Comparison Between Thermoforming Tooling Materials Aluminum and HYVAC-LCM

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Abstract
CMT Materials, Inc. hypothesizes that the heavy-gauge vacuum-and pressure-forming industry lacks an effective and affordable mold material that can be used on small-to-medium sized runs. (For the purposes of this paper, small-to-medium is defined as >500 parts and <5000 parts per year.) While some companies are willing to pay a premium for superior performance and results, the majority of processors continue to use low-cost, low-performance materials such as wood, Renshape and MDF board. Aluminum is most commonly used for longer-running projects and its price and performance is used as a reference by many in the industry. In this paper, we seek to validate the performance of HYVAC-LCM material against aluminum, the industry standard for thermoforming molds.

If HYVAC-LCM, a new alternative material, is usable for thermoforming molds, then it can produce parts at a lower cost.

Individual Performance Objectives
While planning and accomplishing this experiment, multiple objectives had to be met. These objectives are listed throughout the paper and will be explained in each step. The objectives were:

- Comparison between HYVAC-LCM and aluminum in terms of:
  - Overall performance: tool durability, tool cost, tool lead time, tool weight, forming cycle time, and tool temperature
  - Material distribution
  - Part shrinkage
  - Visual inspection – part finish
  - Manufacturing techniques/challenges for syntactic foam for a washing machine door

- Ease of use
- Issues
- Ideas for lay-up
- Time required to make tool
- Tool mounting suggestions

Equipment Used
- MAAC Thermoforming System 9000 Single Station 36” x 48” Model #43SPT
- Shel Lab Oven dryer
- Magna Mike Model 8000
- Strainoptics, Inc. Birefringence Strain Viewer PS 100 SF
- 12 inch digital calipers

Material
The material used on the HYVAC-LCM consisted of two different layers to create a composite mold. The outer shell of the tool is syntactic foam while the inner core is constructed of composite spheres. Syntactic foam gets its name from the ordered structure of the spheres (syntactic) and the cellular structure of the material (foam).

Syntactic foam contains preformed hollow spheres that are held together in a binder. The binder typically is an epoxy, urethane, thermoplastic, glass, ceramic or metal. The hollow spheres can be made of thermoplastic, ceramic, or glass. Glass spheres held together with an epoxy binder are the most commonly found in syntactic foam. Figure 1 is a cross-section of the material zoomed in 100 times to allow for a view of the hollow areas (the hollow spheres) and the material around them (the binder.)

Five different types of polymer sheet were used: High Impact Polystyrene (HIPS) 0.080” thick; Polyethylene Terephthalate glycol-modified (PETG) 0.080” thick; KYDEX T (Acrylic PVC) 0.125” thick; Acrylonitrile Butadiene Styrene (ABS) 0.125” thick; and High Density Polyethylene (HDPE) 0.093” thick.

Machine Set-up
The physical set-up of the machine was the same for both molds used in this study. All timers and delays were the same except for the forming time. Changes to the forming time were necessary to meet the part ejection temperature ranges recommended by the manufacturers of each polymer tested. A common oven heating profile was used to eliminate variables, shown in Figure 2. The oven on the MAAC Thermoformer has 56 heating zones, 30 quartz heaters on top and 26 glassed-faced ceramic heaters on the bottom. The vacuum box for the HYVAC-LCM was built to match the vacuum box for the aluminum mold to eliminate
any variation and for ease of set-up. While processing, the goal was to maintain at least 25in/Hg vacuum. The change over time between molds was 5-10 minutes total. Speed of the change-over minimized oven temperature spikes. All settings remained the same except for the encoders (platen travel) as the vacuum box heights were slightly different.

Figure 2: Oven Profile

The polymer sheets were all cut with matching orientation to a size of 10” x 18.5”. For example, all the orientation in the HIPS sheet prior to forming is the same for each the HYVAC-LCM and aluminum tool; the same approach was used for the other four polymer sheets used in this experiment. Consistent orientation eliminated the possibility of shrinkage or material distribution variation between the two molds.

Tool Durability
In order to test the durability of the syntactic foam, a small part was made into a saucer about 7 inches in diameter and one half-inch thick. This part was gelled and cured. After curing and annealing the part back down to match the mold characteristics, the sample piece was dropped from 4 feet and did not crack or dent. Further tests would be to drop the HYVAC-LCM and observe the results.

