Norman C. Lee

Understanding Blow Molding

ISBN-10: 3-446-41265-4
ISBN-13: 978-3-446-41265-1

Vorwort

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Preface

The material for this book is drawn from a seminar team, lead by the author, that conducts for the Society of Plastic Engineers (S.P.E.) blow molding seminars and workshops on both industrial and high production blow molding (bottles). The focus of *Understanding Blow Molding* is hands on and practical application, which will benefit those new to the plastic blow molding specialty, as well as those who are experienced but who may not have been exposed to all facets of a blow molding plant. People from various disciplines such as marketing, design, research and development, product and manufacturing engineering, as well as operation personnel, will also gain insight into the everyday problems of a blow molding operation.

Those who participated on the seminar team and whose material is quoted and referenced include:

- **John Hsu**, Milacron, Cincinnati, OH (Chapter 7)
- **Robert Slawska**, Proven Technology, Inc., Belle Head, NJ (Chapter 7)
- **John Griep**, Portage Cast & Mold, Portage, WI (Chapter 9)
- **Ralph Abramo**, Abramo Associates, Inc., Holliston, MA (Chapter 10)
- **John McNamara**, Blow Molding Automation Specialist Incorporated, Cincinnati, OH (Chapter 11)
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Further, I am grateful for the work of Loretta A. Lee of CADWORKS for her assistance in editing, preparing the drawings, and bringing together the pieces of the manuscript, without which this book would not have been possible. Further thanks go to Aaron Ulmer, Teaching Assistant with the Technology Department at B.Y.U, for his help with metric conversions.

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February 2000
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2 Basic Process

2.1 The Principles of Blow Molding

A simple explanation of the principle of blow molding is a balloon. If you blow air into a plastic tube that is closed on all sides except the point at which the air enters, the tube will expand and take the shape of the mold that is around the tube. As in the case of the balloon, the further the tube is stretched the thinner it gets (Fig. 2.1).

Fig. 2.1: Balloons

The process begins with a plastic resin hot tube called a parison or pre-form. The parison is placed within a split mold with a hollow cavity. The mold sides are then clamped together, pinching and sealing the parison tube. Air is blown into the tube, which expands the hot resin wall into the shape of the cavity; the mold is cooled with water solidifying the resin into the shape of the part. Once cooled, the part is ejected from the mold and trimmed (Fig. 2.2).

Fig. 2.2: Basic process
There are several methods of blow molding plastic parts. However they all have 5 stages in common (Fig. 2.3).

1. Plasticizing or melting the resin
2. Parison or pre-form production
3. Inflation of the parison or pre-form in a mold to produce the end part
4. Ejection of the part
5. Trimming and finishing of the part

The first four steps take place in sequence; the fifth is performed while the other 4 steps are cycling. Exceptions occur when a number of pieces are produced on the same machine, simultaneously, then the four steps may overlap. Most of the cycle time is taken up by the blowing and cooling step. Therefore (step 3) blowing and cooling control the machine cycle. The speed of the machine that melts the resin and makes the parison must be configured to conform to the blowing/cooling time.
2.2 Parison Formation

The parison or pre-form is formed by either of two techniques for melting the resin, extrusion or injection molding (Fig. 2.4). This diagram shows the family of today’s variation of the blow molding process. Each of the processes to be described has its advantages. The end product and volume to be produced determines the best method for the application.

Fig. 2.4: Flow chart

For small, high production clear parts, injection blow molding would be the process of choice. For larger industrial parts the accumulator method is the process of choice; and higher volume detergent or oil bottles would most likely be produced on a wheel machine.
2.3 Blow Molding Development

History

- The first patent issued in the 1850s for blow molding with a material other than glass was issued to Samuel Armstrong. These early items were made from natural latex, mainly novelty items that were unique because of their soft feel.

- The next major advancement came in 1869 with the commercialization of celluloid, which is considered to be the first true thermoplastic material.

- In the 1880s, cellulose nitrate was introduced and was used to produce novelties and toys. This material was softened by steam; the disadvantage was its high volatility, which kept it from being widely used.

- In 1919 a material which was much more stable, cellulose acetate, was available and had much greater acceptance as a commercial material. By 1930 it was available as a squeeze bottle.

- In the early 1930s, Plax Corporation developed the first blow molding machine. This was crude and produced only small quantities. However, from this early beginning a machine to make 25,000 bottles a day was developed. A photograph of the first blow molding machine can be seen in Fig. 2.5.

