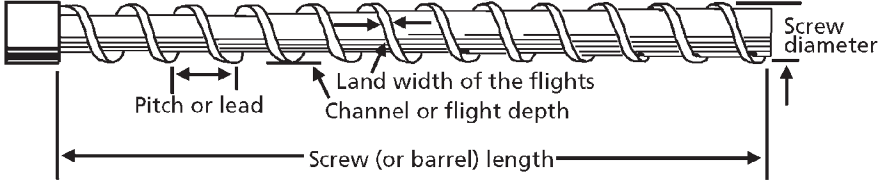


Figure 4.4 Screw terms

4.9.3.1 Longer Screws

For blow moulding machines, the standard length is about 20D, i.e., the screw has a L/D of 20:1. Such standard machines are typically available for PE in diameters of up to 120 mm and for PVC in diameters up to 90 mm. The screw design depends on the material being processed. PVC screws may include, for example, internal cooling of the screw tip area. Longer screw/barrel assemblies of up to 30:1 L/D are available. While they cost more to purchase and operate, these longer assemblies are used when high melt delivery rates and excellent melt homogeneity are required.

A longer screw/barrel assembly will give the same throughput as a shorter one, but at a lower screw speed. This is particularly important when high frictional heat generation must be avoided. A longer screw/barrel assembly adds operating flexibility: for example, there is more opportunity for the use of shearing and mixing elements.

4.9.3.2 Zero Compression Screws

When a conventional screw is used to extrude plastic material, a large amount of heat is generated as the plastic is compressed and sheared in the compression section. When it is necessary to avoid this, a zero compression screw may be used, in which the depth of the screw channels is the same all along its length. As such screws provide little mixing, mixing can be improved by the use of mixing sections located at the screw tip. Zero compression screws are commonly used with grooved barrels.

4.9.4 Barrier Screws

In the compression section of a conventional screw (see **Figure 4.4**), the channels contain both solid resin and melt. If the solid bed breaks up, as has occurred at (5) in **Figure 4.6**, particles of solid material will float or swim in the melt, making it difficult for the screw to press the solid resin against the barrel wall and greatly reducing both the rate and the uniformity of melting.

Barrier screws (**Figure 4.5**) are used to provide more consistent melting. In the compression (transition) section, there are two separate channels that are separated by a barrier flight, which has a slightly greater flight clearance (the distance between the top of the flight and the barrel) than the main flight. As the solid resin melts, the melt passes through this small clearance to the melt channel, while the unmelted material remains behind. Thus, the screw uses the principle of melt pool and solid bed separation to improve output at a given rpm, reduce melt temperature, and ensure complete melting.

4.9.5 Wear-Resistant Screws

The wear resistance of the screw can be improved in various ways. If the screw is deep nitrided to 67 Rockwell C, this will improve wear resistance and give protection against chemical attack; it will also stop the plastic from adhering to and then decomposing on the screw.

Figure 4.5 Milacron Meltstar barrier screw designed to accomplish both distributive and dispersive mixing

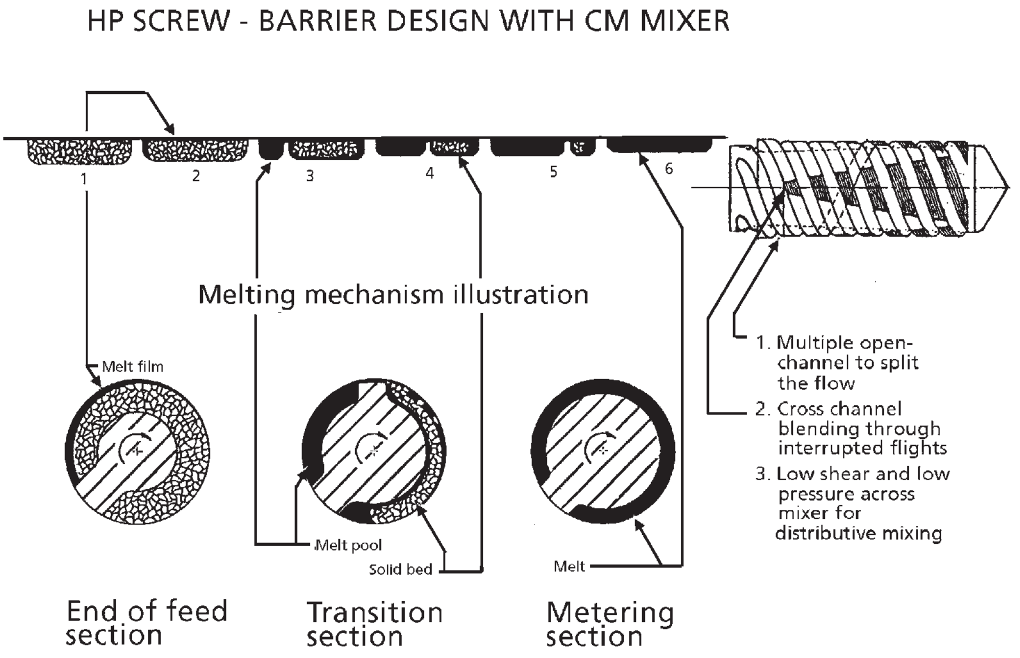


Figure 4.6 Melting progression in a high performance barrier screw with patented Cincinnati Milacron Meltstar mixer

The screw need not be of the same composition all over. Regions that are subject to severe wear can be constructed from 4140 heat-treated steel and the flights can be surfaced with a wear resistant alloy such as Colmonoy 56®. As it is easier and less expensive to replace a screw than a barrel, the screw must be designed to wear first, so the choice of screw flight materials must take into account the composition of the barrel surface.

4.9.6 Mixing Pins and Sections

Conventional or zero compression screws do not provide very good mixing, because of the way the material flows as it is transported along the screw. The melted plastic develops a circular pattern of flow within the channel, so that the resin at the centre of the channel can easily remain undisturbed. This means the output will not be homogeneous, either in composition or in temperature. To improve mixing, pins or other devices may be placed in the channels, or the tip of the screw may be fitted with mixing sections or elements.

4.9.7 Distributive and Dispersive Mixing

When all of the particles of material, including any fillers or additives, are uniform and of the correct size, it is simply a matter of distributing them evenly throughout the melt. Distributive mixing also applies to mixing the areas of different temperature. Distributive mixing requires low shear, and is done by repeatedly splitting and recombining the melt. This is somewhat like mixing two colours of paint with a stick.

In dispersive mixing, large particles are broken up by exposing the melt to intense shear for a brief time. Most dispersive mixing sections force the melt to pass through a narrow gap between the barrel and the screw. The width of the gap is slightly greater than the normal clearance between the barrel and screw. See **Figure 4.7** for a variety of distributive and dispersive mixers.

Figure 4.8 shows how melting proceeds in the transition section. It also shows the flow of material through a common type of dispersive mixing section called a Maddock or Union Carbide mixing section

4.10 The Extrusion Blow Moulding Head and Die Unit

The function of the extrusion blow moulding head and die unit is to maintain the melt at a constant temperature and viscosity and to consistently form the parison at the desired rate and wall thickness. Note: the rate and wall thickness may be intentionally varied as the parison is being formed.

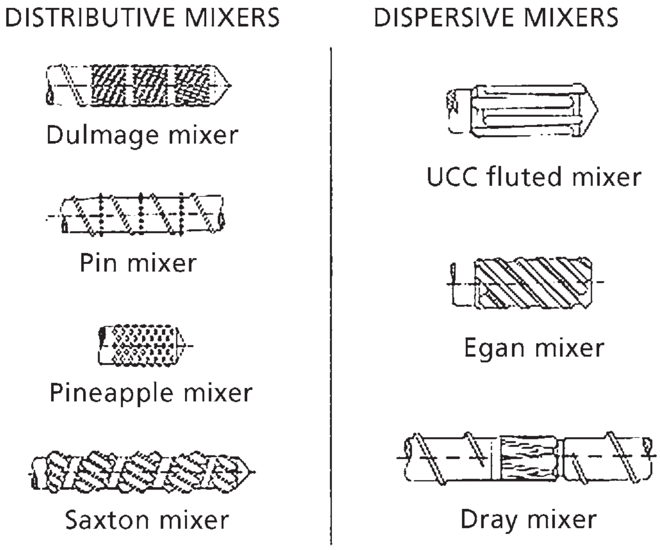


Figure 4.7 Different types of distributive and dispersive mixers

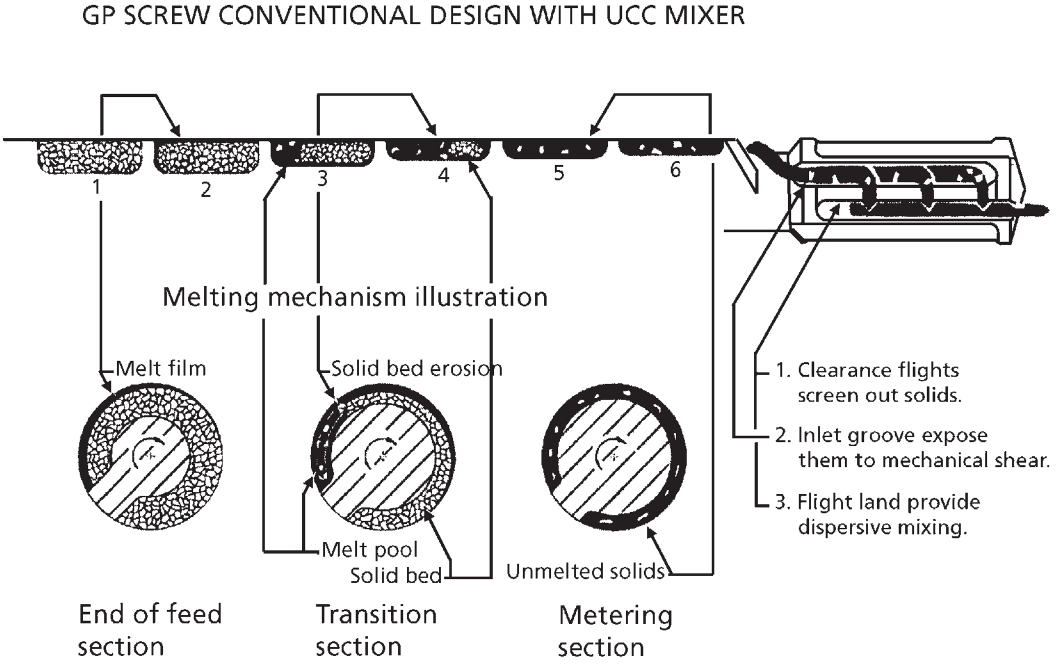


Figure 4.8 Melting progression in a general purpose screw with a conventional design mixer (Union Carbide)

In most blow moulding, the die head unit diverts the melt flow through a 90° angle from horizontal to vertical, extruding the parison downward. In the case of some ‘wheel machines’, the parison may be extruded upward. There are two kinds of parison dies: centre-feed and side-feed.

4.10.1 Centre-Feed Die

In the centre feed die, the flow is vertically downward around the core (see **Figure 4.9**).

The main advantage of a centre fed die is that the melt flows uniformly downward all around the core. There is no reason for one part of the melt to flow faster than another.

A disadvantage of the centre fed die is that the core must be supported inside the die head unit by either a perforated support or a ‘spider’ configuration. The perforated support or spider holds the core centred inside the die, giving the parison a uniform wall thickness as it exits the die. The perforations in the support or the openings between the spider arms permit the melt to pass through. The perforated support is usually the method of choice because it keeps the flow of melt more uniform.

Both types of support cause flow lines (weld lines) in the parison, because the melt stream must split to pass around the solid portions of the support and then be rejoined. Flow lines can result in a blow moulded part with poor appearance and reduced strength in the area of the flow lines. Certain centre and side fed die designs, called spiral flow dies can greatly reduce or eliminate flow or weld lines in the parison and are widely used for this reason.

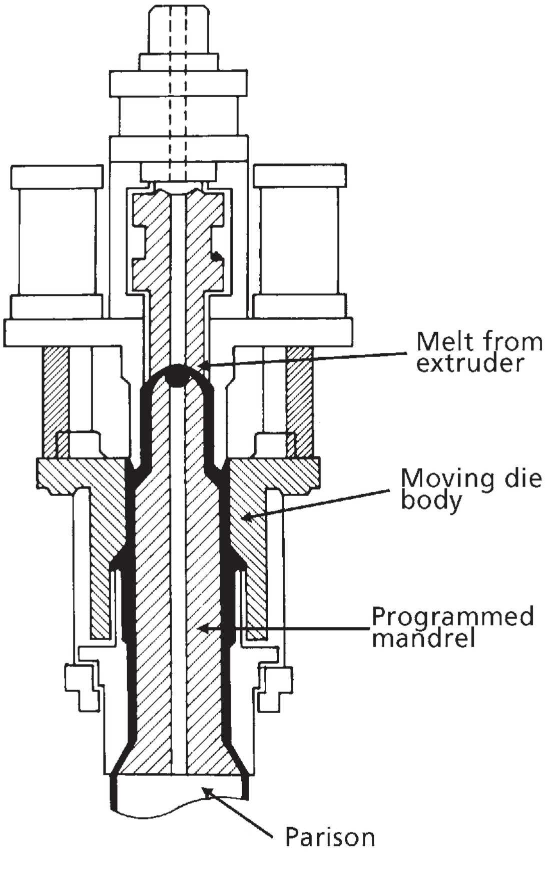


Figure 4.9 Centre feed die

4.10.2 Side-Feed Dies

With the side-feed die head, the melt flow enters at one side of the core (see **Figure 4.10**), and is guided around the core through channels to form a uniform tube to be extruded. There are no multiple weld lines, but it is more difficult to achieve a uniform rate of flow all around the die opening because a portion of the melt must pass around the core, while another portion flows directly to the die opening. Each die maker uses proprietary designs to achieve uniform flow.

4.10.3 Wall Thickness

Wall thickness around the circumference of the parison is adjusted by a set of screws at the die orifice. Control of the wall thickness along the length of the parison is possible with a suitably shaped die and a mandrel that can be moved axially within the die body.

4.10.4 Accumulator Head

Accumulator head machines are used for blow moulding large containers or parts. Resin is melted in the extruder and pumped into the accumulator, where it is held in readiness for the next cycle as discussed in Section 2.3.2. In the reciprocating screw machine, the melted resin is accumulated and held in the barrel then moved through the head by the screw's forward motion.

4.10.5 Die and Mandrel

The die and mandrel (sometimes called a pin) are sized according to the desired parison diameter and wall thickness. At the die face, the melt should flow at a consistent rate all around the die to provide uniform wall thickness. The die land is the ring shaped (annular) section at the end of the die. It is also the working area where the volume is kept constant. The die land length should be between 10 to 40 times the die opening (or die slot) dimensions.

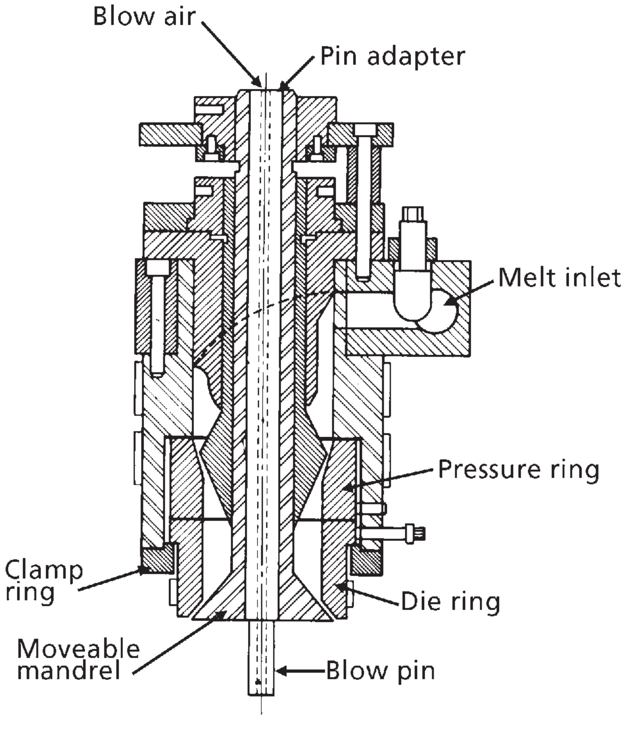


Figure 4.10 Schematic of side feed die

A relatively long die land will reduce parison swell and surface defects caused by melt fracture, but it will increase backpressure on the melt in the extruder. This can improve mixing, but it can also increase the melt temperature and may reduce the extruder's maximum output, possibly limiting the production rate or increasing the drop time (parison formation time). A shorter die land, in conjunction with a high extrusion rate, can result in outer surface roughness in both the parison and the blown part. Determining the right die land length requires a combination of experience and trial and error.

Figure 4.11 shows the two types of mandrel and die: converging, which tapers inward, and diverging, which tapers outward. Whether a converging or diverging design is used depends on the design of the die head and on the type of machine.

4.10.6 Die Swell

As the hot resin leaves the die opening, it swells, growing thicker but shorter. The term for this phenomenon is 'die swell', which is a bit of a misnomer since it is the hot plastic and not the metal die that does the swelling. The amount of swell depends on resin type, machine type, melt temperature, die head temperature, die design, and the rate of parison formation. The size and shape of the die opening or slot must be designed to compensate or correct for die swell.

4.10.7 Parison Adjustment

The purpose of the adjustment ring in a die head is to adjust for an uneven plastic flow from place to place around the parison. One cause is an off-centre mandrel, another is variations in melt or die surface temperatures or variations in the material. The adjustment ring is a movable ring at the base of the die head. It can be moved with the adjustment screws. Moving this adjustment ring changes the die head gap through which the plastic flows. If the melt flow through the die gap is uneven, the parison wall will be thicker on one side than on the other (as will be the blown part). This may cause the parison to curve or swing toward the hotter side, which will be the thicker side.

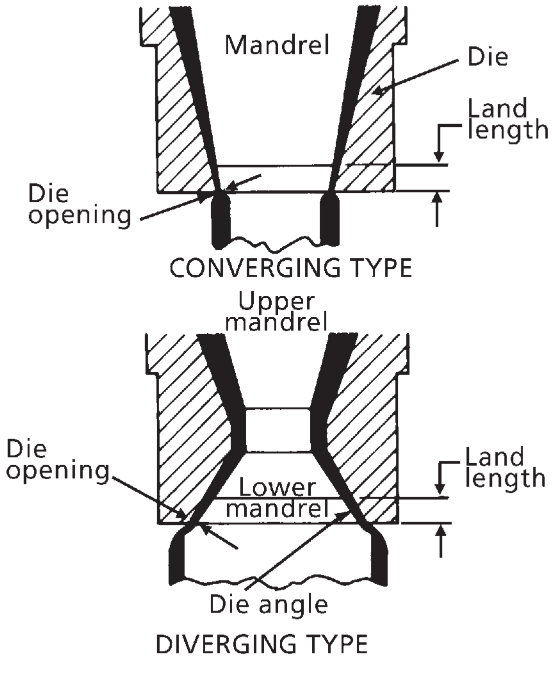


Figure 4.11 Converging and diverging dies

To correct, that is to achieve even flow and uniform wall thickness, always tighten the adjustment ring screws on the side opposite the direction of swing (see **Figure 4.12**).

4.10.8 Die Shaping

'Die shaping' is a technique frequently used to improve the circumferential wall thickness distribution of a blow-moulded part. Die shaping is also referred to as ovalisation or profiling, and may have other descriptive names. Die shaping consists of opening the head tooling die gap at the orifice to increase the thickness of some longitudinal portion of the parison. The thicker section of the parison blows in the 'problem area' of the part, which is usually where it has been difficult to maintain adequate wall thickness, and increases the thickness. Opening the die orifice is done by machining an area at the die face and 'running out' the pin or mandrel part of the way through the land of the die, as shown in **Figure 4.13**.

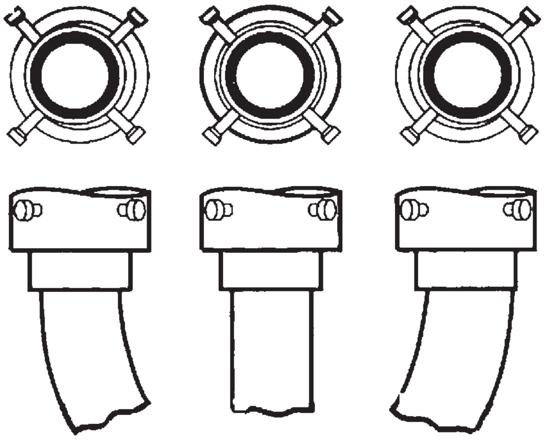


Figure 4.12 Head adjustment to achieve uniform parison wall gauge

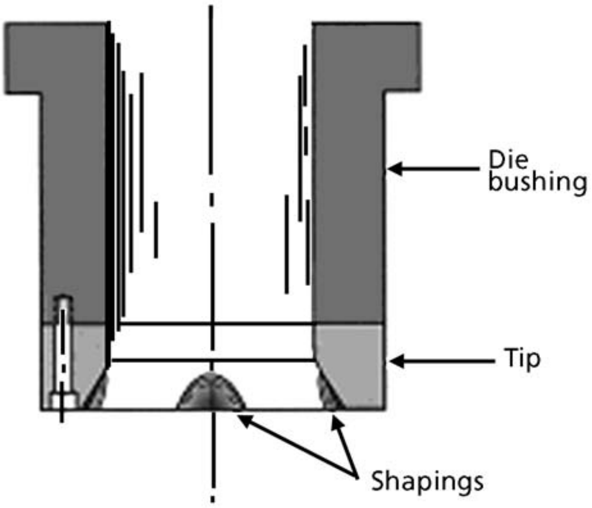


Figure 4.13 Die shaping

4.10.9 Parison Programming

Unless the temperature is too high, the parison will stay in one piece as it is formed, but as it extrudes it is subject to gravity, and therefore thins out at the top. This thinning is referred to as sag, draw down, neck down, or stretch out. Such a parison (and final part) will end up being thicker at the bottom and thinner at the top, resulting in a part with non-uniform wall thickness.

Parison sag is affected by the same factors as swell, that is, by resin type, machine type, melt temperature, die head temperature, die design, and the rate of parison formation. While swell and sag tend to work against each other, that is, the extrudate expands and shortens with swell while it thins and stretches with sag, the net result is usually a parison (and a final part) that is thicker at the bottom and thinner at the top. Sag becomes even more of a problem when parison formation takes a long time, since gravity has more time to act on the parison, resulting in more stretching and thinning.

When the parison reaches some 'critical length', it appears to be extruding faster, indicating that the upper part is stretching and thinning out. This condition can be overcome by gradually increasing the wall thickness during extrusion by moving the mandrel inside the die, a process called parison programming.

It is done with an automatic timing device that raises the mandrel some predetermined distance at the proper time, to extrude more melt while the parison is being formed. When the mould closes, the mandrel returns to its original position (see **Figure 4.14**).

Parison programming can also be used to deliberately alter the wall thickness of the part in selected locations. By moving the mandrel up or down during extrusion, parison wall thickness can be increased or decreased to compensate for irregular part configurations in addition to sag.

The die head gap distance is the most important factor affecting the parison wall thickness.

Modern parison programming devices use a microprocessor to control the up and down movement of the mandrel (controlling up to 100 points is common). A further method of controlling wall

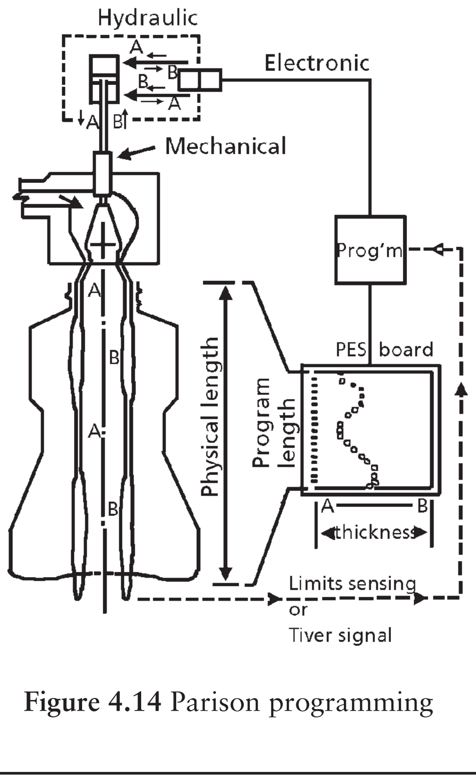


Figure 4.14 Parison programming

thickness is to vary the extrusion pressure through a fixed die opening by changing the screw rpm. Higher screw rpm increases pressure and increases melt output; lower rpm reduces pressure and output (see **Figure 4.15**).

An example of a parison programming controller where pressures can be monitored is shown in **Figure 4.16**.

4.10.10 Blow-up Ratio

The blow-up ratio is defined as the ratio of the average diameter of the finished product to the average diameter of the parison (see **Figure 2.4**).

The maximum blow-up ratio for applications with a thick walled parison is 5:1. For most applications, 3:1 is preferable.

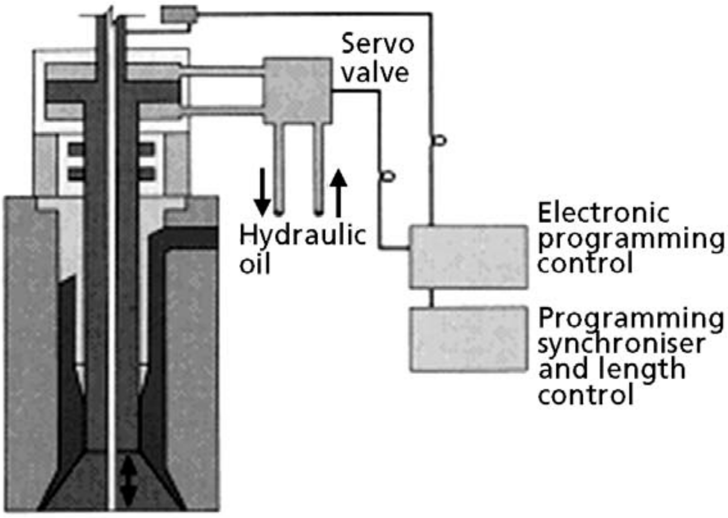


Figure 4.15 Programmed mandrel movement to achieve desired parison and part wall thickness

Figure 4.16 Parison programmable controller

Reproduced with permission from Diakon Molding, Inc., NC, USA.

4.11 Mould Clamping Systems

The blow moulds are mounted on platens, and the platens are moved by the clamping system. Aluminium platens are often used. They are light and stiff, and can be moved quickly by the clamping system. Clamping systems may be of the pneumatic, toggle, or hydraulic type. No matter what system is used, the clamping pressure must be applied consistently and evenly to obtain consistent, reliable, and uniform opening, closing, and clamping. If the closing pressure is not consistent, there may be problems, for example, in the pinch-off trim in the handle area of a container. In order to obtain the control now required, many users prefer machines that have clamping systems based on proportional hydraulics.

Clamping systems vary, based on part configuration. Basically, there are three types. The 'L' shape type has the parting line at an angle of 90° to the centre line of the extruder. The 'T' shape type has the parting line in-line with the extruder centre line. Mould opening is perpendicular to the machine centre line. The third type is the 'gantry' type. The extruder/die head unit is arranged independently of the clamping unit. This arrangement permits the clamp to be positioned in either the 'L' or 'T' shape without being directly tied into the extruder assembly. Regardless of the arrangement, sufficient daylight in the mould platen area is required to accommodate parison systems, that is, single or multiple parisons (multiple head systems), unscrewing equipment, and so on.

