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Blow Molding Handbook

Technology, Performance, Markets, Economics. The Complete Blow Molding Operation.

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Table 3.6 Comparison of Single and Twin Screw Extruders

	Single screw	Twin screw
Flow type	Drag	Near positive
Residence time and distribution	Medium/wide	Low/narrow (useful for reaction)
Effect of back pressure on output	Reduces output	Slight/moderate effect on output
Shear in channel	High (useful for stable polymers)	Low (useful for PVC)
Overall mixing	Poor/medium	Good (useful for compounding)
Power absorption and heat generation	High (may be adiabatic)	Low (mainly conductive heating)
Maximum screw speed	High (output limited by melting, stability, etc.)	Medium (limits output)
Thrust capacity	High	Low (limits pressure)
Mechanical construction	Robust, simple	Complicated
First cost	Moderate	High

3.7.1.1 Single Screw Extruder

Most of the BM lines use a single screw extruder. Features of this machine are shown in Fig. 2.1. Examples of temperature guides for extruders are given in Table 3.7 and Fig. 3.25.

When an extruder requires an improvement in melt, different methods can be used [5] such as the inclusion of a gear pump (Fig. 3.26).

The essential parameter in the extruder's pumping process is the interaction between the rotating flights of the screw and the stationary barrel wall. For the plastic material to be conveyed, its friction must be low at the screw surface but high at the barrel wall. If this basic criterion is not met, the plastic will probably rotate with the screw and not move in the axial/output direction.

In the output zone, both screw and barrel surfaces are usually covered with the melt, and external forces between the melt and the screw channel walls have no effect except when processing extremely high viscosity materials such as rigid PVC and ultrahigh molecular weight PE. The flow of the melt in the output section is affected by the coefficient of internal friction (viscosity), particularly when the die offers a high resistance to the flow of the melt.

The usual and more popular single screw types use conventional designs with basically uniform diameters of the screw and barrel. Examples include extruders that have decreasing screw channel volume, continuous variable speed, pressure control, and a venting (devolatilization) system. Special designs use conical or die mandrel and bushing should be highly polished and chrome plated. This keeps the surface cleaner and eliminates possible areas of resin hangup. Finally, the edges of the pin (mandrel) and die should have slight radii to minimize hangup within or at the exit of the die area. The face of the mandrel should extend 0.010 to 0.020 in. (0.254 to 0.508 mm) below the face of the die to avoid a doughnut occurring at parison exit.

6.2.6 Die Shaping

It is sometimes necessary to deviate from round dies and mandrels for BM, even when finished products are cylindrical, to provide uniform wall thickness. In these instances, it is more desirable to leave the mandrel round and modify the design of the die. The reason is that in assembling the head and installing the die and mandrel in many BM machines, the screw threads that hold the mandrel in the machine are such that there can be no assurance that the mandrel will always be in the same position in relation to the die. Also, in most machines, weight adjustments for BM products are made by adjusting the mandrel either up or down in the head. In certain machines, the mandrel can turn during this adjustment. If the mandrel is made elliptical and rotation does occur, the finished product would be distorted. However, if the die is nonsymmetrical, it can always be installed in the same position in the machine.

An example of this would be a container with a diameter of 5 in. (127 mm) in which the pinch-off is to be kept inside the chimes of the container. In this case, the die diameter might be somewhere around 0.900 in. (23 mm) and the mandrel about 0.750 in. (19 mm), using converging tooling with an included angle in the die of 25° ($12\frac{1}{2}$° per side). To have a uniform wall thickness around the part near the bottom it would be necessary to make the die (ring) elliptical by approximately 0.007 in. (0.18 mm) per side at right angles to the mold closing line.

Differences in extrusion pressure between BM machines may make it necessary to ovalize the die by more or less than the amount indicated. The only sure way to know that the die has the proper design and is ovalized enough is to "cut and try." It is always better to remove metal cautiously, as it is easier to remove metal from the die than it is to add metal to it. It is suggested that before the die is cut in any way, a line be scribed across the die at the molding parting line and the front of the die be marked (one easy method is with a punch). In this manner, the die can always be installed in the machine in the same relative position.

While programming varies the entire wall thickness of the parison, die shaping introduces variations in the cross sectional area of a parison. A well designed die head extrudes a parison that is round and that has a uniform wall thickness. Whenever a round uniform walled parison is blown to form a square-shaped item, the wall thickness of the blown product will be less in the edges and corners than in the flat side surfaces. This occurs because the parison must stretch farther to reach the edges and corners.

To overcome this problem the parison is tailored or made thicker in that section that stretches the farthest so that the wall thickness in the edges and corners of the molded product is increased. Thick areas in the parison are made by removing metal from the corresponding section of the die. The metal can be removed from either the mandrel or the die ring (bushing). A square-shaped item with and without die shaping is shown in Fig. 6.10. Figure 6.11 shows the effects of ovalized die tooling on wall thickness uniformity. The die mandrel or bushing can be easily shaped by machining on the lathe or on a milling machine.

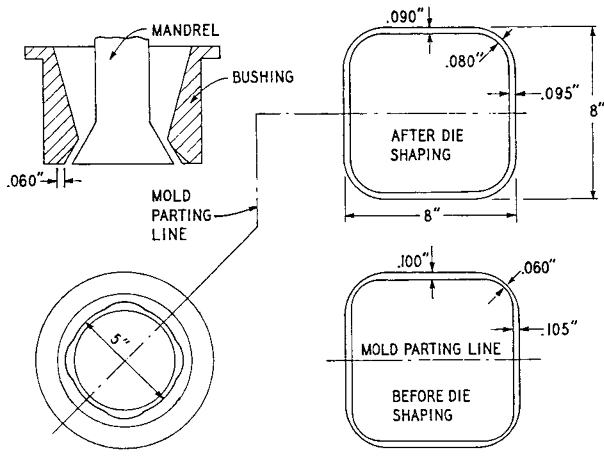

Fig. 6.10 *Wall distribution with and without a shaped die*

Fig. 6.11 *Ovalized tooling promotes wall thickness uniformity: (a) standard round tooling and (b) ovalized die tooling*

An example of a practical method to tailor a die is shown in Fig. 6.12. Here, three lines are scribed across the face on the die—one on the mold closing line, and one 30° on either side of the mold closing line. Metal is then removed on the 30° lines, using the "cut and try" method until the corners are sufficiently strong. The area between the 30° lines is then blended to a smooth radius. Owing to the pressure differential within the head of some BM machines, it has been found that in a situation such as this, turning the die 180° in the machine can make a difference in wall distribution in the corners of the bottles.

