Rush to Judgment

Printed thermoforming tools speed prototyping trials and get initial products to market—and buyers—faster than conventional molds

By Geoff Giordano

The use of 3D-printed tooling for thermoformed parts is an emerging development in additive manufacturing that is paying significant dividends in terms of reduced tooling cost and time for prototype and low- to medium-volume tooling.

From simple trays to intricate molds and large panels for process equipment like 3D printers, thermoformed tooling allows the printing of functional tooling at low cost within days. With typical production runs generally under 10,000 parts, printed tooling also demonstrates that it can withstand the pressures of thermoforming without signs of wear or failure.

Among the available 3D printing modalities, binder jetting, HP's Multi Jet Fusion (MJF) technology, and fused deposition modeling (FDM) are being used to produce tooling.

During the COVID-19 pandemic, 3D-printed thermoforming molds have excelled in rapidly turning out personal protective equipment (PPE) like face shields and masks. User feedback on such products has been quickly incorporated into new tooling to produce improved components.

Such rapid turnaround capability is critical to many users. At RapidMade in Portland, Ore., "We serve a lot of inventors and customers who maybe aren't big companies, and [printed tooling] really helps them get into the market where they may have struggled otherwise," explains Micah Chaban, vice president of sales. "For most people it's not part cost that prevents them from entering the market—it's tooling cost. A lot of people can't put down $10,000 for tooling and wait eight weeks to get their first part off the tool while that money is tied up." If these companies "finally get to market and realize there are design issues [with a conventional tool] based on feedback from customers that they're not able to address … they're sitting there with a $10,000 paperweight."

Applying Additive Technology

Using 3D printing to produce thermoforming tooling requires understanding the nuances of each process, says Darrell Stafford, CEO of Catalysis Additive Tooling of Columbus, Ohio. Knowing how to design tools that can handle the intense pressures of thermoforming, particularly in large parts, while managing the thermal properties of the process, is part of the secret sauce toolmakers must master.

Stafford and his business partner bring a combined six decades of manufacturing experience with Honda, with Stafford having been in charge of the automaker's additive manufacturing research and development across all business teams.

The core business at Catalysis is using 3D printing to make thermoform tooling, Stafford explains, primarily using a proprietary coating package, resin, and tool design along with their strategic partners' printers.

"We are very agnostic" as to printing modalities in use, he says, with FDM, stereolithography (SLA), and other technologies at his disposal. "We have strong partners who have million-dollar machines, and we use them when we need them. We optimize whatever technology makes sense for a thermoforming application."

Based on part size, the quantity to be produced, and the surface finish desired, "We will pick which technology makes sense and then design the tool," he continues. "We have a coating system that we've developed over the years that we use for silica-sand-binder jet printing. It makes the tool strong for thermoforming because there are a lot of forces there," in addition to a typical thermal gradient of 250˚F.

Imagining a tool about 2 feet by 2 feet, Stafford says, and calculating 14.7 psi, "which is the perfect vacuum," the area of that tool could be subject to "a couple of tons of pressure. It is a lot of force." Such pressures can challenge even composite or ceramic tools, especially as parts reach 70 to 80 inches in length.

Catalysis offers several innovative approaches to its tooling.

"We design some unique things on the backside—because you can print anything—to give it the strength and enable us to manage the thermal properties needed for thermoforming," Stafford says. "We have spent a lot of time and money and made lots of mistakes. The whole thing with 3D printing is 'fail often, fail fast,' so we learn and learn and learn; there's a lot that goes into the design of a sand-printed tool to get the strength and to handle thermal management issues."

Porosity is another advantage Catalysis offers. "3D printing with sand is porous; our process keeps porosity, so we don't have any vacuum holes in tools, and they pull over [the entirety] of the part, not just where the small vacuum holes are every inch. It makes a big difference in part quality."

Catalysis was able to produce six tools in about three days for an airline project. The company recently completed a detailed metal thermoforming tool using direct metal laser sintering of 17-4 stainless steel. Catalysis, in fact, made the tooling for all 18 large panels of ExOne's X1 25Pro, a metal binder-jetting 3D printer that premiered at the Rapid + TCT 2019 conference in Detroit. The company also has produced about 2,800 acrylonitrile butadiene styrene (ABS) parts for a drinking fountain component that lets users fill their own plastic bottles.

"The issue with metal is that it is expensive," Stafford notes. "If the part is bigger, we go with binder jetting because of the cost and speed. We can print about 70 inches by 39 inches in 18 hours, and either huge tools or a bunch of small ones."

Taking the Plunge

About six years ago, RapidMade realized that mixing 3D printing and thermoforming "could have a big impact for our customers," Chaban recalls. The company adopted HP MJF technology two years later to replace its composite tooling practices and initially focused on smaller parts; for larger parts, the company mills urethane foam tooling.

"There are times when a customer comes to me and it would be less expensive for a urethane tool, but because they're in a time crunch printing is always going to be my fastest way to make a tool," Chaban explains. "People have come to us with rapid turnaround projects where they needed parts to start shipping out the door in a week, and we were able to accommodate that. We design the tool, print it the next day, get a first article out by day three or four, they approve it, and we're pumping out parts on the fifth business day."

