EXTRUSION BLOW MOLDED FLOATING POOL CARRIER

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Abstract

The floating pool carrier is a pool caddy, which allows the user to store personal items. Typical items would include sunscreen, sunglasses, pool toys or drinks and snacks. This product could be ideal for the pool, fishing trips, and on vacation. The part is molded in different colors and is a cheap, light option compared to bringing a beach bag or cooler. The floating pool carrier will be extrusion blow molded out of PVC since large, hollow parts can be molded much more efficiently than injection molding. Thermoforming operations are additionally inferior to creating this carrier. PVC was the material chosen due to the UV stability, low cost, high impact strength, good chemical resistance, and rigidity.

Introduction

Part Specifications

The dimensions for the floating pool carrier will be 50 cm long by 40 cm wide by 20 cm tall. It is sized to facilitate the carrying of multiple objects without remaining too bulky. It will be blow molded using PVC due to its rigidity, chemical resistance, and UV resistance. The pool carrier will support up to 6.8 kg without sinking or capsizing. There will be a hole in the side to attach a rope. This will allow the carrier to be tethered. The carrier will have a compartment in the center that is about 30 cm x 20 cm to carry snacks and other pool accessories. It will also have 6 compartments each with a 7 cm diameter on the top surface, around the central compartments to carry drinks. The compartments will tack off on the bottom of the part to help the carrier stay afloat and increase the strength of the part. The carrier can hold typical pool objects such as: 6 cans of soda, snacks, sunblock, pool toys, and sunglasses.

The carrier will have contoured handles as part of the construction on both sides in order to be easily held for transportation. Due to the thin walled part, it will be lightweight, likely weighing no more than 3 kg.

The part should have chemical resistance high enough to withstand the chlorine in the pool, as well as food and sunscreen. The part should also have fairly high UV resistance. It should be able to handle 2 years of UV radiation from the sun.

The part is ideal to mold in extrusion blow molding since large, hollow parts can be molded much more efficiently than injection molding [1]. Injection molding a hollow part such as the carrier would require an assembly operation. It would also require a large platen, requiring a larger machine and larger mold, which would increase costs. Additionally, thermoforming would not make a sufficient part. Thermoforming operations would not allow as great of a weld strength, as the sheets are not brought to a very high temperature.

Manufacturing and Design Details

A radius of 5 mm will be used on the rounds of the cup holders, snack compartment, and rope hole to facilitate more uniform filling, and to improve appearance. A 3 mm radius was used on the handles. Draft of 5° was used in the cup holders and 15° in the snack compartment, as it both facilitates the placement of objects inside and allows for more uniform wall thickness distribution. A draft of 10° was used on the rope hole for similar reasons.

The cup holders are to tack off on the bottom of the part and will behave as a sort of conical tack off, which will give a more rigid feel to the part. The compartment will also tack off on the bottom of the part, behaving as a sort of structural rib across the length of the part. The blow ratio is 2.85 in the deep cup holders and 2.15 in the deep central snack section.

The part can be made with a blow pin, since it is a bigger part and may require higher air pressure to
properly expand the part. The pin is placed at the opening at the top end of the part. It can be closed with a cap that can be taken off and reattached as the end user desires. This will allow for the insertion of ballast or ice into the center of the part as the user desires.

The vents for the part are at the parting line towards the last places to fill, at the long end opposite of the blow pin location and on the sides of the part. The deeper cavities require slotted vents at the last place to fill, where the tack-off cores meet the original part geometry.

An accumulator molding head is used since the part is bigger and the parison may sag excessively [1]. Pre-blow and cutting the die will produce a more oval-shaped parison in process.

A pinch parting line is used since a smooth inside diameter is not desirable, as the end user will not be seeing it.

**Material Selection**

After comparing multiple materials for the extrusion blow molding process, it was determined that PVC is the best material based off of the required part specifications. The material selection matrix can be found in Table 1 in the appendix.