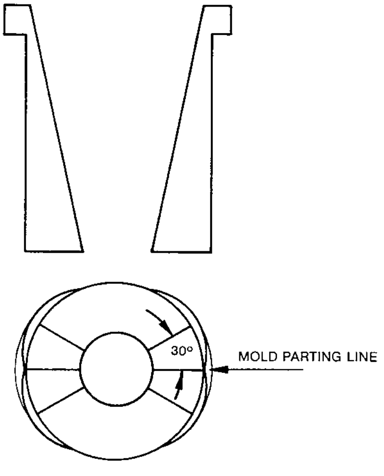

Fig. 6.12 *Example of another tailored die*

There are some applications, particularly in using diverging angles in the die and mandrel to make larger products, when it is more convenient to shape the mandrel than to shape the die. There are still other applications in which it is necessary to shape both the die and mandrel.

6.2.7 Die Orifice

Another important characteristic is the effect of the orifice shape (Fig. 6.13) on the melt. It is related to the melt condition and the die design (land length, etc.), with a slow cooling rate having a significant influence, especially in thick products. Cooling is more rapid at the corners; in fact, a hot center section could cause a product to blow outward and/or include visible or invisible vacuum bubbles.

Other factors are considered, such as the angle or taper of entry and the parallel length of the die land. For most thermoplastics (TPs), the entry angle must be as small as possible to ensure good product quality, particularly at high output rates. The abrupt changes in the direction of melt flow tend to cause rough or wavy surfaces and principally internal flaws; the condition is called melt fracture. Figure 6.14 shows examples of mandrel/die designs.

The approach used for shaping cavities in the dies is important, requiring three-dimensional (3D) evaluation that includes streamlining. Where possible, all dies should be designed to promote streamlined melt flow and avoid the obvious pitfalls associated with the areas that could cause stagnation: right angle bends, sharp corners, and sections in which flow velocities are diminished and are not conducive to streamlined flow. In certain cases such as profiles, complex shapes do not lend

(a)

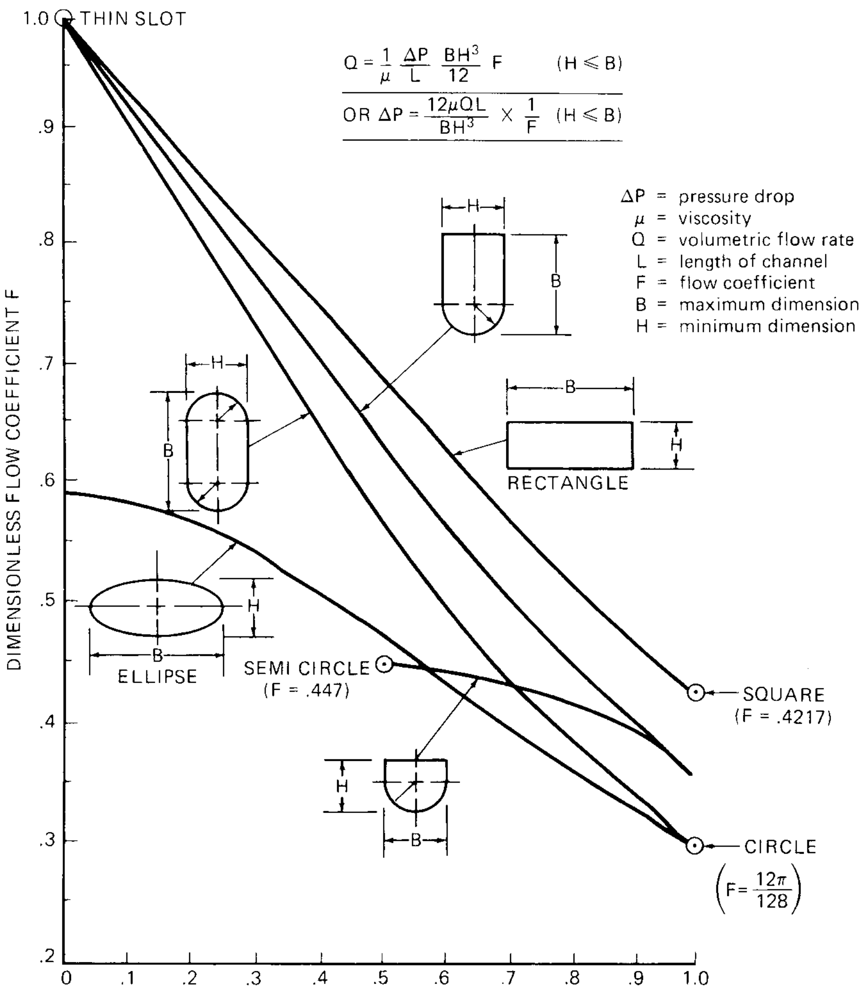

Fig. 6.13 Guide to developing orifice die opening

themselves to absolute streamlining. In these instances the stability of the plastic melt must be watched much more closely than one with a clean flowing die.

There are different approaches to developing the streamlined shapes. They range from totally trial-and-error to finite element analysis (FEA) (Chapter 8). The trial method usually involves gradually cutting or removing the die orifice metal. Between cuts an examination is made of the extrudate and the metal cavity surface to check on melt hangups, melt burning, streaks, and other stagnating problems. With FEA one can easily determine streamline flow patterns for some simple, well balanced wall thickness shapes using appropriate rheological plastic data and for others it provides a guide.