4.11.2 Clamping System Requirements

The clamping system is required to do several things. For example:

a) To close and clamp the mould – even on large moulds, the mould closing speed should be 250 mm/s. The amount of clamp force required for holding the mould closed during the blowing process will depend on the projected surface area of the part and the blowing pressure needed to expand the hot parison completely inside the mould cavity. In general, for every square inch of part surface area, approximately 1 MN/m^2 clamping force is normally needed for clamping.

b) To pinch the material at the base to form a weld and (almost) sever the flash – 0.6 to 6 MN/m of pinch section may be required.

c) To move the mould at different speeds to minimise shocks, reduce product tearing, and to give stronger welds – final high speed closing can improve weld strength.

d) To mould and shape the top of the product.

e) Open the mould so that the product may be ejected.

4.11.3 Clamp Operation

It is extremely important that the daylight, maximum, and minimum opening of the platens, be readily and simply adjusted to compensate for various mould sizes and shut heights. Platen closing must be synchronous and parallel to produce acceptable parts. If this is not the case, there will be excessive wear on the bushings and unacceptable parts will result. The overall closing of the platens should be smooth, with no hesitation or bounce-back, especially during final closing as a bad pinch-off will result.

4.11.4 Press Types

The accumulator method usually uses a stationary press, sometimes on a rail track that is moved only for mould set up. In the continuous method, there are several alternative press systems.

4.11.4.1 Shuttle or Reciprocating Press

The shuttle or reciprocating press, frequently used with multi-cavity moulds, has one or more parisons being extruded from the die head while the mould halves are rising upwards or moving sideways. A blow pin or hollow needle enters the parison while the mould halves are rising or sliding sideways.

4.11.4.2 Rising or Vertically Moving Press

A hydraulically operated cylinder on the platens' clamps a mould around the parison and separates it from the extruding parison. The mould drops back down for the blowing and cooling cycle. After ejection of the part, the clamp rises again to receive another parison that had been extruded in the meantime (see **Figure 4.17**).

4.11.4.3 Sliding (Horizontal Moving Press)

In this type of machine the clamp assembly moves a mould to one side for blowing and cooling, while a second clamp assembly closes another mould over the continuously extruding parison. After cooling, the first part is ejected, and the clamp assembly moves back to pick up another parison as the second clamp assembly moves aside (see **Figure 4.18**).

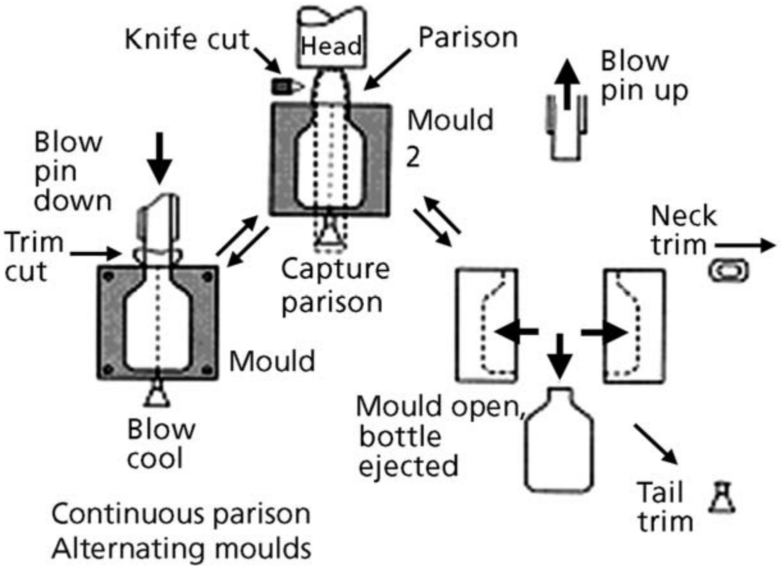


Figure 4.17 Rising (vertical) press

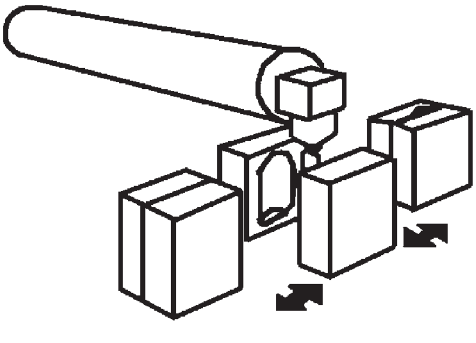


Figure 4.18 Sliding horizontal moving press

Both the rising and sliding methods reduce cycle time since no time is lost while blowing and cooling are completed. The parison extrusion rate is adjusted so that it matches the lag time required for the blow-cooling stage of the cycle.

4.11.4.4 Directional Valve

In this type of machine, a directional valve mounted at the end of extruder diverts the melt stream from a die head assembly on one side, to a die head assembly on the other side. One side is therefore blowing-cooling as a parison is being extruded on the other. As with other continuous methods, the extrusion time has to be matched to the blowing-cooling time. These die heads may also have several parison streams so that multiple cavities can be used to produce several parts at the same time. A blow pin needle is positioned in the mould, preferably near the 'pinch-off', to penetrate the parison effectively for blowing. In the case of bottle moulds, a blow pin is mounted in the clamp assembly.

4.11.4.5 Rotary Wheel Continuous

For very high production and long run parts such as personal care products, a rotary wheel is the preferred production method. A vertical wheel is mounted next to the extrusion die. Multiple split blow moulds are mounted on the wheel. Each of the moulds is independently operated, either hydraulically or pneumatically. While the wheel turns, one mould at a time passes under the die to receive and close around the parison. The motion is continuous. The blowing air is introduced through a hollow needle and penetrates the parison when the mould closes or shortly afterwards (see **Figures 4.19** and **4.20**).

The air is fed through the wheel axle, as is the water used to cool the moulds. Rotary cams, located in the wheel axle, control the mould opening, mould closing, blowing air start and blowing needle insertion.

Machines of this type may extrude the parison either downwards or upwards, where it is pulled along as needed. These wheels may carry up to 20 or more moulds. Rotation of the mould carrier is arranged to provide ample time for each mould to blow, cool, and eject the product. The extrusion speed of the parison is coordinated with the rotation speed of the wheel. The ejected parts are connected by sections of the parison, which requires trimming and finishing steps at both ends of the parts. The weight, and therefore the wall thickness of the blown parts can be reduced or increased (within limits) by varying the extruder speed or the rotation speed of the wheel.

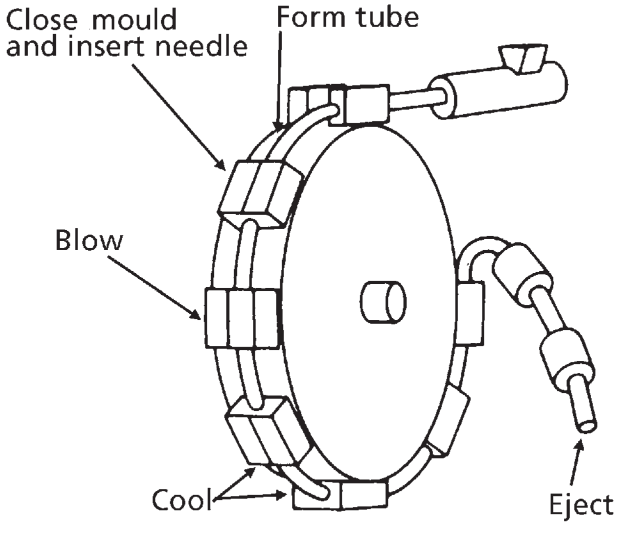
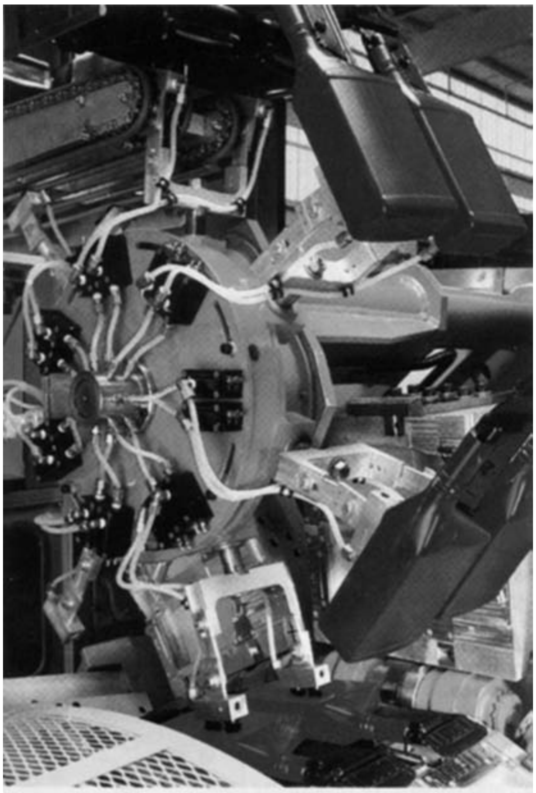


Figure 4.19 Vertical wheel

4.11.4.6 Rotary Wheel Shuttle

This type of machine combines the advantages of both wheel and shuttle technologies and may have four or more stations. The parison is extruded continuously. The mould closes and the parison is cut, then the wheel rotates to bring the next mould into position to clamp over the parison. This process is repeated continuously, with blowing and cooling taking place in non-active stations. In the last station, the part is ejected. This method is used for high production rates with larger containers and is more flexible for mould changes (see **Figure 4.21**).



Siemens technology controls this vertical wheel blow molding system
Photo courtesy of Uniloy Milacron

Figure 4.20 Milacron vertical wheel blow moulding system

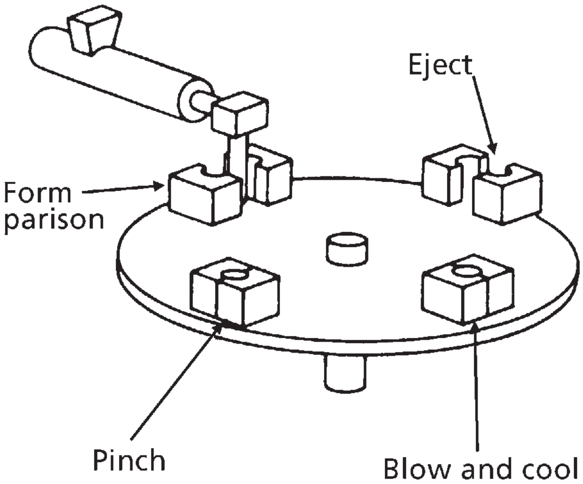


Figure 4.21 Rotary wheel shuttle

5 Extrusion Blow Moulding Advanced Systems

5.1 Co-Extrusion Blow Moulding

'Co-extrusion' refers to the technology used to make products that contain multiple layers in their wall structures. Such products are said to be co-extruded. The layers may be made of the same or different materials, coloured or uncoloured material, or recycled and virgin materials. Packaging of various types is the primary application of co-extruded products, as better barrier properties are the main reason for the multilayer structure.

The multi-layered structure of co-extruded products is created by combining two or more melt layers in the die head before their extrusion as a parison. The main difference between multiple layer and single material extrusion blow moulding is in the extrusion system. In co-extrusion, each material is extruded from its own extruder. Examples of products made from this process are ketchup bottles and automotive gas tanks.

5.1.1 Arrangement of Extruders for Co-Extrusion

An arrangement of extruders to produce co-extruded, multi-layer structures is illustrated in **Figure 5.1**.

5.1.2 Multi-Layered Structures

A coextruded, multi-layered structure (**Figure 5.2**) may be created to provide one or more characteristics that cannot be provided by a single-layer product. These may be based on a physical requirement, for example, a better heat barrier or increased resistance to permeation. Also, cost considerations may require that a virgin wall material be replaced by reclaimed material, or that a costly colour be used in only one layer of the structure instead of throughout the entire wall thickness.

5.1.3 Co-Extrusion Systems

The extrusion system in co-extrusion blow moulding must simultaneously supply several streams of melted material to the die. Some streams are smaller, by design, in volume than others, in order

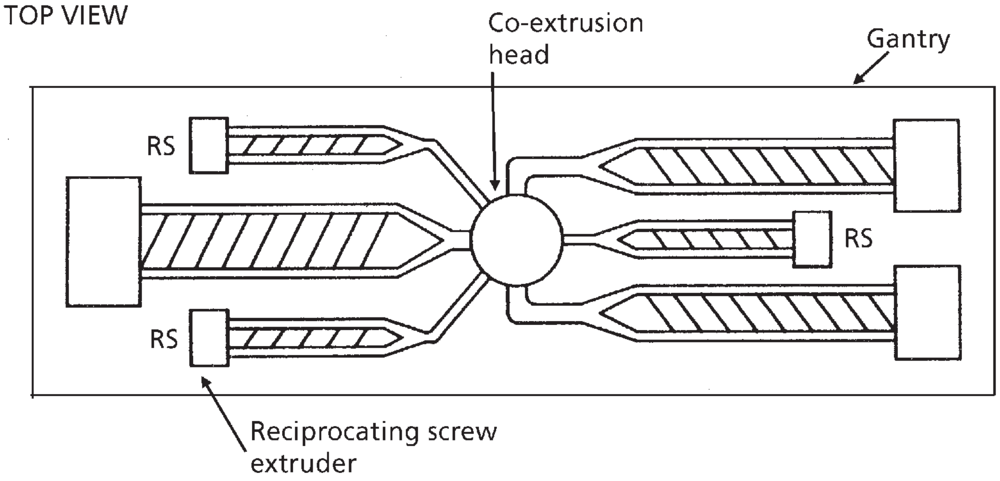
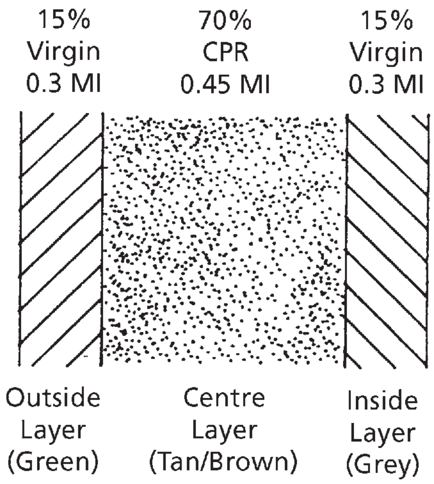
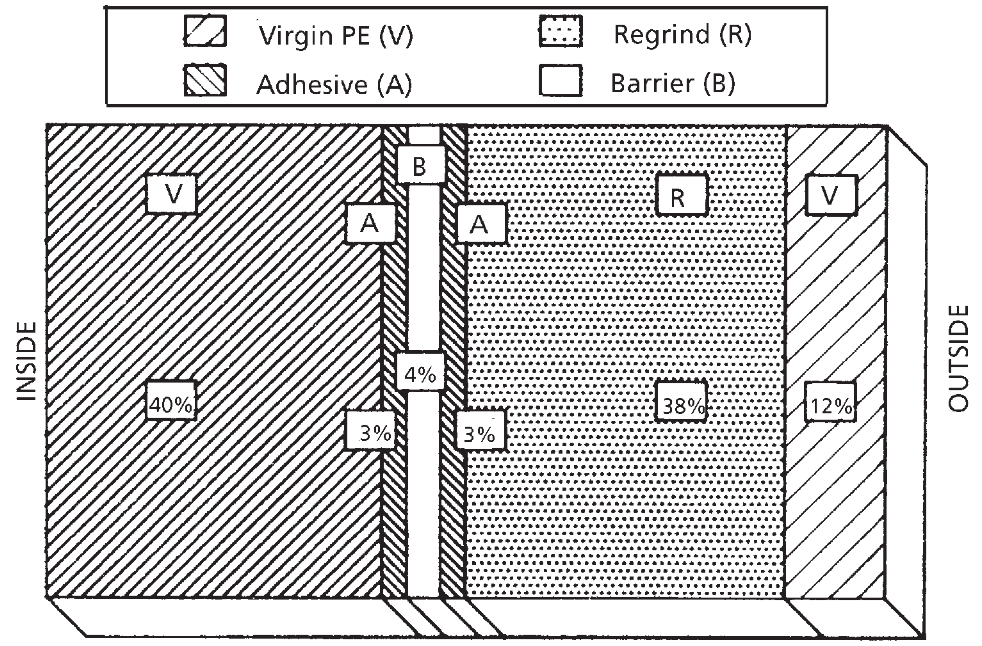


Figure 5.1 Co-extrusion blow moulding. RS = reciprocating screw



Three Layer HDPE Structure 32 Gallon Trash Can



Typical Fuel Tank Layer Thickness in Barrier Co-Extrusion

Figure 5.2 Multi-layer structures

to produce thinner layers. The processing conditions may also differ from one material to another. **Figure 5.3** shows a typical co-extrusion die head.

5.2 Three-Dimensional Blow Moulding

5.2.1 Introduction to 3-D

Three-dimensional blow moulding is a concept developed several years ago in Japan and further refined in Germany in recent years.

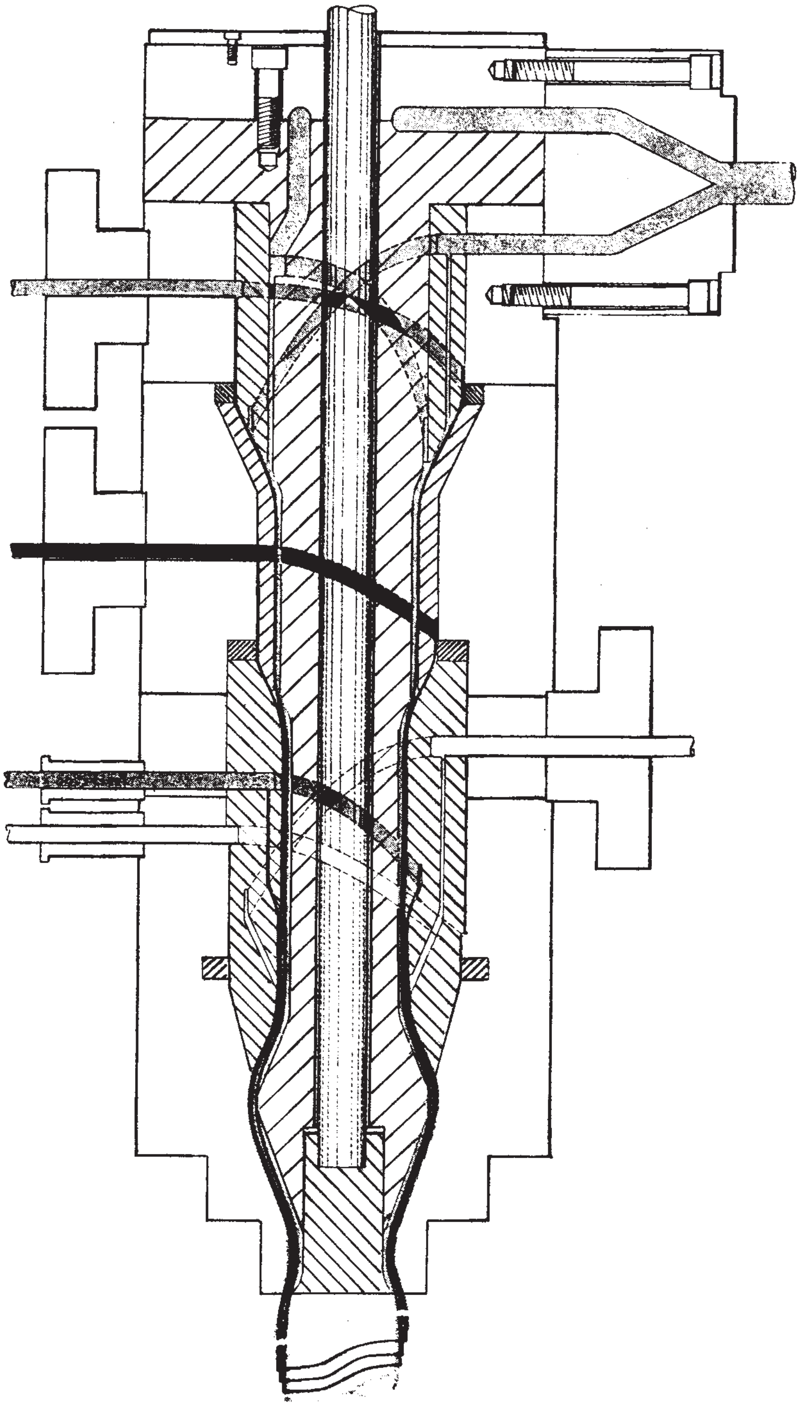


Figure 5.3 Co-extrusion die head

Parts with irregular shapes which are conventionally blow moulded create large areas of flash whereas a seamless moulded part only has flash at the top and bottom of the part, see example of air duct shown **Figure 5.4**.

The advantages of the reduced flash are:

- A smaller extruder can be used
- Less power is used
- Use of granulating equipment, thus less regrind handling. Other advantages include: even wall thickness, improved mechanical strength, no finishing at outer diameter resulting in high product quality, and lower clamp forces are required.

5.2.2 3-D Extrusion Processes

There are three choices of 3-D technology methods available: suction blow module, vertical clamp parison manipulation and horizontal segmented mould parison manipulation (See **Figure 5.5**).

5.2.3 Suction Blow Moulding

Figure 5.6 shows the four phases of the suction blow moulding process.

Examples of suction blow moulding are shown in **Figure 5.7**, **Figure 5.8** and **Figure 5.9**.

Figure 5.10 shows a coolant pipe with a transition from round to square.

Figure 5.4 Air duct parts: top 3-D blow moulded part; bottom conventional blow moulded part

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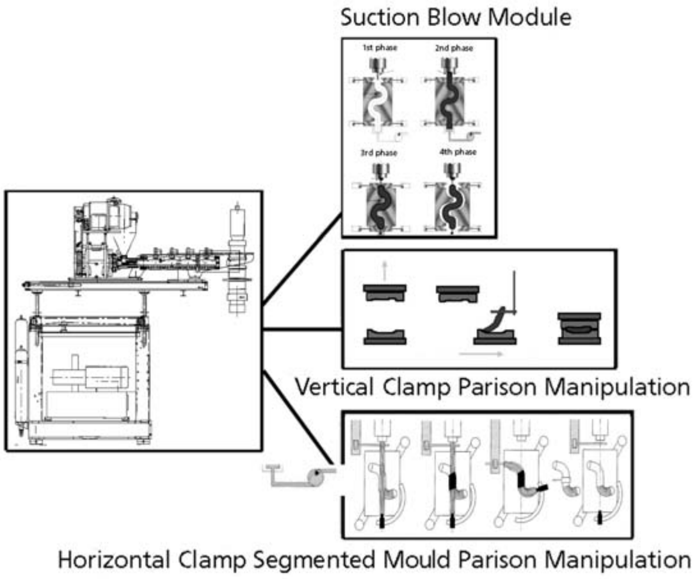

Figure 5.5 3-D Extrusion system

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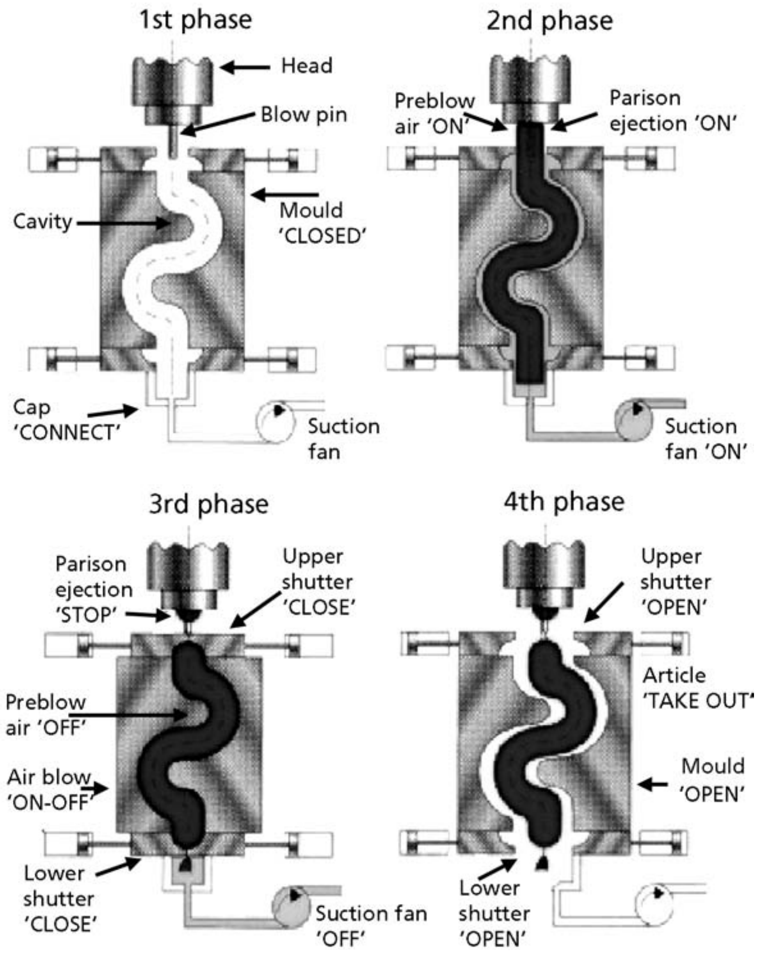

Figure 5.6 Suction blow moulding

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Figure 5.7

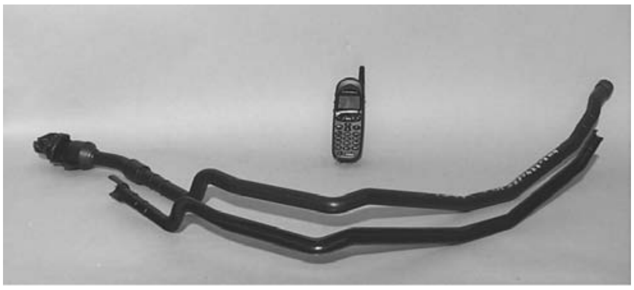

Figure 5.8

Figure 5.9

Figures 5.7, 5.8, and **5.9** Coolant pipes

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Figure 5.11 shows an integrated mounting with moulded in brackets to facilitate mechanical attachment.

Figure 5.12 shows the vertical clamp method.

Figure 5.10 Transition from round to square

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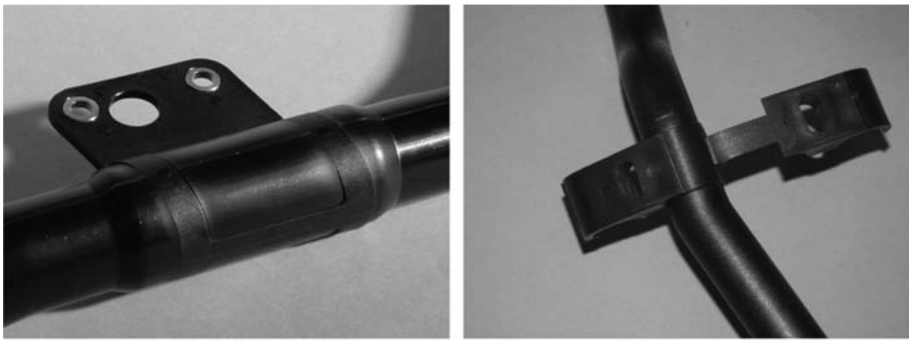

Figure 5.11 Moulded-in brackets to facilitate mechanical attachment

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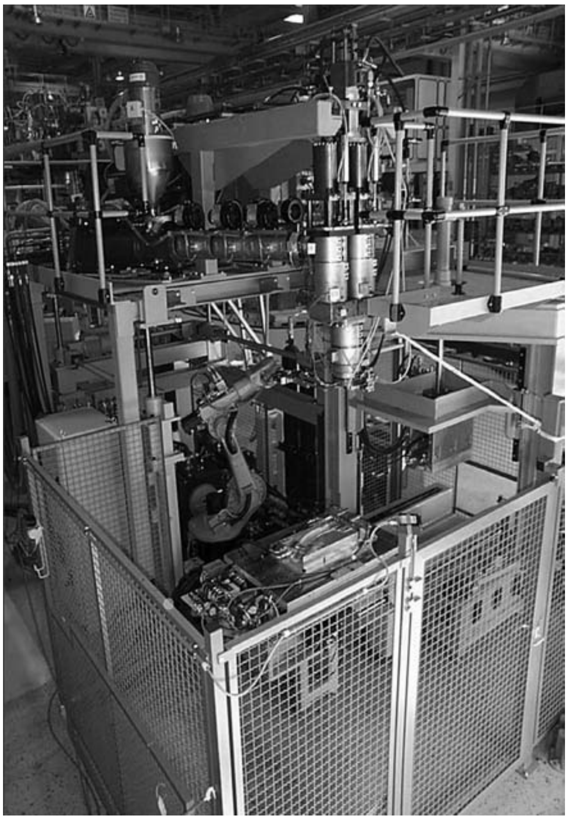

Figure 5.12 Vertical clamp method

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5.2.4 Parison Manipulation

5.2.4.1 Vertical Clamp Method

In this method the mould opens vertically, the lower half slides out and the parison is placed in the cavity, the mould slides back and blows (see **Figure 5.13**).