Tool Cost
The aluminum tool (donated to PCT by Bayer MaterialScience) was machined from 6061 aluminum that is easily polished for processing clear polymers. The estimated cost for this mold is $2500. The estimated cost to produce a duplicate mold using HYVAC-LCM is calculated using the material cost and the labor necessary to make the tool. The actual raw material cost came to $51.10: $31.54 for the putty and $19.56 for the beads, resin and hardener. This product will eventually be sold in kit form, and the total cost will depend on the size of the mold being built. The necessary labor time is about 10 hours at a rate of $50 per hour. For our purposes, the total cost for the tool ran approximately $550. In this evaluation, a negative cavity was available and was used to create the mold. No cost was calculated for making a negative cavity. HYVAC-LCM can be machined to shape as a built-up mold or packed in to a negative cavity with no machining required.

Tool Construction
The following tool construction is based on building a tool for a front-load washing machine door. This door was used to further study building techniques and a glass door was used so voids could be seen in the syntactic foam lay-up process. Tool construction required two, eight-hour days to complete. The first step was to wax the mold and lay the putty (syntactic foam) along the walls in a 0.5”-thick wall. Next, a batch of beads was mixed and coated in an epoxy with catalyst to attach all the beads together so they could be packed into the mold (about 2 hours.) The mold was placed in a 170 degree Fahrenheit oven and gelled overnight. The mold was then slowly cooled to room temperature by lowering the heat in the oven and allowing the part to anneal (about 12 hours of heat and 4 hours to reach room temperature.) After reaching room temperature the voids in the mold surface were filled with the putty again (about one hour) and the mold was placed back in the oven to gel again (12 hours to heat, approximately 4 hours to cool.) Sanding then took place to eliminate all the spots that were filled (about 3 hours). After sanding was complete, the mold was put back in the oven for a final cure at 280 degrees Fahrenheit for 6 hours. The heat was then turned off to allow the mold to anneal back at room temperature (about 6 hours of heating and 4 hours to anneal.) Next the inserts were interpolated by first drilling holes and vacuuming all loose debris out of the area. Some of the holes were filled with Gorilla Glue. The shell of the metal inserts were also coated with Gorilla Glue and the inserts were then placed in the holes (about one hour) allowing the glue to cure and expand. The glued areas were then retouched to fill any extra gaps. Once the glue dried the mold was mounted to a mounting plate with specific holes cut out under the tool to allow vacuum to travel into the beads. It is estimated that it would take about 3 days to create this tool.

Tool Weight
The tool weight is very significant, as the HYVAC-LCM is much lighter and easier to handle than the aluminum tool. The HYVAC-LCM mold and mounting plate weigh only 3.5 pounds. The tool, vacuum box and mounting fixtures combined weigh only 21.5 pounds. The aluminum tool weight including the vacuum box is 38.5 pounds – a total difference of 17 pounds (44% more). The use of a lighter tool has a great possibility to reduce machine wear and allow for machine sustainability. The lighter tool will also increase the safety of workers involved with machine set-up.

Forming Cycle Time
The forming cycle differs from polymer to polymer due to differences in starting material thickness and ejection temperatures. Samples produced from the HYVAC-LCM were formed using two cooling cycles to document the rate of change in temperature over a 10-cycle run and to achieve the ejection temperature suggested by the manufacturer. Using High Impact
Polystyrene (HIPS) as an example, the forming (cooling) time for the HYVAC-LCM was set for 40 and 80 seconds. For the aluminum tool, the forming (cooling) time was set at 60 seconds. The same approach was taken with the other polymers with forming times and ejection temperatures.

**Tool Temperature**
The tool temperature was measured before and after forming. The data of importance is that of after forming to see how hot the tool became. As mentioned above, samples were processed in sets of ten, documenting the rise in temperature. The data shown in Figure 3 represents mold temperatures (when processing HIPS material) after forming each of the ten samples, both with a 40 and 80 second forming (cooling) cycle. Temperatures were taken at two points on the tool, illustrated in Figure 4. The tool was measured immediately upon the ejection cycle. The LCM mold can only be cooled by heat dissipation due to its low thermal conductivity. Syntactic foam is approximately 50% air by volume which virtually eliminates thermal conductivity to prevent the sheet from instantly “freezing” upon contact with the mold. Initial tests showed the mold maintaining a stable temperature after a few shots. In the event the mold continues to rise in temperature, it is possible to regulate the temperature by use of external cooling fans.

