WHITE PAPER

Low-Volume Rapid Injection Molding With 3D Printed Molds

This white paper provides methods and guidelines for using stereolithography (SLA) 3D printed molds in the injection molding process to lower costs, reduce lead times, and bring better products to market. Through the real-life case studies with Braskem, Holimaker, and Novus Applications, you'll learn how 3D printing enables on demand fabrication of rapid tooling to quickly produce small batches of thermoplastic parts.

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3D-MODEL formlabs

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Introduction

INJECTION MOLDING

Injection molding is one of the leading processes for manufacturing plastics. It is widely used for mass-producing identical parts with tight tolerances. It is a cost-effective and extremely repeatable technology that yields high-quality parts for large series. It can produce volumes from 1,000 to 100,000+ of parts at very low unit costs. Injection molding has a short cycle time, with each machine capable of building new parts every 15 to 60 seconds. It is a fast, intensive process where high heat and pressure are involved to melt thermoplastic and force it inside a mold.

Because of these extreme molding conditions, the tools are traditionally made out of metal by CNC machining or electric discharge machining (EDM). These are expensive industrial methods that require specialized equipment, high-end software, and skilled labor. As a result, the production of a metal mold typically takes four to eight weeks, and costs anywhere from $2,000 to $100,000+ depending on the shape and the complexity of the part. For smaller part quantities, the cost, time, specialized equipment, and skilled labor required to fabricate the mold out of common tooling metals and manufacturing methods often makes injection molding at this scale unobtainable. However, there are alternatives to machining molds out of metal. Leveraging 3D printing to fabricate injection molds for prototyping and low-volume production significantly reduces cost and time compared to metal molds, while still producing high-quality and repeatable parts.

Desktop 3D printing is a powerful solution to fabricate injection molds rapidly and at low cost. It requires very limited equipment, saving CNC time and skilled operators for other high-value tasks in the meantime. Manufacturers can benefit from the speed and flexibility of in-house 3D printing to create the mold and couple it with the production force of injection molding to deliver a series of units from common thermoplastics in a matter of days. They can even achieve complicated mold shapes that would be difficult to manufacture traditionally and can be used on both desktop and industrial molding machines, enabling development teams to be more innovative. Furthemore, product development benefits from the ability to iterate on the design and test the end-use material before investing in hard tooling.

Even though 3D printing molds can offer these advantages when used appropriately, there are still some limitations to be aware of. We should not expect the same performance from a 3D printing polymer mold as from a machined metallic one. Critical dimensions are harder to meet, cooling time is longer because the thermal transfer occurs slower in plastic, and printed molds can more easily break under heat and pressure. However, companies across the industry are continuing to implement 3D printed molds into their short-run injection molding workflows, enabling them to quickly produce hundreds to thousands of parts. From designing functional prototypes with end-use materials, fabricating parts during pilot production, or manufacturing end-use parts, 3D printing injection molds is a cost-effective and quick way to produce parts in limited quantities.

FAST FABRICATION OF SHORT-RUN INJECTION MOLDS

Stereolithography (SLA) printing technology is a great choice for molding. It is characterized by a smooth surface finish and high precision that the mold will transfer to the final part and that also facilitates demolding. 3D prints produced by stereolithography (SLA) are chemically bonded such that they are fully dense and isotropic, producing functional molds at a quality not possible with fused deposition modeling (FDM). Desktop SLA printers, like those offered by Formlabs, can seamlessly be integrated into any injection molding workflow as they are easy to implement, operate, and maintain.

Formlabs Rigid 10K Resin is an industrial-grade, highly glass-filled material that serves as an ideal molding material for a wide variety of geometries and injection molding process conditions. Rigid 10K Resin has an HDT of 218°C @ 0.45 MPa and a tensile modulus of 10,000 MPa, making it a strong, extremely stiff, and thermally stable molding material that will maintain its shape under pressure and temperature to produce accurate parts. Novus Applications has injected hundreds of intricately threaded caps with a single Rigid 10K Resin mold. As more companies get their hands on Rigid 10K Resin we expect it to be Formlabs' best choice to print sophisticated molds for injection molding.