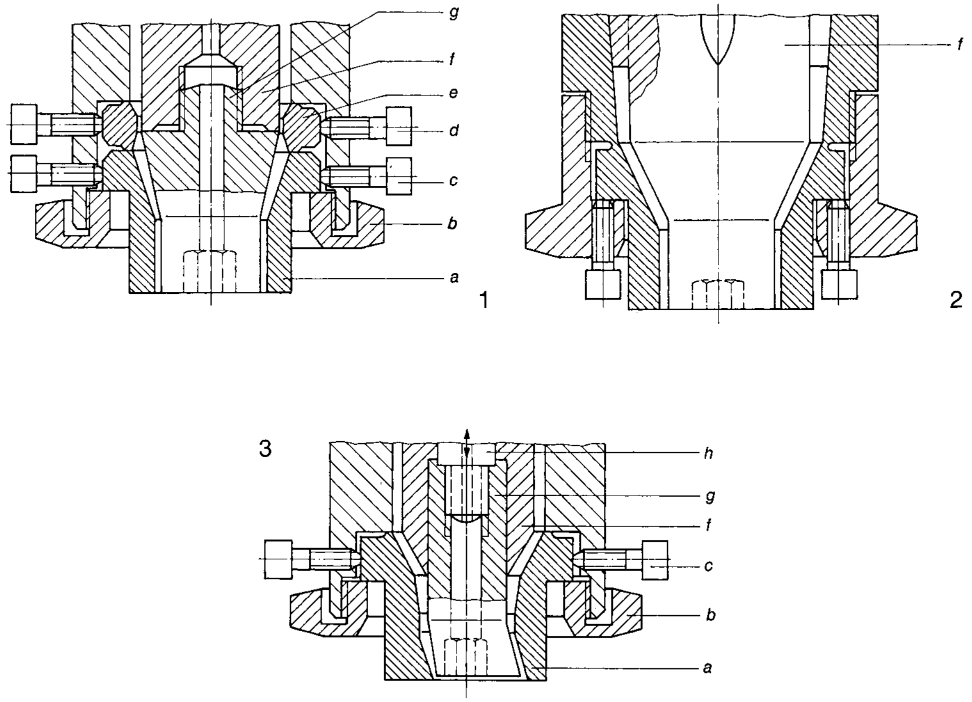

Fig. 6.14 *Typical mandrel/die designs: (1) die with conical inflow zone and adjustable choke ring; (2) die with torpedo, spider supports, and elastically deformable extrusion die head housing for die alignment; and (3) conical die for programmed adjustment of die gap. a, orifice; b, retaining ring; c and d, adjusting screws; e, adjustable choke ring; f, mandrel (or, second view, torpedo); g, core or interchangeable core, and h, sliding rod for programming die gap adjustment*

Streamlining can provide a variety of advantages: (1) Dies can operate at higher outputs; (2) pressure drops are lower and more consistent over a range of melt temperatures and pressures; (3) generally the melt uniformity across the extrudate is more uniform and shape control is enhanced; and (4) streamlining is sometimes crucial for high production output rates where plastics have limited stability and cause hangups/degradation going through nonstreamlined dies.

The land is the parallel section of the pin and bushing just before the exit of the die head in the direction of the melt flow. Its length is usually expressed as the ratio between the length of the opening in the flow direction and the die opening, for example, 10 : 1. It is vital to shaping the extrudate parison and providing thickness dimensional control. A very important dimension is the length of the relatively parallel die land, which in general should be made as long as possible. However, the total resistance of the die should not be increased to the point where excessive power consumption and melt overheating occur.

6.2.8 Coextrusion Die

The die is as important as the material for the coextrusion BM process. It has to receive the required amount of melt stream from each extruder and form it into a coherent parison with perfectly concentric material layers. As would be expected, the uniformity and the wall thickness distribution depend on precise rheological sizing of the die channels and very exact fabrication methods. Die design, fabrication and process control parameters are well advanced with both continuous and accumulator

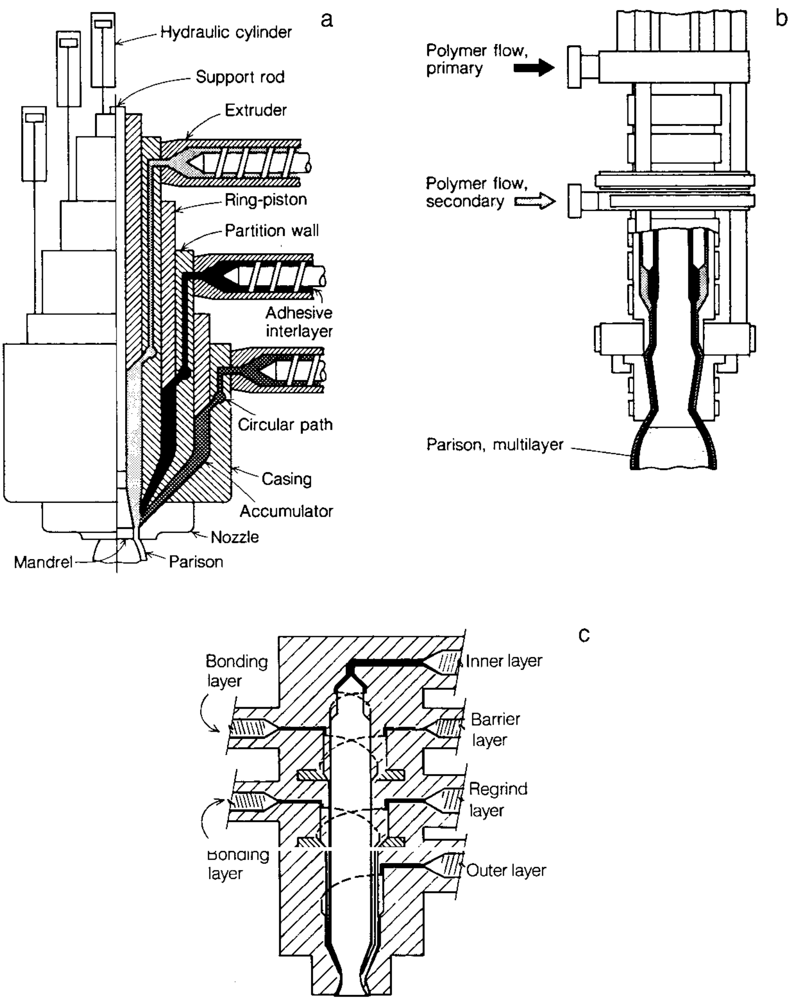

Fig. 6.15 Examples of coextruded accumulator head

The preblow pressure causes the parison to “flash” between one mold half and the movable member, resulting in good wall thickness in that leg. Blow air is introduced and the bar moved inwardly in an attempt to form the second leg. Because the movable bar is fastened to this mold half, plastic must blow into the narrow width “leg” between the bar and mold face.