**Material Thickness Profile**
Material distribution is a main contributor to the overall efficiency of using HYVAC-LCM. When comparing the average thickness by position for each type of polymer, illustrated in figure 5, the HYVAC-LCM had a more uniform wall thickness. HYVAC-LCM allows the polymer to “slide” over the tool instead of freezing and stretching as observed on samples produced from the aluminum mold. In addition, it appears that the HYVAC-LCM allowed for distributing material from the perimeter flange or skeleton of the part, resulting in improved material distribution. Figures 6 and 7 show the different measuring points used. These points are the same points used for industry project studies conducted by the Plastics Innovation and Resource Center (PIRC), with the addition of points I and J.
Figure 8: Birefringence View of the Aluminum Tool Molded PETG

Figure 9: Birefringence View of HYTAC-LCM Molded PETG

Part Shrinkage
After comparing the two tools, the HYVAC-LCM showed less shrinkage in both the length and width. On all the polymers, the shrinkage was greater when using the aluminum tool, however the data could be skewed slightly due to part warpage, particularly in the length axis. The part tends to curl away from the mold, which in turn, artificially increases the overall length. As seen in Figure 10, the length axis is warped creating a longer distance.

Figure 10: HIPS Part Warpage

Visual Inspection
On the top of the vertical wall of each part, there is an area where the material freezes off and is forced to stretch. This mark is called a chill mark, or flow line. Chill marks are very noticeable with the PETG and KYDEX T parts formed on the aluminum tool shown in Figure 11. This is because the aluminum draws out the heat from the polymer and freezes it to the top of the mold, forcing the remainder of the sheet to stretch and form the part. On the HYVAC-LCM the chill mark is smaller because the tool does not draw the heat out as quickly as the aluminum tool does (see Figure 12). This allows the polymer to adhere to the syntactic foam and evenly cool the entire part to reduce the freezing and stretching of material.

Figure 11: Chill Mark on KYDEX T Sheet on Aluminum mold

Figure 12: Chill Mark on KYDEX T Sheet on HYVAC-LCM

Part Finish
The part finishes on the aluminum tool are suitable minus the noticeable chill marks. The HYVAC-LCM part finishes are less than ideal because the mold has a significantly lower surface quality. One issue with the HYVAC-LCM product is the inability to completely eliminate voids when laying up the putty initially. It is possible to miss a few of the microscopic voids, which are not easily seen. This requires reapplication of the putty, sanding and curing at least one other time to achieve a suitable finish. A possibility to obtain a higher surface quality part would be to form the similar mold but extra material around the tool to later be CNC machined. Syntactic foam machines nicely and can save a lot of time and do a better job then filling voids and hand-sanding the mold.
HYVAC-LCM Techniques / Challenges
The HYVAC-LCM was easy to use while working with the putty (syntactic foam). In order to create fewer voids and have an easier piece of putty to work with, the putty must be kneaded to allow heat to enter and make it more pliable. Once the putty is pliable, it must be flattened out to a half-inch thickness. The putty is then cut with a knife into two-inch wide strips, shown in Figure 13. This was the easiest way to lay up the mold instead of just arbitrarily arranging the putty around the mold. Without using a uniform lay up process there will be many voids in the putty. Using the strips creates fewer voids and makes the material easier to work with. Taking just a ball of putty and pressing it onto the glass door created many voids. The strips eliminated many voids, although still left a fair amount.

Time Required Making The Tool
The time it took to create the tool for the front load washing machine door was approximately two hours of lay up time, including time to mix up the epoxy and beads and pack the beads (Figure 14). The part that took the longest was time in the oven, which was about eight hours of consistent heat and then left off overnight to anneal to room temperature. After the mold was cooled to room temperature the voids could be filled. Half the mold was fixed using the putty to fill any voids while the other half mold used Loctite 495 with ground up syntactic foam dust to create a liquid composite. After filling the voids on each half, the mold was set back in the oven for another eight hours plus overnight to anneal to room temperature. The syntactic foam side was fairly easy to sand using 800 grit sandpaper, while the side with the Loctite 495 was rock hard. Using a Dremel sander, the tool was spot sanded for a couple of hours with 180 grit sandpaper. The Loctite was tearing through the 180 grit after just a couple of minutes. After most of the sanding was done, the mold had to be set in the oven for a final cure. Time was limited to do a perfect job sanding and almost all the time was used to sand the Loctite 495 side. On average it took over nine hours to sand the mold. (CMT has since developed a putty format that may be applied to a finished mold for easy patch/polish).