A key to RapidMade's success is hollowing out parts to save cost. A proprietary method ensures that the tooling holds up to vacuum pressure and lower thermal expansion. "Every mold we make is shelled out, and we add an internal

Catalysis Additive Tooling designed and printed 18 vacuum forming tools in three weeks for the enclosure panels of the ExOne 3D printer. Courtesy of Catalysis

RapidMade began producing printed tooling for protective masks for the COVID-19 pandemic. As customers provided feedback, improvements were quickly made to the tooling. Courtesy of RapidMade

rib structure—a cross hatch with vertical and horizontal ribs that run the length and height of the part and intersect with the outer shell." This ensures a strong structure. "With a lot of prints, if you print them fully dense, it generates a lot of heat and causes defects, not to mention cost issues."

Hollow is also huge for airflow and drilling holes. "It really helps our process; we don't have to drill through six inches of material to get a vacuum hole—we can just drill through a 0.8 to 0.1-inch surface shell that makes our life a lot easier."

In terms of tool life, Chaban adds, "We have done over 5,000 forms off a nylon tool and it looked fine. We're effectively able to print customers' permanent tooling quickly and inexpensively."

Accuracy of tooling trim tends to range between 0.15 to 0.2 percent, he says. "Our engineer is going to calculate the shrink of the plastic into the tool size; he'll calculate the expansion of our tooling into the tool as well. We come up with pretty accurate parts; it doesn't seem like we're way out of bounds of what a milled aluminum tool would be."

That helps enable creation of complex tooling, from customized part trays for material handling to chocolate molds with logos on them. Those projects are ideal for printed tooling "because the time it would take a machine shop to intricately engrave and texture every surface is a nightmare."

And in terms of cost, a roughly fist-sized mold might run $100 to $150. "We're able to serve a lot of customers' markets that maybe have more of a shoestring budget as long as we're not talking massive 2-foot or 4-foot molds."

Molds can be made from many materials, Chaban notes, although some like polypropylene or high-density polyethylene are particularly difficult to form. "You want to control your mold heat or create a mold that dissipates heat well … and in those instances cast or milled aluminum is the way to go. But a lot of times when you talk to customers and they're not as attached to a material, we can run almost anything else, like PETG or ABS."

During the pandemic, RapidMade switched gears to produce PPE, including trays and instrument components for test kits. "This product didn't exist before the outbreak; time was by far the most valuable thing for our customer. And they had features in these trays that they couldn't form because it didn't really fit the rules of thermoforming—it would thin out too much or they tried to make tighter features than the material would allow. So, we redesigned parts to accept printed inserts, and the final part is a mix of printed and formed components. If you had to print the trays it would be incredibly expensive, so we printed a small part of the tray and assembled it afterward."

RapidMade also began designing and thermoforming face shields and filtered masks. "Within a week per product we had production lines up and running to start pumping out thousands of units a week," he says. "That amount of time to market is crazy fast, and we started selling products to local first responders and took our products to Amazon quickly, and it's taken off." Customer feedback received during the launch period helped the company build improvements into the tooling within a week or two and continue production.

MJF's Advantage

Since its market debut in 2016, HP's MJF 3D printing

HP Multi Jet Fusion printers like the 5200 series give makers of thermoforming tools a significant advantage in production flexibility. Courtesy of HP

technology offered an important advance in layer-by-layer part production.

MJF lets manufacturers "create fully customizable parts point by point through a series of fusing and detailing agents," explains David Woodlock, application development and design manager for HP. "Unlike other 3D printing technologies, HP Multi Jet Fusion technology prints each layer of new material and agents on top of a previous layer that is still molten so both layers fuse completely, delivering strong, quality, detailed, and functional 3D printed parts."

When MJF is used to produce thermoform tooling, he continues, "we are able to hollow out the tool to remove thermal mass and improve printing and dimensional stability. This is ideal for producing complex and highly personalized parts that can offer greater material properties and performance over traditional methods." Traditionally machined thermoforming tools "turn out thick and heavy."

MJF's accuracy and flexibility let makers of thermoforming tools "create sharp interior angles … as well as parts that can be designed so that they are made more efficiently, with less material and in less time," Woodlock adds.

When compared to other process tools like injection molds, "3D printing brings a competitive edge, providing users with the flexibility to shift directions quickly to produce parts into the hundreds or low thousands," he notes. "The cycle time of printed tooling versus injection molds should be similar, but it can be slower than metal tooling due to the lower thermal conductivity." Nevertheless, he notes, "3D printing is squarely in the driver's seat as a bridge technology, allowing manufacturers to get parts out quickly until less nimble processes such as injection molding and machining can be ramped up to full-scale production. 3D printing has big lead time advantages—often two to three weeks."

The competitive edge 3D printing offers in thermoforming extends past design flexibility to part cost. "As cost per part for 3D printing continues to aggressively drive down, higher-volume applications become more and more accessible," Woodlock concludes. "The cost delta between 3D printing technology and technologies like injection molding is rapidly reducing, or in some cases, being eliminated completely."

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