Thermoforming & Vacuum Forming Design Guide

› Why use Vacuum Forming?
› How to design for Vacuum Forming?
› Manufacturing capabilities

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Note: In this document, the term "thermoforming" and "vacuum forming" are used interchangeably.

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Table of Contents

1 Thermoforming 3
   1.1 What is Thermoforming/Vacuum Forming? 3
   1.2 What is Vacuum Forming used to make? 3
   1.3 Why use Vacuum Forming? 3
   1.4 Vacuum Forming vs. Injection Molding 3

2 Basic Part Design 4
   2.1 Controlled side 4
   2.2 Male vs. Female Molds 4
   2.3 Plug Assist 4
   2.4 Mold Material & Construction 4
   2.5 Single & Multi-Cavity Molds 5
   2.6 Good Molding Design Makes Good Parts 6

3 Detailed Part Design 7
   3.1 Draft Angle 7
   3.2 Corners & Radii 7
   3.3 Draw Ratio 7
   3.4 Ribs & Bosses 7
   3.5 Undercuts 7
   3.6 Surface Texture 7
   3.7 Tolerances 7

4 Vacuum Forming Materials 8
   4.1 Material 8
   4.2 Colors and Minimums 8

5 Forming Equipment 9
   5.1 Single Station 9
   5.2 Double Ended 9
   5.3 Rotary 9
   5.4 Pressure Forming 9
   5.5 Thin Sheet—Roll Feed 9

6 Part Trimming & Machined Features 10
   6.1 CNC Machining 5-Axis 10
   6.2 CNC Machining 3-Axis 10
   6.3 Die Cutting 10
   6.4 Manual Trimming 10

7 Part Finishing 11
   7.1 Deburring 11
   7.2 Printing 11
   7.3 Assembly & Adhesives 11
   7.4 Packaging 11
   7.5 Labels 11

Disclaimer: The information provided in this document is true to the best of our knowledge. Specific details are discussed individually with our customers, as dimensions and methods vary from part to part.
1 Thermoforming

1.1 What is Thermoforming/Vacuum Forming?
Thermoforming is a relatively simple process to convert a flat plastic sheet into a three-dimensional object. In its simplest form thermoforming involves heating up a plastic sheet until it is pliable, then stretching it over a mold and letting it cool, so it sets to the mold shape. By adding small holes through the mold and attaching a vacuum pump, the heated plastic can be sucked down over the mold. This is vacuum forming, the most widely used type of thermoforming. We use the term vacuum forming as that is what we do.

1.2 What is Vacuum Forming used to make?
It is used to make a wide range of things from clear packaging for salad and cupcakes, all the way up to hot tubs and truck bedliners.

1.3 Why use Vacuum Forming?
Plastic vacuum forming has several distinct advantages over other methods of manufacturing plastic parts. Chief among these is the low cost of tooling for short and long run production parts. Many products once thought to be injection molded parts, can many times be redesigned for Vacuum, Pressure forming or even Fabrication processes.

Another advantage of vacuum forming is the ability to generate prototypes and tooling rapidly. PDI Plastics generates tooling in house using CAD 3D geometry and CNC machining to produce all molds. We typically machine molds directly out of aluminum. We also work with synthetic tooling board and wood depending on the project.

1.4 Vacuum Forming vs. Injection Molding
Injection molding is used to make a wide range of parts but is often not the most cost effective process, especially for lower volume parts.

<table>
<thead>
<tr>
<th>Vacuum Forming</th>
<th>VS.</th>
<th>Injection Molding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ideal for flatter parts</td>
<td>Single surface</td>
<td>Full 3-D</td>
</tr>
<tr>
<td>Only one side contacts the part</td>
<td>One part</td>
<td>Nearly any shape possible</td>
</tr>
<tr>
<td>Easy to machine</td>
<td>Aluminum</td>
<td>Mold Type</td>
</tr>
<tr>
<td>Only one part to mold and has to handle atmospheric pressure 14.5 psi. Generally $1,000 to $5,000</td>
<td>Low</td>
<td>2 halves</td>
</tr>
<tr>
<td>Wipe down to clean. No significant wear, typically lasts for 1 million + cycles.</td>
<td>Minimal</td>
<td>Part enclosed on all sides</td>
</tr>
<tr>
<td>10 to 10's of thousands</td>
<td>Low to Medium</td>
<td>Part Quantity Suitability</td>
</tr>
<tr>
<td>CNC machine or die cut to remove sheet edges and add holes &amp; other features</td>
<td>Medium</td>
<td>Medium to High</td>
</tr>
<tr>
<td>Mold Cost</td>
<td>High</td>
<td>2 halves to mold and has to withstand several tons/sq. inch of pressure. Typically $30,000 to $100,000.</td>
</tr>
<tr>
<td>Mold Maintenance</td>
<td>High</td>
<td>Mold Material</td>
</tr>
<tr>
<td>Minimal</td>
<td>High</td>
<td>Tool Steel</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>Hardened after machining.</td>
</tr>
<tr>
<td>Part Trimming</td>
<td>Low</td>
<td>Mold Cost</td>
</tr>
<tr>
<td>Medium</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>With high cost molds minimal excess plastic to remove. Holes etc. can be molded in.</td>
<td>Low</td>
<td>Part Trimming</td>
</tr>
</tbody>
</table>