The floating pool carrier must be able to support 6.8 kg (max weight allowed for holding sunglasses, beverages, snacks, sunscreen, pool toys, etc.). The part must be able to withstand impact from dropping. The part must have good chemical resistance, in case chlorinated water, suntan lotion, sunblock, or carbonated beverages come into contact with the carrier. UV resistance is important because this part will most likely be used all day outside, and potentially stored outside. Colorability is an important factor because this part will need to attract consumers to purchase, along with potentially hiding any surface defects.

By minimizing costs, the product will be able to be sold cheaper, and in larger volumes, thus resulting in more profit. The part will potentially be under load, while being exposed to chemicals (listed above) so a material with good environmental stress cracking resistance is preferred. Rigidity will aid in minimizing deflection on the part when under the load of 6.8 kg. Since we are using an intermittent process, melt strength is not as important of a factor to consider.

An extrusion blow molding grade may be necessary, but any grade with a higher viscosity may do. PolyOne’s Geon 2797 is an extrusion grade of rigid PVC that may be acceptable for the application due to its medium impact resistance and high chemical resistance [1]. The properties for Geon can be found in Table 2 in the appendix.

**Mold and Tooling Design**

![Figure 1 - Diverging Mandrel Reference – Adapted from Chevron Phillips Diagram [2]](image)

The die and mandrel design are based off design guidelines from Chevron Phillips [2] (Figure 1). The group decided to use a diverging die because the overall generous size of the pool carrier (500mm diameter in the parison direction). The material that will be used for construction will be 416 Stainless Steel to minimize frictional build-up in the mandrel and die. 416 Stainless Steel also offers corrosion resistance, heat hardening abilities, strength, machinability, and wear resistance throughout the tooling. The final design can be seen in Figure 2.
The mold material to be used will be an anti-corrosive 7075-T6 aluminum to accommodate for the use of corrosive PVC. The mold will be machined. The mold design was based off a mold design guide from Advanced Elastomer Systems [3].

A sandblasted surface finish is acceptable for the part since high gloss is not necessary for the low cost consumer application. High gloss may reflect sunlight, blinding users and may cause ejection problems. The chosen surface finish is sand blasted SPI Finish C-3 for the mold.

A blow pin will be used and the blow pin channel is shown in Figure 3 circled in red. A blow pin is the most efficient way of inflating a parison for blow molding and the hole it creates was designed into the part to fill the part with a weighted substance for stabilization. The blow pin will also be used as the means of ejection.

The mold will utilize two parallel cooling channels, one on the bottom half and the top half. The top half of the mold also has eight baffles throughout the parallel cooling circuit to allow for cooling into the deep cores that make the middle pocket and six outer cup holders.

The tool has two pinch off areas at the top and bottom of the mold spanning a 300mm width and has two venting areas spanning a 400mm width with 20mm of venting to atmosphere and 20mm shutoff pattern going across this distance. This can be seen in Figure 4.
Figure 5 shows a detail view of the parting line venting being used in the mold. These channels have a 0.16mm land depth and a 0.8mm vent depth. Parting line venting is possible due to the simple, flat parting line allowed by the geometry of the part.

Figure 6 displays the pinch off detail design that was used inside the mold. As shown, the pinch land length is 0.75mm and overall pinch relief depth is 4mm, 2mm on each side of the mold. The length of the relief changes variably with the cavity’s changing outer diameter. This is a standard design derived from Advanced Elastomer Systems Extrusion Blow Molding Guide.

Analysis of Design

Once the mold was modeled, an ANSYS PolyFlow simulation was run on the most intricate mold half. The analysis was run to check for processibility as well as to highlight any issues that may arise after molding (visual defects, blowout, etc.).

Figure 7. The furthest it stretches when blown out is 0.5 mm.
Figure 8 displays the parison fully formed onto the mold. It should be noted that this part of the simulation ended with an error because the mesh particles were too coarse. The coarse mesh elements were too large to trigger adaptive meshing in the deep draws of the cavity and therefore the mesh did not touch the mold walls in all areas. However, the analysis still provided helpful data.