The use of this method is ideal for multi-layer applications, for example fuel filler pipes, with conventional mould halves that provide a lower mould cost. The mould is also very accessible and double clamp stations can be used for higher volumes.

5.2.4.2 Segmented mould/horizontal clamp

In this process (**Figure 5.14**) the parison is extruded and the mould begins to close, the parison is inflated, then the parison is manipulated to the cavity configuration, the mould completes its closure, cools and opens with part ejection.

The parison manipulation is accomplished with a six axis robot (**Figure 5.15**). Complex shapes can be produced by using segmented mould technology, with the incorporation of value added design features through the use of clamp function, pinchoff for twin tubes, brackets, and so on. High part quality is obtained because of the minimum contact between the parts and the mould.

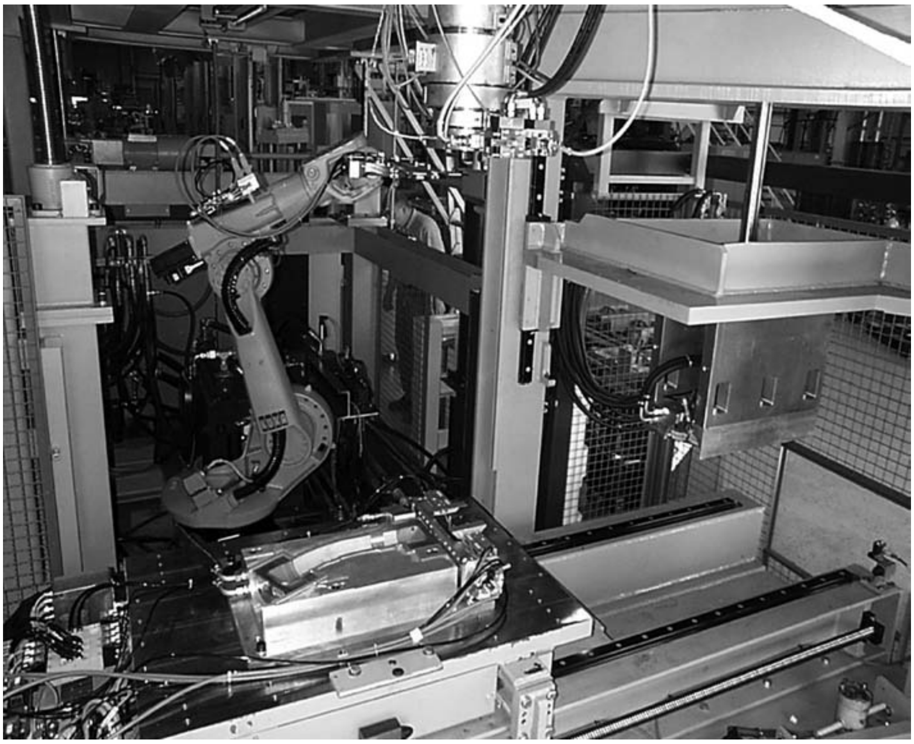

Figure 5.13 Integrated mounting

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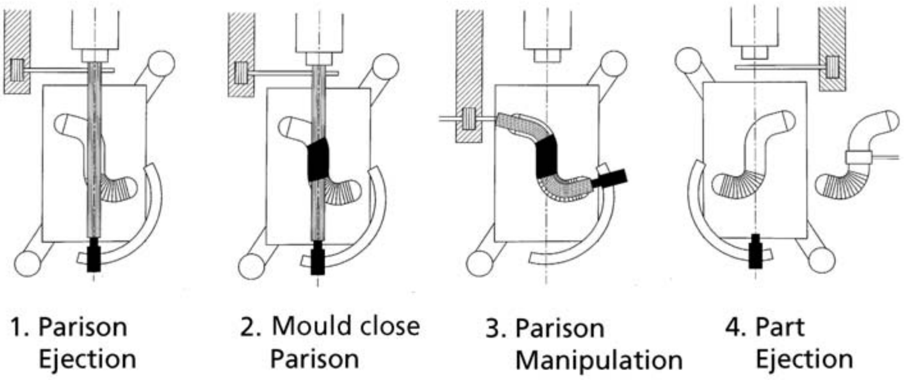

Figure 5.14 Horizontal clamp

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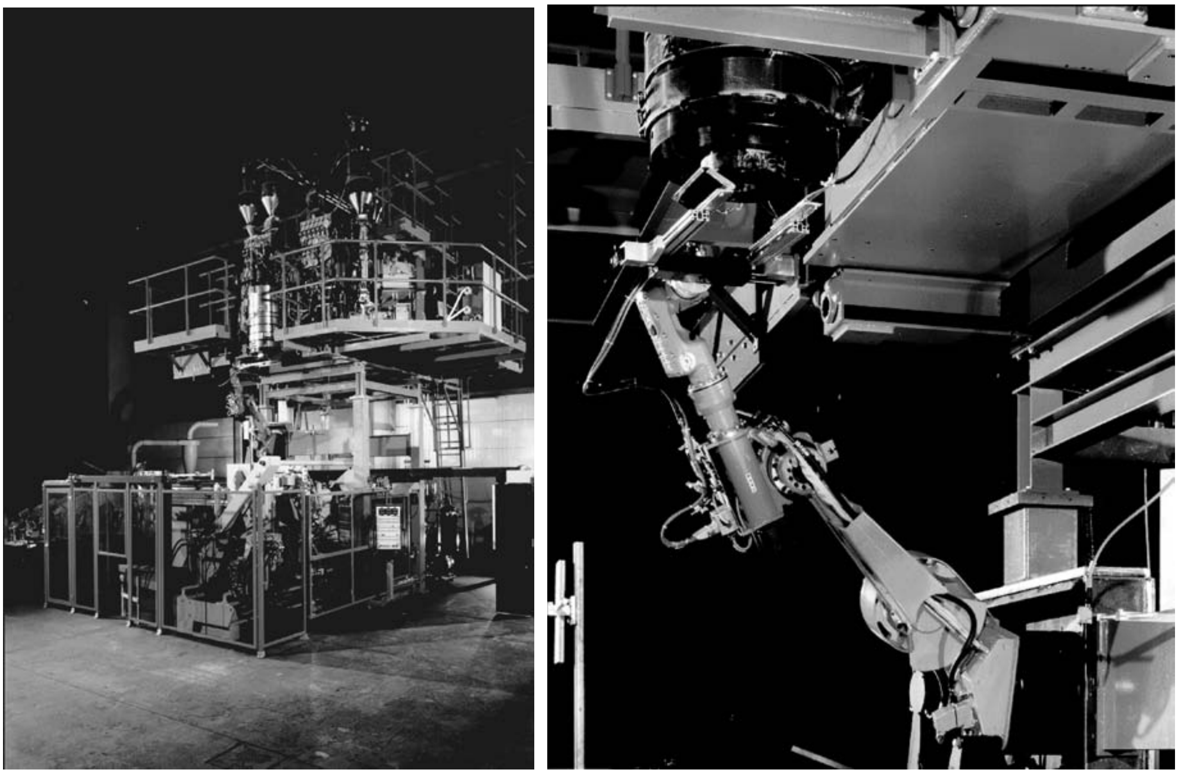

Figure 5.15 Parison manipulation *via* robot

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5.2.5 3-D Extrusion Systems

5.2.5.1 Mono-Layer

Conventional extrusion methods with a single resin use a two-layer Seco Process. Dual durometer (2-3 layers) l co-extrusion (Seco) is accomplished with multi-extruders which sequentially layer resin into a common head (**Figure 5.16**). The extruders are sequenced to extrude resin at required intervals.

5.2.5.2 Two-Layer Seco Process

Dual durometer (2-3 layers) sequential co-extrusion (Seco) is accomplished with multi-extruders, which layers resin into a common head. The extruders are sequenced to extrude the resin at required intervals (**Figure 5.17**). The resin is extruded between areas of change providing an overlap for good adhesion.

Applications are illustrated in **Figures 5.18** and **5.19**.

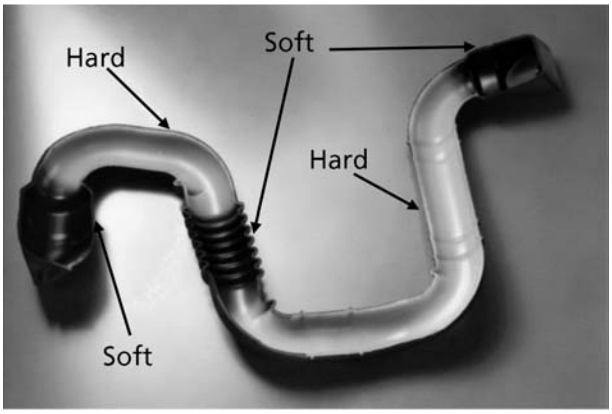

Figure 5.16 Dual durometer (hard-soft-hard)

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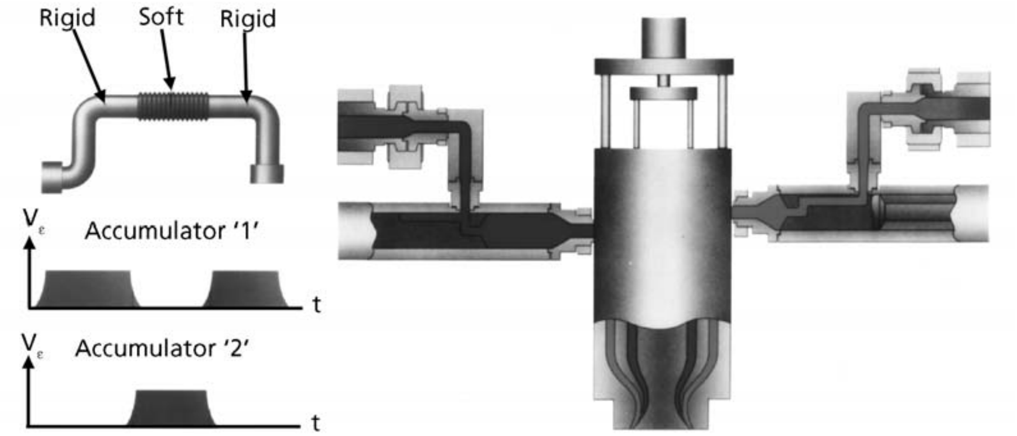

Figure 5.17 Two layer dual process

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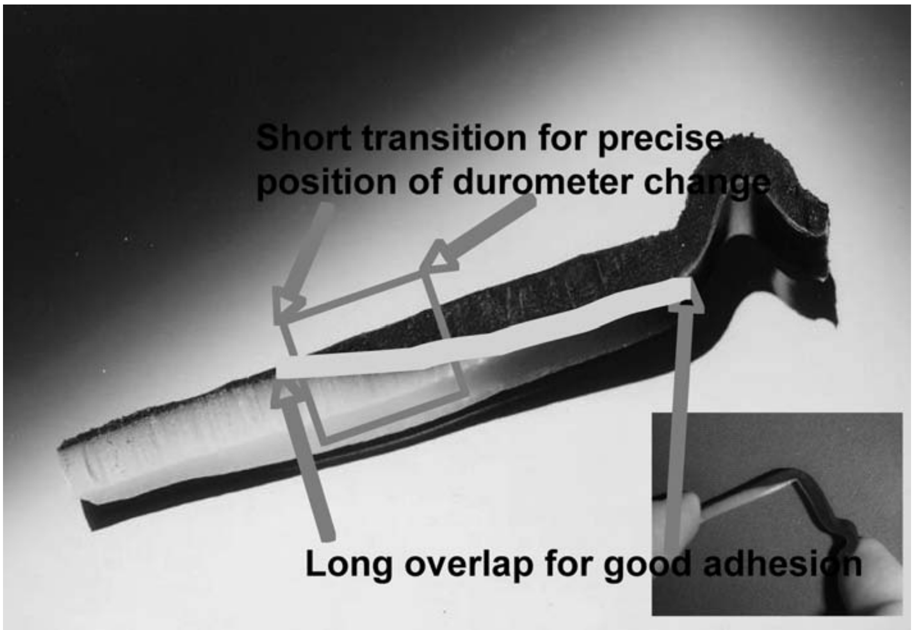

Figure 5.18 Two layer dual durometer transition

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Figure 5.19 Two layer dual durometer transition

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Figure 5.20 shows a cross-section of a two layer dual durometer transition. Effective transition requires:

- Two resins with similar rheological behaviour and melt strength and a narrow blow ratio range.
- Minimum exposure to high stress under normal use conditions.

- Coolant system – improved hydrolysis resistance; 2 to 3 layers.
- Improved visual appearance and/or soft touch – 2 layers.

5.2.6 Head Adapter Radial Wall System

To give even wall distribution around curves and bends, a radial wall die head is required. The die is moved with two cylinders horizontally which changes the cross-section of the parison at the appropriate time, thus compensating the wall thickness as required (see **Figure 5.21**). The die gap can be widened at each circumferential point (360 degrees) and is narrowed on the opposite side through eccentric ring movement. A die gap ratio of 1:3 can be achieved, see **Figure 5.22**. Applications are illustrated in **Figures 5.23** and **5.21**, also six extruder layouts (**Figure 5.23**). In addition a 6-layer filler pipe in shown **Figure 5.24** and a part using the radial system in **Figure 5.22**.

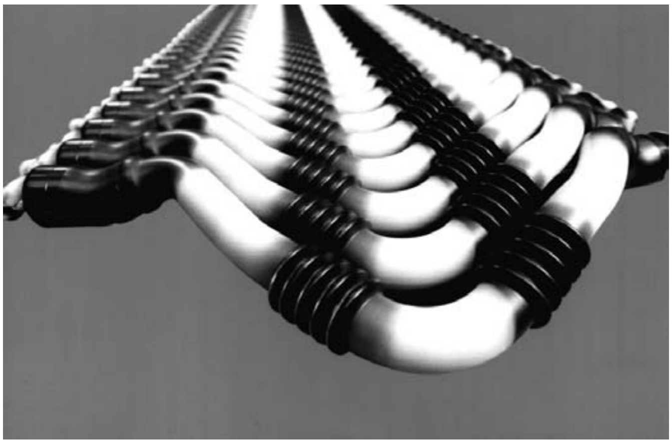

Figure 5.20 Application with six transitions

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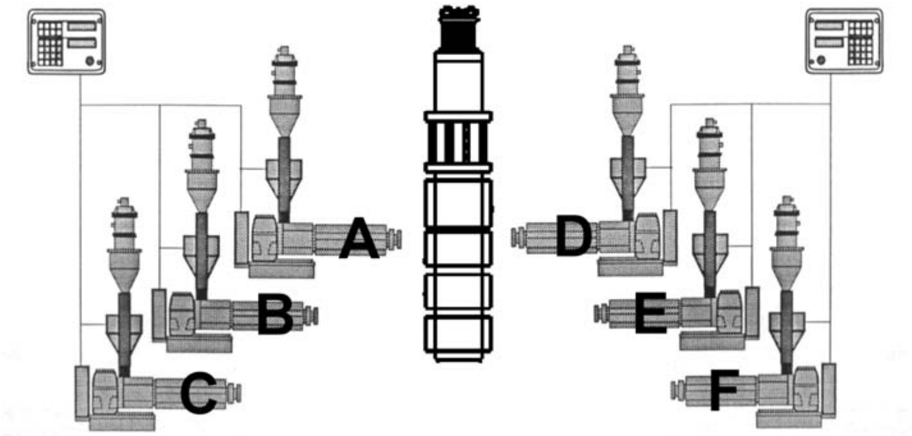

Figure 5.21 Parison manipulation/segmented mould. Co-extrusion of a 6-layer filler pipe with pinch-off

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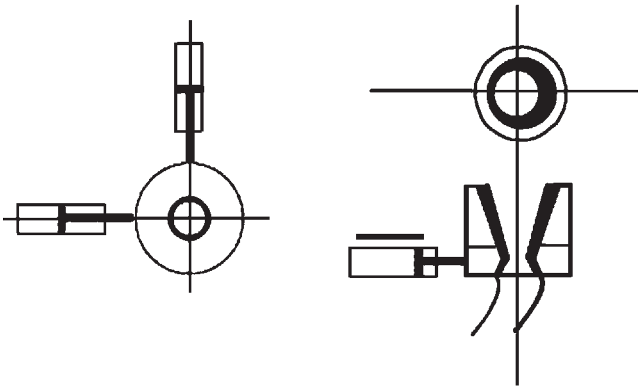

Figure 5.22 Part configuration, which uses a radial wall system

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Figure 5.23 Diagram showing six extruders

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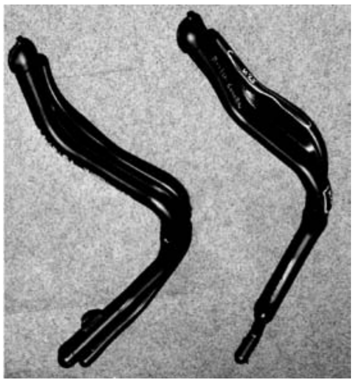

Figure 5.24 Parison manipulation/segmented mould. Co-extrusion of a 6-layer filler pipe W/pinch-off

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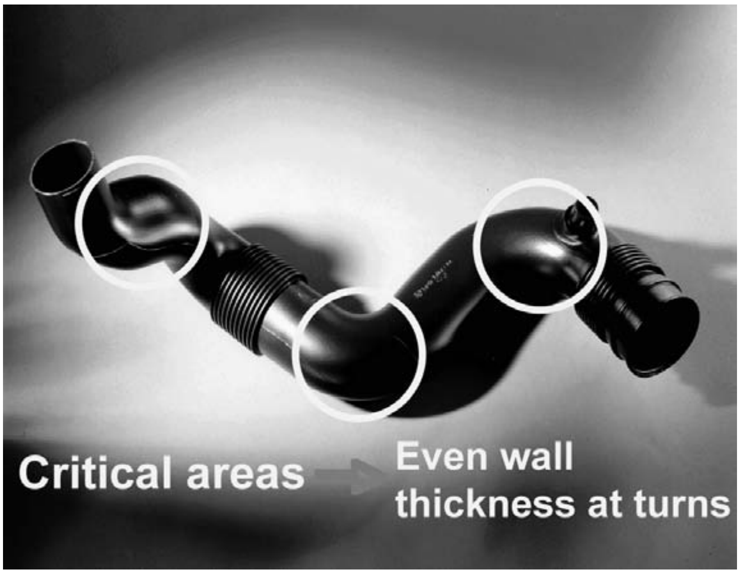

Figure 5.25 Head adapter – radial wall distribution system

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5.3 Double Walled Parts and Containers

Double wall parts mostly cases with shallow draft angles were developed in the early 1970s with pivots, latches, a modular mould system and also a special blow machine. At that time the design and process patents for double wall cases were issued to Peter Sherman, who licensed several, moulders in different regions of the USA and Europe.

A typical part and manufacturing sequence is:

1. Shows a typical shallow case.

2. The parison is usually produced on a continuous extrusion machine with a transfer parison into a mould or a shuttle press.

3. The parison has been pre-pinched on the bottom. It has been pre-blown with low pressure to form a pillow.

4. As the mould halves close, the parison bulges and forms over male core side of the mould. The side and top of parison begins to be trapped around the edges, essential for producing the successful double walled part.

5. Mould further closes with air preventing walls from collapsing.

6. In the cooling and high pressure air phase, the parison conforms to the mould core and cavity. The high pressure air is usually blown through a hollow needle.

6 Injection and Stretch Blow Moulding Machines

6.1 Introduction

As previously outlined in Chapter 1, the term injection blow moulding is the compatible integration of two processes, injection moulding and blow moulding. This integration system is one, which is designed exclusively for injection blow moulding with a plasticiser, hydraulically operated clam unit, electrical controls, other machine components and functions. See Chapter 1, Section 1.2.1.4 for the advantages of this process.

As with extrusion blow moulding it is a two-step process. The first stage consists of injection moulding the preform in a mould consisting of a cavity and a hollow core. The second involves moulding and cooling in a follow-on mould (see **Figure 6.1**). The preform is injection moulded at a temperature which is in the temperature range of the moulding resin and blown at a temperature in the thermoplastic range. Products made by the injection blow moulding process are shown in **Figure 1.8** and **Table 6.1**. Materials (resins) suitable for injection blowing are given in **Table 6.2**.

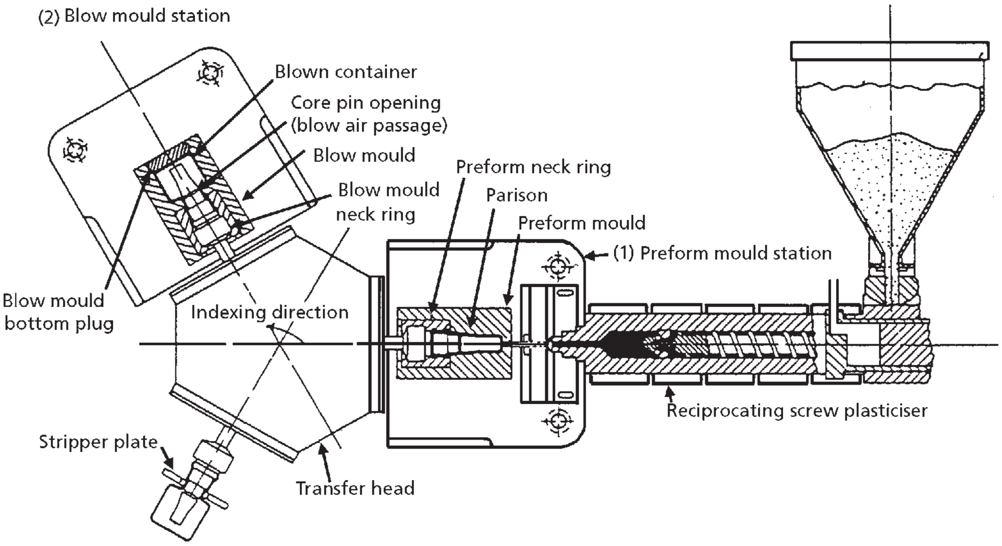


Figure 6.1 Basic injection blow mould

Table 6.1 Products made by injection blow moulding process	
Bottles	Pill bottles
	Mascara tubes
	Toiletries
	Dropper bottles
	Jars
	Hair dryer bottles
Automotive parts	Constant velocity joint bellows
	Steering rack bellows
Petroleum can parts	
Liquor miniatures spice jars	

Table 6.2 Resins suitable for injection blow process
Polyethylene
Polypropylene
PET
Thermoplastic elastomers
Polystyrene
PVC
Acrylonitriles
Polycarbonate
Polyurethane
SAN
EVA

6.1.1 Injection Moulding Process [1]

The injection moulding process is a complex process that involves a series of sequential process steps. The different phases are: the mould filling phase, the packing phase, the holding phase, the cooling phase, and part ejection.

- *Mould filling*: After the mould closes, the melt flows from the injection unit of the moulding machine into the relatively cool mould through the sprue, the runners, the gates and then into the cavity.

- *Packing*: The melt is pressurised and compressed to ensure complete filling and detailed surface replication.

- *Holding*: The melt is held in the mould under pressure to compensate for shrinkage as the part cools. A holding pressure is usually applied until the gate solidifies. Once gate solidification occurs, melt can no longer flow into (or out of) the cavity.

- *Cooling*: the melt continues to cool and shrink with no shrinkage compensation.

- *Part ejection*: The mould opens and the cooled part is then stripped from the core or cavity, in most cases using a mechanical ejector system.

6.2 Process Characteristics

There are two process systems:

6.2.1 One step Machine

This is an integrated system where all stages are integrated and combined in sequence into one machine, namely, injection moulding, blowing and cooling and ejection of the part. The hollow core in the injection stage is used to blow air into the preform at the blowing stage.

6.2.1.1 Types of Machine

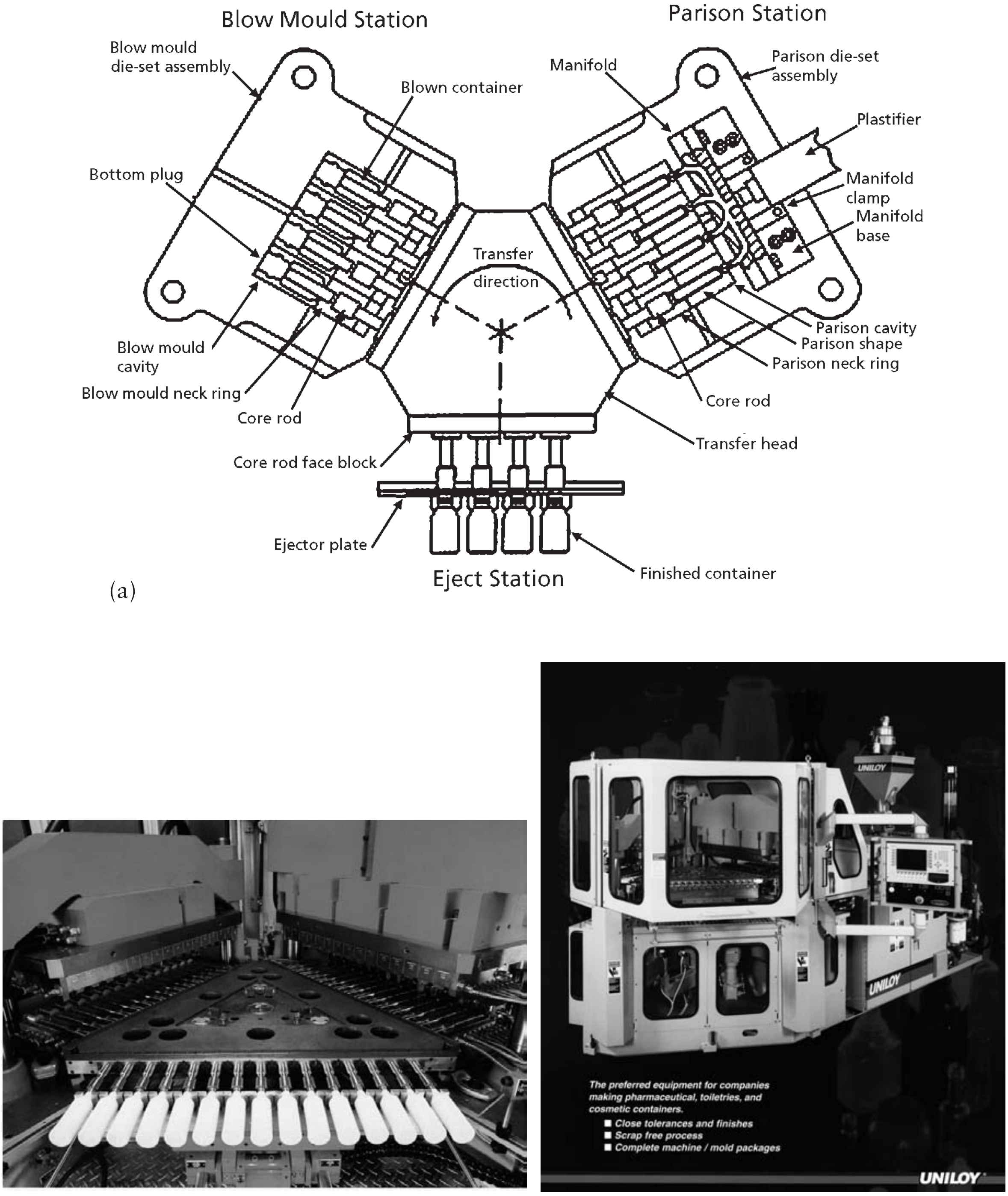
There are two types of this machine, a three station and a four station.