A complete refrigerator compartment separator was not made by a custom molder in $1\frac{1}{2}$ years of trials, modifications, and further trials. Blowouts or ruptures always occurred in corners of the leg formed between the moving member and that mold half (Fig. 8.24). Wall thicknesses of up to $\frac{1}{2}$ in. (1.3 cm) with corresponding part weights of 17 lb (7.7 kg) still resulted in ruptured and/or paper thin corners. At this time the mold was evaluated at the Plastics Technical Center. Although much better parts were made at half the weight, ruptured or extremely thin corners still occurred.

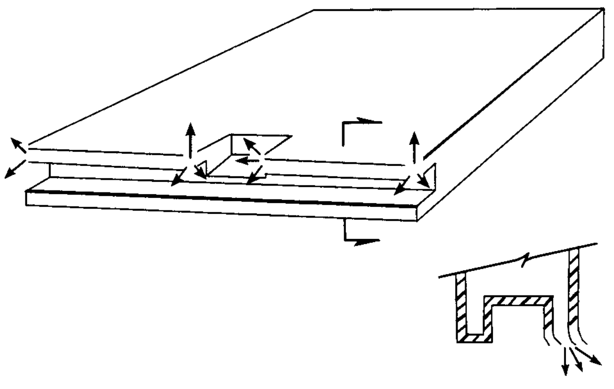

Figure 8.24 *Ruptured corners encountered with moving member attached to one mold half*

8.4.3 The Newer Technology

The new technology was simply to detach the moving member from its location on one mold half and locate it in a stationary position midway between mold halves. The member (hereafter called a third member or a “bar”) was mounted to a beam which was affixed to the press frame. This arrangement results in a second parting line—one on each side of the third member.

The molding sequence consists of extruding a high density polyethylene parison between the mold halves and adjacent to the vertical side of the third member (Fig. 8.25). The parison is then prepinched and preblown while the mold halves are open. This results in the parison starting to fold or wrap around both sides of the third member (Fig. 8.26). Because there is open space between both sides of the third member and the mold halves, the flow of the preblown parison around the member is unimpeded. This is the principle design feature of this technology.

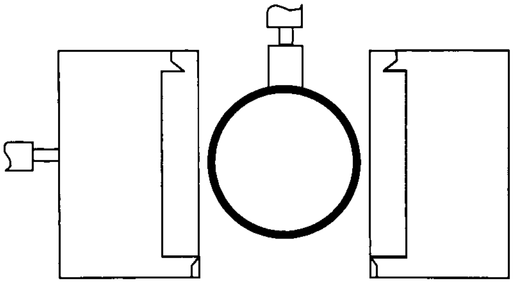

Figure 8.25 *Parison extruded adjacent to third member*

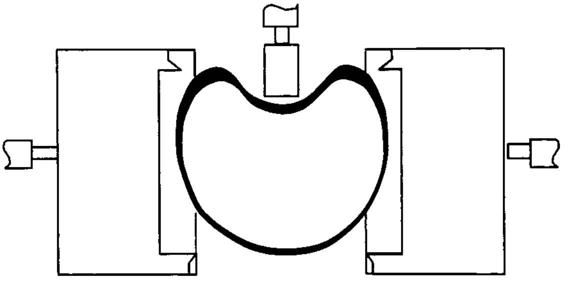

Figure 8.26 *Prepinched and preblown parison starts to fold around third member*

The closing action of the mold halves further compresses the trapped air inside the parison forcing the molten plastic tube around both sides, top and bottom of the bar (Fig. 8.27). Adequate material is trapped around the third member to form legs having relatively uniform thickness (Fig. 8.28). The mold halves have pinch blades on the sides, top and bottom of the parting line cavity edges and index at the appropriate area of the third member. The mold halves then close on the third member,

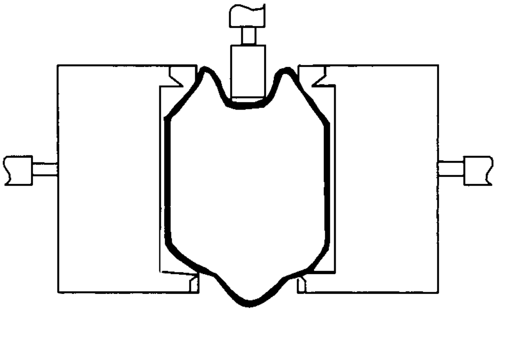

Figure 8.27 *Closing action compresses trapped air inside the parison, forcing molten plastic tube around both sides, top and bottom of bar*

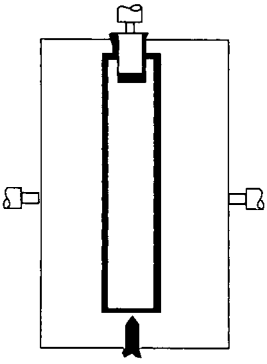

Figure 8.28 *Formed legs are relatively uniform*

conventionally pinch welding the “flashed” plastic on all sides of the bar. The part is blow molded. Part ejection is achieved by pulling the separator off the third member or by retracting the third member out of the part undercut prior to mold opening.

Reciprocating the third member is an option which would be desirable to form deep undercut parts. This was evaluated and found unnecessary for this particular part.

Production rates are the same as with any other part that is prepinched and preblown. Rates depend on wall thickness, part geometry, surface appearance, flatness, etc.—all the same factors that control cycle times for any large blow molded part.

