Blow molding makes hollow, thin-walled, plastic parts, such as bottles and containers. Parts with these characteristics are traditionally created by inflating hot plastic so that it conforms to the walls of a metal mold cavity.

Manufacturing these items with metal molds is a rapid and cost-efficient process, but machining the molds requires significant time and cost, and alterations after pilot runs can be problematic. Yet, blow molding companies have largely avoided prototype molding with production plastics because there are few reasonable options and hollow parts with thin walls are not good candidates for CNC machining. And while 3D printing has become an effective means of evaluating prototype designs, it is not able to fully simulate the properties and appearance of common blow molded plastics such as polyethylene (PE), polypropylene (PP), polyethylene terephthalate (PET) and polycarbonate (PC).

For the two primary methods of blow molding — extrusion blow molding (EBM) and injection blow molding (IBM) — PolyJet™ 3D printing can provide an alternative means of producing prototypes. With only small adjustments to the mold design and molding operations, PolyJet 3D printed molds can produce hundreds of parts in production-grade PE, PP and PET quickly and cost effectively.

PolyJet 3D printing builds plastic objects layer-by-layer, using data from computer-aided design (CAD) files. Combined with the properties of PolyJet materials, it can create high-resolution, smooth surfaces which are ideal for short-run blow molding applications like prototype evaluation and low-volume manufacturing. What's more, the finished parts have the appearance and function of those from a production run. PolyJet blow molds, when used in conjunction with machined injection molds for preforms, will even produce clear bottles in PET on IBM process machines.

PolyJet molds are not intended to be replacements for soft or hard tools used in mid- and high volume production. Rather, they are intended to fill the gap between soft tools and 3D printed prototypes. The advantages of PolyJet 3D printed molds over machined molds include significant cost and time savings, enhanced process automation, and greater design freedom. As a result, redesigns are practical and easy to make should a design flaw be discovered.

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1. OVERVIEW

1.1. Application:

PolyJet 3D printed molds are suitable for blow molding prototypes and short-run production via extrusion blow molding (EBM) or injection blow molding (IBM) processes.

1.2. PolyJet is a best fit:

- Quantity is low to moderate.
  - 1 - 1,000 blow molded parts
- Part is small to moderately sized.
  - 1 ml - 1 liter (0.03 - 35 oz)
- Production materials are needed.
  - PP, LDPE, HDPE and PET

1.3. Successful adopter traits (first iteration and long-term):

- Use good mold design practices.
  - Follow blow molding best practices.
  - Modify PolyJet molds as recommended.
- Use a PolyJet mold when it is the best alternative.
  - Consider cost, time, quality and quantity.
- Seek product validation.
  - Review is critical before machining a production mold.
- Modify molding parameters.
  - Cycle times are acceptable.
  - Not validating mold or molding prior to production.

1.4. PolyJet adoption obstacles:

<table>
<thead>
<tr>
<th>OBSTACLE</th>
<th>SOLUTION*</th>
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<td>Adhering to traditional practices.</td>
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</tr>
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<tr>
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</tr>
<tr>
<td></td>
<td>Apply to applications where slight visual defects are acceptable.</td>
</tr>
</tbody>
</table>

*Additional solutions may exist.*
1.5. Benefits:

- Lead time reduction
  - Average lead time savings: 85% - 95%
- Cost reduction
  - Average cost savings: 75% - 95%
- Greater efficiency
  - Automated tool-making
- End-use material testing
  - LDPE, HDPE, PET and PP
- Design validation
  - Evaluate form and function.
- Facilitates revisions
  - Quickly and easily revise parts and molds.
- Enhanced quality
  - Match look of production molded parts.
  - Create smooth surfaces.
  - Capture fine details in molded parts.
- Real material
  - Use spec resin for true-to-life functional evaluation.
  - Create highly transparent bottles.
2. TRADITIONAL PROCESS OVERVIEW

Blow molding is a manufacturing process in which air pressure inflates heated plastic in a mold cavity. The pressure forces the plastic to conform to the contours of the cavity, producing thin-walled, hollow parts.

2.1. The steps in the traditional blow molding process are:

2.1.1. Make blow mold.
   • Machine molds from aluminum or steel (Figure 1).
   • Assemble mold.

2.1.2. Mount blow mold.
   • Place mold on blow molding machine.
   • Mold parts.
     − Heat plastic and place in mold.
     − Inflate with air pressure.
     − Allow part to cool.
     − Eject part.