Fig. 2.5: First blow molding machine. One of the first automatic blow molding machines developed by Plax in the early 1930s. Courtesy of Innopak Corp.
In 1939 low density polyethylene was introduced by I. C. I. (England). This material was much more amenable to the blow molding process and opened up the way to further development.

In the 1940s Plax introduced the first LDPE bottle.

The first injection blow molding machine was introduced. This hybrid machine featured high precision neck dimensions with tolerances as tight as glass bottles.

Continental Can was issued a patent for a continuous extrusion blow molder in 1950.

The beginning of industrial blow molding can be said to have started in 1953 with the development of high density polyethylene. This material was developed simultaneously by Phillips Petroleum Co. in the United States and by Professor K. Ziegler in Germany.

By 1956 the commercialization of the blow molding process and explosive growth of the industry had begun.

During the 1950s industrial blow molding machines were developed first in Europe, since Plax and Continental tightly held patents in the United States.

European machines became available in the United States by 1958. The first machine was bought by Empire Plastics to make toy bowling pins.

Several individuals and companies built machines, and I was personally involved in converting a Reed injection machine to make a blown baseball bat.

Ideal Toy ordered six machines built by Walden-Hartig (Hartig machines are now made by Davis Standard), to make doll bodies with a head design from Empire Toys.

By 1960 with patents now freed ZARN, Inc. made milk bottles on Uniloy machines for Borden Dairy in High Point, North Carolina (Fig. 2.6).

In the ’70s biaxially oriented polyethylene terephthalate (PET) was developed, which led to the introduction of the twostep process by which pre-forms and final bottles are produced on separate machines by Cincinnati Milacon, U.S.A. in 1977 Nisser, ASB Company (Japan), began to offer biaxial orientation of PET using blow molding equipment based on a one-step process.

Also during the ’70s, Multilayer blow molding came to the U.S.A with the introduction of the ketchup squeeze bottle.

With the introduction and the application of the microprocessor, resins with a wide range of material properties became available. Also, the availability of larger, more robust equipment and microprocessor technology made the production of a range of industrial products such as automotive fuel tanks, etc., possible. Then too, from Japan and Germany, complex shapes and with irregular contours were possible with the introduction of 3-D blow molding.
Today bottles still represent a large share of the blow molding market with an 80 percent share; the other 20 percent are considered to be industrial blow molding.

Additional Reading
Mooney, P., Plastic Custom Research Service. Advance, NC
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9 Understanding Extrusion Blow Molds

The mold determines the shape of the end product with all its details. It helps provide the end product with essential physical properties and the desired appearance. Usually, the mold maker builds the blow mold according to the molder's or the customer's specifications, but frequently, minor adjustments or improvements which would not justify its return to the mold maker, can be made with equipment and knowledge available in the blow molding shop.

9.1 Main Characteristics of the Mold Halves

The blow mold 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 mold halves are usually alike. There are usually no male and female sections.

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

Both mold halves must have built-in channels for the cooling water. Sets of guide pins and bushings or side plates in both mold halves ensure perfect cavity alignment and mold closing. Accurate guiding devices in both mold halves reduce setup time. Figure 9.1 shows the two halves of a blow mold for small bottles. Figure 9.2 shows the location of the cooling water channels.

Fig. 9.1: Milk bottle mold halves. Courtesy of Johnson Controls Inc., now Uniloy Division, Milacron, Manchester, MI
Mold closing

On some blowing presses, mold closing is carried out in two steps, first at high speed, with lower pressure, say, 6.5 to 13 mm (0.25 to 0.5 in) of daylight. The second step is slower with higher pressure to protect the mold 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.

Molds are not necessarily positioned vertically, that is, in line with the parison. They may occasionally be tilted (Fig. 9.3). This will result in a nonuniform distribution of resin which may be helpful, for instance when such irregular pieces as a pitcher with a handle are being blown. It may also result in some savings in parison length.
Because of the comparatively low clamping and blow pressures, the blowing mold need not be made of a high tensile strength material, with the possible exception of molds for very long production runs, say, hundreds of thousands or millions, which are sometimes made of steel. The predominant raw materials for blow molds are machined from aluminum billet, cast aluminum alloys, zinc alloys such as kirksite, and occasionally, bronze. Beryllium copper, because of its expense and difficulty in machining, is usually reserved for pinch inserts or cores where rapid heat transfer is needed. All these alloys are excellent materials for blow molds. Table 9.1 compares the properties of common mold material.