2 Basic Part Design

2.1 Controlled Side
With vacuum forming only one side of the plastic sheet meets the mold. The side that contacts the mold is known as the 'controlled side' as it will closely reproduce the surface of the mold. Due to the stretching of the sheet over or into the mold, the thickness of the formed part varies across the part. This results in the 'non-controlled side' of the sheet less accurately reproducing the mold surface.

2.2 Male vs. Female Molds
Mold terminology borrows from biology with male molds protruding and female molds being recessed. Many parts can be made from either type of mold. Key considerations in deciding which to use include:

<table>
<thead>
<tr>
<th>Controlled Side</th>
<th>Surface Finish</th>
<th>Depth of Mold/Part</th>
<th>Part Edge Thickness</th>
<th>Mold Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Male Molds</strong></td>
<td>Underside of convex part, good for covers etc. that fit over another part.</td>
<td>Retains texture on upper side of textured sheet</td>
<td>Best for shallower parts</td>
<td>Edge can be thinner than starting material thickness.</td>
</tr>
<tr>
<td><strong>Female Molds</strong></td>
<td>Under side on concave part, good for covers etc. that fit into another part.</td>
<td>Best for deeper parts</td>
<td>Edge close to starting material thickness.</td>
<td>Typically higher as more material has to be removed.</td>
</tr>
</tbody>
</table>

To make a matched set of parts that closely fit together, one should be made with a male mold and the other with a female mold so the controlled sides contact each other.

2.3 Plug Assists
To help stretch the sheet material into a female mold, a plug assist can be used. It is typically a wood or resin form that is pushed into the heated sheet right before it goes into the mold. This is particularly useful for making deep draw parts.

2.4 Mold Material & Construction
Historically wood and resin molds were used for both prototype and production molds. For higher volume items cast aluminum molds were used. Some forming companies still prefer these old methods. At PDI Plastics we make nearly all our molds in house. We use the 3-D model of the part to design the mold, adjusting for expected shrinkage of the plastic, which varies with plastic type. We then directly CNC machine the mold from solid aluminum plate, adding cooling water channels to the underside and also the small vacuum holes. Larger molds can be constructed from stacked aluminum plates. Machined aluminum molds are far more accurate than cast molds and can be produced a lot quicker. We use cast aluminum for larger deep draw parts. Cast molds are less accurate as you have to factor in both the shrinkage of the aluminum when cast, as well as the shrinkage of the plastic. Cast aluminum molds take longer due to the extra steps involved.
2.5 Single & Multi Cavity molds

A number of factors determine mold setup:

- Size is usually the first consideration. One large mold may fill the entire forming zone.
- Volume of parts required is another.
- Part yield for a given size of plastic sheet.
- Cost of the tooling is another consideration.

PDI calculates all of these factors for the optimum manufacturing process. Small parts are normally ganged together to reduce cycle time and optimize plastic/part yield.

Multi-Cavity Production Molds

A single cavity is machined from aluminum for prototyping. The prototype mold can later be incorporated into the production mold. Reusing the aluminum prototype makes the process cost efficient for our customers, compared to using other materials for prototypes that can not be reused for the production mold.
2.6 A Good Mold Design Makes Good Parts

The drawings below illustrate good and poor mold design for the same part with both male and female molds.