Because of the greater amount of pinch welding in this technology, greater press clamping force than usual would be helpful. The amount of flash trimming is proportionally increased by the amount of pinch blade length. Good pinch blade quality is important to this methodology.

Preblowing parisons between split mold sections results in parts that inherently have more trimmed offal to be granulated. There is an added cost for the extra regrinding; however, this is not a high cost if normal blow molding temperatures are used, the trimmed offal is kept clean and handled efficiently.

8.4.4 Orienting 3D Parison

An overview of this EBM technique is presented. It is also called 3D (three-dimensional) BM and nonaxisymmetric BM. In conventional EBM, the parison enters the mold vertically rather in a straight tube. In 3D BM, the parison is oriented in the open or closed mold. It is manipulated in the tool cavity, providing complex geometric products that can have uniform or nonuniform wall thicknesses, corrugated and noncorrugated sections, and so on. It provides a means to significantly reduce scrap/flash (etc.) waste and quality.

Different techniques are used for placing the monolayer or coextruded plastic parison into 3D positions such as:

- articulate the extruder nozzle,
- articulate the mold platen,
- robotically orient the parison (Fig. 8.29a), and suction BM (Figs. 8.29b and c).

Sequential BM can be used to integrate hard and soft regions of different plastics on a single tubular structure (parison) as shown in Fig. 8.29d. This diagram shows two extruders controlling the sequence coextrusion (SeCo) of operation. It can use rigid–soft–rigid, soft–rigid–soft, and so on plastic combinations via accumulators "1" and "2."

As reviewed by Dr. Michael Thielen and Frank Schuller, 3D was introduced some years ago [83]. In the meantime a certain number of different systems became established in the market: suction BM, 3D BM with parison manipulation, and a split mold, horizontal machine with vertically opening mold and a six-axis-robot laying the parison into the cavity or a machine without using a closing unit. All these systems can be combined with six- or seven-layer coextrusion or with sequential coextrusion running hard–soft–hard plastics one after the other.

If strongly bent, 3D curved products, such as filler pipes for automobiles, are produced with traditional EBM technology. Flash areas near the mold parting line cannot be avoided and result in high flash percentages and surrounding pinch lines. In extreme cases the amount of flash can reach several times the actual article weight. The very long pinch lines lead to extremely high clamping forces.

With 3D, substantial savings are possible that may be achieved by using BM machines specifically designed for the production without (or at least with significantly reduced) pinch line. In these processes the extruded parison (with a diameter smaller than the article diameter) is deformed and manipulated and then moved directly into the mold cavity so that the remaining pinch line length is reduced to a minimum. The 3D manipulation of the parison with programmable manipulators or six-axis-robots and special devices allows the pinchless production of complex articles. These advantages require a higher effort as to the machine technology, depending on the article quality required and therefore also to type of process applied.

8.4.4.1 Advantages

In comparison to conventional BM technology with surrounding flash, the 3D technology presents a number of advantages. They include lower clamping force required, less effort for deflashing necessary, no refinishing work on outer article diameter, and improved quality of the article owing to wall thickness distribution and no reduction of strength due to pinch lines.

The significantly reduced flash weight brings further advantages such as smaller extruders can be used, less effort is necessary to grind flash and for recycling of regrind, and less degradation of sensitive materials.

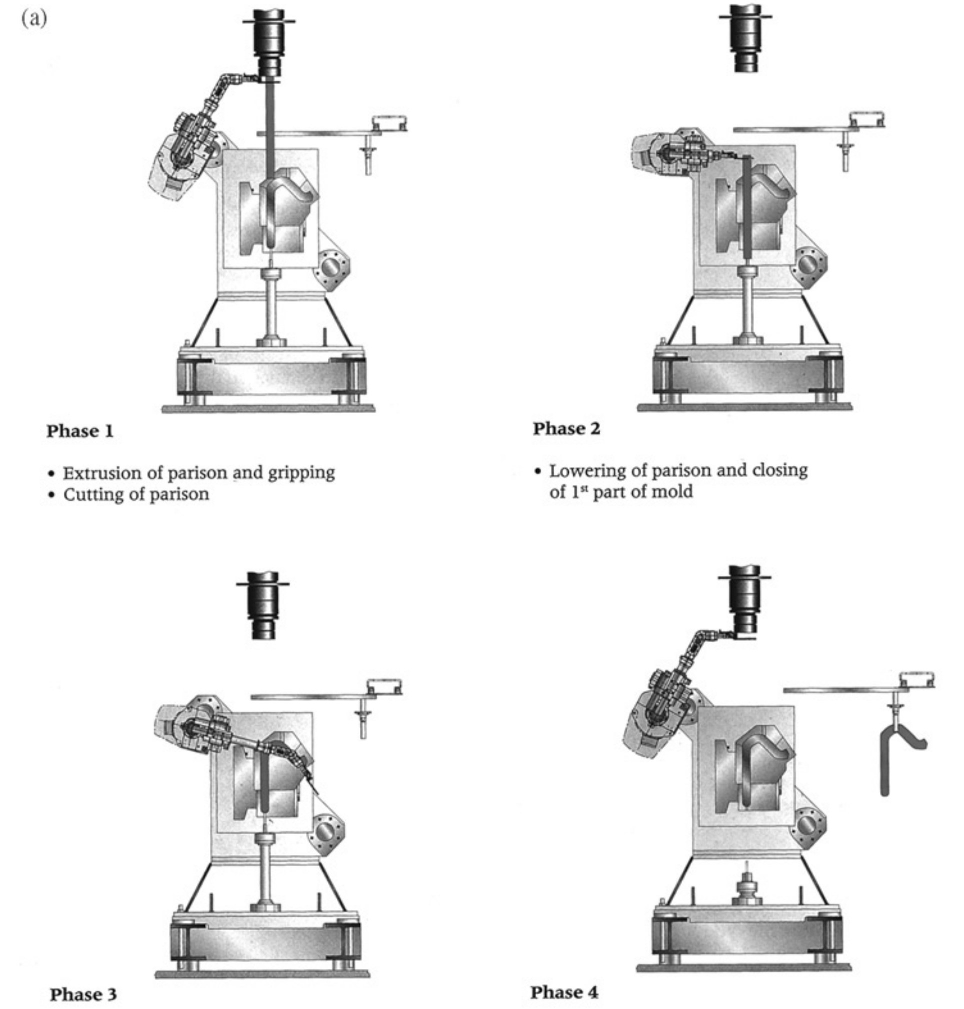

Figure 8.29 *(a) SIG Plastics' schematic example of a six-axis robot control that manipulates a parison in a 3D-mold cavity to BM a 3D product*