The first problem identified in Figure 8 showed that the wall thickness in certain areas (light blue to dark blue) is too thin to support drinks and other items that a customer may want to hold inside the product. This problem could be fixed by starting with a thicker parison in the range of 1.2mm – 1.5mm. A thinner wall thickness, however, is desirable to reduce material usage and final part weight.

The second problem identified by the PolyFlow results is webbing from the outside of the part to the middle of the cups and from the middle of the cups to the inside wall. This webbing is minimal and is not expected to cause any structural issues but is not aesthetically pleasing. To fix this issue, the part could be made larger overall and cups moved further away from the edges. Keeping in mind that the overall dimensions of the part have been picked based on the ergonomics of carrying the item, the team would instead make the webbing look intentional by including a cut from the outside of the part to the cup, and from the cup to the middle compartment.

ANSYS was also used to simulate the stresses of the part would receive from loading it fully, with a can of pop, at 4.45 N of force, in each holder. The maximum stress was found to be 2.60 MPa, which is well below the PVC’s yield stress of 45.9 MPa. The mesh used in the analysis had 117,202 nodes and 117,543 elements.

The model was verified by implying that the loading at the bottom of the part was similar to the loading of an annular plate fixed at the inside diameter and free to deflect under a load at the outside diameter. Average diameters for the elliptically shaped part were used, to simplify the mathematical model.

The maximum stress in the part is 0.935 MPa based on the MathCAD hand calculations of this simplified plate can be seen in Figure in the appendix. The maximum stress based on the ANSYS analysis in the same region is a similar value, 0.978 MPa, as can be seen in Figure 9. The deformation was handled in a similar manner. The ANSYS estimated the maximum deformation to be about 0.429 mm, while the MathCAD estimated it to be 1.41 mm. This result makes sense, since the part has the improved stiffness from the tackoffs and the large, cross-sectional moment of inertia from the hollow part.

The carrier was also evaluated for buoyancy under a load of 6 cans of pop and 40 N of force from miscellaneous pool items. Figure , in the appendix, shows that since the part displaces enough water with its bottom half, it can carry a total of 66.7 N of force from items without sinking.
Figure, in the appendix, told the team that the carrier is likely to tip due to its low center of buoyancy. This issue can be solved by filling the bottom of the carrier with sand or some other substance with significant weight. However, this decreases the amount of items that can be held by the carrier. Additionally, a more traditional boat-like hull could be designed into the part, where it is deeper and broader to allow for the part’s center of gravity to sink further into the water. Figure shows that the part rotates only 5 degrees under the weight from one soda, so it should not immediately sink but may tip due to its inherent lack of stability.

The last analysis worth mentioning is the total mold cost. This analysis took all expected machining processes into consideration, mold material type and volume, and hours spent on the machining. From Figure 12 in the appendix one can see that the estimated cost for the workpiece including all machining operations is $39,352.60. Using aluminum greatly decreased costs from what the comparative amount was for stainless steel (approximately $120,000). The workpiece increased in price, but the cost of machining greatly decreased, due to the increase in speed. The sandblasted finish was relatively cheap. Major machining cost was from machining the entire core side without using inserts, but was alleviated by the lower time spent to machine the aluminum.

Conclusion

Through this study, it is apparent that a blow molded pool carrier can be effectively produced. Vents, a cut die, and pinch off all make the mold and part design feasible. PVC is to be used to mold the part due to its chemical resistance, UV resistance, mechanical properties, and cost.

Based on the results of the Polyflow analysis, the part can be molded, with a few fixes to improve part quality. According to the results of the structural ANSYS analysis, the part can withstand carrying the weight of items typically desired in the pool. Generally, however, the part is unstable in the water.