2.1.3. Finish part.
   • Trim flash and finish to specifications.

2.2. Types of blow molding

There are three types of blow molding:
   • Extrusion blow molding
   • Injection blow molding
   • Injection stretch blow molding (ISBM)

Each process uses the steps listed above, but the blow molding operation changes.

2.2.1. Extrusion blow molding

An extruder drops a parison — a hot, hollow tube of plastic — between two mold halves (Figure 2). One end of the mold cavity is sealed and the other end is left open. Air is injected through the open end, forcing the malleable plastic against the walls of the mold. Upon cooling, the plastic retains the contour of the mold. This process can produce very large and oddly shaped containers, but it is not suitable for all materials.
2.2.2. Injection blow molding

This two-step process begins with injection molding of a preform, which is then heated, placed in a blow mold and inflated (Figure 3). Compared to EBM, this process allows for more careful control of part walls, and results in better transparency and surface quality (Figure 4).

2.2.3. Injection stretch blow molding (ISBM)

This method incorporates an additional step: The injection-molded preform is heated and then mechanically stretched before inflation. This contributes to the part’s strength and wall uniformity.

Note: For purposes of this document, ISBM is regarded as a sub-segment of IBM.

2.3. PolyJet adjustments:

2.3.1. Modify mold design.

- Modify pinch-off. EBM
- Provide machine stock on parting line.
- Integrate in machined mold base (optional).

2.3.2. Modify blow molding process.

- Use a semi-automatic blow molding machine. IBM
- Reduce clamping pressure.
- Reduce extrusion temperature and extrusion rate. EBM
- Increase cycle time and add a dwell every 3 - 10 cycles.
3. MOLD DESIGN

Begin with a blow mold design that would traditionally be machined in metal. Then, make the following alterations for a PolyJet blow mold in the CAD model.

Note that for IBM, the preform must be injection molded in a machined, metal mold. Although PolyJet has been successfully used to make injection molds, the combination of 3D printed injection molds and blow molds will not produce satisfactory results. IBM is often used for clear parts that require precise temperature controls and highly polished mold surfaces when injection molding preforms.

3.1. Apply shrinkage compensation.

Start by designing the mold cavity so that it includes compensation for the shrinkage of the blow molded material. Global adjustments for shrinkage cannot be made to the entire CAD model after the following steps are completed because it will yield poor fits for alignment and mounting.

Note that due to longer solidification time, rates of shrinkage will differ from those of metal molds. For example, shrink rates with the EBM process are often 50% - 100% higher when using PolyJet molds.

3.2. Adjust parting line.

The parting surface of the mold halves must be flush, and have a sharp corner where it meets the cavity, otherwise there will be excessive flash on the blow molded part. Also, parting lines that are not straight will negatively affect the appearance of the part.

For a straight, flush parting line, extend the parting surface on each mold half by 1.0 - 1.5 mm (0.04 - 0.06 in) to provide machine stock (Figure 5).

3.3. Adjust blow-pin entry area.

To improve tool life and prevent loss of pressure in the mold cavity, incorporate standard metal blow-pin plates. The plates eliminate wear of the mold where it comes in contact with the blow-pin, while also providing a good sealing surface.

Select a suitable plate for the application and determine its size. Next, add a recess to each mold half that will receive a plate (Figure 6). Make the dimensions of the recess 0.1 mm (0.004 in) larger than the plate on all sides.

For mounting, add screw holes that match the location of those on the plate. Size the holes to match those in the plate. For example, if M8 socket screws will be used, add 6.8 mm (0.27 in) screw holes. Alternatively, add pilot holes for self-tapping screws.
3.4. Adjust pinch off.

In extrusion blow molding, the pinch-off is responsible for sealing the closed end of the mold and cutting the parison to length. A good seal is critical for the production of properly blow molded parts.

For metal molds, the pinch-off land is commonly 0.1 - 0.5 mm (0.004 - 0.020 in) long. For printed molds, due to the high stress applied to the pinch-off, it is recommended to include a land that is at least 2 mm (0.08 in) long (Figure 7). This will also ensure that there is a good seal. However, the increased land length may prevent the parison from being cut completely. For low-volume molding, simply remove this “tail” flash manually.