- Rounded corners are thicker & stronger as the material is stretched less
- Substantial draft angle helps maintain wall thickness and makes part easy to remove from the mold.
- Rounded corners & a good draft angle allows the material to stretch more evenly over the mold which prevents 'cold capping'.
- A larger overall mold producing a good draw ratio of 2 to 3 or higher results in better parts with thicker walls.
- Sharp corners will be thin and weak, can lead to cracking of the part.
- Little or no draft results in a part with thin walls and is hard to remove from the mold.
- Material stretches unevenly over the mold and can result in 'cold capping' an unsightly effect where the plastic that first contacts the mold solidifies and bunches up.
- A smaller mold with a poor draw ration below 2 to 3 will produce parts with thinner wall thickness as there is less material to stretch.
3 Detailed Part Design

3.1 Draft Angle: Draft is the degree of angle on a vertical sidewall. Typically, we like as much draft as we can get. Draft allows the plastic to flow much easier into the mold cavity as in a female mold or over the mold sides on a male mold. Draft also facilitates removing the part from the mold.

- Male Tooling: 2 degrees minimum up to 6 inches depth; 5 degrees above 6 inches depth
- Female Tooling: 1 degree if less than 2 inches depth; part specific if more than 2 inches

3.2 Corners & Radii: The part’s appearance and function really determine the radii. Large radii distribute the material more evenly and make a better product, with stronger corners.

- Male Tooling: Outside radii should be one material thickness + .03 minimum to + .06
- Female Tooling: Inside radii can be as small as .03 which will appear as 0, or sharp.

3.3 Draw Ratio: The ratio of the horizontal dimension versus the vertical dimension. We use a 2 to 3 minimum. Our goal is to achieve a part with consistent thickness and reduce thinning. Other factors come into play like sheet size and part yield.

3.4 Ribs and Bosses: Ribs and bosses can be placed in the part to strengthen areas such as large flats on sides or bottoms. These features will stiffen the part where otherwise they might seem flimsy or distort.

3.5 Undercuts: Occasionally undercuts are desired on a product. Most of the time these are simple snap and lock features that can be formed without the use of a retractable device. For more complex deep undercuts a mechanical device must be made that creates the undercut, while forming and retracts for de-molding. This adds considerably to the mold cost.

3.6 Surface Texture: Textured plastic, formed over a male vacuum form mold is common. “Hair Cell” is the industry standard texture. Texture can be added to a mold to make the product more aesthetically pleasing or remove any cosmetic imperfections. This is more common with female and/or pressure formed parts.

3.7 Tolerances: General tolerances are listed below for CNC trimmed parts. Other trimming operations include die cutting, hand routing, and sawing. Those operations are considered on a per part basis.

<table>
<thead>
<tr>
<th></th>
<th>0” – 12”</th>
<th>12” – 60”</th>
<th>&gt; 12”</th>
<th>&gt; 60”</th>
<th>Plunge Cut</th>
<th>Routed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trim to Trim Tolerance</td>
<td>±0.020</td>
<td>±0.030</td>
<td></td>
<td>±0.001 per inch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Form to Trim Tolerance</td>
<td>±0.030</td>
<td>±0.060</td>
<td></td>
<td>± 0.001 per inch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilled Hole Center to Center</td>
<td>±0.015</td>
<td>± 0.001 per inch</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilled Hole Diameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>±0.007</td>
<td>± 0.015</td>
</tr>
</tbody>
</table>

We prefer dimensions reflect the control side or mold side of the part. Critical features and dimensions along with tolerances should be noted.
## 4 Vacuum Forming Materials

### 4.1 Material

We form products using a wide variety of plastics resins. Each of these plastics has its own set of properties, some better suited to your particular job. Below is a list of materials often selected by our clients:

<table>
<thead>
<tr>
<th>Material</th>
<th>Full Name</th>
<th>Uses</th>
<th>Cost</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>HIPS</td>
<td>High Impact Polystyrene</td>
<td>Retail trays, displays, packaging</td>
<td>low-med</td>
<td></td>
</tr>
<tr>
<td>PETG</td>
<td>Polyethylene Terephthalate</td>
<td>Packaging esp. medical</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>HDPE</td>
<td>High Density Polyethylene</td>
<td>Trash can lids, containers</td>
<td>low</td>
<td>Can distort after forming</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
<td>Packaging, trays</td>
<td>low</td>
<td></td>
</tr>
<tr>
<td>Acrylic</td>
<td>Polymethyl Methacrylate</td>
<td>Displays, transparent parts</td>
<td>medium</td>
<td>Available in many colors</td>
</tr>
<tr>
<td>TPO</td>
<td>Thermoplastic polyolefin</td>
<td>Outdoor applications</td>
<td>medium</td>
<td>Blends of plastic &amp; synthetic rubber</td>
</tr>
<tr>
<td>PolyCarb</td>
<td>Polycarbonate</td>
<td>Very high strength clear parts</td>
<td>high</td>
<td>Long heating &amp; forming times</td>
</tr>
<tr>
<td>ESD HIPS</td>
<td>Electrostatic Dissipating HIPS</td>
<td>Electronic component trays</td>
<td>med-high</td>
<td>High carbon content dissipates static</td>
</tr>
<tr>
<td>Kydex®</td>
<td>Proprietary PVC-Acrylic blends</td>
<td>Fire resistant transportation, displays.</td>
<td>med-high</td>
<td>Readily available in smaller quantities and colors. Longer forming time due to density</td>
</tr>
</tbody>
</table>