Tool Mounting Suggestions
In mounting the HYVAC-LCM to the mounting plate, there was not enough time to do multiple tests with mounting techniques.

Figure 13: Syntactic Foam Lay-up Strips

Figure 14: Mixed Composite beads Coated in Epoxy

Figure 15: Washing Machine Door Filling Comparison

Holes were drilled and threaded aluminum inserts installed into the bead area of the mold as recommended by CMT Materials for use in solid syntactic foam products. What was encountered was the Loctite 495 adhesive did not hold the inserts properly in the HYVAC-LCM porous core. Instead, an alternative method of using Gorilla Glue was used. The Gorilla Glue is more effective as the holes were not perfect and were larger due to the epoxy beads chipping away during the drilling process. The Gorilla Glue expands while drying to fully secure the inserts into the beads, creating an extremely strong bond.

Conclusion
In conclusion, the HYVAC-LCM is a feasible mold material depending on the desired applications. If the application requires tight-tolerance products to be produced without flaws, then the HYVAC-LCM is probably not the best option at this point. With further testing and development this tool is capable of producing
parts with high clarity and minimal imperfections. For the cost of the mold and the properties received off of the tool, the HYVAC-LCM could be a big development for the thermoforming industry to use syntactic foam as a mold and not just as a plug.

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8. Matt Vandiver - Primex Plastics – PETG, HIPS
9. Sekisui-SPI – KYDEX T (Acrylic PVC)

References

Need help with your technical school or college expenses?
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Here is a partial list of schools and colleges whose students have benefited from the Thermoforming Division Scholarship Program:

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Penn College’s Plastics Resources to Be Touted at European Conference

April 29, 2015 — European visitors’ recent first impression of Pennsylvania College of Technology’s Plastics Innovation & Resource Center will lead to a second look when they promote the facility to a continental conference next year.

The four international guests and their American host talked with employees and students in labs featuring each of the college’s five plastics processes (injection molding, extrusion, blow molding, rotational molding and thermoforming) during a March tour of the PIRC and its Thermoforming Center of Excellence.

The group also learned from Director C. Hank White about the PIRC’s role in helping the industry remain competitive.

“We want to be the place to go in North America for training and research and development,” White told the group.

The goal of the tour (sponsored by the National Society of Plastics Engineers Thermoforming Board Executive Committee) was to showcase the facilities to the mutual benefit of the PIRC and its potential international partners, and – judging from the response – it was an objective well-met.

“Our visit was indeed an eye-opener!” said Jeff Pitt, director of Plas-Logic Ltd. in the United Kingdom. “In Europe (and, in particular, the UK) there has been a lack of comprehensive ‘ground roots’ training for students and apprentices wanting to follow a specific practical plastics technology.”

The norm for training in that sector has been basic, practical engineering courses,” he explained, followed by more specific training “downstream” – more often than not the direct responsibility of employers.

“To have the facility on offer at Penn College would relieve the employer of that burden and would, in my view, be a great attraction,” Pitt said. “To that end, we will promote (the PIRC) to the European audience that attends our 2016 European Thermoforming Conference in Barcelona.”

Pitt was accompanied by Andy McGarry, managing director at Cox Wokingham Plastics, also in the UK; Lars Ravn Bering, managing director at Gibo Plast, Denmark; and Francois Berry, president at Top Clean Packaging, France. Joining the contingent were Katharine Skopp, from the state Department of Community and Economic Development, and J.P. Tambourine, manager of economic development for FirstEnergy.

The visit was coordinated by Ed Probst, principal at Probst Plastics Consulting LLC in Wisconsin.

For more information about the PIRC, visit www.pct.edu/pirc or call 570-321-5533.

For more about the college – one of only five plastics programs in the nation offering degrees accredited by the Engineering Technology Accreditation Commission of ABET – visit www.pct.edu, email admissions@pct.edu or call toll-free 800-367-9222.