Future Work

The hull of the part should be redesigned to displace more water and to lower the center of buoyancy. Doing so would greatly improve the seaworthiness of the part by increasing its floating stability. Other additions to be considered include improvement of the design to hold more weight. Ribs can be added to mask the webbing present between the cores of the part.

Acknowledgements

The group would like to thank Mr. Jonathan Meckley, Mr. Jason Williams, Mr. Phil Jones, and Mr. David Johnson, for without their assistance in the design and simulation aspect of this study, none of it would be possible. Additionally, the team would like to thank Penn State Behrend, for their capabilities and software used to design and simulate the part.

References


Appendix

### Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>PE</th>
<th>PP</th>
<th>PET</th>
<th>PVC</th>
<th>PC</th>
<th>PS</th>
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<tbody>
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<td>Impact strength</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td>-</td>
<td>x</td>
<td>o</td>
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<tr>
<td>Chemical Resistance</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>o</td>
<td>o</td>
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<td>o</td>
<td>-</td>
<td>x</td>
<td>x</td>
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<td>o</td>
<td>x</td>
<td>x</td>
<td>x</td>
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</tr>
</tbody>
</table>

*Table 1: Material Selection Matrix*

### PolyOne Geon™ Vinyl Packaging 2797 Polyvinyl Chloride, Rigid (PVC, Rigid)

**Categories:** PolyOne Geon™ Vinyl Packaging 2797 Polyvinyl Chloride, Rigid (PVC, Rigid)

**Material Notes:** Information provided by PolyOne

**Vendors:** No vendors are listed for this material. Please click here if you are a supplier and would like information on how to add your listing to this material.

#### Table 2: PolyOne Geon 2797 Properties

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Metric</th>
<th>English</th>
<th>Comments</th>
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<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.33 g/cc</td>
<td>1.33 g/cc</td>
<td>ASTM D792</td>
</tr>
<tr>
<td>Apparent Bulk Density</td>
<td>0.001 g/cc</td>
<td>0.029 lb/ft³</td>
<td>ASTM D1505</td>
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</table>

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>Metric</th>
<th>English</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness, Shore D</td>
<td>81</td>
<td>81</td>
<td>ASTM D2240</td>
</tr>
<tr>
<td>Tensile Strength, Yield</td>
<td>45.5 MPa</td>
<td>6600 psi</td>
<td>Type I, 51 min/min; ASTM D638</td>
</tr>
<tr>
<td>Tensile Modulus</td>
<td>2.54 GPa</td>
<td>385 ksi</td>
<td>Type I, 5.1 min/min; ASTM D638</td>
</tr>
<tr>
<td>Flexural Strength</td>
<td>66.1 MPa</td>
<td>9500 psi</td>
<td>ASTM D790</td>
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<tr>
<td>Flexural Modulus</td>
<td>2.46 GPa</td>
<td>365 ksi</td>
<td>ASTM D790</td>
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</table>

<table>
<thead>
<tr>
<th>Thermal Properties</th>
<th>Metric</th>
<th>English</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Deflection, Temperature at 1.8 MPa (264 psi)</td>
<td>@Thickness 3.15 mm</td>
<td>54.2°F</td>
<td>Unnotched, ASTM D507</td>
</tr>
</tbody>
</table>
Figure 11 - Overall Mold Dimensions
Figure 12 - Structural Analysis of Whole Part (hand calculations)
Buoyancy Equations

**Floatability under weight from items**

\[ \rho_{\text{water}} = 1 \frac{gm}{cm^3} \]

\[ V_{\text{water}} = 9000 \text{ cm}^3 \]  
*Maximum Volume of Water Displaced*

\[ F_{\text{items}} = 15 \text{ lb} \cdot 32.16 \frac{ft}{s^2} \]