8.4.4.2 Available System

Due to the problems of conventional BM of certain 3D products and the advantages of 3D BM as described in the preceding, quite a number of different machine technologies were developed in recent years. Not all of them have reached significant market maturity. The most important developments are the Placo system, where an inclined clamp is moved in coordinates while the parison is placed into the mold

Table 3.7 EBM General Temperature Processing Guide

Suggested starting points only

Material	Zone 1 temp °F	Zone 2 temp °F	Zone 3 temp °F	Zone 4 temp °F	Head (A) temp °F	Melt temp °F	Mold temp °F
ABS	380–440	390–440	400–440	400–440	400–440	400–440	110–170
Acrylic	370–460	380–460	390–460	400–460	400–460	400–460	130–200
LDPE	320–340	320–350	330–360	340–370	330–380	340–380	40–100
HDPE	350–390	360–400	370–410	370–420	370–420	370–420	40–100
Nylon 6	440–480	450–480	460–480	470–490	440–510	450–510	140–200
Nylon 6/6	470–550	480–540	480–540	490–530	520–540	510–540	140–200
PC	440–480	450–480	460–480	470–490	460–510	460–510	140–220
PC/ABS	420–445	430–455	440–465	450–475	440–490	450–490	120–220
PP General purpose	340–430	350–440	360–450	370–450	390–460	390–450	40–120
PS General purpose	340–360	360–390	390–420	400–440	360–450	360–440	40–120
PS High impact	370–390	390–420	420–450	430–470	420–460	420–460	40–120
PVC Flexible	250–290	260–300	270–310	280–320	310–375	310–375	50–100
PVC Rigid	280–300	300–320	320–350	340–370	330–390	340–390	50–100
TPE (Hytrel)	300–400	310–410	330–430	350–450	370–460	370–450	60–140
TPU	360–450	360–460	360–460	360–470	370–475	340–465	60–140
TPU/PVC (Vythene)	300–320	310–330	320–340	330–360	340–365	350–365	60–120

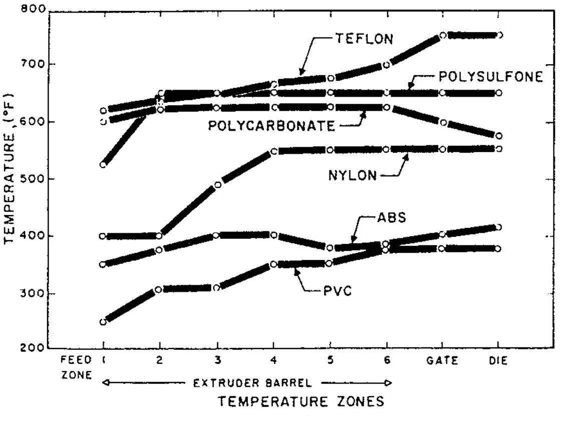

***Figure 3.25** Temperature profiles of different plastics going through an extruder having six temperature zones*

parabolic screws for special mixing and kneading effects. They can include eccentric cores, variable pitch superimposed flights of different pitch, kneading rotors, fitted core rings, and periodic axial movement. Barrels may have internal threads, telescopic screw shapes, and feeding devices.

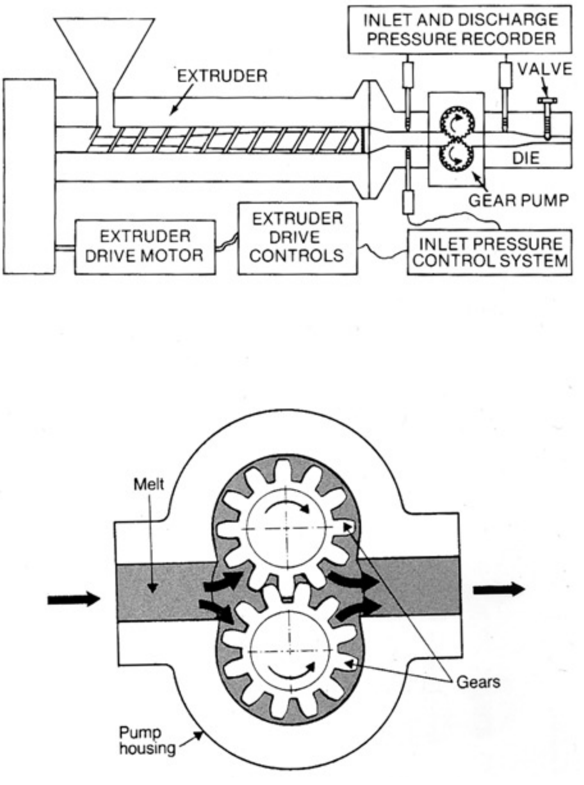

Figure 3.26 *Schematics of a gear pump location and operation*

3.7.1.2 Multiple Screw Extruder

With the development of extrusion techniques for newer thermoplastic materials, it was found in the past that some plastics with or without additives required higher pressures and needed higher temperatures. There was also the tendency for the material to rotate with the screw. The result was degraded plastics. The peculiar consistency of some plastics interfered with the feeding and pumping process. The problem magnified with bulky materials, also certain types of emulsion PVC and HDPE, as well as loosely chopped PE film or sticky pastes such as PVC plastisols.

During the early 1930s, twin and other multiscrew extruders were developed to correct the problems of the single screw extruder that existed at that time. The conveyance and flow processes of multiscrew extruders are very different from those in the single screw extruder. The main characteristic of multiscrew extruders include: (1) their high conveying capacity at low speed; (2) positive and controlled pumping rate over a wide range of temperatures and coefficients of frictions; (3) low frictional (if any) heat generation which permits low heat operation; (4) low contact time in the extruder; (5) relatively low motor power requirements for self-cleaning action with a high degree of mixing; and (6) very important, positive pumping ability which is independent of the friction of the plastic against the screw and barrel which is not reduced by back flow. Even though the back flow theoretically does not exist, the flow phenomena in multiscrew extruders are more complicated and therefore far more difficult to treat theoretically than single screw flow.