6.2.1.2 Three Station

The three station is illustrated in **Figure 6.2**.

6.2.1.3 Four Station

The four station is illustrated in **Figure 6.3**.



(a)

(b)

(c)

Figure 6.2a, b, c Illustration of a three station machine

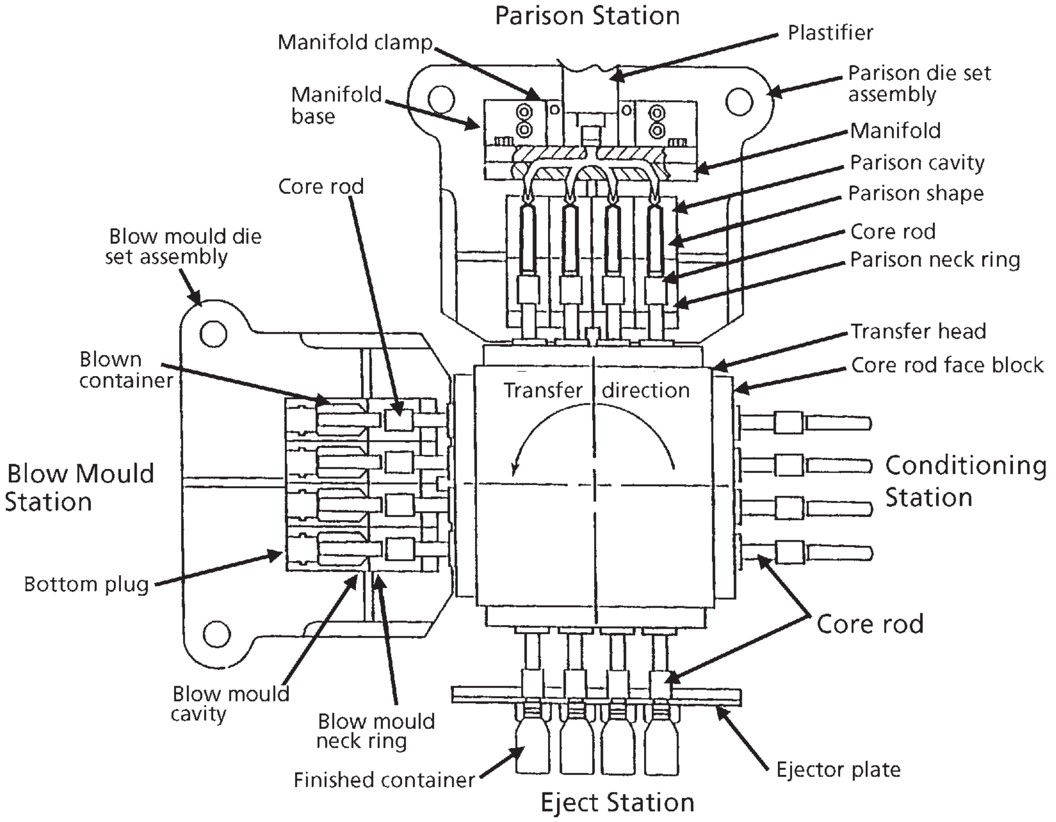


Figure 6.3 Illustration of a four station machine

6.2.1.4 Differences between Three and Four Station Machines

The difference between three and four station machines is the dry cycle. In the four station machine, the dry cycle consists of the opening of the moulds or clamp, and the time which has a shortened actual closing time (no processing) of 1.5 seconds. This is accomplished because the index rotation movement is 120 *versus* 90 degrees.

6.2.2 Two Step Process

The second step is that the preform is moulded on a standard injection moulding machine. The preform is stored until ready to use and then transferred to a blow moulding machine which consists of an equilibrating unit (usually an infra-red heated oven), a blowing station and an ejection station.

6.2.3 Moulding Process

In both cases the preform is moulded over a core pin and if a bottle, the final neck thread is formed in the injection stage. The core cavity is shaped so that the plastic wall is thick or thin to produce the desired part in the blowing cavity.

6.3 Tooling

6.3.1 Introduction

Preform design and production is the heart of the injection (and stretch) moulding system. Each container has its own preform design therefore its own core rod and cavity designs. The more thorough the advance design work is, the less costly it will be in terms of both time and money for modifications during pre-production trials of the mould.

6.3.1.1 Core Rod L/D Ratio

The first step in the core rod design is the evaluation of the container shape. The container should not be too tall in relation to the neck diameter. This is determined by the ratio of the finished neck diameter. This is checked by determining the ratio of the core length to the finished neck diameter ‘E’. In general the L/D ratio should not exceed 12:1. Below this diameter the core rod defection will be minimised and a uniform material (resin) wall distribution will be maintained (see **Figure 6.4**).

6.3.1.2 Blow-Up Ratio

The container should have a blow-up ratio of 3:1 or less for optimum processing. The blow-up ratio is: container body diameter divided by finished neck diameter ‘E’. In exceptional cases ‘blow-up’ ratios of 3.5:1 can be achieved (see **Figure 6.5**).

6.3.1.3 Oval Containers

Oval containers must be checked to see if they fit within the ovality ratio. This is the ratio of the container width to depth. An ovality ratio of up to 1.5:1 is satisfactory (see **Figure 6.6**).

6.3.1.4 Preform Design

With the container shape determined as outlined, the preform is now considered. In the annular area, anywhere along the profile, except the neck, where a nominal wall thickness is desired, there

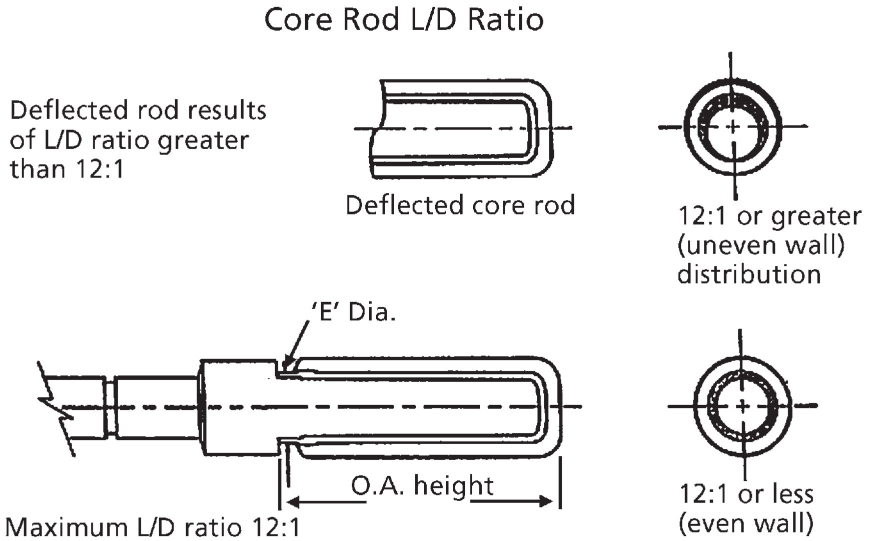


Figure 6.4 Core rod L/D ratio

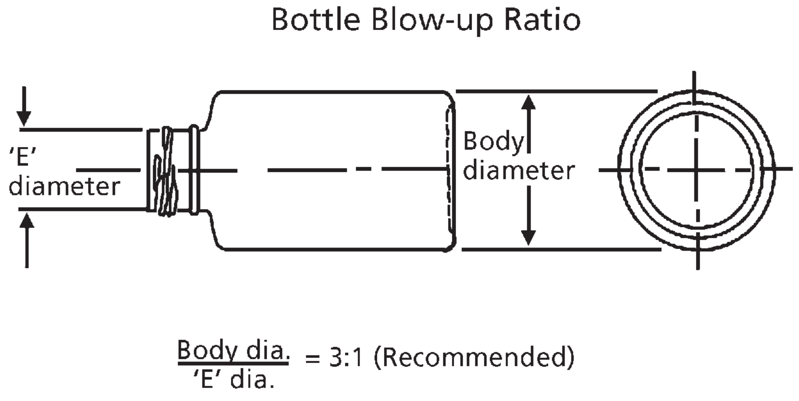


Figure 6.5 Blow-up ratio

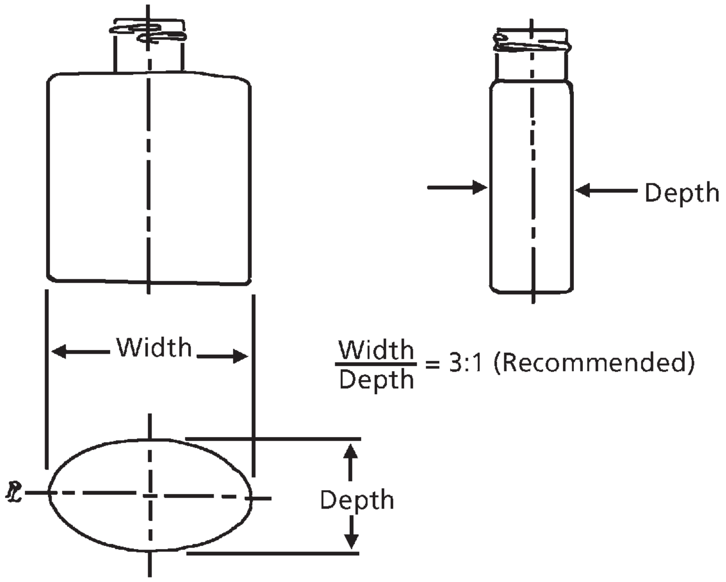


Figure 6.6 Ovality ratio

could be a compromise between the parison wall thickness and blow-up ratio. To maintain the bottle weight and minimum wall thickness the preform will be smaller in diameter which in turn increases the blow-up ratio. When considering preforms for an oval container, the parison is usually ovalised in the direction of the container depth. To prevent weld lines, the maximum wall thickness should be keep to the minimum, the preform across section should be less than 1.5. Because it is difficult to adequately condition in the preform cavity during the blowing process, a wall thickness of less than 0.35 mm is considered unsuitable.

6.3.1.5 Core Rod

The preform establishes the core rod and preform diameter and length. It is noted that the diameter of the core rod body must be smaller than the smallest diameter of the neck finish of the preform in order for the container to be stripped from the core rod in the ejection stage, in the 'two step' process or in the event of a mishap in the 'one step' method before the blowing station. For the same reason, a core taper of at least 0.5 degrees has proved to be popular. Further details are discussed in core rod assembly, Section 6.3.1.11 (see **Figure 6.7**).

6.3.1.6 Preform Neck Ring

The finished shape of the threaded neck shape is formed in the neck ring of the container. It also performs the task of centring and securing the core rod inside the preform cavity to prevent core rod deflection during the injection moulding sequence of the moulding cycle. As this is to be the finished neck diameter on the product, polymer shrinkage needs to be accounted for in the neck dimensions.

6.3.1.7 Preform Cavity

The preform mould has two halves, a stationary lower one and a movable upper. The cavity dimensions are determined by the core rod layout. The outside physical dimensions are governed by the specific machine upon which it is to be mounted.

Temperature control is critical and is an essential in the layout of the cavity design. Temperature control zone channels are created by drilled holes in the mould body to form the circulation of the liquid cooling system. These channels are connected to separate individually controlled zones. The number and location of the zones are a critical factor since it affects the efficiency of the final production. The positioning of the zones along the cavity profile is such that the temperatures are varied to cause a uniform blowing of the parison (see **Figure 6.8**).

6.3.1.8 Blow Mould Neck Ring

The blow mould neck ring serves to contain the already formed finished neck of the preform. The dimensions of the finished sizes should be slightly larger (0.05-0.25 mm) than the preform neck dimensions. Separate cooling should also be added to give thermal control.

6.3.1.9 Blow Mould Cavity

The blow mould cavity has two mould halves as the preform cavity. In this case the mould is not exposed to the same severe pressure conditions as the preform mould. The clamping being 0.69-1.03 MPa. As with the preform cavity the most important consideration is a provision for optimum cooling (see **Figure 6.9**).

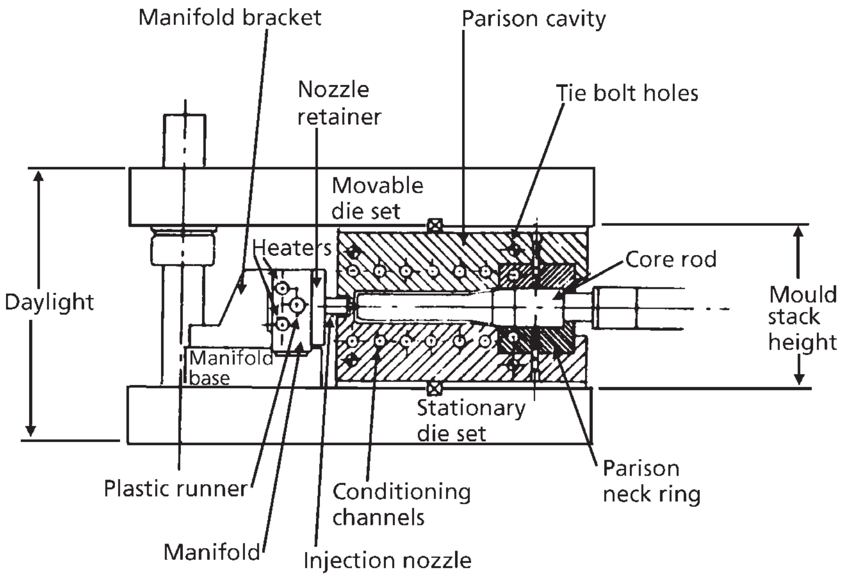


Figure 6.7 Core rod assembly

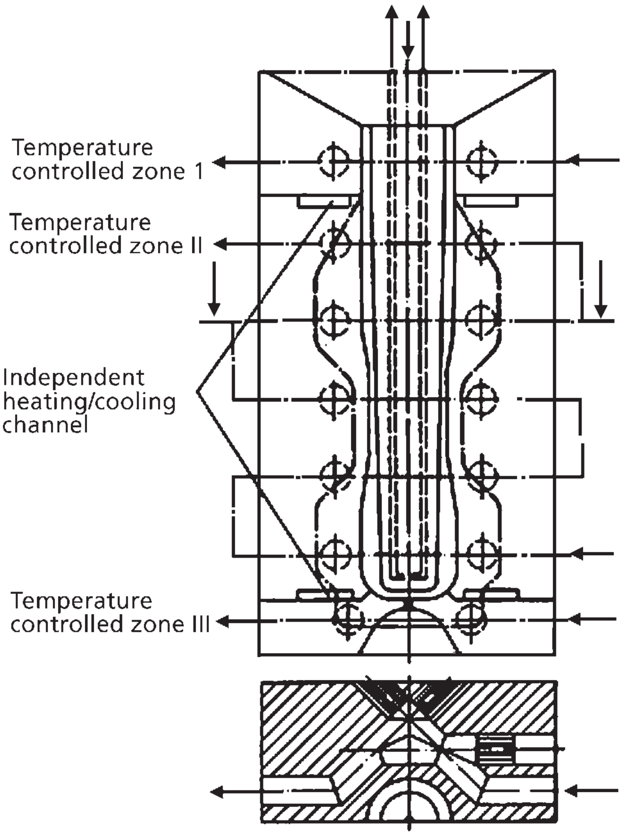


Figure 6.8 Preform cavity

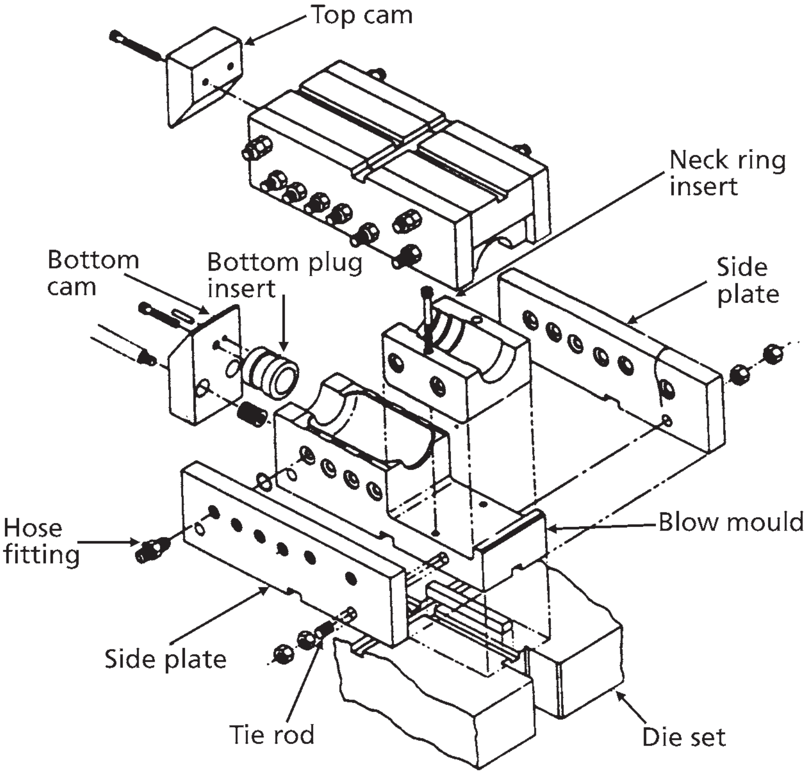


Figure 6.9 Blow mould cavity

6.3.1.10 Bottom Plug

The bottom plug is needed to provide push up heights of 1.5 mm for polyolefins and 0.75 mm for rigid materials. These may be stripped out of the moulds - anything greater would require movable bottom mechanisms.

6.3.1.11 Core Rod Assembly

The purpose of the core rod is to provide the inside diameter of the neck finish and the inside shape of the preform. It also includes the air channels and valving to blow the plastic melt to the final sizes of the container. There are several factors that come into play when deciding the location of the air outlet, these include: length of the core rod moulding and type of moulding material. When more heating is needed in the body of the preform to blow the resin, the top opening is used. The bottom opening is used when the L/D ratio of the moulding area becomes greater and core rod rigidity is necessary to alleviate deflection. A cam nut spring and star nut located at the back end of the core rod, is the mechanism that opens/closes the air pressure during the open position and the preform injection closed position (see **Figure 6.10**).

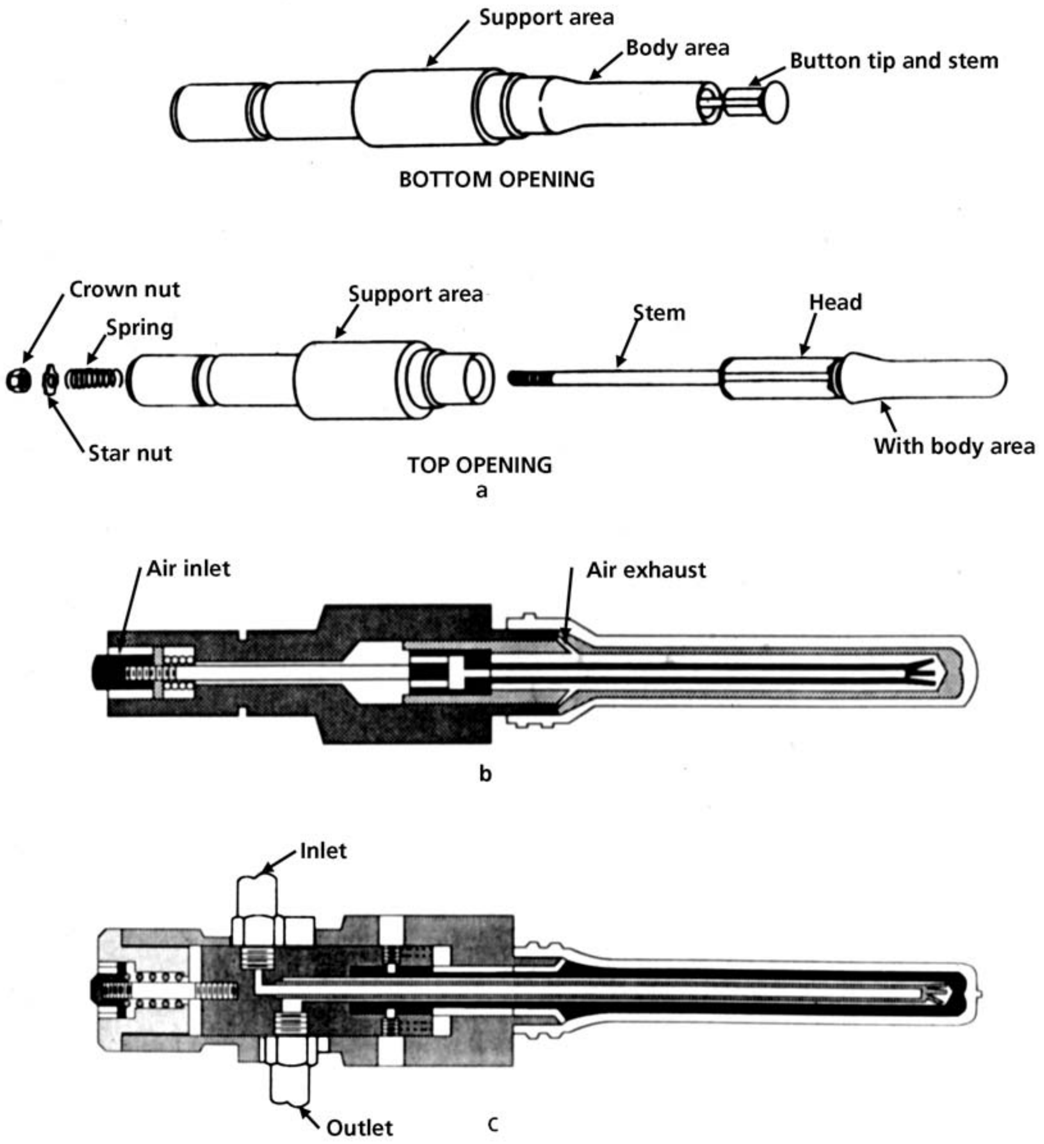


Figure 6.10 Core rod assembly. a = Exploded view; b = Section showing open position; c = Section showing closed position

6.3.1.12 Injection Nozzles

The gate dimensions vary according to preform dimensions. It is desirable that the follow-up pressure used in the injection stage and the amount of pressure as well as the time hold is dependent on the size of gate and type of plastic.

The main point is that serviceable containers can only be obtained from visually perfect preforms, that is those that are free from folds. For different gating designs see **Figure 6.11**.

6.3.1.13 Manifold

The manifold assembly is similar to a hot runner used on a regular injection moulding machine. The assembly is mounted on a die set and is made up of a base, clamps and nozzle clamps (see **Figure 6.12**).

6.3.1.14 Die Set

Die sets are used to hold preform and blow moulds on to the machine platens. For part line alignment these are keyed in both directions and retained by screws in the top and bottom of the die set (see **Figure 6.13**).

6.3.1.15 Pick-off Assembly or Stripper

The pick-off assembly is attached to the stripper station, which is the last one on the machine. It serves two functions: one is to pick off the finished container after moulding, the other is to externally cool the core rod in specific areas along the core rod profile (see **Figure 6.14**).

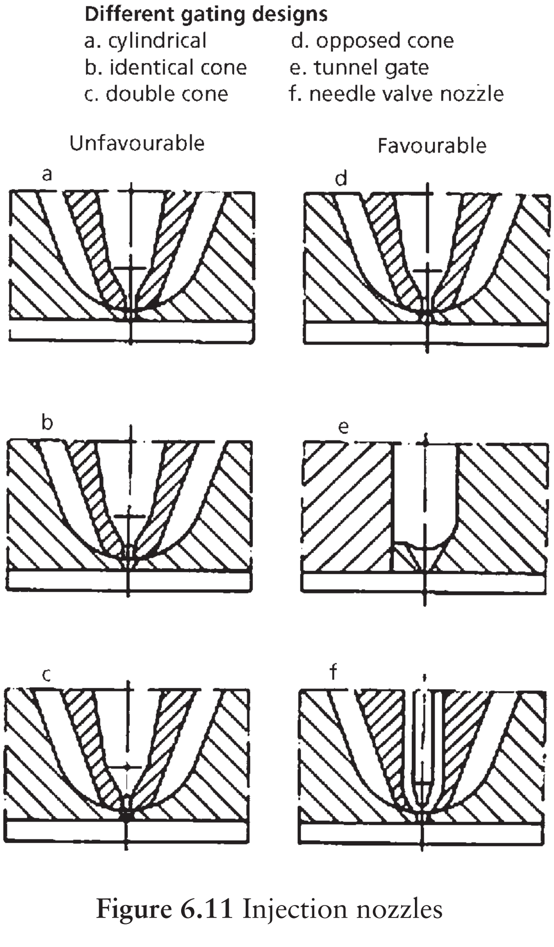


Figure 6.11 Injection nozzles

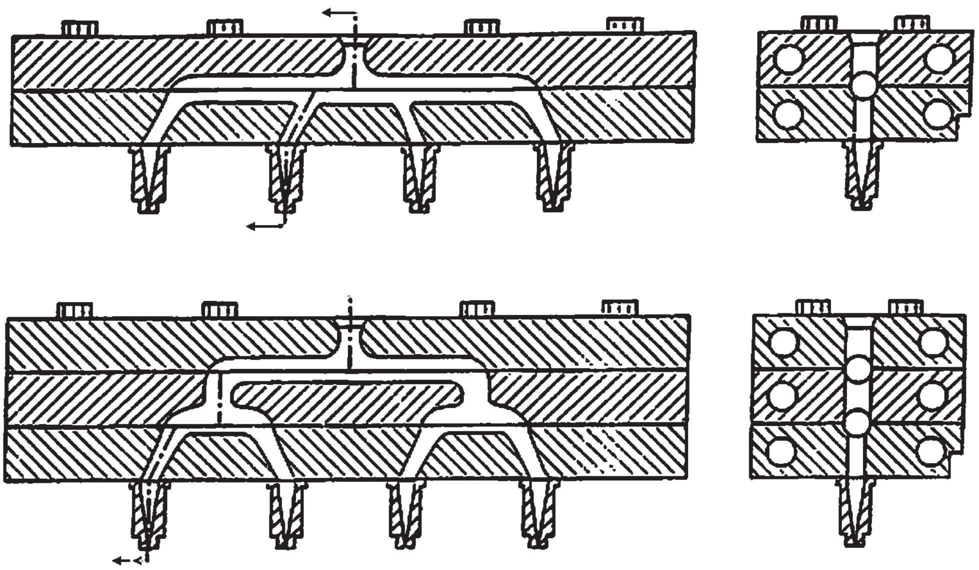


Figure 6.12 Manifold assembly

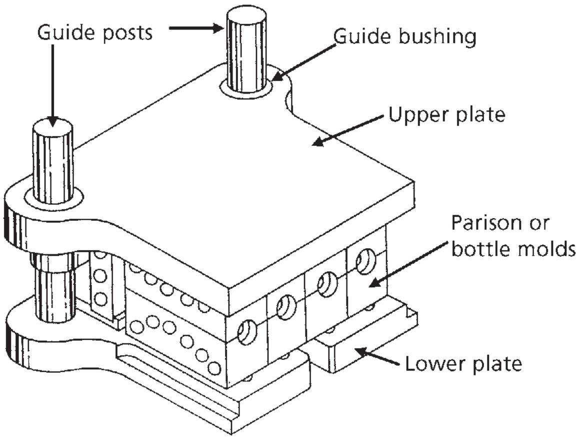


Figure 6.13 Die set assembly

6.4 Stretch Blow Moulding

6.4.1 Introduction

Stretch blow moulding came about because the preform core rod is limited to a L/D ratio 12:1 (discussed in Section 6.2.1.1).