For the best performance of the pinch-off, it is recommended to leave a gap of 0.2 mm (0.008 in) between the pinch-off surfaces of the two mold halves (Figure 8). This will ensure that the plastic melt has room between the surfaces of the closed mold.

3.5. Add mold alignment features.

For alignment between the mold halves, use pins and receiving holes. One mold half will have pins, and the other will have receiving holes. The pins may either be printed or added after printing.

3.5.1. Printed pins:

Add several large, robust pins to one half of the mold (Figure 9). A diameter of 10 mm (0.4 in) or larger is recommended.

3D printed pins may also be designed and printed separately (see Section 3.5.2.) and installed after machining the parting surfaces (see Section 6.3.1.). This latter option reduces print time and makes machining easier.

For the receiving holes, make the diameters 0.1 mm (0.004 in) larger than the pin diameter. Add a 2 mm (0.08 in) radius to the circumference that will help to guide the pins into the holes. For the depth, make the holes 1 - 2 mm (0.04 - 0.08 in) deeper than the pins’ lengths.

3.5.2. Inserted metal pins:

Select a pin from inventory and measure for size. Create holes in one mold half in which the pins will be press fit (Figure 10). Make the holes with a diameter 0.1 mm (0.004 in) larger than that of the pin and a depth equal to one-half the length of the pin.

Make the diameter of the receiving holes 0.1 mm (0.004 in) larger than the pins’ diameter. Add a 2 mm (0.08 in) radius to the circumference to guide the pins into the holes. For the depth, make the holes 1 - 2 mm (0.04 - 0.08 in) deeper than the pins’ lengths.
3.6. Incorporate mold mounting features.

PolyJet molds may be mounted on the blow molding machine in three ways:

- Stand-alone: PolyJet mold is mounted directly to the blow molding machine’s platen (Figure 11).
- Mold base: Rectangular PolyJet mold inserts are placed in a metal mold base (Figure 12).
- Mold shell: Contoured PolyJet mold inserts are placed in metal shell inserts that are mounted in a metal mold base (Figure 13).

To reduce the size for faster print speed and lower material expense, mount the PolyJet mold inserts into a metal mold base that is then attached to the platen.

For the fastest and most affordable printed inserts, have them conform to the shape of the cavity. These are then placed into a metal shell, which is placed in a metal carrier and mounted to the platen.

3.6.1. Stand-alone:

To withstand the temperature and pressure of the blow molding process, make the mold substantially larger than the mold cavity. The mold halves should be 25 - 50 mm (1 - 2 in) larger than the cavity’s side and back faces (Figure 14).

For mounting the molds to the molding machine’s platens, add holes to the backs of each mold half (Figure 15). To create secure attachment, threaded inserts that are 0.1 mm (0.004 in) larger than the diameter of the insert are suggested.

3.6.2. Mold base:

Select or fabricate a metal mold base that will hold the PolyJet mold inserts. The rectangular pocket of the mold base must allow the PolyJet insert to be at least 20 mm (0.75 in) larger than the molding cavity on the sides, bottom and back (Figure 16).

Design the inserts to fit within the mold base’s pocket, but inset all contact surfaces by 0.1 mm (0.004 in) to avoid secondary machining for fit adjustment.

3.6.3. Mold shell:

This approach is similar to the mold base, but it uses contoured PolyJet inserts, contoured metal shells and a metal carrier. Additionally, other metal mold components, such as a bottom die, may be included.

Make the PolyJet inserts 12 mm (0.5 in) larger than the mold cavity on the sides, bottom and back faces. However, instead of making a rectangular insert, allow it to loosely follow the contours of the cavity (Figure 17). For example, the insert for a bottle would have a cylindrical shape.
Next, machine a metal shell that will hold the PolyJet insert. Inset all of the insert’s surfaces that contact the metal shell by 0.1 mm (0.004 in) (Figure 18). This metal portion of the tool may include cooling lines, if desired.

Finally, machine a metal carrier that will hold the metal shell and attach to the molding machine’s platens.

3.7. Generate STL files.

When the mold design is complete, export the STL files for both halves of the mold. Ensure that settings, such as chord height, deviation and angle, will produce a fine mesh (small facets). This will minimize post-processing efforts and preserve accuracy.
4. FILE PREPARATION

Import the blow mold STL files into Objet Studio™ software and process them for printing on an Objet™ 3D Printer (Insert > select STL).