15 lbs = 6 cans of pop, and 9 lbs of pool things to put in middle

\[ V_{\text{part}} = 645.743 \text{ cm}^3 \]

\[ \rho_{\text{part}} = 1.33 \frac{gm}{cm^3} \]

\[ F_{\text{water}} = \rho_{\text{water}} \cdot V_{\text{water}} \cdot \frac{m}{s^2} \]

\[ F_{\text{part}} = \rho_{\text{part}} \cdot V_{\text{part}} \cdot \frac{m}{s^2} \]

\[ F_{\text{part}} = 8.425 \text{ N} \]

\[ F_{\text{parttot}} = F_{\text{items}} + F_{\text{part}} \]

\[ F_{\text{water}} = 88.29 \text{ N} \]

*F_{\text{water}} > F_{\text{parttot}}* means the part will float under balanced load

\[ F_{\text{parttot}} = 75.119 \text{ N} \]

**Stability - Center of Gravity vs Center of Buoyancy**

\[ h_{\text{CoG}} = 50 \text{ mm} - 6.0546 \text{ mm} \]

\[ h_{\text{CoG}} = 43.945 \text{ mm} \]

When Center of Gravity is higher than Center of Buoyancy, the boat is less likely to return to proper position with after tilting

\[ a = 600 \cdot \text{mm} \]

From CAD - Dimensions of furthest cross-section under tipping load - also simplified as spherical

\[ h = 50 \text{ mm} \]

\[ R = \frac{h}{2} + \frac{a}{8} = 925 \text{ mm} \]

https://en.wikipedia.org/wiki/Circular_segment

\[ \theta = 2 \cdot \cos \left(1 - \frac{h}{R}\right) = 0.661 \]

\[ h_{\text{CoB}} = R - \frac{4 R \cdot \left(\sin \left(\frac{\theta}{2}\right)\right)^3}{3 \left(2 \cdot \left(\frac{\theta}{2}\right) - \sin(\theta)\right)} = 29.953 \text{ mm} \]

Center of Gravity > Center of Buoyancy, so, based on stability, the carrier is not seaworthy, and will tend to tip.
Angle the Part Rotates under the Weight of one Drink

\[ \alpha := 287 \cdot 2 \; \text{mm} \]
\[ h := 50 \; \text{mm} \]
\[ R := \frac{h}{2} + \frac{a^2}{8} h = 848.69 \; \text{mm} \]
\[ \phi := 72.9 \; \text{mm} \]
\[ \theta := \sin \left( \frac{\phi}{R} \right) = 4.928^\circ \; \text{Max angle part rotates under 1 drink weight} \]

From CAD - Dimensions of longest cross-section under tipping load - gives greatest moment

<table>
<thead>
<tr>
<th>Part</th>
<th>X</th>
<th>Y</th>
<th>( \phi )</th>
<th>New ( \phi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drink A</td>
<td>1.5</td>
<td>2.3</td>
<td>4.45</td>
<td>10.83</td>
</tr>
<tr>
<td>Drink B</td>
<td>2.1</td>
<td>2.3</td>
<td>4.45</td>
<td>10.83</td>
</tr>
</tbody>
</table>

Figure 15 - Buoyancy Equations (Angle part rotates under weight of one drink)
\[ t_{\text{Finishing}} = \frac{\text{Surface Area}_{\text{Finishing}}}{R_{\text{Finishing}}} = 133.4 \text{ hr} \]

\[ C_{\text{Machining}} = (t_{\text{Milling}} + t_{\text{EDMing}} + t_{\text{Drilling}}) \cdot R_{\text{Machining Rate}} + t_{\text{Finishing}} \cdot R_{\text{Finishing Rate}} = 7931.30 \]

**Total Mold Cost**

\[ C_{\text{Workpiece}} = \text{Volume}_{\text{Workpiece}} \cdot \rho_{\text{Insert}} \cdot k_{\text{Insert}} = 31421.31 \]

\[ C_{\text{Total}} = (C_{\text{Workpiece}} + C_{\text{Machining}}) \cdot \text{NOC} \cdot f_{\text{Discount}} = 39352.60 \]

*Figure 12 - Total Mold Cost*