6.4.1.1 Biaxial Stretch Blow Moulding

Biaxial stretch blow moulding is the method of making a preform that is stretched in both the hoop and axial directions (see **Figure 6.15**).

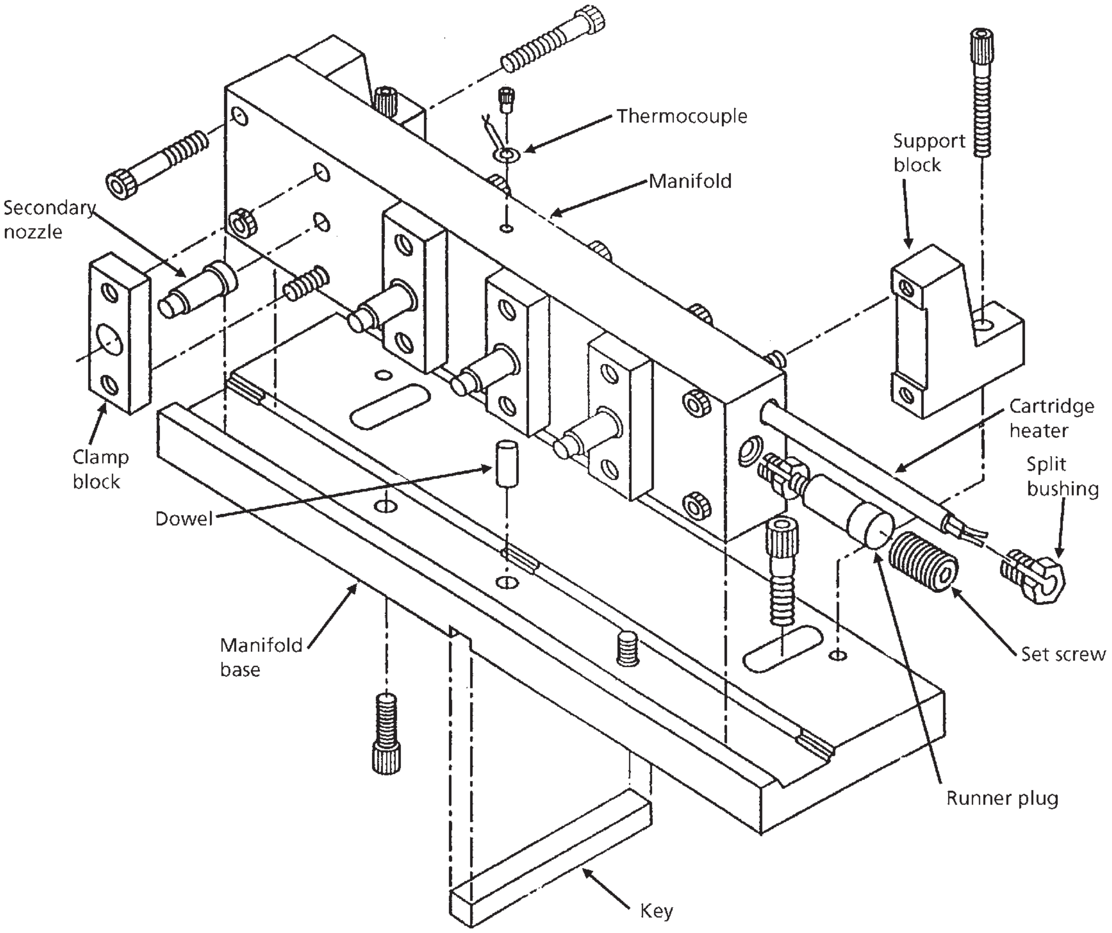


Figure 6.14 Stripper

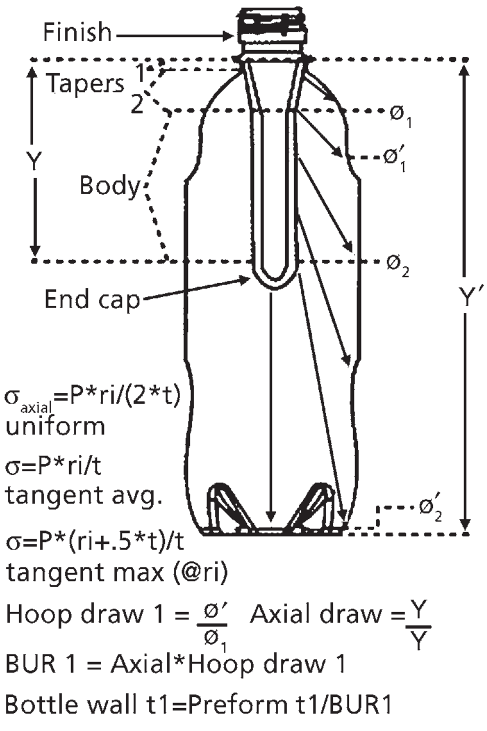


Figure 6.15 Hoop and axial ratios. BUR = Blow up ratio

6.4.1.2 Materials

Materials such as: (polystyrene, polyvinyl chloride, Nylon, polycarbonate, polysulfone, acetyl, polyacrylonitrile (PAN), polypropylene (PP), Surlyn and polyethylene terephthalate (PET) are all candidates for moulding by stretch blow moulding. Amorphous materials such as PET, that have a wide range of thermoplasticity, are easier to stretch than crystalline ones such as PP. It is noted that, in contrast to other processes, that when a container is produced by biaxial stretch blow moulding the properties are enhanced. Therefore, it produces a container from less raw material with improved economics as well as better bottle properties.

6.4.1.3 Stretch Blow Moulding Machines

Again as with injection blow moulding there are two types of machines: two stage and single stage machines.

6.4.1.3.1 Two-stage Stretch Blow Moulding Machine

In the two stage machine, injection premoulded preforms are loaded into a blow moulding machine. They are transported through an oven where they rotate continuously to achieve even heating throughout. (Note: The finished or threaded area is protected by shields so that they are not heated.) Once heated, they exit the oven and are allowed to equilibrate.

Once equilibrated, the preforms are transferred to the waiting blow mould. The blow mould closes and clamp pressure is achieved, a centre rod or stretch rod enters the preform through a stuffer and axially stretches the preform until it bottoms against the mould cavity opposite the stuffer. The stuffer is a seal which the blow air enters, and can be either a top seal or an inside seal. Initial oil-free air enters and blows the heated preform and axially stretches it (this is low pressure air at 1.03-1.38 MPa). Then once the bottle is formed, high pressure air (4.14 MPa) fills the bottle. The bottle cools as it contacts the cool cavity surface (normally 3-10 °C). The blow mould then opens and the centre rod retracts to allow the stretch blow bottle to be ejected.

6.1.1.3.2 Single Stage Blow Moulding Machine

In the single stage process all the stages take place in one machine. The preform is injection moulded in the first station and upon cooling the cavity mould half drops down and the core rod mould half rises, leaving the injected moulded preform supported by the thread insert splits in the horizontal rotary table. The table indexes 90 degrees to the conditioning station, where each preform is equilibrated or conditioned via external and internal heaters to the proper temperature for stretch moulding. The table again indexes 90 degrees to the third station, where the preform is stretch blow moulded. It is noted that there are two differences here from the two stage process. First, because the preforms are held in the thread splits there is no need for clamping to use pressure from the stuffer sealing and preform prior to entry of the centre rod and blow air. Secondly, the single stage process normally uses only one air pressure, approximately 2.07 MPa.

References

1. *Injection Molding Handbook: the Complete Molding Operation: Technology, Performance, Economics,* Eds., D.V. Rosato and D.V. Rosato, Van Nostrand Reinhold Company, New York, NY, USA, 1985.

7 Safe and Efficient Set-up, Start-up, Operation, Shutdown Procedures and Safety

Note: these procedures represent good practice. In an actual production environment, always follow the procedures for that particular plant.

7.1 Start-up

During the start-up of a blow moulding machine, precautions should be taken, for example: no-one must stand in front of the die or nozzle and that the hopper should be firmly in place so the screw cannot be accessed. Start-up is the most hazardous time in the process because material left in the barrel from the last run can overheat and degrade, spewing hot gases and degraded plastic from the nozzle or die at high pressure. Another potential hazard is that many steps must be taken, and often quickly.

7.1.1 Start-Up Preparations

An understanding of the settings is needed before starting up a blow moulding machine. Obtain advice from someone who is very familiar with the equipment, or better yet, consult the written procedures. A general procedure is:

- Turn on the main power switches and then select or set the temperatures.
- Ensure that the cooling water is on and check to see that it is flowing through the feed throat.
- Preheat the hydraulic oil to its correct operating temperature. This may be done either by pumping the oil back into the tank or by using a preheater fitted for this purpose.

Once the machine has reached the required temperature, it should be allowed to settle down before any material is introduced into the barrel. The settling-in (equilibration) time, sometimes called ‘soak’ time, is the time needed for the barrel, screw, breaker plate, and die or mould temperatures to stabilise close to the temperature set points. The equilibration or soak time will depend on the size and type of machine. It may take 20 minutes for a small machine and it may take several hours for a larger machine. This time should be used to prepare for the production run.

Other start-up steps include:

- Check the nozzle/die and moulds to see if they are clean and operational.
- Review the production order for colour, quantity, and other requirements.
- Check for necessary tools and equipment, and be sure they are in place and working properly.
- Make sure that all auxiliary equipment is clean and operational, to include hopper loaders, conveyors, grinders, vacuum pumps, and leak testers.

7.1.2 Melt Temperature

Two methods are commonly used to measure melt temperature in a blow moulding machine:

- Extrusion or injection of the material onto a suitable surface, then measuring the temperature of the plastic mass with a thermocouple probe.
- Direct reading by a thermocouple that is placed in the barrel and is in direct contact with the melt.

When the temperature of the melt is measured with a probe, care should be taken during the measurement to ensure that the purging of hot plastic does not cause an accident. As has been mentioned previously, molten material will cause serious burns because it is very hot and it adheres to the skin and is very difficult to remove. Burns are a common injury in moulding operations, so long sleeves, gloves and face shields should be worn when handling hot material or where there is danger of being splashed with hot plastic melt, particularly during start-up or purging. As with other situations requiring personal protective equipment, the plant's requirements must be followed.

7.1.3 Warming up an Empty Machine

The machine's warm-up cycle should be programmed so that thermal overshoot does not occur and heating times are kept reasonably short. Once the machine is at the set temperature, it should be allowed to equilibrate ('heat soak') before material is introduced into the barrel. It is advisable to keep this time as short as possible so that any resin left in the barrel after purging does not degrade. Check the machine for correct temperatures by briefly rotating (jogging or 'inching') the screw. If the screw requires excessively high motor currents or will not rotate, then allow the machine to equilibrate further. The set-up sheets should show the normal heat soak time.

Before starting the machine, be sure that the set conditions are satisfactory by purging a few pounds of resin out of the die (or nozzle) at slow screw speeds. Check the melt temperature with a melt probe and also check the general appearance of the melt. It should be smooth and free of dark specks, streaks, bubbles, or other signs of degradation. If no material is delivered when the screw is turned, check to see that plastic feed is available to the screw, check for faulty heater bands, and find out if the feed has 'bridged' (stuck together) in the hopper.

Checking for bridging or material blockage in the machine feed throat requires caution and the immediate attention and expertise of trained personnel wearing the appropriate safety equipment. This is because of the potential for serious personal injury from the hot gases, and degraded and overheated plastic that may spray violently back through the hopper.

7.1.4 Warming up a Full Machine

When material is in the barrel or die head, the machine is said to be full. A full, cold machine might result when there is a power failure or when the machine is deliberately shut down because of deterioration of the material by oxidation or depolymerisation. The machine must be heated in a safe way because decomposition produces gases under pressure and can cause serious accidents.

To warm a cold machine, set all temperatures just below the melting temperatures of the material, for example, at 135 °C for low-density polyethylene (LDPE). Allow the machine to reach and equilibrate at these temperatures, and then raise the temperature of the die (nozzle) to the process set point. To reduce the potential for dangerous pressure build-up in the barrel, wait for a period of time to allow the plastic in the die or nozzle to melt, and then raise the other barrel temperatures to the set point. Allow the machine to equilibrate to these temperatures before beginning to purge.

7.1.5 Initial Operation and Purging

When the machine is fully up to temperature, put a small amount of material in the hopper, make sure the hopper lid is in position and the hopper gate is open, and start the screw at 10-15 rpm. Do not allow the screw to turn in an empty machine, because this can damage the barrel and screw.

Check to see that the set process conditions are correct by running for a minute or so on an extruder or by running a few purge cycles on an injection machine. A machine with a grooved barrel may require careful hand feeding of material by trained personnel, because it is easy to over-feed the machine.

After a short period of operation, check the melt temperature with a melt probe, and also the general appearance of the melt. Dispose of the hot, sticky plastic melt in a safe way once being satisfied that the material is feeding well, and the melt looks satisfactory. On an extruder, also check the drive motor current. It should be with the normal start-up range. If it is too high, there is probably unmelted material in the barrel. If it is too low, there may be feeding problems. On an injection moulding machine, material should flow freely from the nozzle. If it doesn't, the nozzle may be blocked by unmelted plastic. Do not attempt to clear a blockage by turning the screw or injecting under high pressure.

If all is well, fill the hopper to the normal level for running. Check to see that the monitoring equipment is working, and in extrusion blow moulding, when material starts to extrude from the die, turn on the screw cooling if it is required.

7.1.6 Commencing Moulding – Manual Operation

When purging is complete and satisfactory melt is being produced, moulding may begin. The moulding process usually begins with manual operation, in which the operator initiates each part of the moulding cycle by pushing buttons according to the operation sequence. When the mould is closed, clamping pressure should be checked.

To begin extrusion blow moulding, produce a parison and check its temperature and appearance. The parison must be long enough to reach the bottom of the mould for pinch-off. Start moulding, and adjust conditions and settings as needed to obtain a satisfactory part. Increase screw rpm gradually until it reaches the normal operating speed, while constantly checking the parts.

A periodic check should be made to ensure that the hopper has enough material and that the melt is not leaking or weeping from around the nozzle/die/adaptor areas. Product quality should be closely watched to see that parts are free from froth or unmelted resin particles, and when the cycle is stable and the parts are good, production can begin.

Note: If for some reason a different material was used for purging, it must be removed from the barrel according to procedures required by the material manufacturer, before moulding begins.

7.1.7 Commencing Moulding – Automatic Operation

Automatic operation is only started after satisfactory melt is made, after the purging procedure, and after the machine settings have been established based on experience or process records, or as determined from the manual operating conditions if this is a new product.

Commence moulding on an automatic, or semi-automatic cycle (in which the operator opens and closes the safety gate to start the cycle) using pre-determined cycle times. These may be calculated, based on experience, or determined from the manual operating conditions. Gradually adjust conditions until product of the required quality is obtained at an optimum rate. After each adjustment, allow the machine to settle down for a reasonable time (approximately six cycles) before making further adjustments. With intermittent extrusion machines, adjust the cooling time until the moulding can be ejected without distortion. Screw start delays and screw speed (rpm) can be adjusted to fill this time.

7.1.8 Changing Conditions and Dimension Verification

Any changes must be well thought out in advance and should be made gradually. As an example, any increase in screw rpm may cause not only an increase in output but also an increase in temperature. Changes must be made one at a time. The machine must be allowed to settle down and the effect of the change noted, otherwise no one would know what is going on. Frequent or incorrect changes in the process can cause time to be lost and large amounts of scrap to be made.

7.1.9 Recording Production Conditions

The object of moulding is to make mouldings (parts) to the required specification (quality) and at the quoted cost. To do this, it is essential to keep accurate records. On many machines, data are recorded by computer. This data should be preserved. Critical parts, such as those for medical applications, have bar codes and the data are stored. When this is not possible, an appropriate record sheet should be completed initially and then periodically updated throughout the run. It is also good practice to keep sample mouldings. Logs of key events - the reasons, and observations are also useful.

7.2 Safety in Normal Machine Operation

7.2.1 Operation

Once the machine has settled in, controls and heaters should operate between an upper and a lower limit. This allows parts to be successfully made to specification. Most machines have process controls that warn when a condition is moving outside of a limit. The operator should advise the process technician so that the cause can be found quickly and the problem corrected both to minimise the production of bad parts and to reduce the likelihood of hazardous overheating or excessive melt pressure.

7.2.2 Safety Considerations

Machines that are set to run automatically usually eject the parts onto a conveyor for finishing operations, so that the operator does not have to reach into the press. For some large industrial parts, an automated picker or robot picks the part from the press and delivers it to the finishing operations.

Many times, particularly on small runs and when using a semi-automatic press cycle, the operator removes the parts by reaching into the press and removing the part from the mould. Redundant safety switches and devices must be in place and working to prevent the press from inadvertently closing on the operator.

In all cases, the operator must wear gloves (‘cooled’ plastic parts are extremely hot to the touch when ejected), safety glasses, and usually earplugs. In plants with several different types of equipment running, the noise generated could damage hearing if protection is not worn.

Entrances into plant areas that require sight, hearing, and sometimes helmet protection are usually marked with signs at the entrance indicating the type of safety protection required before entering the area.

In September 2000, the American National Standards Institute (ANSI) issued a new safety standard, SPI B151.15 [1], on extrusion blow moulding machines operating in the US. The clauses in **Table 7.1** are from this specification.

In the UK, safety at blow moulding machines is addressed in the *Plastic Processing Sheets No.3* and 5 [3, 4], published by Health and Safety Executive (HSE) in consultation with the Plastic Processor’s Health and Safety Liaison Committee.

The standards outlined in **Table 7.2** describe commonly accepted and practicable safeguards for the significant hazards on blow moulding machines supplied before February 1996. On 15 February 1996 the European Standard BS EN 422:1996 [5] was published and came into effect for new blow moulding machines.

Table 7.1 Safety standards for extrusion blow moulding machines

Clause	Safety Caution
Operator's Gate	Operator's gate, window and mounting hardware to keep the operator away from hazards associated with moving parts and hot parison(s) including electric, hydraulic and pneumatic interlocks.
Power Operated Gates	A. Leading edges mounted with pressure sensitive switches to stop or open the gate. B. Closure of the gate shall not initiate cycle start.
Operator's Gate Electrical Interlock with Monitoring	To prevent all clamp, carriage, calibration or take-out motions when the gate is open.
Operator's Gate Hydraulic and Pneumatic Interlock with Monitoring	To prevent hydraulic or pneumatic powered motions when the gate is open including monitoring and alarm.
Emergency Stop Button	At least one emergency button to be provided near the point of operation.
Reset	Resetting a safety interlock shall not directly initiate a cycle.
Rear Guard	A fixed guard for the moulding area opposite the point of operation.
Top Guard	A fixed guard to prevent reaching over another gate or guard.
Additional Safety Requirement for Large Machines only	Presence sensing device; mechanical latch; double acknowledge system.
Emergency Stop	At least one emergency stop button in a walk-in mould area.
Blow Air Release	Monitoring of blow air to prevent mould opening under full blow pressure.
Part Discharge Opening	Guarding required near conveyor openings.
Windows to Moulding Area	All windows to conform to ANSI Z97.1 [2].
Guards	Fixed guards (or movable guards with interlocks) at all other hazardous points.
Guarded Feed Throat Opening	Guarding where access to the rotating feed screw is a hazard.
Extruder Barrel Covers	Cover or barrier to prevent inadvertent contact with high voltage or high temperature.
Window	All windows to conform ANSI Z97.1 [2].
Safety Signs	Safety sign kit to current standard.

7.3 Shutting Down

A great deal of money can be saved by using the proper shutdown procedures. For example, if the material could be prevented from degrading or burning, a large amount of purging could be eliminated. Additional money would be saved if a complete machine shut down and cleanout were unnecessary, and start-up would certainly be easier.

7.3.1 Temporary Stops

It is a good idea during a temporary stop to periodically purge the cylinder or barrel by passing material through the machine and/or making air shots. If the plastic material starts to look a bit discoloured, increase the frequency of purging. When a minor machine repair is required, set the heaters on the plasticising cylinder to low values (about 150 °C) to minimise thermal degradation.

Table 7.2 Health and Safety Executive (HSE)

Hazard	Safeguard
Dangerous moving parts in the mould area	Guards interlocking with the drive(s) (pneumatic, hydraulic or electrical) for the dangerous parts and sufficient fixed guards to complete the enclosure. The interlocking system should be dual channel and both channels should be monitored to prevent any further dangerous movement if a fault is detected.
Other dangerous moving parts	If not protected by the guard systems specified for the mould area, use: • Fixed guards; or • Distance guards positioned to take account of safety distances to prevent the operator reaching the danger zone; or • Single-channel interlocked guards, monitored to prevent any further dangerous movement if a fault is detected. And for large machines a monitored, person sensing safety device should be installed, for example: • A pressure-sensitive mat which extends between the mould; or • An electro-sensitive device; or • A mechanical latch which prevents involuntary guard closure and which can only be released from outside the mould area. Having triggered such a device, it should be necessary to do one of the following before initiating another cycle: • Reset the safety devices • Close the guards; and • Actuate an enabling device to confirm the danger area is clear. Reset and enabling device actuation positions should provide a clear view of the danger areas. It should not be possible to actuate the enabling device from the danger area. Accessible emergency stops should be fitted on both sides of the mould. On large rotary machines they should be placed at intervals of 2 m or less inside the danger area.
Dangerous moving parts which can be reached through the delivery aperture	If not protected by the guarding systems specified for the mould area, use • Fixed guards; or • Distance guards positioned to take account of safety distances to prevent the operator reaching the danger zone; or • Interlocked product delivery systems, monitored to prevent any further dangerous movement if a fault is detected. Such product delivery systems would include: – Single-channel interlocked guards, consisting of outward opening doors which are activated to let articles out but otherwise act as an interlocked guard; or – Two electro-sensitive sensing units arranged so they let articles out but prevent access; or – Other equally effective means, for example, pressure-sensitive mats built into the delivery system or scanning devices.
Power-operated guards	Either: • Sensitive edges (fitted on both sides of the guard) which arrests or reverses guard closure; or • A reduced-pressure closing system.

7.3.2 Overnight Stops

For overnight stops with thermally stable plastics such as polyethylene (PE) at blow moulding temperatures, close the gate at the base of the feed hopper and turn off the barrel heaters. With the nozzle/die heat on, purge the barrel clean by pumping the screw dry. As soon as nothing more comes from the die/nozzle, stop the screw drive and set the barrel cooling (if equipped) to maximum. When the machine is cool, shut everything off.

7.3.3 High Temperature Work

When extrusion blow moulding at very high temperatures (with a material that does not melt until 265 °C) oxidation and material removal can be a problem. Depending on the material type, it may be purged with a 'wet' high-density polyethylene (HDPE) (approximately 2% of water is added to the HDPE before use). The water reduces the viscosity. In condensation polymers such as polyamide and polycarbonate (PC), the water further reduces the viscosity because it causes depolymerisation. Water also acts as a lubricant with polyamide.

To purge, shut the gate at the base of the feed hopper and run the machine until it is free of high temperature material. With an accumulator extrusion blow moulding machine, open the die gap and keep the machine and cylinder temperatures at a high value (270 °C); run 'wet' HDPE through the system and fill the accumulator. The melt will foam and there will be crackling and spitting noises. Keep purging, reduce temperatures to 215 °C, and open the die gap fully. Introduce dry HDPE and then purge the barrel clean by pumping the screw dry. Turn off the heaters when no more material comes through the die, set barrel cooling to the maximum, and then when machine is cool, turn everything off. Note: a 7 kg accumulator machine may require 90 kg of 'wet' HDPE and 45 kg of dry HDPE to properly purge out a high temperature resin.

7.3.4 Heat-Sensitive Materials

A major problem with heat-sensitive materials is decomposition ('burning') of the plastic in the machine. The results may be discoloration and rejection of the moulded part. When decomposition occurs, a complete shut down is usually necessary, although it may be possible to purge the heat sensitive material with another, more heat stable material to clean the machine of contaminated resin.

7.3.5 Purge Materials

Purge compounds are materials used to clean the cylinder (barrel), and may be purchased for this purpose. Instead of a commercial purge compound, a resin such as LDPE may also be introduced into the barrel to push out a thermally unstable material such as polyvinylchloride (PVC).

Many purge materials do not melt or flow as ordinary resins do, so to prevent blockage it is advisable to remove the die assembly before purging. The die should be thoroughly cleaned. Once the purge compound has come through, the shut down procedure should be followed.

When PE is used as a purge, it may be stored in a small hopper alongside the main hopper, from which it can be introduced rapidly into the machine by a power-operated valve. When PVC degrades, the rapid introduction of purge material is often necessary. With a stoppage of more than 0.5 of an hour when running PVC, the barrel should be purged with PE. Stripping, cleaning and purging should be done when re-starting a PVC run after a power failure or some other unplanned shutdown.

7.3.6 Shutting Down an Injection Blow Moulding Machine

For injection blow moulding machines, retract the barrel away from the parison meld's sprue bushing. Run the screw dry by allowing the screw to turn just until no more melt exits the nozzle. Do not allow the screw to continue turning, because it may cause unnecessary and possibly damaging wear to the screw and barrel.

Follow with a small amount of purge material, the type of which will depend on the type of material that had just been run. In the case of PE, purging is not usually necessary. It is generally safe to simply leave the screw in the forward position and turn off the barrel heats.

Other materials may require different purging materials and procedures. For glycol-modified polyethylene terephthalate (PETG) (a material used to make soda bottles and many other types of beverage bottles), polystyrene (PS), low melt index HDPE, or cast acrylic are the typical purging materials. PC are generally purged with a low melt index HDPE or a cast acrylic resin. Polyetherimide resins, which are moulded at very high temperatures (in the 370-400 °C range), are purged in either a one-step or a two-step process. In the one-step process, extrusion grade HDPE (with a low melt index, in the range of 0.3 to 0.35 g/10 min) is run through the machine after as much of the resin as possible has been pumped out. The barrel temperatures are reset to the normal melt processing range for HDPE once the HDPE begins to exit the barrel. HPDE is run through the machine until the purge exiting the nozzle is clear and clean. The screw is left in its forward position inside the barrel, the heaters are turned off, and the machine is shut down.

In the two-step process, a material that is intermediate in melt temperature between the high temperature material and the lower melt temperature purge material is used. For example, a PC, which normally processes in the 293 to 310 °C range may serve as an intermediate temperature material that is used for an initial purge. Once the PC begins to exit the nozzle, the barrel temperatures can be reduced to that for moulding PC.

The next step is to purge the PC; either with a low melt index HDPE or a cast acrylic resin. Acrylics and PS should not be used as purge materials for resins that are processed at high temperatures, that is, at temperatures above 310 °C.

Chemical purging compounds which are designed to work with certain families of materials are often used, usually in conjunction with a plastic purge material.

Always check with your supervisor or team leader for the material manufacturer's recommendations regarding purging materials and the safe procedures for their use.

Note: When purging materials from the injection barrel, always wear a full face safety purge shield, always move the barrel (injection carriage) to a rearward position, never inject or purge through an open mould, and always make sure the purge safety guard is functioning and closed to avoid a serious burn accident.