Aluminum is the softest of the mold materials in use and is most easily damaged in the shop. Furthermore, aluminum molds wear easily. On the other hand, they are easiest to machine. Aluminum and beryllium copper cast molds may be slightly porous, and occasionally, blow molders have experienced some permeability of such molds to the viscous resin. This may affect the appearance of the blown part. The remedy for this problem is coating the inside of the mold halves with a sealer (such as radiator sealer). This will not affect the heat transfer between the resin blown against the mold and the mold walls.

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

**Table 9.1: Properties of Common Mold Materials**

<table>
<thead>
<tr>
<th>Composition</th>
<th>Thermal conductivity (watts/(cm²) (°C/cm)) (BTU in/ft² H°F)</th>
<th>Density kg/cm² (lb/in³)</th>
<th>Hardness</th>
<th>Tensile Strength kPa (psi)</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beryllium copper alloy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA 172</td>
<td>1.11034 (770) 82.4864 (0.298)</td>
<td>37 RC</td>
<td>1.0342 × 10⁶ (150,000)</td>
<td>1.8% Be</td>
<td></td>
</tr>
<tr>
<td>CA 824</td>
<td>1.08150 (750) 84.1472 (0.304)</td>
<td>34 RC</td>
<td>9.3079 × 10⁴ (135,000)</td>
<td>1.65% Be</td>
<td></td>
</tr>
<tr>
<td>Aluminum alloy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7075 T6</td>
<td>1.29780 (900) 27.9568 (0.101)</td>
<td>150 BR</td>
<td>4.9642 × 10⁴ (72,000)</td>
<td>1.6% Cu, 0.23% Cr</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.6% Zn, 2.5% Mg</td>
</tr>
<tr>
<td>AISI P = 20 steel</td>
<td></td>
<td>30-60 RC</td>
<td>8.2737 × 10⁴ (120,000)</td>
<td>0.35% C, 1.0% Ni</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.28840 (200) 78.0576 (0.282)</td>
<td>290-330 BR</td>
<td>8.2737 × 10⁴ (120,000)</td>
<td>and 1.0% Cr</td>
<td></td>
</tr>
<tr>
<td>AISI 420 stainless steel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.23937 (166) 77.5040 (0.28)</td>
<td>50 RC</td>
<td>1.4686 × 10⁶ (213,000)</td>
<td>0.38% C, 0.8% Si</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.6% Cr, 0.5% Mn, 0.3% V</td>
</tr>
<tr>
<td>Kirksite A</td>
<td>0.92288 (640) 69.20 (0.25)</td>
<td>100 BR</td>
<td>2.4132 × 10⁵ (35,000)</td>
<td>contains Cu, Al, Mg</td>
<td></td>
</tr>
</tbody>
</table>

*RC, Rockwell C; BR, Brinell

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### 9.3 Importance of Fast Mold Cooling

Fast heat transfer of the material of which the mold is made is of utmost importance because, as has been explained, the cooling step controls the length of the blow molding 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 molds, the above mentioned alloys are generally preferred to the usually more durable steel.

Considering only their heat transfer rate, the principal blowing mold materials follow each other in this order:
Occasionally, several different alloys are used in the same mold to obtain desired strength and special cooling conditions. However, as these mold materials have different heat transfer rates, a blow mold, with the exception of steel pinch-off inserts (see Section 9.4), should be made of only one material. Different materials with consequently different heat conductivity at various points of the mold will result in nonuniform cooling. This, in turn, might set up areas of stress in the finished piece, which would be susceptible to splitting in use. The blow mold halves must always be adequately cooled to solidify the part quickly, immediately after the parison has been blown out against the mold 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 instance, in winter, it should be chilled by a heat exchanger to 4 to 20°C (40 to 70°F). Such low temperatures may, however cause water condensation on the outside mold walls. Some molders, though, use noncooled 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 fresh tap water to maintain the desired temperature and to economize.

The water usually circulates through the hollow mold halves. Sometimes, a copper tubing system is cast into the mold. However, to create the most useful flow, water channels are machined into the material cast into the mold halves. Well-placed channels will ensure that the cooling water comes as close to the mold cavity as feasible (see Fig. 9.2). Cooling channels should also be as close to the (lengthwise or other) parting lines caused by the separation lines of the two halves or by inserts. Parting lines will practically always show along mold separation lines. Cooling these areas will result in better finish of the piece along the parting lines.