4.1. Orient STLs.

Orient the mold halves with the cavities facing upward so that the molding surfaces will be glossy and have no support material contact (Figure 19) (Left click on part > Transform > Rotate).

Also adjust the orientations so that the top (blow-pin area) and bottom of the cavities are along the X axis of the 3D printer, which is the direction of print head travel. This alignment reduces build times, and orients printing lines along the length of the molded part, for a more pleasing cosmetic appearance.

If they will fit, place both at the same point on the Y axis to minimize printing time.

4.2. Select surface finish.

For a smooth, and potentially mold-ready finish, print the mold halves using the “Glossy” finish mode (Figure 20) (Left click > Glossy).

4.3. Set printing mode.

Select “High Quality” for the printing mode, when available, to produce the smoothest surfaces and minimize post processing (Build > Printing Mode).
5. MATERIALS

5.1. Material options:

Blow molds may be made with the following PolyJet materials:

- Digital ABS™ (RGD5160)
- FullCure™720 (FC720)
- Vero™ family

If available, Digital ABS is highly recommended (Figure 21). Its mechanical and thermal properties will offer longer mold life and reduced cycle times.

Figure 21: Use Digital ABS material for longer tool life and shorter cycle times.
6. MOLD PREPARATION

6.1. Remove support material.

For rectangular stand-alone molds and mold base inserts, simply scrape the support material from the mold halves using a putty knife or similar tool.

For the metal shell inserts, which will have non-planer exterior surfaces, place the mold halves in the Waterjet Station. Use the pressurized water to separate the support material from the mold halves.

6.2. Smooth surfaces (optional).

The surface smoothness of the PolyJet cavity will contribute to the cosmetic appearance of the resulting blow molded part, so it is important to have all surfaces as smooth as those needed for the intended application.

6.2.1. Sanding:

Sand all surfaces of the mold’s cavities to a smooth finish (Figure 22). Start with a medium-grit wet / dry sandpaper (180- to 220-grit) and sand until the surfaces are visibly smooth. Complete this sanding step with fine-grit sandpaper (320- to 400-grit).

This is a good level of smoothness for most finish types.

6.2.2. Buffing:

Use a buffing wheel to polish the mold’s cavities (Figure 23).

6.3. Assemble mold.

6.3.1. Prepare parting surfaces.

Using a milling machine, cut the parting surfaces to make them flat, flush and true. Cut only to the depth of the machine stock added to the CAD model (see Section 3.2.)

6.3.2. Add threaded inserts.

For holes designed to use self-tapping screws, no action is required. For all others that do not have threaded inserts, use a tap to create appropriately sized threads.

For holes designed to receive a threaded insert, position the inserts and press fit them to seat. If the insert seats too loosely, remove it and coat the exterior with adhesive. Then, replace the insert and allow the adhesive to cure.
6.3.3. Add pins.

If the mold design uses printed or metal press-fit alignment pins, insert them into the designated holes.

The fit with the alignment holes will be tight due to the small increase in diameter (see Section 3.5.). Test fit the pin and hole alignments by mating the mold halves and adjusting accordingly.

6.3.4. Attach blow-pin plate.

Mount the blow-pin plates to each mold half and attach with screws (Figure 24).

6.3.5. Mount in mold base or shell base.

Press the PolyJet inserts into the mold bases or metal shells (Figure 25).

For metal shells, place the assemblies into the metal corners that will attach to the molding machine’s platens (Figure 26).
7. BLOW MOLDING MATERIALS

Commonly blow molded materials including LPDE, HDPE, PP and PET have been successfully used in PolyJet molds (Figure 27). Other materials are possible when the melting point is below 260°C (500°F).

- PP, LDPE and HDPE
- PET

Figure 27: Clear PET bottle blow molded with a PolyJet tool.
8. BLOW MOLDING

To accommodate the properties of a PolyJet printed mold, molding rates and temperatures will differ from those used in final production with a metal mold.

When using an automated, injection blow molding machine, extended cycle times and intermittent dwells may not be possible, so a semi-automatic machine will be needed.

8.1. Mount mold.

Attach the mold halves to the blow molding machine's platens (Figure 28).

8.2. Adjust settings.

Success with PolyJet blow molds requires adjustments to the molding process. These adjustments are made in consideration of the strength, temperature threshold and thermal conductivity of the plastic mold.