7.3.7 Check Recommendations

It is important to fully understand the correct procedures before a machine is started or shut down, or before a resin change. Material suppliers issue process brochures and material data sheets with specifications and a great deal of other information. These should be studied and used to develop plant procedures for each material, particularly for high temperature materials and those that are extremely heat sensitive or thermally unstable.

References

1. SPI B151.15, *Plastics Machinery – Extrusion Blow Moulding Machines – Safety Requirements for Manufacture, Care and Use*, 2003.

2. ANSI Z97.1, *Safety Glazing Materials Used in Buildings – Safety Performance Specification and Methods of Test*, 2004.

3. *Managing Machinery Safely in Small Plastics Factories*, Plastics Processing Sheet No.3, HSE, Sheffield, UK, 1999.

4. *Safety at Blow Moulding Machines*, Plastics Processing Sheet No.5, HSE, Sheffield, UK, 1999.

5. BS EN 422, *Rubber and Plastics – Machines - Safety – Blow Moulding Machine Intended for the Production of Hollow Articles – Requirements for the Design and Construction*, 1996.

8 Fault Finding – Causes and Effects

8.1 Introduction

From the outside, extrusion blow moulding looks simple, even though the machines may not. Yet the many variables interact, and fixing one problem can cause another. No, it’s not really simple at all, but everything in blow moulding happens for a reason. A logical, thoughtful approach is the best approach to a problem.

In this chapter, the problems and solutions related to extrusion blow moulding will be considered. A method for problem solving, common causes of product defects, what to do if equipment malfunctions: including preventive and corrective actions. And because of it's potential to cause problems, material handling and packaging will be covered as well. We'll begin with problem solving.

8.2 Troubleshooting

Troubleshooting is figuring out what happened when there is a problem. While it may seem odd at first, the best troubleshooting procedure is not necessarily the quickest. It's the one that gets the right answer in the shortest time.

Good problem solving requires four steps:

1. Data collection is the first step. Get good information. Without it, solving a problem, except by luck, is impossible. That's why keeping good records is so important.

2. Interpretation is next. What does the information mean? Experience, or a good troubleshooting guide, will help to sort out what is important and what isn't.

3. Step three is taking action - doing something. Repair the machine, change a setting, try a different material to see what happens.

4. Check to see what happened as a result of the action you took. It might be necessary to go through these four steps several times.

Remember that every change that is made in the blow moulding process, whether it is intentional or accidental, will affect several, or many, other things. Solving one problem can often create another. And don't make a change, then immediately make another. Wait to see the results first.

8.3 Brainstorming

What do you do when you've tried everything, and nothing works? Brainstorm! Bring together a group of people, and let them throw out ideas. Some will be obviously unworkable, but write them all down. There will be time to sort them out later. Ask people who may not know much about the process because they often bring fresh thinking to the brainstorming session.

Don't let anyone say ‘it won't work’, not while the ideas are being written down. Saying ‘it won't work’ quickly ‘turns off’ the creativity and imagination that people bring to brainstorming sessions.

Once the brainstorming is done, collect all of the ideas and talk about them. Let the group decide which ones should be tried, and someone, usually an engineer or technician, will try them in the plant.

When the problem is solved, a report should be issued to the group so that they can all learn from the experience.

Brainstorming is a powerful tool, even for experienced engineers, technicians, and operators, because everyone gets into habits. We tend to see things in terms of what has worked before. Sometimes, that won't work.

8.4 Problems and Causes

Problems with the machines and equipment aren't common, but catching small problems before they can become big problems is important for safety and to keep the machines from breaking down.

- You've just come back from a break, and there's plastic coming out from the extruder just behind the die head. Is that normal? What's happening? Over the last few minutes, the smell of the material has changed, and it now seems 'sour' or 'burned'. What does it mean? Is it bad? The robot isn't running smoothly, and once in a while it drops a part. Why is that?

All of these things are signs that something has changed, and they could be saying that there's a serious problem.

- Your eyes, nose, and ears are the best defence against problems with the machines and equipment. Look around - what can you see?
- Gauges and displays – check them often. Has anything changed? Changes to the readings, especially if they're outside the range shown in the setup sheets, mean problems. Even if the parts are OK for now, they may not be for long.
- Oil or water leaks. These can create a safety hazard, as well as process problems.
- Material leaking around the die or behind the die. A bad leak could mean a serious problem, and it will soon cause bad parts.
- Melted material building up at the die opening, called 'die drool', that was not there before.
- A rough, rippled, or wavy surface on the parts. Blow pressure, mould temperature, or melt temperature may be wrong.
- Black specks or streaks in the material as it leaves the die. Even if the temperature readings are OK, there may be a heater problem.
- Hard specks, lumps, or holes in the parts. The parison may not look right either. Check all the temperatures and the melt pressure.
- Any colour change may indicate a problem with the blender or mixer.
- Thin places and bad welds can have several causes, related to moulding:
    - The level of material in the hopper. If it's down, the loader may not be working.
    - Smoke that wasn't there before.
    - Delamination, where layers of the material peel apart.

Find out what is causing them:

- Do any of the electric motors smell hot or burned?
- Do you smell burning rubber, or anything else burning?
- A new, unusually bad smell from the material - it usually means that the material is being overheated.

Tables 8.1, **8.2** and **8.3** show some causes and effects of problems with finished containers, forming, and parisons.

Table 8.1 Finished container

Observation	Action: Machine *Running*	Action: Machine *Stopped*
1. Rough surface	Check for moisture or condensation in the mould, blast with air hose and raise coolant temperature.	Additional mould venting.
2. Excessive shrinkage	Increase blow cycle. Lower melt temperature.	Check die-mandrel concentricity.
3. Warpage	Check mould cooling. Increase blow cycle. Lower melt temperature.	Same as 2
4. Weld-line breaks	Same as 3	Same as 2 Increase pinch-off areas.
5. Thin wall at parting line	Increase mould clamp pressure.	Inspect mould alignment. Inspect mould venting.

Table 8.2 Forming

Observation	Action: Machine *Running*	Action: Machine *Stopped*
1. Parison blow out	Lower melt temperature. Reduce blow pressure.	Check mould for 'hot spots'. Check parison alignment. Check for contamination inside tooling.
2. Container sticking	Lower melt temperature. Lower mould coolant temperature.	Check mould design.

Table 8.3 Parison

Observation	Action: Machine *Running*	Action: Machine *Stopped*
1. Excessive stretch	Lower melt temperature. Lower die temperature. Increase extrusion rate.	
2. Rough surface	Reduce extrusion rate. Raise temperature.	Clean die tip. Clean tooling. Change tooling.
3. Uneven parison	Reduce extrusion rate.	Align die and mandrel. Inspect for contamination. Inspect for heater band outage.
4. Fisheyes (bubbles)	Lower melt temperature. Lower feed section temperature.	Check resin for moisture and for contamination.
5. Streaks	Raise extrusion back pressure.	Inspect tooling for contamination or damage. Check tooling design.
6. Curl	Increase extrusion rate.	Check tooling temperature profile. Check tooling alignment.
7. Wrinkles	Lower melt temperature.	Check tooling temperature profile. Check tooling alignment.

8.4.1 Background Sounds of the Plant

There are many sounds in a blow moulding plant, and after a while we don't pay much attention to them. Any new sound, or a sound that isn't normal should be checked out right away.

Any sound that has stopped should also be checked out right away. Silence can be an early sign that something, such as a loader or pump, has stopped.

Is there any squeaking or grinding near the water pumps, trimmers, or robot?

Is the blender scraping or rattling?

Is the extruder squeaking or groaning?

Are there sirens or alarms from anywhere – the machine, or elsewhere in the plant? More than any other sound, sirens or alarms demand immediate attention.

The blow moulding machine operator knows the equipment better than anyone, and is close by all the time. An alert operator is the best defence against accidents, quality problems, or down time resulting from equipment failure.

8.4.2 Quality Problems

What causes them? Sometimes the cause isn't easy to find. Everything about the blow moulding process, including the machines, the material, and the process, can have an effect on the moulded part quality.

Some of these things are within the operator's control, while others are not. Some companies ask the operators not to make changes, but to be watchful and report whenever anything happens that isn't normal.

8.4.3 Machine and Equipment Problems

Problems with the machines and equipment can include:

- A broken heater band or thermocouple. The temperature of the melted material, a key variable, may change.

- A worn screw, because the rate of plastic flow may change, causing parison dimensions to change.

- The failure of any sensor, which is a device that measures pressure, temperature, position, or time and 'reports back' to the control box. Many problems can come from this, depending on what has failed.

- Wear, or something stuck in the die. How the parison is affected depends on what happened but it will often show up as lines in the part, part dimensions 'out of spec', or an uneven parison.

- An air leak, heater failure, or clogged filter in the dryer, which means that the material will not be dry. This can cause pits, holes, or weakness in the parts.

- A water temperature controller that can't maintain the temperature of the mould cooling water, resulting in dimensional, strength, or warping problems. The cause may be heating up of the plant cooling water system.

- A clog or leak in a feeder or blender, which will lead to changes in the colour, or changes in the way the parison forms because the percentage of regrind being added isn't the same.

8.4.4 Importance of Consistent Material

Consistent material is an important part of making good products. Any change in the lot number, grade, or supplier of the material can cause changes in colour, strength, dimensions, wall thickness, or surface appearance, as well as requiring adjustments to the process.

Changing the percentage amount of regrind that is put in with the ‘virgin’ material, which has not been moulded previously, can cause trouble unless it's done deliberately and the process is adjusted. It can cause changes in the colour, strength, dimensions, and surface appearance of a blow moulded part.

Anything that is in the material and should not be, such as black pellets, dirt, bits of different materials mixed in, or if there are quality problems at the producer's plant, will either cause defects directly or upset the process. Some blow moulders use so-called ‘wide-spec’ material for cost reasons, and it can be used for non-critical parts and jobs successfully, if the plant knows what it is and how to handle it. If not, it can be difficult or impossible to make the process run consistently.

8.4.5 Process Settings

The process includes the settings and the actual value for all of the temperatures, pressures, times, vacuum, speeds, mixing ratios, and other values that control the operation of the many pieces of equipment. Any change, whether it is deliberate or accidental, in the settings on any of the equipment can cause one or more changes in the product or other parts of the process. There are dozens, perhaps hundreds, of ways that process changes can affect the parts.

8.4.6 Ambient Conditions

As odd as it may seem, any change in the blow moulding area's temperature, air currents, or humidity, perhaps caused by simply opening or closing a nearby door, can sometimes cause a problem. This is a serious matter in extrusion blow moulding because the parison is formed in open air and stays exposed while it is being formed.

As important as these things are to quality, there are several factors in the plant that can make the job easier for the operator while adding to quality and productivity:

- Good lighting,
- Adequate room to work,
- A moderate, constant temperature, and
- Clear instructions as to what is expected.

8.5 Preventive and Corrective Actions

What are preventive and corrective actions?

‘Preventive actions’ are what must be done to keep problems from happening in the first place. Corrective actions are what must be done when a problem has already occurred.

8.5.1 Corrective Actions

Corrective actions have two parts: fix the problem, and find a way to keep it from happening again.

Some preventive actions that an operator could take are:

- Regularly monitor the process and the product.
- Be aware of any unusual sights, sounds, or smells.
- Talk to the next shift about anything they should know: any problems, changes to the specifications, changes in procedures.
- Guard the material and any regrind against contamination from dirt, trash, or other plastic materials.

Stay alert and aware. Fatigue, distractions, or illness can easily lead to safety or quality problems.

There are many corrective actions that might be required to bring the product up to the customer's specifications. If the problem is not an equipment malfunction, minor changes in the process may be all that is necessary.

To change the wall thickness:

- Adjust the die opening.
- Lower the temperature of the material.
- Speed up or slow down the rate of parison formation.

To eliminate rocker bottom:

- Extend the cooling time.
- Relieve blow pressure sooner.
- Lower the mould temperature.

To eliminate black specks in the surface:

- Lower the melt temperature.
- Use less regrind or get all the ‘fines’ (plastic dust) out of it first.
- Check the material for black specks in the pellets.
- Check the material for dirt, dust, or bits of paper.

To reduce or eliminate warping:

- Lower the mould temperature.
- Increase the cooling time.
- Reduce melt temperature.

If the colour is changing:

- Check the feeders and blender. Is there enough material? Is it feeding properly? Is it mixing properly?

- Check the amount of regrind in the mix.

There are many other possible problems, and many steps that could be taken to correct them, but remember that every defect or machine problem may have more than one cause, and there could be more than one way to correct it. Remember too that every change could cause other things to happen besides correcting the problem.

8.5.2 Corrective-Action Team

Some problems are too big for one person to handle, so many plants use corrective-action teams to get them solved quickly.

A corrective-action team must have the knowledge to figure out the solution, and the authority to get things done. The team may be composed of:

- An operator,
- A supervisor,
- A technician or engineer,
- Someone from the Quality Department, and
- A representative of management.

It is the job of the corrective-action team to:

- Find out what happened,
- Find out why it happened,
- Come up with a way to keep it from happening again,
- Try the solution to be sure that it works,
- Write it all down.

One reason that problems in blow moulding can sometimes be difficult to solve is that there are many variables, as we have seen, and many ways that they can interact with each other. But problems in blow moulding are either a machine or materials problem, a procedure problem, or an unusually strict customer requirement.

8.5.3 Root Cause

Find the cause and fix it. That seems simple enough, but finding the root cause may not be as simple as it appears.

And if the root cause isn't fixed, the problem will come back. Let's look at an example.

The surface on some tool cases had become less well defined, and the parts seemed to be coming out of the mould a little warmer than normal. All of the process readings were normal, but the operator noticed that the blow air pressure is coming up to set point slower than usual. Maintenance is called in and they clean the pneumatic valves in the blow air line. A week later the same problem occurs again. Why? Because the root cause wasn't found and corrected.

This time, the team finds that the air filter in the blow air system is filthy and has broken through. Oily debris has again, dirtied the valves, slowing their response. The blow air is again building slower than normal. But the real root cause of the problem proves to be even further removed. It turns out to be an inventory control problem in the stock room. The stock room was out of new filters and had not ordered any. The maintenance technician doing scheduled maintenance on the machine had not been able to replace the filter. He then became busy with other things and failed to pursue the issue with the stockroom.

In this example, the solution wasn't cleaning the pneumatic valves, but correcting the inventory problem and making sure that the maintenance technicians understand the importance of the air filter cartridges.

8.6 Packaging

In many ways, how parts are handled after they are made is as important as making them. Dirty, damaged, or mislabelled parts are unusable by the customer. If they are returned, they may have to be reworked, reground, or scrapped.

Packaging specifications can be quite detailed, and are based on the customer's requirements as well as the producing company's desire to protect the parts during shipment. They might include:

- The part number or exact description of the box itself.
- Any grids, dividers, bags, or wrap that must be used (they may also have part numbers).
- How the pieces must be placed in the package.
- How long to wait, to package the parts after they are moulded.
- What kind of pallet to use.
- What size pallet to use.
- How many pieces per box.
- How many boxes per pallet.
- How the boxes must be arranged on the pallet.
- How the pallet is to be wrapped.
- The labelling of parts, boxes, and pallet.

To some customers, packaging is as important as the product itself. They may not accept a shipment that has not been packaged to their specification.

How parts are packaged to move from one department to another in a plant can also be important. Warehousing and inventorying depend on an accurate parts count, complete and correct labelling, and packaging that prevents damage to the parts. When the assembly department receives blow moulded parts, they need to know that the parts are what they expect and are in good condition, ready for assembly. Sometimes the differences between similar parts are small, and proper labelling will ensure that the customer receives what they expect.

8.7 Scrap

What is scrap? To most blow moulding plants, scrap is material or parts that must be discarded because they cannot be used. Scrap is a loss that can't be recovered.

The extrusion blow moulding process always leaves excess material attached to the blow moulded part. This material, called tail trim or trim scrap, is material that can be re-used. In fact, saving and using this material can make the difference between making a profit and not making a profit for a blow moulding plant. No matter what it's called, it is not scrap.

Plastic material that comes from regrinding should be handled as if it were virgin material. Accidentally mixing colours or materials, allowing dirt or bits of trash to get into the containers, or losing track of what the material is has the same effect on regrind as it does on new material: it must be thrown away.

Keep regrind segregated, which means keeping like materials and colours together and separate from other colours and materials. Know what can and can't be mixed.

When regrinding trim or unusable parts, it's easy to accidentally mix materials or colours. Take time to start with a clean granulator and a clean granulator hopper, and be sure that the material that's already in the storage container is exactly the same.

Sometimes accidents happen, and something else falls into the granulator and is ground up. Immediately stop feeding the granulator and turn it off. What's already in the hopper is now scrap, so don't dump it into the regrind container.

8.7.1 Contaminated Material

Contaminated material should be labelled and set aside where it is not likely to be taken to the machine and used.

Take your time and be careful. A little of the wrong thing in a lot of something else can make the entire batch of material unusable.

8.7.2 Reworked Parts

Blow moulded parts may have to be reworked for several reasons. It's easy to think of them as scrap, but they are actually more costly than new parts because of the extra work needed to get them ready to ship. Protect them, keep them clean, keep them labelled, and keep them separate from regular production.

Especially in the automotive, medical, and food industry, more and more customers are requiring plastic product manufacturers to know, and keep track of, everything that went into the manufacture of their products. This information may include:

- When the parts were made.
- Where they were made, and by whom.
- The processing conditions.
- The results of any testing (test results).
- The raw material supplier.
- The lot numbers of the raw materials.

- What they were made from.

When products are made in lots, the lot number travels with every part, sub-assembly, and assembly, and goes ‘out of the door’ on the customer's packaging.

Being able to trace a lot depends on everyone, from the receiving clerk, to the material handler, to the machine operator, to the shipping office to ‘get it right’ every time you read, record, fill in, or transfer the lot number. It also requires good records at every step of the process.

9 Auxiliary Equipment: Design, Function, Operation, and Safety

9.1 Bulk Material Handling Systems

When plastic materials are moulded in high volumes, the plastic pellets are usually fed from large holding bins or silos through conveying lines to a receiver, and then moved by vacuum to a loader. The loader may be located at the machine, on a dryer, or at a blending station. The silos may be located inside the plant, or if they are large, outside the plant.

An advantage of storing materials inside the plant during the cold season is that less heat is needed to heat the plastic from storage temperature up to its melt temperature. Heat is energy, and energy is expensive. A disadvantage of storing large quantities inside is the cost of space that might otherwise be used for additional moulding equipment or for secondary operations to produce additional products and income.

Bulk material handling systems may include mechanical conveyors or screw augers, but for longer distances, most use air pressure or vacuum to create a fast-moving stream of air inside a pipe to carry the material along. The highest volumes and longest distances are handled by air at moderate pressure from a blower.

9.2 Dryer

Drying the material before it is moulded requires a dryer that can remove moisture down to the specified level (often measured in weight per cent) within the time allowed by the moulding machine's material demands. The drying of plastic materials depends on time, temperature, air flow, and how dry the air is that is going through the material. Therefore, the dryer must have a way to move air through the material, to dry the air going through the material, to heat the air going through the material, and to control the temperature. The most common types of dryer in use today are hot-air dryers and dehumidifying dryers.

9.2.1 Hot Air Dryers

Hot air dryers simply heat plant air to a high temperature, up to 149 °C, and circulate it through the plastic material to be dried. The moisture quickly evaporates and is either vented off or returned to the dryer. While they are useful, hot air dryers cannot dry plastics to the very low moisture levels required by materials that are subject to hydrolysis, such as polyethylene terephthalate, polyamide and polycarbonate.

9.2.1.1 Desiccant

Most dryers in use today are the dehumidifying or desiccant type. This means that the dryer uses a special material (desiccant or molecular sieve) that is held in one or more containers, called desiccant beds. This material can remove nearly all of the moisture from air that passes through it.

The desiccant dryer is a sealed system. Very dry, heated air from the desiccant bed passes through a hopper that contains the plastic material, and the moisture transfers from the plastic to the dry air. The moisture laden air then flows out of the hopper and back to the desiccant bed, where the moisture is absorbed and the cycle is repeated. When the desiccant has absorbed as much moisture as it can hold, it is taken out of the circuit, and the moist airflow is diverted to a dry and waiting desiccant bed to continue the drying process. As often as required, the dryer takes the desiccant bed out of the loop and passes very hot air (hot enough to melt plastic) through the moisture laden desiccant to remove its moisture, venting the moisture to the atmosphere of the plant. Removing the moisture from the desiccant to return it to its dry state is called 'regeneration'.

A desiccant dryer has at least two heater systems. One system, called the process air heater, heats the air that flows through the material. The temperature of the process air must be carefully controlled, because plastic materials can easily be under- or over-dried. Problems with over- and under-drying will be discussed shortly. The second heating system is separate from the process heater and is used during regeneration. Regeneration time and temperature are automatically set by the controller and are not the responsibility of the operator.

Many desiccant dryers are equipped with a dewpoint readout. The dewpoint is a measure of how dry the process air is, and may be measured either as the air leaves the desiccant bed on its way to the hopper or after it passes through the material. Most readouts indicate the dewpoint of the air after it leaves the desiccant beds. The desiccant loses its effectiveness over time – and the length of time can vary significantly – so measuring the dewpoint of the air as it leaves the desiccant beds is a good way to determine when the desiccant should be replaced. New desiccant can dry air to a -40 °C dew point.

There are specific problems associated with drying:

- If the air is too hot going through the material, the material will begin to soften in the dryer. In extreme cases it can actually melt the material in the dryer hopper, possibly destroying the hopper or requiring hours, perhaps days, to remove the hardened material.

- If the process air is too cool, the material will not dry correctly and moisture will remain. When the material is processed, moisture may cause streaks, voids, blisters, and brittleness.

- The air can be at the correct temperature but some materials can be dried too long. Drying the material too long will remove some or all of the lubricants that help the material to flow and can cause discoloration or loss of properties. Some plants now use moisture analysers to test the actual moisture level in the material, helping to ensure that the material will not be over-dried.

- If the process air temperature is correct and the air is at the correct dewpoint, but the airflow is restricted by clogged filters or kinked hoses, the material will not dry properly. The problems associated with under-dried material (see previously) will appear.

- In connection with over- and under-drying, the dryer should be sized to match the machine's demands and the required drying time. If the dryer is too small, the material will not be dried. If it is too large, it may over-dry. If a large dryer is kept partway filled, airflow inside the dryer can be altered, resulting in under-dried material.

In addition to the two types of dryers previously described, dryers operating with compressed dry air and vacuum technologies are gaining in popularity for their efficiency and reduced drying time benefits. Whichever dryer is used, it is important to remember that poor drying can cause processing and appearance problems, and with some materials, a loss of properties in the moulded product.

9.2.2 Dryer Operation

9.2.2.1 Operation Checks

1. Regularly check all of the hoses in the dryer system, whether it is a hopper dryer at the machine or a central system. There should be no loose hoses, loose clamps, broken clamps or hoses, kinks, or air leaks.

2. Check the filter. Most filters need to be cleaned daily. If the material contains powders, or if regrind is used, it may be necessary to clean the filter as often as every shift. If the filter is clogged

with dust, airflow will be severely hampered or non-existent, leading to under-drying. On dryers with an airflow gauge, check to be sure that the gauge is reading the correct airflow.

3. On dryers with a dew point meter (dehumidifying dryers), check the readout. The meter should be reading -40 °C if the dryer is working properly. Remember that the reading normally indicates the moisture level in the air coming from the desiccant beds and does not relate to the level of moisture in the plastic.

4. Set the drying temperature and time, if they are not already set.

5. Make sure the hopper is filled to the correct level, which may not be to the top. The amount depends on how long the material must be dried and how many kilograms per hour will be used. For example, if the extruder uses 115 kg per hour, and the material must be dried for four hours, the dryer must have a capacity of 460 kg. Using a smaller dryer will not allow the material to dry to the necessary moisture level.

9.2.2.2 Dryers for Non-Hygroscopic Materials

Hot-air dryers used for drying non-hygroscopic materials – that is, materials that do not absorb moisture into the pellets but may have moisture on the surface – have an air separator or air trap cone in the bottom of the dryer. The air separator cone keeps contaminated air from entering the hopper and must be fully covered for proper drying. Hot air enters the machine hopper through a delivery hose and a perforated cone or diffuser assembly that uniformly distributes the hot air through the plastic material and helps to reduce the tendency of the plastic to flow more rapidly in the centre than along the sides.

- Before starting the production run, check to see how long the material has been drying. The material must be dried for the recommended period of time. Loading the dryer just before starting up will result in under-dried material.

- Once production is running, occasionally – or as often as required – check the dew point reading to ensure that the dryer is still maintaining the dew point. If it is not, the dryer may under-dry the material.

9.2.3 Dryer Safety

Dryers can get very hot, especially during the regeneration cycle. Usually the covers on the dryer will protect an operator from serious burns, but if the cover is off do not touch anything, especially the desiccant beds.

The hoses and pipes that carry drying air can get hot enough to cause a burn.

Gas-fired dryers are carefully designed to prevent gas flow when the flame is off, but if there is a line break or a control or valve failure, gas could escape. The smell of gas should be investigated IMMEDIATELY.

9.3 Blenders and Metering Equipment (Feeders)

Metering and blending equipment may be a part of the material loading and conditioning system if the facility is producing coloured products or if regrind is used in the process. Metering equipment actually measures the amounts of different materials and additives, while blending equipment mixes them until they are uniform in blend – a task that is not as simple as it appears. Metering and blending are usually, but not always, performed by the same piece of equipment.

9.3.1 A Volumetric Blender

A volumetric blender is a type of metering system that measures by volume. Volumetric blenders cost less and they work well if the bulk density of the materials is relatively consistent. However, if the bulk density of material varies, this system will not be able to compensate and a gravimetric system may be required.

9.3.2 Gravimetric Systems

Gravimetric systems measure by weight. Typically gravimetric blenders are more expensive, but they are not affected by changes in the bulk density of the material and they also 'know' when they are not delivering material at the correct rate. However, a gravimetric blender cannot compensate if the material to be weighed is a blend of two or more materials and the amounts of each have changed.

9.3.3 Metering and Blending Equipment

Metering and blending equipment usually functions well, however, as with all equipment, problems can occur. The following list addresses most of the major concerns when working with metering and blending equipment:

- The settings may be programmed incorrectly.
- The blending time is not long enough, so the materials are not thoroughly blended.
- The metering equipment has gone out of calibration, so the actual amounts being metered are not as expected. Volumetric systems must be calibrated for each material that is measured.
- There is a bridge or blockage somewhere in the system, not allowing a material or materials to flow. Gravimetric metering equipment can sense when this is happening, while volumetric equipment cannot.

9.3.4 Machine Operation

1. Be sure that the materials to be metered and blended are the correct materials for the production job. Be careful. Many materials look alike but are completely different, and sometimes labels or tags aren't complete or readable.
2. Check each control setting to ensure that the settings match the setup sheets. These settings may be dials, buttons, switches, or digital keypads.
3. The material handler or a technician is usually responsible for calibrating and setting blenders and metering equipment. However, it is good practice for the operator to know the settings and what proper operation looks like.
4. Once the metering and blending equipment has been checked and is functioning correctly, turn the unit on.
5. Some plants mix materials by hand. Whether they are mixed by hand or automatically, check the blend to assure that the ingredients are mixed well. One handful is not a good sample. Look (don't reach) into the mixer, or lock it out, take a large sample, and spread the material out on a flat surface.
6. Once production has begun, watch the colour consistency during the run. Check for any change in the appearance of the moulded parts. It may be an indication that the blending or metering

equipment is malfunctioning, that one or more ingredients have run out or are not being picked up, or that contamination has entered the system.