Larger molds 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 required 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 nonuniform shrinkage and resultant warpage, which the customer will reject. That is why frequently even a simple mold has two or more cooling systems for each half.

Occasionally, the blowing pin is also being cooled. Sometimes, air cooling from the outside is provided for the pinched “tail” of the parison sticking out of the mold 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 molding cycle. It has been experienced that an increase, or decrease, of 5°C (10°F) in melt temperature can extend, or shorten, the cooling cycle by as much as one second.
9.4 The Pinch-Off

Because of the comparatively high pressure and mechanical stress exerted on the mold bottom when (in the closing step) it pinches one end of the parison together, the pinch-off in a nonferrous metal mold 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 Fig. 9.4). Its protruding edges 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 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.

The pinch-off should not be knife-edged, but, according to some molders, should be formed by lands about 0.1 to 0.5 mm (0.005 to 0.015 in) long. The total angle outward from the pinch-off should be acute, up to 15° (Fig. 9.4). These two features combine to create a welding line, which is rather smooth on the outside and forms a flat 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. Figure 9.5 shows a cross section through a well-shaped container bottom and one through a poor one due to an incorrectly constructed pinch-off insert.

One method of obtaining more uniform weld lines is to build “dams” into the mold halves at the parison pinch-off areas. These dams force some of the molten resin back into the mold cavities to produce strong, even weld lines (Fig. 9.6).

Fig. 9.4: Parison tails

Fig. 9.5: (A) A good pinch-off result; (B) a groove results from a bad pinch-off
A high quality mold cavity finish and undamaged inside surfaces are essential in polyethylene blow molding to avoid surface imperfections in the end product. If the highest possible gloss of the end product is desired, the mold cavity should be sandblasted with 100-grit flint sand, and there should be vacuum assists for the removal of entrapped air. If other endproduct finishes are desired, the mold cavity should be finished accordingly. Even a first-class machining job inside the mold cavity cannot prevent the occurrence of parting lines, especially if the blown item has a very thin wall. See Fig. 9.7 for an illustration of a complex machining job.
9.6 Effects of Air and Moisture Trapped in the Mold

In highly polished molds, air may be trapped between the mold walls and the hot, still soft piece, marring the surface of the piece. This will happen especially when thickwalled, large pieces are blown. In such cases, the mold must be vented by either sandblasting – resulting in a matte outer surface of the piece – or by grooves in the separation lines or, in extreme cases, by valves in the mold.

Generally, about one-half of the parting line periphery is vented to a depth of 0.05 to 0.102 mm (0.002 to 0.004 in). 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 to 0.254 mm (0.008 to 0.010 in) in diameter. Particular care must be taken when drilling these holes so that the mold cooling cavity is not pierced (Fig. 9.8 (A) and (B)).

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.

Fig. 9.8: Vents
Injection of the Blowing Air

Injection of blowing air can be done by various means, such as downward through the core, through a blowing needle inserted sideways through the mold wall, or from below through a blowing pin moved up into that end of the parison which will become the (frequently threaded) neck of a bottle (Fig. 9.9 (A), (B), (C), (D)).

Sometimes, different blowing devices are used in combination. Like every step in the blow molding 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 mold must, of course, be adequate.

The thinner the wall thickness and the lower the melt and mold temperature, the faster the blowing rate should be and the higher the blowing pressure, up to about 10.5 kg/cm² (150 lb/in²) for very cold molds and thin-walled parts. (Compressed air injected into a cold mold may lose some pressure because cooling gas contracts.) High blowing pressure requires correspondingly high clamp pressure to keep the mold tightly closed during the blowing step.
9.8 Ejection of the Piece from the Mold

Ejection of the blown piece can be effected forward between the mold halves or downward, provided the press is built in such a way that a free fall from between the open mold halves is possible. Many machines have an automatic ejector, or stripper, assembly. Ejector, or knock-out, 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 mold by an air jet from behind. The operator sometimes manually removes very large pieces from the mold. To reach the piece, the operator must first push the protective gate or shield aside, which automatically stops every mold or platen movement so that the operator’s hands are in no danger of being hurt between the mold halves.

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

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

Additional Reading

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A Short Course in Blow Molding High Density Polyethylene (1970) Chevron Chemical Co., Houston, TX