*Kydex is a trademark of SEKISUI Polymer Innovations, LLC. Boltaron is a trademark of Boltaron Inc.*

### 4.2 Colors & Minimums

Vacuum forming sheet materials are generally purchased via two different routes:

A. Plastics distributors stock large sheets (typically 4' x 8') of common thicknesses of many of the materials listed above. For smaller jobs these sheets can be cut into the size needed. However with ABS, HIPS and several other materials, only black and white sheets are normally available from inventory. Acrylic is main exception with several colors available from distributors. This route is more expensive but if the material is available, allows quick turn around on a job.

B. Custom Sheet Extruders are our main source of supply. There are many options with custom extruded sheet:

- Sheet is cut to the required size as it comes off the extruder.
- Sheet thickness can be optimized for the specific job, saving on material cost.
- A wide range of surface finishes are available including smooth, matte and numerous textures and even patterns.
- Colors can normally be matched to whatever sample the customer supplies.
- On colored sheet there is normally a 2,000 lb. minimum purchase which is fine for larger jobs or regularly run items.
- On standard (utility) black or white the minimum is generally less than 2,000 lbs.
- For smaller jobs requiring colored sheet, one option is to use the more expensive Kydex® & Boltaron® materials where a 600 lb. minimum is generally available.
5 Forming Equipment

5.1 Single Station—General Use

Our single vacuum forming station is capable of producing parts up to 40”x30”x27”. This station is equipped with a moving clamp frame that takes the material into and out of the oven.

5.2 Double Ended—Large Parts

The double ended station is capable of vacuum forming parts up to 96”x45”x29” at both ends. This equipment has mechanically driven heaters. The heaters move over the material, to heat it and then are sent to a neutral position, in the center of the machine.

5.3 Rotary—Medium/High Volume

This vacuum forming equipment has three synchronized stations and a rotating clamp frame that shifts the material to each station. Material is loaded and unloaded in Station 1. The material is heated in Station 2. The material is then sent to Station 3, where it is formed. This equipment forms parts up to 60”x48”x23”. Since this equipment molds and heats material simultaneously, more parts can be produced per hour.

5.4 Pressure Forming—High Quality Finish

Similar to the single station, the pressure former produces parts up to 40”x30”x27. With pressure forming capabilities, this machine can make parts with fine details.

5.5 Thin Sheet—Roll Feed

Used for high volume packaging (100,000’s). PDI Plastics does not have this type of equipment.
6 Trimming and Routing Equipment

6.1 CNC 5-Axis Router

Machining head can swivel and machine the part on any of 5 sides. Good at machining holes, slots and cut outs. Can machine at angles and on curved surfaces.

6.2 CNC 3-Axis Router

Only machines with tool in the vertical position. Good for edge trimming and drilling holes. With a small circular saw tool can part off on vertical sides of trays etc.

6.3 Die Cutting

Used to separate edge trim small parts, primarily on multi-cavity molds. Suitable for thinner materials only.

6.4 Manual Trimming

Uses conventional routers mounted on a router table. Generally used on lower volume, straight forward parts to edge trim.
7 Part Finishing

7.1 Deburring
   Deburring removes sharp edges, for a smooth finished part. Mostly done with hand tools.

7.2 Printing
   PDI has established relationships with local printing companies for silk screen and pad printing.

7.3 Assembly & Adhesives
   PDI can paint, label, and assemble a single part or an entire set of parts into a finished product.

7.4 Packaging
   Smaller parts are normally packaged in corrugated cardboard cartons with 200 lb. burst strength. Larger parts are individually boxed or stacked on pallets, with suitable protection. All palletized material is stretch wrapped and banded in both directions.

7.5 Labels
   PDI can label individual parts, boxes of parts, or pallet loads to suit customer requirements, including applying bar codes and 2-D codes.

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