9.4 Machine Safety

Bulk handling equipment, dryers, blenders and feeders are relatively safe compared to many other pieces of equipment. However, they are not without hazards.

Blenders and feeders offer pinch and amputation hazards. Typical designs involve rotating augers that meter the material or rotating plates that open and close openings for flow. Either design offers opportunities to cut off fingers should they get in the wrong place at the wrong time. Unless the equipment has been properly locked out, no part of the body should ever enter this type of equipment.

9.5 Hopper Loader

The main function of the material loading system is to convey material from a container to a feed hopper or dryer at the machine. The material loading system is powered by electricity, compressed air, or a combination of both. Some systems use a central vacuum blower and a series of pipes, valves, and controls to bring material from containers located outside the moulding department to the machine or dryer hopper. Other plants use individual hopper loaders to feed material from containers in the department, or small systems that feed two machines. Although each plant or department may use a different layout, the basic function and operation are the same.

The loader is a vacuum chamber, usually mounted on top of the dryer or hopper. When the vacuum is applied, the material is conveyed through piping or hoses from the storage container, filling the loader. When the loader is full, the vacuum stops and a door at the bottom opens, dropping the material into the dryer or machine hopper. When the material is to be loaded from a box or drum, the loader is attached to a pick-up tube (wand) *via* a hose. The wand is put into the material itself for material pickup.

Most loaders have a simple on/off switch and a timer to tell the loader how long to run each time it is switched on. Once the loader fills the hopper or dryer to a certain level, there is a switch in the hopper that tells the loader to stop and wait until more material is required. Central vacuum systems work the same way, except that the control system decides the sequence when multiple loaders are calling for material.

Leaks in the loader seals, kinks or breaks in the hoses or piping, faulty level switches, empty material containers, or a pick-up wand that is stopped up or no longer immersed in the material can cause loading to be slow, unreliable, or completely stopped.

The receiving hopper or dryer hopper holds the material prior to delivery to the machine itself. Hoppers come in many shapes but the most common is a cone at the bottom of a cylinder. Some are simple cones, without the cylinder. The hopper permits a certain amount of material to be held ready for use. If the hopper is part of a dryer, it is also where drying takes place.

Loaders that operate by compressed air – and some small electrically-powered loaders – may pull a vacuum on the feed throat itself, without a separate hopper or vacuum chamber. The ‘hopper’ is often transparent and is no larger than the feed throat opening. Such a system eliminates the problems of inconsistent flow in a conventional hopper and helps to ensure a constant rate of feed into the feed zone.

9.5.1 Loader Operation

Material loading systems have become fairly common in most moulding facilities. Consider the following steps as a general outline when operating a material loading system.

1. If the parts are showing streaks or other visual defects, there may be contamination. The system should be inspected for cleanliness. This is usually done by a material handler or technician, but it may be the responsibility of the operator. In any case, one piece of contaminant material can cause a bad product.

2. Check to be sure that the material being loaded is the correct material for the job. Different materials are often similar in appearance or labelling.

3. Make sure the pick-up tube (sometimes called the snorkel) is in the material container so that the tube and loading system will pick up material. If the material is coming from a remote location, be sure the loader is connected to the right pipe. It's easy to make a mistake.

4. Start the loader and observe the loading system to see that the material is being delivered to the feed hopper. Also, observe the loader to be sure it stops once the feed hopper is full. The loader should not continue running once the feed hopper is full. If it does, a switch may not be functioning correctly. This should not be allowed to continue, because it can cause premature motor failure and in central systems, it may cause another machine to run out of material.

5. Periodically during production, inspect the loader system to see that the loader is maintaining the correct level of material in the hopper. Running out of material is a common and easily avoided problem that can shut down production.

While loaders do not appear to present hazards, material conveying systems can pull a high vacuum. It is important to keep hands away from the vacuum flaps when the system is on to avoid getting pinched, and never bring open vacuum lines or material pickup tubes near your face or ears. Most loaders are powered by electricity, so there could be a shock hazard if wires or terminals are accidentally exposed. In addition, stay out of electrical and control cabinets.

9.6 Water Temperature Controllers

As has been established, cooling the moulded parts at the proper rate is necessary for quality. Among other things, consistent cooling requires consistent water temperatures. A common method is to use a water temperature controller.

A water temperature controller consists of a heat exchanger, pump, thermostat, and temperature indicator. It may also contain a water heater, used to bring the water up to proper temperature before the machine is started, and to add heat if the cooling process does not add enough to keep the water at the desired temperature. The controller is connected to the plant water system through the heat exchanger so plant water normally doesn't flow through the moulds.

A common water system in a blow moulding facility includes a cooling tower and associated pumps and controls. A cooling tower cools by permitting some of the water to evaporate and by exposing the water to air, which also helps to cool it. This brings the warm process water closer to the ambient temperature outside or wherever the cooling tower is located. A cooling tower is relatively inexpensive to operate, but it is more effective in cold, dry weather than in hot, humid weather. In mid-winter, the return water from the cooling tower will be much cooler than in the middle of summer, when the air outside is hot. This means that the cooling tower cannot provide the same amount of cooling all year and by itself cannot always provide cooling water at the required temperature.

If it is necessary to cool the water beyond what a cooling tower can deliver and to maintain a consistent temperature all year long, the plant may use a chiller (refrigerator) system that can chill water to between 4-10 °C.

9.6.1 Operation

Cooling water temperature controllers are found in all types of plastic processing facilities. Basic operations include the following:

1. Check the water level in the tank and make sure that it is at the proper operating level. Some systems use automatic valves to keep the tanks full.
2. Check all valves to ensure that they are in the proper operating position. This may be the responsibility of the maintenance technicians.
3. Check the temperature setting to be sure it is the same as the set point shown on the setup sheets.
4. Once all settings are verified, start the temperature controller. Check any gauges that indicate water flow or water pressure. Once the parts are in production, observe the gauges and ensure that the temperature and coolant flow readings stay in the proper operating range.

9.7 In-line Inspection and Testing Equipment

Because blow moulding can be a high volume process, in-line inspection and gauging equipment play an important part in monitoring product quality. There are several basic types:

- Laser beam for outside dimensions,
- Ultrasonic gauge used for measuring inside dimensions and wall thickness,
- Vision equipment for visible defects, and
- Sliding, rolling, and other mechanical contact devices used for checking dimensions.

9.7.1 Laser Measurement

Very accurate, fast, and repeatable measurement of outside dimensions is possible with laser measurement devices. Laser light shines across a narrow gap to a set of sensors. The product runs through the gap, and the shadow that it casts is read by the machine as a measurement. To measure in more than one direction at once, more than one laser device is used.

Laser systems can take many measurements in a second and can update a display once a second, an important ability with any high-speed production.

9.7.2 Ultrasonic Testing

Wall thickness in hollow products is something that cannot be tested by laser, visual, or mechanical gauges unless the testing is done at a cut end. If an unintended change occurs in the process between measurements and goes undetected, it can mean many dollars in scrap and lost production. Ultrasonic testers can measure the wall thickness of hollow products as they run, by sending high-frequency sound waves at the moving product. The waves will bounce back differently as they hit different materials and different thicknesses. The controller of the device measures the time it takes for the signals to return and how they return, and from that it can determine the wall thickness. These gauges work very well for single layer products and for products with distinctly different layers. When the materials being used are not significantly different from one another, the gauge finds it difficult to differentiate between the layers.

These units are small and can be made to fit most places. Some gauges will give printed readouts while others give a digital display that can either show the value of the wall thickness or inner diameter or can display it graphically on a screen in the form of raw data, a control chart, or a bar graph.

As with other on-line measuring devices, ultrasonic gauges can be connected to alarms so that if the product is varying or approaching unacceptable dimensions, the operator can be alerted before the products become unusable.

9.7.3 Vision Systems

Vision systems are a major component of many automated systems. Typical components of a vision system are a controller and software for machine and user interface, video cameras, and one or more lighting sources. Camera based systems are used to detect defects such as black specs, flow lines and gels. Vision systems are increasingly used to detect missing, wrinkled, or skewed labels, bar codes, and other product identification media as well as to detect the presence or absence of a component or feature such as a lid, untrimmed flash, formed threads, or proper fill height of the liquid product in a beverage bottle. A computer is used to capture, analyse and archive the data while a video monitor displays the screen images.

Figures 9.1 and **9.2** show vision systems for scanning bottle labels and necks.

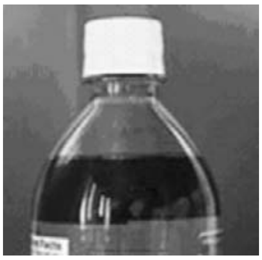


Figure 9.1 Scanning bottle labels for unacceptable skew

Reproduced with permission from Packaging Inspection Technologies, Tuckahoe, NY, USA.

Figure 9.2 Scanning bottlenecks for defects related to thread profile, neck slant, flash, and neck diameter and height

Reproduced with permission from Packaging Technologies and Inspection, LLC, Tuckahoe, NY, USA.

Typical defects detected by vision systems include:

- Holes
- Thickness variations
- Gels
- Contaminants
- Shape and dimension
- Wrinkles/creases
- Streaks
- Tears
- Printing defects
- Missing or skewed tabs, labels, bar codes

9.7.4 Mechanical

Sliding, rolling, and other mechanical contact can be used, for example, to check dimensions or to test for bottle or container leakage using pressurised air to detect holes or weak weld lines. **Figure 9.3** shows blow moulded containers being automatically tested for leaks. Defective containers are automatically diverted from the inspection line to a holding area or container for defective or otherwise non-conforming product.

9.8 Conveyors

Conveyors are commonly used in blow moulding. The operation of conveyors is usually automatic. Check to be sure that the conveyor is running properly. If a blow moulded part or piece of trim or flash should jam, it can stop the conveyor and cause premature failure of the conveyor belt or motor, cause product to back up and jam the prior operation or station, or even stop the line. Regardless of the cause of a jam, if something is stuck in the conveyor, always STOP the conveyor before removing the stuck object unless it can be done without risk. Conveyors may not look like

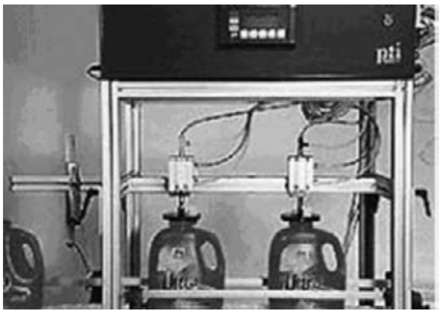


Figure 9.3 Container inspection systems using pressurised air to detect holes or weak spots in blow moulded containers

Reproduced with permission from Packaging Technologies and Inspection, LLC, Tuckahoe, NY, USA.

a piece of equipment with a lot of power and speed. Do not be deceived, because they can cause serious injury if not properly operated. Stay away from drive chains, belts, or gears, and never step on a conveyor.

9.9 Granulators

Because plastic materials are valuable, most blow moulding facilities must be able to reclaim startup waste, defective products, edge trim, flash, and (sometimes) purgings. The equipment of choice is the granulator. The main function of the granulator is to reduce these items into pieces that are small enough to go back into the machine to be moulded once again.

Most of the time, this recovered material is called ‘regrind’ and the machine is referred to as ‘the grinder’. This implies that the plastic is ground up, but that is a bit misleading. The granulator actually cuts or chops the pieces with a series of very sharp blades. One set of blades is carried on a rotating drum or axle, driven by an electric motor and belt drive system, while the other knife or set of knives is fixed.

The moving blades pass by one or more stationary bed knives, at a clearance of only a few thousandths of an centimetre. The plastic is cut and re-cut into smaller pieces. A heavy-duty metal screen with holes of a specified size keeps the plastic in the cutting chamber until the pieces are small enough to fall through the screen. The smaller the desired size of the material, the smaller the holes. Purge blobs are handled by a machine that actually shaves them into pieces. It takes a great deal of force to cut plastic, and granulators are strongly built and very powerful.

9.10 Safety

There are some important things to remember about the operation of granulators:

- Always wear the proper safety equipment. Granulators can be loud so hearing protection is a must. Pieces of plastic can be ejected from the granulator, so always wear safety glasses. Some plants may require that the operator wear protective clothing, depending upon the type of material that is being reduced.

- Never overload the granulator by stuffing it full. Feed it at a steady rate. Overloading can clog the feeding section of the granulator, stopping the reduction process until it is stopped and the excess material removed. This causes downtime that could have been avoided.

- Frequently check the material collection drawer to be sure it is not overfilled. An overfilled drawer or box will cause the granulator to clog and eventually heat the material to the point it will melt, creating a very costly mess. Some moulding facilities use automatic unloaders on the granulators to continuously vacuum the material from the collection drawer.

- The blades are sharp and the granulator is a powerful piece of equipment. It is meant to cut pieces of plastic that are very tough, much tougher than the finger or arm of an operator. DO NOT reach into the granulator for any reason when it is running. Stay clear of the blades.

- When cleaning the granulator, unplug it or lock it out before any work is done. Even though modern granulators have safety switches and interlocks, the safest way to avoid injury by a granulator is to ensure that it has no power.

- Never work on a granulator without cut-resistant gloves, and don’t let anything – tool or body part – get between the moving knives and the bed knife when the drum or axle is turned by hand.

- Before starting the granulator, check to be sure it is clean. Just like the rest of the material handling system, one piece of foreign material can contaminate many pounds of reground material. Checking to ensure the granulator is clean includes making sure the granulator catch bin is clean.

- Be sure there is no metal or other contamination in the material to be granulated. Containers of startup waste or bad product are often mistaken for garbage containers. If anything other than the correct plastic material gets into the granulator, STOP. Discard what's in the granulator and catch drawer, lock out the granulator, and clean it carefully. If an automatic unloader is in use, it will be necessary to inspect or discard a significant amount of material.

- Remember that in spite of guarding and feed chutes, the granulator may occasionally eject a piece of plastic, or even a large chunk, with lightning speed. Eye or facial injuries are possible. Stand to one side if possible, and do not look directly into the granulator.

10 Finishing

The finishing of a blow moulded part should be considered in the product design, mould engineering, and process planning phases.

A good way to do this when in the initial stages of part design is to imagine that the mould has opened but the part is still hanging in the mould, and the flash is still attached. Depending on the part and process, the following secondary operations may need to be considered:

a. Removing a dome or other sections from the part body.

b. Removing the flash and performing drilling operations (see **Figure 10.1**).

c. Decorations: hot stamping, heat transfer and serial numbering by the hot stamp method.

d. Automatic weighing and recording equipment.

e. Safety: ergonomics and noise control.

10.1 Planning for the Finishing of a Blow Moulded Part

10.1.1 Product Design

The following considerations should be made in the planning for the finishing of blow moulded parts:

1. Radii, no square corners in either inside or outside.

2. Wherever possible, include orientation and register features, for positioning and holding in downstream tasks.

3. Lay out flash pockets in the product drawing.

    a. Wide enough to accept normal flash variations

    b. Circumferential flash is to be avoided, if at all possible.

    c. When circumferential flash is unavoidable, compensate for it in the mould design.

Figure 10.1 Finishing an extrusion blow moulded traffic safety barrel

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10.1.2 Mould Engineering

1. Can the part be moulded together or 'Siamesed' (**Figures 10.2a** and **10.2b**).
2. Is the application suited for 'family' moulds?
3. Can container handles or similar components be moulded-in as inserts instead of being added later (**Figure 10.3a** and **3b**).

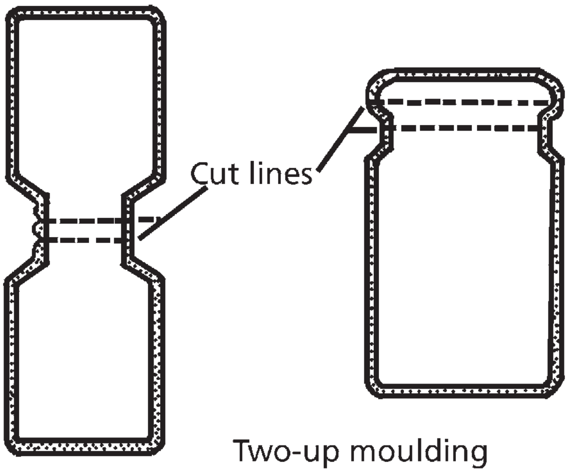

Figure 10.2a Two-up moulding

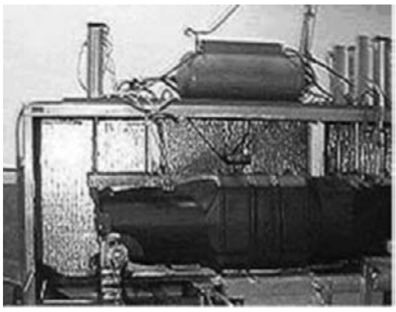

Figure 10.2b Container moulded Siamese or two-up, on a specially designed machine for automatic separation and trimming

Reproduced with permission from WEK South Corporation, Reidsville, NC, USA.

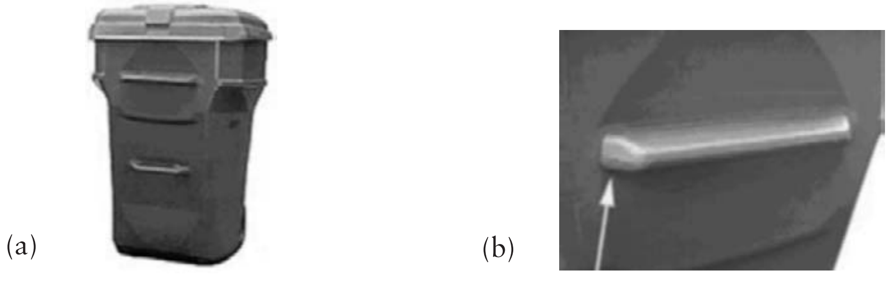

Figure 10.3a and **3b** Container with pre-moulded handle inserted into the mould as an insert to produce a container with a strong and integral handle

Reproduced with permission from WEK South Corporation, Reidsville, NC, USA.

4. Flash Pockets
    a. Depth – calculate and plan to cut 'metal safe'. Don't count on the old rule of thumb, 1.8 mm deep per side.
    b. DO keep flash pocket depth tight enough to get cooling contact, so that the flash is rigid. Molten wavy flash, in addition to encouraging 'burn accidents' enlarges the potential for rejects due to parisons and/or parts welding together, and minimises the potential for using deflashing dies.
    c. Consider 'corrugating' the flash, especially head and tail tabs. It is more expensive, but provides superior results, and can decrease cycle time.
    d. Evaluate 'blowing the flash', which provides a dimensionally stable, cool flash. Again, a fringe benefit can be decreased cycles.
5. Accommodate circumferential flash. Consider employing 'flash breaker' pinch offs, so that flash can be removed in sections, this is especially important when deflashing is performed by machine. A full ring flash is usually removed by hand, and is very difficult to automate.
6. Pinch offs – extremely important:
    - Width – keep to minimum – 0.39 mm recommended.
    - Hardness – beryllium copper, preferably, or steel, are preferred over aluminium, for long life and maintaining sharpness.
    - Incorporate 'in machine replaceable inserts', whenever and wherever possible.
7. Part ejection – configure the mould to eject the part so it clears the mould without human intervention:
    - Utilise re-pinch mechanisms as strippers.
    - Pre-plan to include mechanisms to retain the part in the preferred mould half, and then include ejection features.

10.1.3 Process Planning

First, lay out the entire process, step-by-step. What has to be done, when, and where? Whenever possible, finish the part to the maximum degree possible, possibly even to include packaging, in the moulding room and adjacent to the blow moulding machine. Doing this promises the best economics as it eliminates the labour involved in warehousing, transport, and storage. An additional benefit is that quality problems can be quickly communicated back to the moulding department.

A common problem in blow moulding plants is moving parts to separate finishing departments which work on completely different schedules or only on day shift, while moulding is often an around the clock, 24/7 operation. Careful planning and an efficient plant layout are required when designing for:

- Labelling
- Decorating, e.g., labelling and hot stamping

- Drilled holes:
    - In compression moulded areas, consider punching in-mould.
    - In blown areas, consider a ‘bubble’ which can be ‘snare cut’, rather than drilled – chipless!
- Threads:
    - Internal threads can be formed by using unscrewing cores.
    - External threads can be formed by threaded cavity sections that are split along parting lines.
- Deflashing:
    - In entirety.
    - Partial, in stages.

More specific considerations should include:

1. Investigate making the flash productive during its limited life. Can it be configured to serve as a temporary handling, positioning or registration device?
2. Part handling – removal:
    - Automatic – preferred, enables ‘gate closed’ consistent operation:
        - Stripper ‘pop and drop’,
        - *Via* side takeout,
        - *Via* bottom takeout.
    - Manual - operator controlled.

Unless the operator is exceptional, the cycle time in some operations can vary from shot to shot, creating inconsistencies in thermal history, which leads to shot-to-shot variation in product weight, location of programming points, and dimensional variations. This is demonstrated by the readily visible symptom of variation in the tail length, and overall parison length. The operator will say that ‘those tails keep changing on me’. Actually the operator is changing the tail length by running an inconsistent cycle.

3. Part handling - secondary cooling:
    - Parts up to 2.3 mm thick, if moulded in a well-cooled mould with reasonably designed flash pockets, should not require secondary cooling.
    - Medium wall parts are sometimes conveyed by a fan, which is also used for cooling.
    - Heavy wall parts – 9.52 mm and heavier – may be passed through chilled water spray, or conveyed through a chilled water bath.

    Having to hold the parts until they cool, prior to deflashing, is more often than not due to the retained heat in the flash. Deflashing early, rather than later, minimises the hazard of the retained heat migrating back into the part, which, in turn increases the possibility of warpage.

4. Parts handling – warp control or shrink fixturing.

Not all parts will require shrink control. For those that do and depending on part shape, place in shrink fixtures for whatever amount of time is necessary. Thicker parts tend to require more time in the fixture than thinner parts. There are no real rules of thumb – experimentation with the actual part is the norm. Shrink fixture dwell time is usually stated on the shop floor by number of shots, for example, ‘retain in fixture for five shots’.

Control of shrink fixture dwell time can be handled in the following ways:

a. Shrink table, with manually operated clamps. Operator keeps track of where coolest part is, replacing it with a fresh from the mould part. Least desirable.

b. Carousel or turntable shrink fixture. Operator indexes the table each shot, removing and replacing parts in rotation.

c. Indexing conveyor, as part of an automatic finishing line.

5. Parts handling – conveying

The first consideration is whether the part to be conveyed has been deflashed or not. Deflashed parts generally can be moved with simple, single speed, constant running belt conveyors without problems.

Conveying ‘fresh from the mould’ parisons with hot flash tends to be the cause of rejects because the hot flash sticks to other parisons, or worse yet, to other parts. Depending on flash configuration, when conveying parts straight from the mould, parisons with hot flash must be cooled as soon as possible; conveyors with support rails for the flash are recommended. When parts are circumferentially flashed, conveyors with separators are required to guarantee that the hot flash from one part cannot touch an adjacent part or its flash.

6. Trimming and deflashing

These terms are reasonably synonymous in industrial and large part blow moulding and refer to flash removal. ‘Trimming’ is more descriptive in container blow moulding where blow domes are cut away.

In some plants and for some products, computer numerically controlled (CNC) routers are used to trim flash and remove unwanted material automatically, *versus* manually, when part volumes are high enough to justify the cost of automation (see **Figure 10.4**).

Figure 10.4 Using a CNC router to automatically trim blow moulded panels

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A router will cause serious injuries if it makes contact with any part of the body while it is rotating. CNC machines move rapidly and must never be approached while in operation.

An alternative to the router is the laser. Laser cutting uses a powerful enough beam of light to cut plastic by heating and vaporising a very small area. A laser is used to make highly accurate, intricate holes and complex patterns. The laser power can be adjusted to just etch the surface of the plastic, or to penetrate deeply, even drill through. Laser cutting provides a clean, finished appearance and is more precise than conventional cutting methods.

Never look into a laser when it is on, or when it could be turned on at any time. Laser protection goggles must be worn at all times to avoid serious eye damage when working with high power laser cutting equipment. As with CNC robotic routers, stay away from the machine while the head is active, even if it is not moving at the moment.

A third alternative for making complex, precise trimming cuts is the water jet. While it may seem as impossible to cut with water as to cut with light, water-jet cutters use a thin jet of water at pressures up to 379 MPa to quickly cut the toughest plastics. Water-jet cutting is very accurate, creates no smoke or dust, and produces a relatively smooth cut edge. As with a laser, most water-jet cutters are mounted on a robot or a rotating head. Personal protective equipment will not protect against close contact with the high-pressure jet. Do not go near the water-jet cutter nozzle unless the machine has been turned off and locked out.

Even with the introduction of robotic devices for flash removal and trimming, the most common method of flash removal with large industrial parts is manual, using a knife to trim and a hammer to remove the parison tail.

Increasingly in the high-speed production of containers, machine deflashing is used. While each application has its own requirements, most employ an assortment of pneumatic and hydraulic deflashing presses. A common deflash press uses female bottom nests into which the parts are placed. For the most part, these presses are semi-automatic, operator loaded, and unloaded. The majority are simple designs with nests mounted on tables. A few have channels for the scrap to drop to a conveyor below. Parts with circumferential flash cannot ordinarily be trimmed in this way.

Where interior flash webs must be removed, the bottom nest includes a die or cutout. The top tooling includes a punch. Deflashing presses may be either bottom or top acting. The part, cradled in the nest, contacts the deflashing die, which over-strokes slightly. A top acting stabiliser/ejector member is generally required.

For head and tail flash, as well as circumferential flash, the tooling will vary depending on whether or not the parting line is flat or irregular. Flat parting lines are well handled by a die plate. The flash to be removed rests on a hard, smooth surface, and a sharpened blade in the shape of the area to be trimmed is pressed with considerable force against the plastic, cutting through it and coming into contact with the die plate below.

Irregular parting lines are better handled by ‘opposed chisel’ tooling, which works by shearing the plastic between two sharp edges.

A feature common in deflashing machinery is the guillotine, which is used to chop-off blow channels and neck-like areas. Guillotine cutters work like the ancient capital punishment devices, but usually have an air or hydraulically assisted fall (moving blade) to ensure proper cutting every time. Guillotine cutters are available in manual or automatic models.

Because of their size and the difficulty of adequately guarding the blade, they are carefully designed and include several safety devices. Some include photo eyes that detect the thickness of what is under the guillotine. If the thickness is too great, the machine will not function. All systems guard the blade area, and to ensure that the operator is safely away from the cutter some machines have pressure mats that must detect a human's weight before the blade will move. Some manual systems require two distant buttons to be pushed to ensure that the operator's hands are safely away from danger.

There is a category of secondary equipment referred to as 'fixtures'. Generally fixtures are job specific for a specific part and designed for secondary machining. Some 'fixtures' include deflashing, both partial – an interior section needs to be punched out – and complete exterior deflashing.

10.2 Removing Domes and Other Sections

Rotating saw blades are often used to remove domes or other sections from the part body.

Disadvantages are:

1. They are very noisy.
2. Clips and fluff made by the saw blades when cutting the part create a mess in the work area and may require the wearing of respirators.
3. There is danger from exposed saw blades and chips being flung that may get into the eyes.
4. Finished cuts are not very smooth and require extra trimming.

A better way is to use a knife cut when possible. See **Figure 10.5**, which shows a groove for a knife cut. Groove size will depend on part size and wall thickness. Generally, the height and depth of the groove should be at least twice the wall thickness, with shaped corners to prevent the knife from wandering.

As with all cutting devices, the knife must be guarded during operation. Always turn off the machine and lock out the knife movement mechanism before working on it, and wear cut-resistant gloves when working on or around trimming knives.