3.7.1.3 Twin Screw Extruder

Although there are fewer twin screw than single screw extruders, they are widely employed for manufacturing certain products, in particular specialty operations such as compounding applications. The popular common twin screw extruders (in the family of multiscrew extruders) include tapered screws with at least one feed port through a hopper, a discharge port to which a die is attached, and process controls such as temperature, pressure, screw rotation (rpm), melt output rate, and so forth.

For all types of extruders if the goal is to deliver a high quality melt at the end of the screw, the plasticating or melting process should be completed prior to reaching the end of the screws. Twin intermeshing counterrotating screws are principally used for compounding. Different types have been designed with basically three available commercially that includes corotating and counterrotating intermeshing twin screws; nonintermeshing twin screws are offered only with counterrotation. There are fully intermeshing and partially intermeshing systems and open- and closed-chamber types. In the past major differences existed between corotating or counterrotating; today they work equally well in about 70% of compounding applications, leaving about 30% in which one machine may perform dramatically better than the other. Figure 3.27 shows the different designs used with the twin screw extruders.

Similar to the single screw extruder, the twin screw extruder, including the multi-screw, has advantages and disadvantages. The type of design to be used will depend on performance requirements for a specific material to produce a specific product. With the multiscrews, very exact metered feeding is necessary for certain materials; otherwise output performance will vary. With overfeeding, there is a possibility of overloading the drive or bearings of the machine, particularly with counterrotating screw designs. For mixing and homogenizing plastics, the absence of pressure flow is usually a disadvantage. Disadvantages also include their increased initial cost due to their more complicated construction as well as their maintenance and potential difficulty in heating.

3.7.2 Extruder Operation

The extruder plasticates/melts the plastic solid and pumps the extrudate through an orifice in the die.

A successful extrusion operation requires close attention to many details, such as (1) the quality and flow of feed material at the proper temperature, (2) a temperature

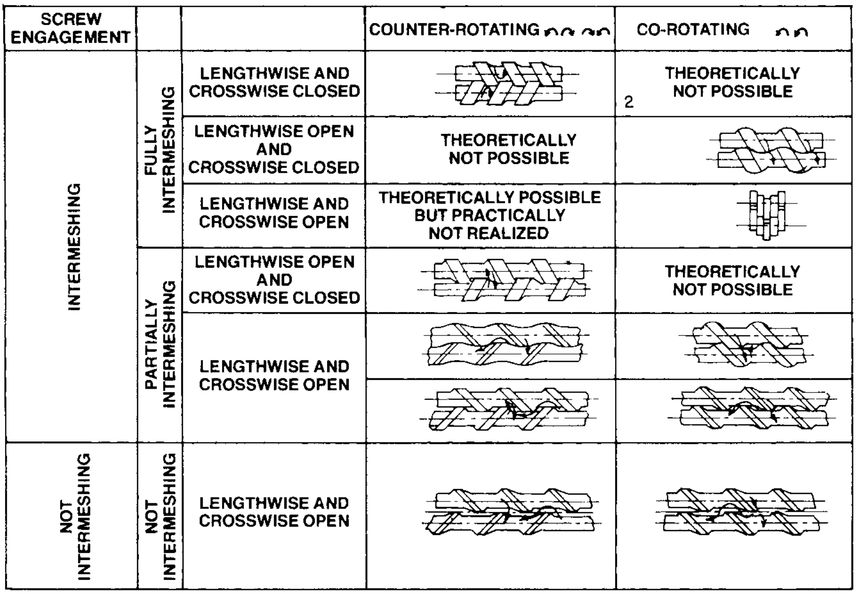

Figure 3.27 *Examples of different twin-screw mechanisms*

profile adequate to melt but not degrade the polymer, and (3) a startup and shutdown that will not degrade the plastic.

Care should be used to prevent conditions that promote surface condensation of moisture on the plastic and moisture absorption such as by the pigments in the color concentrates. Surface condensation can be avoided by storing the sealed plastic container (for hygroscopic plastics) in an area at least as warm as the operating area for about 24 h before use. If color concentrate moisture absorption is suspected, heating for 8 to 16 h in a 250 to 300 °F (120 to 150 °C) oven should permit sufficient drying. Hopper dryers have proven very useful in drying plastics. They can also enhance extruder capacity in operations where the output is limited by the heating and melting capacity of the extruder. Figure 3.28 shows the relative difference in heat input required from the extruder to melt the plastic, with and without the hopper dryer used as a preheater.

The extruders form a homogeneous plastic melt and force it through a die orifice that is related to the shape of the product's cross section. The formed TP melt (extrudate) is cooled or the TS melt heated as it is being dropped downward away from the die exit or drawn through downstream equipment.

After the extruder has started up and is running, the target is to ensure that the melt temperature, pressure, and output rate (time) are consistent within a processing "window" of operation. These factors directly affect the final product. The time

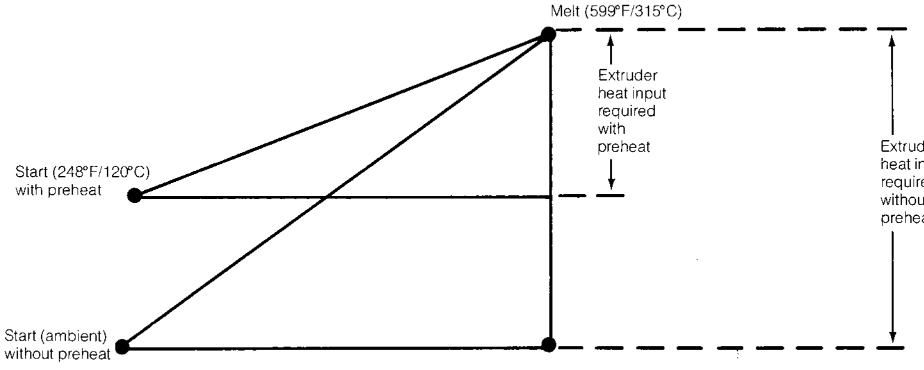

Figure 3.28 *Plastic heat input*

period for the melt exiting is influenced by such factors as the rotating speed of the extrusion screw. The usual plastic melts have rather wide operating windows. However, it is best to determine their ideal process control settings in order to obtain maximum performance/cost efficiency.