8.2.1. Clamping pressure:

Avoid excessive clamping forces that will compress and possibly crack a standalone PolyJet mold.

8.2.2. Blow pressure:

Use standard blow (inflation) pressures for molding parts.

8.2.3. Extrusion temperature and rate:

In conjunction with the test runs for clamping pressure, also test extrusion temperatures for the plastic parison. Start with the lower threshold recommended by the material manufacturer. After each test, gradually increase the temperature until the material flows to conform to the entire mold cavity.

Decrease the parison extrusion rate to the lowest speed recommended by the material manufacturer. Low extrusion rates will minimize shrinkage in the blow molded parts. The PolyJet mold retains heat, which prevents rapid solidification. Decreasing the extrusion rate results in less orientation of the polymer molecules, which creates a weaker recoil and decreases material shrinkage.
9. MOLDING

9.1. Apply mold release: **EBM**

For EBM, apply a mold release agent to the mold cavity before the first cycle and after every three cycles.

9.2. Adjust cycle times:

Because PolyJet molds are poor thermal conductors, the temperature of the mold will increase with each cycle, resulting in unsolidified parts (EBM) and / or warping (IBM). Therefore, molding cycle times must be increased to allow additional time for material solidification.

- **EBM**

  A lengthy dwell will be needed after approximately three molding cycles (Figure 29). The dwell allows the mold to return to a suitable operating temperature of approximately 50°C (122°F).

  To decrease the dwell time, blow compressed air onto the cavities of both mold halves.

- **IBM**

  Injection mold, condition and heat preforms in the usual manner (Figure 30). For PET, heat the preform to 85 - 100°C (185 - 212°F).

  A lengthy dwell will be needed after approximately 5 to 10 molding cycles (Figure 31). The dwell allows the mold to return to a suitable operating temperature of approximately 50°C (122°F).

  To decrease the dwell time, blow compressed air onto the cavities on both mold halves.

9.3. Finish parts:

Trim the flash and any remnants of the parison from the molded parts (Figure 32).
10. KEY PROCESS CONSIDERATIONS

10.1. Obstacle details:

The following table presents common obstacles for blow molding when using PolyJet molds along with recommended solutions.

<table>
<thead>
<tr>
<th>Obstacle</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessive Flash</td>
<td>Large amounts of flash on molded part.</td>
</tr>
<tr>
<td>Sticking</td>
<td>Molded part sticks to mold cavity.</td>
</tr>
<tr>
<td>Partial Conformity</td>
<td>Gaps between cavity and molded part surfaces.</td>
</tr>
<tr>
<td>Mold Life</td>
<td>Few parts successfully molded from tool.</td>
</tr>
<tr>
<td>Cosmetics</td>
<td>Surface imperfection on molded parts.</td>
</tr>
</tbody>
</table>

Table 1: Common obstacles and resolutions.

10.1. Resolution details:

- Machining:
  - Face-mill the parting surface.

- Clamping pressure:
  - Increase pressure to minimize flash.
  - Decrease pressure to avoid mold cracking or cavity deforming.

- Extrusion parameters:
  - Decrease parison temperature to reduce material shrinkage.
  - Decrease parison extrusion rate to reduce material shrinkage.

- Cycle time:
  - Extend molding cycle time to allow plastic to solidify.
  - Add a dwell cycle for every 3 - 10 molding cycles.

- Blow pressure:
  - Increase blow pressure to force material into all surfaces of the cavity.

- Mold release:
  - **Apply mold release after every three cycles.**

- Material:
  - Use plastics that have lower melting points.

- Fit & finishing:
  - Eliminate interference between inserts and mold bases / shells.
  - Sand and optionally buff the cavity for a smooth, polished surface.
11. TOOLS & SUPPLIES

11.1. Required items:

- Items common to the blow molding process
- Semi-automated blow molding machine
- Plates (blow-pin)

11.2. Optional items:

- Pins and threaded inserts
- Sand paper and buffing wheel
- Mold bases
12. RECAP - CRITICAL SUCCESS FACTORS

12.1. Actions:

- Machine parting surfaces.
- Increase cycle times.
- Add dwell cycle.
- Decrease extrusion speed and temperature.
- Reduce clamping forces.

12.2. Eliminate obstacles:

- Use recommended blow molding materials.
- Use reasonably sized molds.
CONTACT:

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