10.3 Flash Removal

10.3.1 The Cutting Machine – Round Parts versus *Parts with Corners*

- Round parts can typically be cut in a machine, which rotates the part. The blade may be brought in manually or automatically.

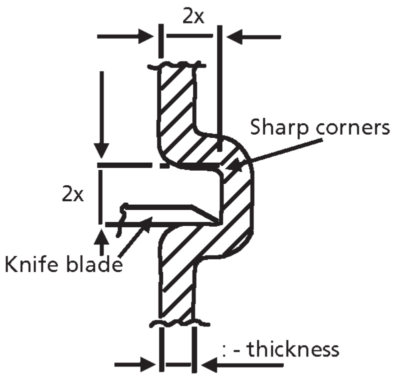


Figure 10.5 A groove for a knife cut

- Squared parts that are rotated need some type of control to maintain the depth of the blade into the part, something to automatically bring the knife in and out, and something to start and stop the machine in the same orientation each time. Other operations can also be added to the cutting machine if needed.

11 Decoration of Blow Moulded Products

Typical decorations used for blow moulded products include:

- Spray painting,
- Screen printing,
- Hot stamping,
- Pad printing,
- Labels and decals.

Surface treatment involves changing the surface tension of areas to which decoration is to be applied. The majority of blow moulded products are still olefins, the polyethylenes (PE) and polypropylenes. These materials have a low surface tension, making it difficult for other materials, coatings, or inks to adhere to their surfaces.

Flame treatment is typically used to increase the surface tension of the moulded part by carefully exposing its surface to a gas flame (see **Figure 11.1**). An alternative to flame treatment is corona treatment, in which the part is subjected to a corona (high voltage spark) discharge. More common in container blow moulding, corona treatment is not widely used in large part moulding.

11.1 Testing Surface Treated Parts

The most simple is a water test, dipping the part in water. A well-treated surface will wet out, to form a smooth layer of water over the surface. On an untreated or poorly treated surface, the water will bead instead. On an untreated surface, the water will bead up like water on a freshly waxed car's paint.

A more discerning test can be performed with commercially available marking pens, whose inks are available in a range of different surface tensions.

With materials other than olefins, other techniques are used to surface treat include:

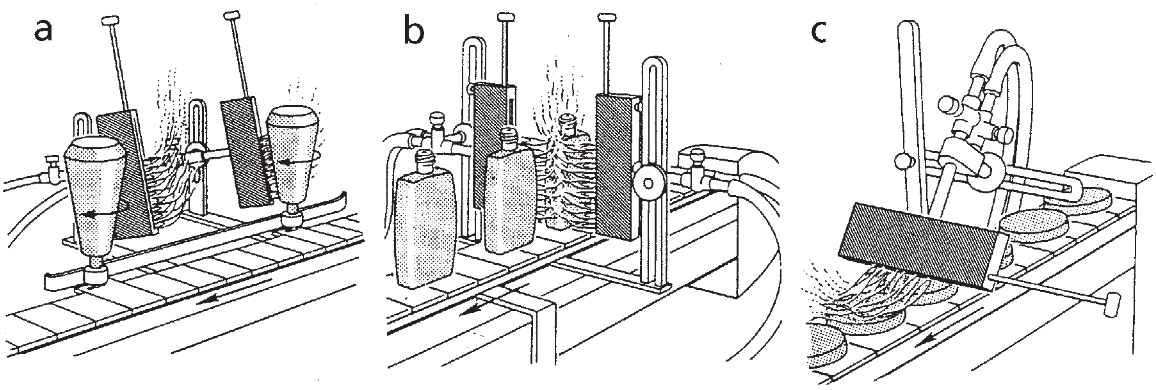


Figure 11.1 Automated flame treating using ribbon burners and a conveyor. a = Container rotating past burners; b = Flat containers passing through two burners; c = Flat discs passing under burner

- Washing with water-based chemicals,
- Solvent cleaning and etching,
- Mechanical abrasion - sanding,
- Chemical etching, and
- Additives compounded into the resin.

11.2 Spray Painting

Air atomisation and airless sprays are the most common. Methods used by blow moulders tend to follow those used in other fields. This process is excellent for applications involving large areas, irregular surfaces, or multiple, separated surfaces in a part. Masking is required to separate areas (see **Figure 11.2**).

11.3 Screen Printing

Screen printing is a special process in which ink is forced through open areas of the screen. Open areas of the screen determine the print pattern. This principle is illustrated in **Figures 11.3** and **11.4**. This process is simple and versatile.

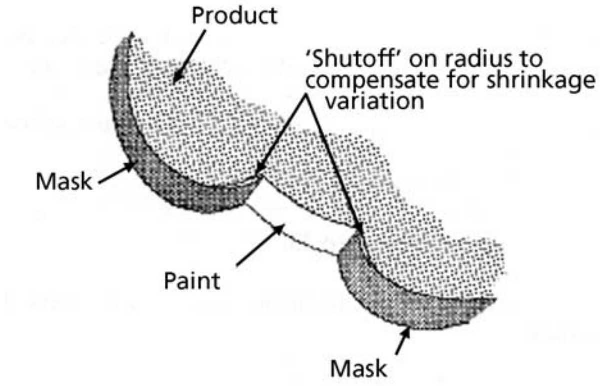


Figure 11.2 Section to be painted in masked part

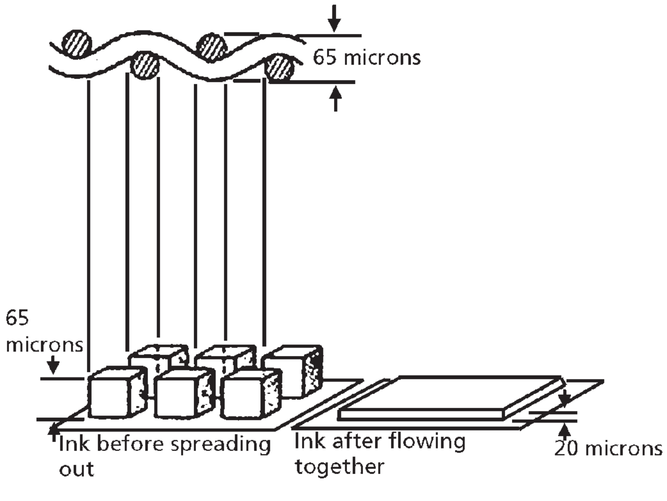


Figure 11.3 Formation of film from ink dots

Screen printers range from basic hand-operated units to fully automatic machines. There are three types: flat bed, rotary, and cylinder. In a flat bed machine, the printing stock and screen are stationary, and the squeegee moves along the screen to deposit the ink. Production rates are up to 100 parts per minute. The rotary screen printer has a drum that is constructed from a metal screen. The squeegee is positioned inside the drum and the ink is pumped into the inside. In this process the squeegee is stationary, and both the screen and the printing stock move. The cylinder consists of a stationary squeegee and moving printing stock and screen. The process is similar to the rotary machine except stock is fed intermittently with rates up to 8000 per hour. The types of screen printers are shown in **Figure 11.5**.

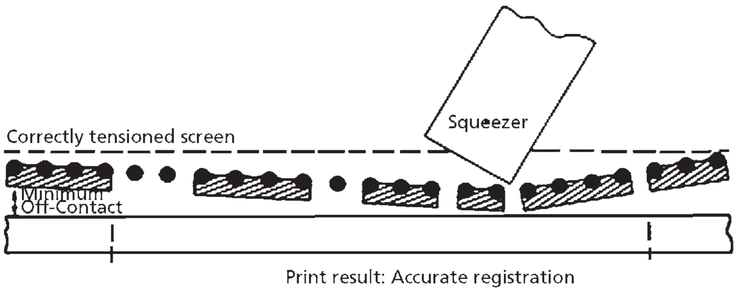


Figure 11.4 Mechanics of the screen printing process

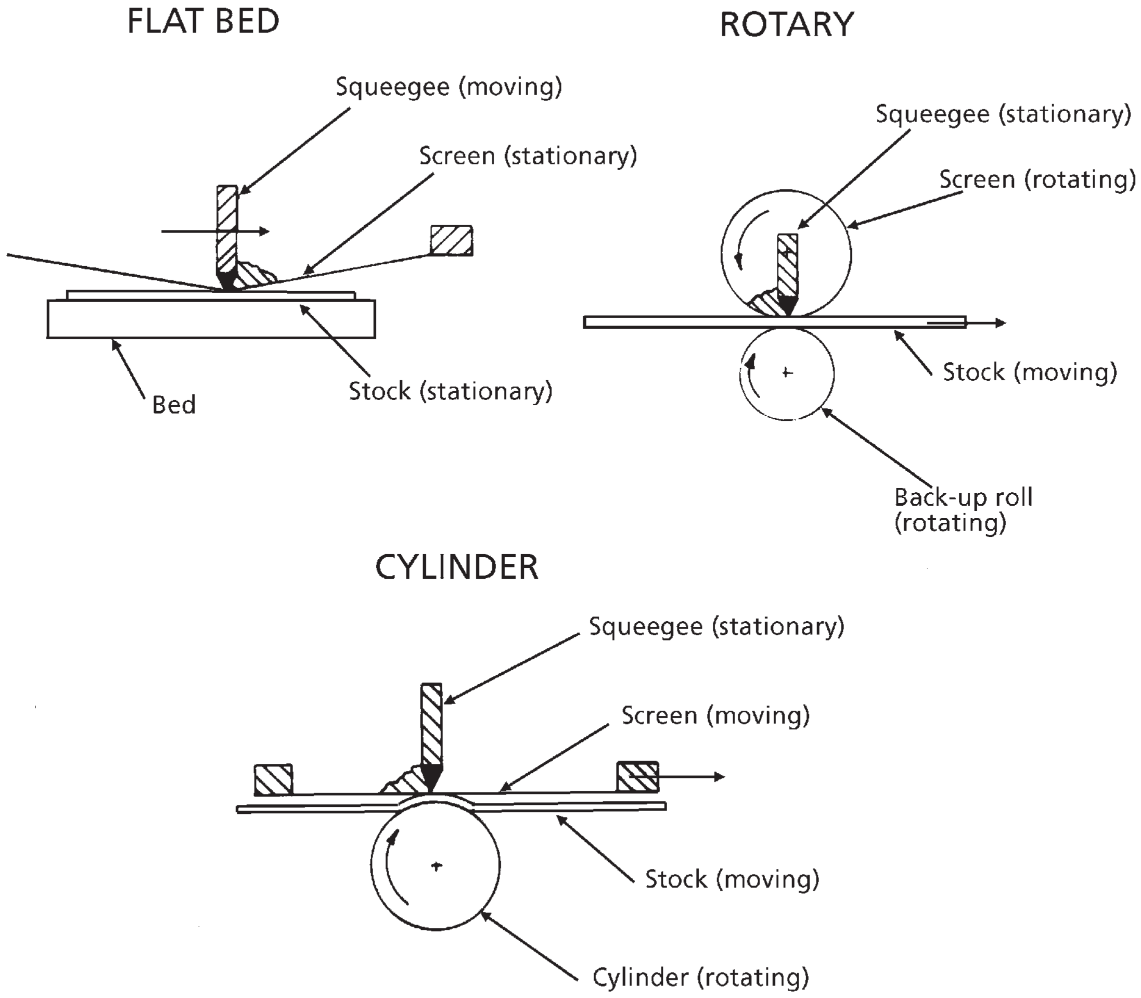


Figure 11.5 Three basic types of screen printing processes: flatbed, rotary and cylinder

11.4 Hot Stamping

This process involves transferring a coating from a carrier (ribbon or tape) to the receiving surface, by pressing a hot die with the image to be transferred against the part. For each image, the tape must be advanced. This process is usually employed in small areas, for example, for printing and logos. Hot stamping is a time, temperature, and pressure dependent process. A typical application would be part numbers on appliance parts (see **Figures 11.6a, b,** and **c**).

11.5 Pad Printing

This process permits the printing of irregularly-shaped surfaces, generally 20 cm x 20 cm maximum. It requires the work piece to be precisely located and sufficiently rigid to withstand the forces used in the process.

The image is engraved into a hard plate, called a cliché. Cliché materials include copper, zinc, magnesium, or steel. Photo-etched Nylon and PE plates are also employed. The volume of impressions usually determines the choice of the plate material. Harder materials are more costly but provide better wear resistance, and are usually preferred for longer production runs.

The ink is applied to the cliché. A doctor blade is then passed across the cliché, spreading the ink evenly, and removing it from the surfaces outside the cavities formed by the engraved images.

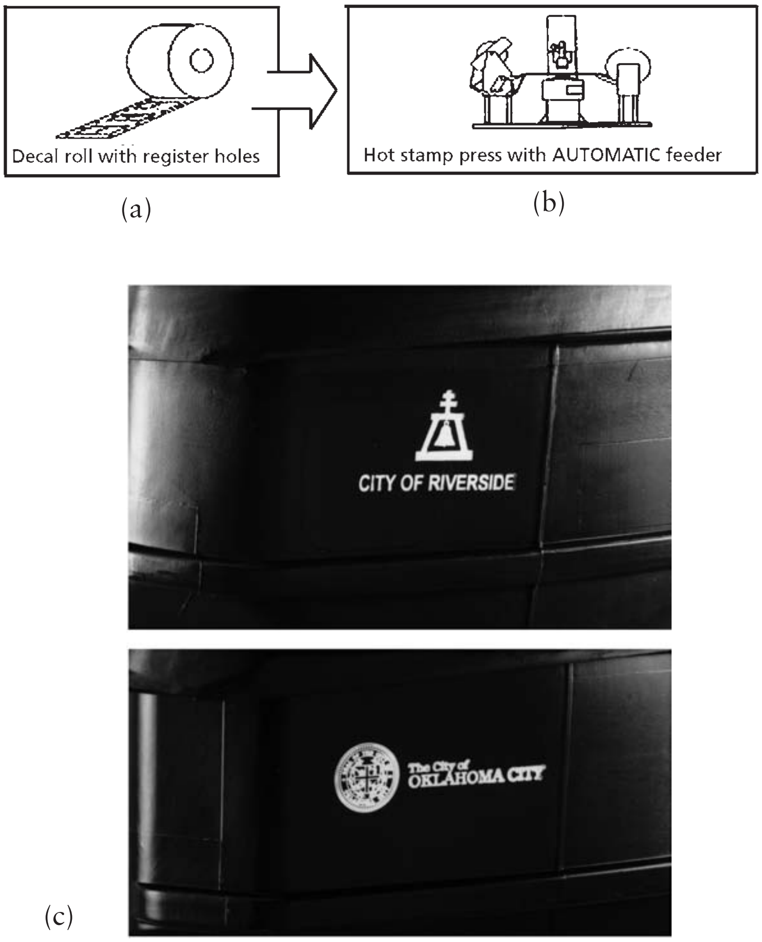


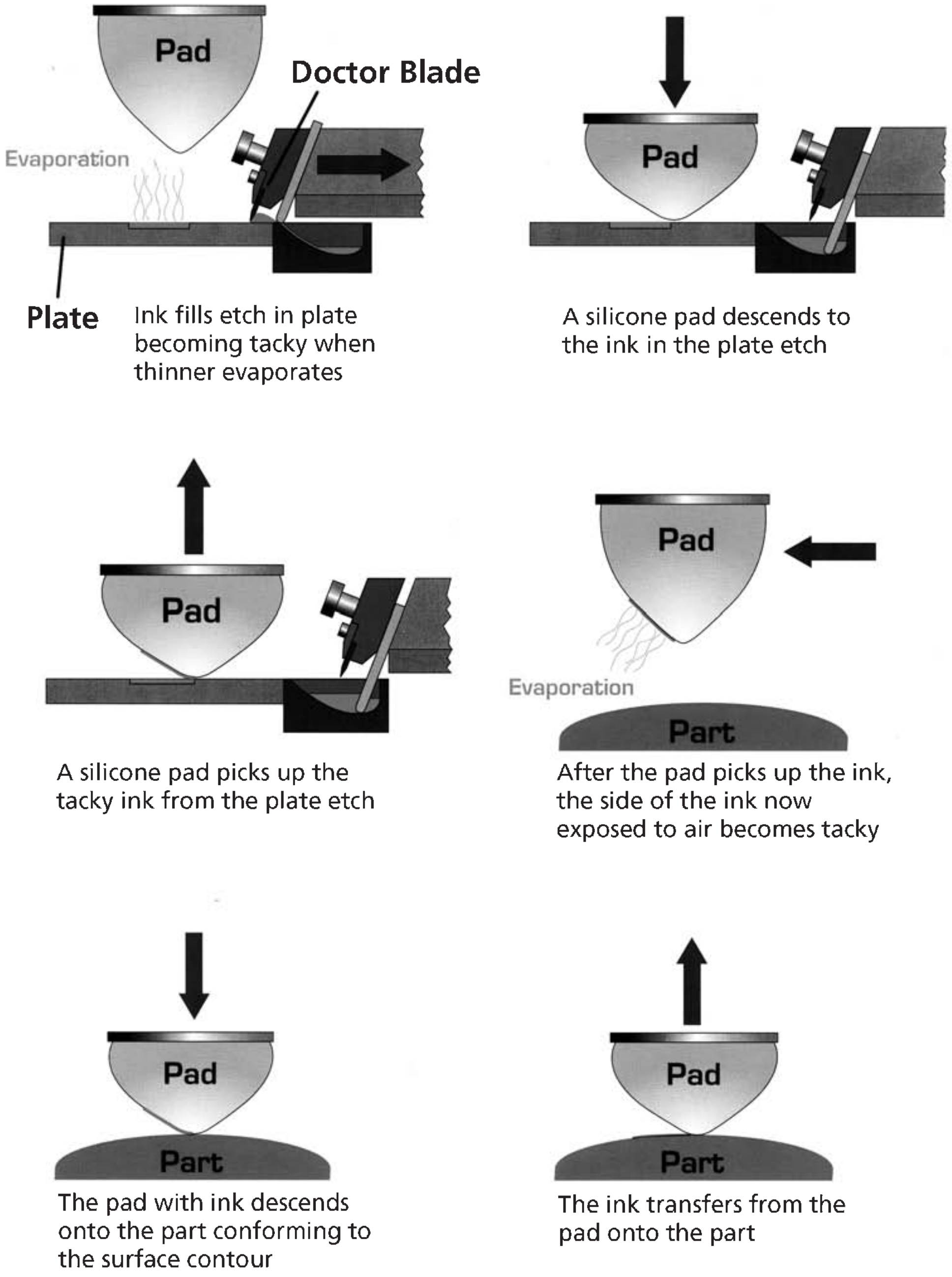
Figure 11.6 a) Decal roll with register holes; **b**) Hot stamp press with automatic feeder; **c**) Hot stamp examples

c) Reproduced with permission from WEK South Corporation, Reidsville, NC, USA.

A soft silicone rubber pad (see **Figure 11.7**) is pressed against the cliché and picks up the ink on the surface. The inked silicone pad is then indexed to the point of printing and pressed against the work-piece, transferring the ink (**Figure 11.8**).

As the soft silicone pad's surface is distorted during the compression elements of the process, the engraving on the cliché is distorted, enabling the transferred image to be accurate.

An example of a printing press with an inked rubber pad is shown in **Figure 11.9**.



Ink fills etch in plate becoming tacky when thinner evaporates

A silicone pad descends to the ink in the plate etch

A silicone pad picks up the tacky ink from the plate etch

After the pad picks up the ink, the side of the ink now exposed to air becomes tacky

The pad with ink descends onto the part conforming to the surface contour

The ink transfers from the pad onto the part

Figure 11.7 Inking a cliché and removal of excess ink from surface using a doctor blade

Reproduced with permission from Teca-Print USA, Billerica, MA, USA.

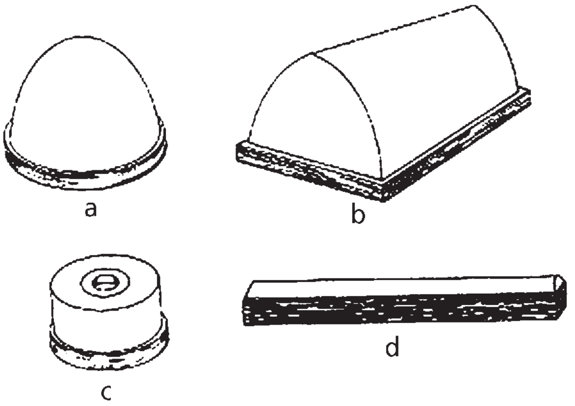


Figure 11.8 Examples of different printing pad designs – a) standard; b) wedge; c) doughnut; d) ribbon

Figure 11.9 Pad printing press with inked rubber pad ready to pad print on object (football)

11.6 Labels and Decals

Universal product codes and bar codes have been responsible for the major part of the increase that industrial blow moulders have experienced with regard to the need to apply labels. Quite often, the most cost-effective method of application is by hand, due to irregular shapes and relatively slow production speeds. While some automation is used for label application in industrial blow moulding, high speed packaging applications are better suited to automated label application.

Of all the ways in which marking can be done, pressure-sensitive labels appear to be the most cost-effective overall and are the easiest to apply, although they are not as permanent.

12 Glossary

Amorphous:	Usually refers to plastic materials that are not crystalline. The long molecular chains have no defined structure, but are arranged at random.
Abrasive wear:	Wear caused by contact with hard particles.
Additive:	Anything compounded into or blended with a polymer to modify its characteristics, such as flame retardants, pigments, and so on.
Adhesive wear:	Wear resulting from metal-to-metal contact, such as between screw flights and the inside of a barrel.
Ball check:	A specific design type of non-return valve used in injection blow moulding. It is placed at the end of the screw, to prevent plastic from flowing backward during injection. It works by using a ball that allows the material to flow in one direction, but restricts the flow in the other.
Barrel:	The thick-walled steel cylinder in an extruder or moulding machine. It contains the screw and is normally fitted with heater bands and cooling devices. Most barrels are made with a hard, wear-resistant liner.
Barrier screw:	A screw in a plastics processing machine that has two sets of flights, one having a slightly smaller diameter than the other. It improves melting by separating solid from melted polymer.
Blister:	An imperfection on the surface of a part. It resembles a blister on human skin and can have several causes.
Blow needles:	Small-diameter hollow steel tubes that are used to inject blowing air into a part. They are smaller in diameter than blow pins and can be positioned in different locations in the mould cavity walls. They are usually attached to air cylinders and are forced through the wall of the parison after the mould has closed.
Blow pin:	A hollow tubular device of varying diameter that can be positioned on the top or bottom of a mould, and is used to introduce air into the mould.
Blow pressure:	Air pressure used to inflate the parison once it is captured in the mould. Higher pressure generally means closer parison to mould contact, but requires more clamp force.
Blow up ratio:	The ratio of the maximum blown part diameter to the original parison diameter.
Bore:	The inside diameter of a barrel.
Chemical resistance:	The resistance of plastic material to attack by chemical.
Colour:	A dye or pigment used to change the colour of a plastic.
Compound:	What results after the plastic and the compounding ingredients have been melt mixed together.
Creep:	The slow dimensional change of a plastic when it is placed under load for a long period of time.

Crosslinking:	A means by which plastic molecules are linked or tied together to reduce or prevent molecular motion. Mild crosslinking, such as occurs in certain polymers, effectively increases the molecular weight and viscosity and may result in gels.
Cycle time:	The total time needed to produce one part.
Degradation:	A negative change in the chemical structure, physical properties or appearance of a plastic.
Density:	Mass per cubic volume or how heavy something is for a given space. Usually measured in grams per cubic centimetre (g/cm^3).
Desiccant drier:	A device in which moisture is removed from resin by means of hot air which has been dried by passing through a desiccant (moisture-absorbing material).
Die Swell:	A ratio describing the increase of a parison diameter over the dimension of the die.
Dispersive mixing:	A type of mixing in which the mixing device briefly subjects the melt to high shear, to break down large particles into smaller sizes.
Distributive mixing:	Distributing particles or additives to achieve uniform concentrations and resulting properties throughout the melt.
Dropping a parison:	Extruding a parison of sufficient length to position it between the two mould halves and produce a part.
Flash pockets:	Relief areas in the mould outside the pinch-offs that are, ideally, deep enough to lessen the compression of the flash material, while providing enough surface contact to cool the flashed material.
Lay flat:	The width of a tubular parison in a flat orientation.
Mould venting:	The purpose of mould venting is to exhaust air from mould cavities to enable the inflation of the part. Drilled holes, vent bushings and continuous venting along mould seams are typical methods. If venting is needed on appearance surfaces, the vents are sometimes textured to match the part finish.
Parison:	A round, hollow, tube of molten plastic that is extruded from the head of the blow moulding machine.
Parison curtaining:	The tendency of a parison to lose its tubular shape because of conditions in the extrusion process. Generally, the bottom of the parison tends to drape irregularly, causing the entire parison to lose its original shape and creating difficulties in moulding the part.
Parison melt strength:	The resistance of the parison to deformation (normally caused by gravity). Parison melt strength depends directly on the melt characteristics of the resin being extruded. The ability to extrude a parison of sufficient dimensions to produce the desired part depends on the melt strength of the parison. The larger and heavier the parison, the greater are its melt strength requirements.

Parison pinch bars:	Various methods are used to close or seal the bottom of the parison before moulding closing or part inflation. The devices are called pinch bars and are usually spring loaded or hydraulically or pneumatically actuated. They may be attached to the bottom of the mould or positioned directly under it.
Parison preblowing:	Introducing air pressure into the parison before closing the mould halves. This provides better distribution of wall thickness and prevents the parison wall from coming in contact with the mould before the inflation of the part.
Parison programming:	Varying the wall thickness in a parison to conform to the wall thickness requirements of a given part.
Parison tail:	The bottom portion of a parison that is severed by the lower pinch-offs and fails outside the mould.
Pinch-off:	A pinch-off is needed when the parison falls outside the cavity of the mould. It is the protruding edge separating the cavity from the flash pocket, and it compresses the flash to the point of severance. Inserted beryllium copper is preferred because the alloy has thermal conductivity equal to that of the aluminium alloy used in the mould. Steel pinches are used when pinch wear is critical – for example, when moulding materials such as polycarbonates are used.
Push Up:	Bottom contour of a plastic container designed to prevent the container or bottle from rocking by giving the bottom an outer edge to rest on.
Spider:	In the extrusion of a parison, thin metal legs or supports that connect the inner part of the die to the outer part.
Torpedo:	A streamlined metal block, shaped like a torpedo, that is placed in the melt flow path, often in an extrusion die, to spread the flow into thinner layers for more intimate contact with heated surfaces.

Abbreviations

3-D	Three-dimensional
ABS	Acrylonitrile-butadiene-styrene
AC	Alternating current
ANSI	American National Standards Institute
BS	British Standard
BUR	Blow up ratio
CAD	Computer aided design
CAM	Computer aided manufacturing
CIM	Computer integrated manufacturing
CMM	Computer Mould Maintenance
CNC	Computer numerical control
CPM	Critical Path Method
DC	Direct current
EDM	Electrical discharge machining
HDPE	High-density polyethylene
HSE	Health and Safety Executive, UK
ICI	Imperial Chemical Industries
L/D	Length to diameter ratio
LDPE	Low-density polyethylene
MI	Melt index
OD	Outer diameter
PAN	Polyacrylonitrile
PC	Polycarbonate
PE	Polyethylene
PERT	Program Evaluation and Review Technique
PET	Polyethylene terephthalate
PETG	Glycol-modified polyethylene terephthalate
PP	Polypropylene
PPO	Polyphenylene oxide
PS	Polystyrene
PU	Polyurethane
PVC	Polyvinyl chloride
Re	Reynold’s number
RIM	Reaction injection moulding
rpm	Revolutions per minute
RS	Reciprocating screw
SPI	Society of the Plastics Industry
UV	Ultraviolet

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