Within various types of plastics (PE, PVC, PP, or others), each type can have different profiles. Experience shows how to set the profile and/or obtain preliminary information from the material supplier. Degrading or oxidizing certain plastics is a potential hazard that occurs particularly when the extruder is subject to frequent shutdowns. In this respect, the shutdown period is even more critical than the startup period.

3.7.2.1 Extruder Checks

Prior to startup one must check certain machine conditions:

- Unless the same plastic is ready in the machine from a previous run, the entire machine should be cleaned and/or purged, including the hopper, barrel, breaker plate, die, and downstream equipment. If a plastic was left in the barrel for a while, with heat off, the processor must determine if the material is subject to shrink. It could have caused moisture entrapment from the surrounding area, producing contamination that would require cleanup (this situation could also be a source of corrosion in/on the barrel/screw).
- One must check heater bands and electrical connections, handling electrical connections very carefully.
- Check thermocouples, pressure transducers, and their connections very carefully.
- Be sure the flow path through the extruder is not blocked.
- Have a bucket or drum, half filled with water, to catch extrudate wherever purging or initial processing of plastics contained contaminated gaseous byproducts.

- Inspect all machine ventilation systems to ensure adequate air flow.
- Check operating manual of the machine for other startup checks and requirements that have to be met such as motor load (amperage) readings.

3.7.2.2 Startup

The following startup procedure provides a general review since each line has specific requirements. When starting up a new extrusion setup, start the screw rotation at about 5 rpm. Gradually look into the air gap between the feed throat and throat housing and make sure the screw is turning. Screws have been installed without their key in place, or the key has fallen out during installation. Also make sure that antiseize material is applied to the drive hub, to help installation and removal. Also if the key is left out and the drive quill is turning and the screw is not, the screw will not gall to the drive quill.

Details for operating the machine are based on what the plastic being processed requires, such as temperature settings, screw rpm, etc. available from the material supplier and/or experience. Startup procedures involve certain precautions:

- Starting with the front and rear zones (die end and feed section), one should set heat controllers slightly above the plastic melting point and turn on the heaters. Heatup should be gradual from the ends to the center of the barrel to prevent pressure buildup from possible melt degradation.
- Increase all heaters gradually, checking for deviations that might indicate burned-out or runaway heaters by slightly raising and lowering the controller set point to check if power goes on and off.
- After the controllers show that all heaters are slightly above the melt point, adjust to the desired operating temperature (based on experience and/or plastic manufacturer's recommendation), checking to ensure that any heat increase is gradual, particularly in the front/crosshead.
- The time required to reach temperature equilibrium may be 30 to 120 min, depending on the size of the extruder. Overshooting is usually observed with on/off controllers.
- Hot melts can behave many different ways, so no one should stand in front of the extruder during startup, and one should never look into the feed hopper because of the potential for blowback due to previous melt degrading, and so on.
- After set temperatures have been reached, one puts the plastic in the hopper and starts the screw at a low speed such as 2 to 5 rpm; some plastics, such as nylon, may require 10 to 20 rpm.
- The processor should observe the amperage required to turn the screw; stop the screw if the amperage is too high, and wait a few minutes before restart.
- When working with a melt requiring high pressure, the extruder barrel pressure should not exceed 7 MPa (1,000 psi) during the startup period.

- One should let the machine run for a few minutes, and purge until a good quality extrudate is obtained visually. Experience teaches what it should look like; a certain size and amount of bubbles or fumes may be optimum for a particular melt, based on one's experience after setting up all controls. If plastic was left in the extruder, a longer purging time may be required to remove any slightly degraded plastic.
- For uniform output, all of the plastic needs to be melted before it enters the screw's metering zone, which needs to be run full. When time permits, after running for a while, the processor should consider stopping the machine, let it start cooling, and remove the screw to evaluate how the plastic performed from the start of feeding to the end of metering. Thus one can see if the melt is progressive and can relate it to screw and product performances. Turn up the screw to the required rpm, checking to see that maximum pressure and amperage are not exceeded.
- Adjust the die with the controls it contains, if required, at the desired running speed. Once the extruder is running at maximum performance, set up controls for takeoff/downstream equipment, which may require more precision settings.
- Extrudate can start its tract from the die by "threading" through the downstream equipment to its haul-off.
- One may get into a balancing act of interrelating extruder and downstream equipment. Extruder screw speeds and haul-off rates may then be increased. Downstream equipment is adjusted to meet their maximum operating performance, such as having the vacuum tank water operate with its proper level and vacuum applied.
- The extruder can be "fine-tuned" to obtain the final required setting for meeting the desired output rate and product size (Chapter 8).

3.7.2.3 Shutdown

It is common to run the extruder to an empty condition when one is shutting down. This action ensures that there is no starting up with cold plastic, a condition that could overload the extruder if improper startup occurred. Some extruders, such as those processing PE film, are shut down with the screw full of plastic. This prevents air from entering and oxidizing the plastic. Because PVC decomposes with heat, to ensure that this material is completely removed at shutdown, purging material is used such as low melt PE that can remain in the barrel eliminating PVC decomposition. On startup, it is preferable to raise barrel heat slightly above its normal operating temperatures; the higher temperature ensures that unmelted plastic will not produce excessive torque in the screw.

Degrading or oxidizing certain plastics is a potential hazard that occurs particularly when the extruder is subject to frequent shutdowns. In this respect, the shutdown period is even more critical than the startup period.

Shutdown procedures vary slightly, depending on whether or not the machine is to be cleaned out or just stopped briefly. If the same type of plastic is to be run again,