High Temp Resin is an alternative material that can be considered when clamping and injection pressures are not too high and Rigid 10K Resin cannot meet the required injection temperatures. High Temp Resin has a heat deflection temperature (HDT) of 238°C @ 0.45 MPa, the highest among Formlabs resins and one of the highest among resins on the market, allowing it to withstand high molding temperatures and minimize cooling time. This report will go through a case study with Braskem, a company that ran 1,500 injection cycles with one mold insert printed with High Temp Resin to produce mask straps. The company printed the insert and placed it inside a generic metallic mold integrated in the injection system. This is a powerful solution to produce medium series quickly. The printed mold can be replaced as the design evolves and in case of failure. It allows for creating molds on-demand with elaborate geometries that would be difficult to manufacture traditionally while still running multiple shots.

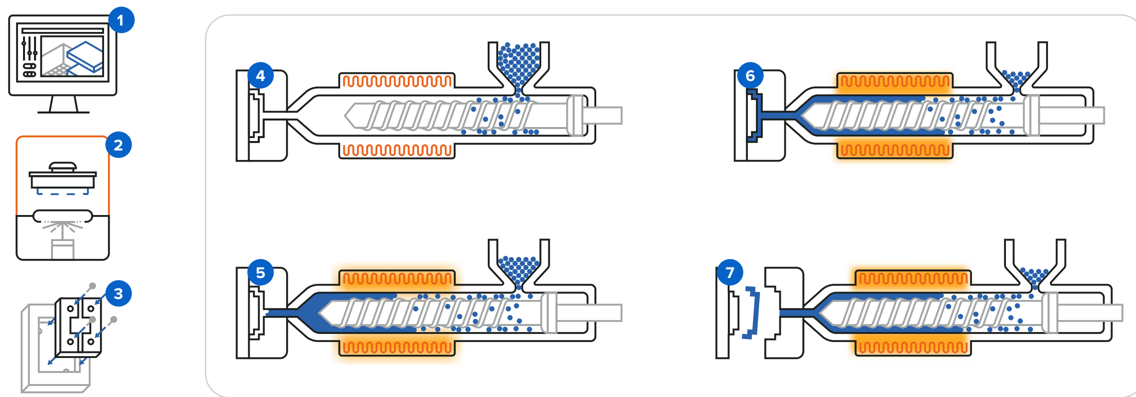
High Temp Resin, however, is quite brittle. In the case of more intricate shapes, it warps or cracks easily. For some models, reaching more than a dozen cycles can be challenging. To solve this challenge, French startup Holimaker turned to Grey Pro Resin. It has a lower thermal conductivity than High Temp Resin, which leads to a longer cooling time, but it is softer and can withstand hundreds of cycles.

This white paper will first give a general overview of the workflow, design guidelines, and best practices for 3D printing molds for injection molding. Then, it will go into the details by covering three case studies on how each firm found success with their 3D printed mold.

Method

PROCESS WORKFLOW

INJECTION MOLDING PROCESS WITH 3D PRINTED MOLDS



1 Mold design 2 Mold 3D printing 3 Mold assembly 4 Mold clamping 5 Injection 6 Cooling 7 Demolding

There are a few things you should take into account when using 3D printed injection molds:

- Dimensional accuracy of the mold: it is important to note that the dimensional accuracy of a 3D printed mold may not be as good as a metal machined mold. However, many choose to sand or machine the 3D printed mold to better meet critical dimensions.
- Breakage or cracking of the mold under pressure and heat: 3D printed molds typically have shorter lifetime than metal molds and therefore are recommended for lower volume production.
- Cycle time: the cooling time is longer than with a metallic mold as the thermal transfer occurs slower in plastic parts. However, cooling methods such as using compressed air or having interchangeable stacks are a great way to reduce cycle time with 3D printed molds..
- Demolding process:
    - Adhesion of the part to the mold can cause deterioration of the mold during extraction. Demolding agents can be used to assist with this part of the process.
    - Flashing may occur and slow down the demolding step. This is an excess of material coming out of the mold during the injection when the mold is overfilled, or if the parting plane is not perfectly flat.

These issues can be mitigated by reducing the injection pressure, optimizing the CAD file, and adapting the demolding process. These three parameters will largely influence the success of the operation.

The complexity of the injection molding process is mostly driven by the complexity of the part and the mold structure. A broad range of thermoplastics can be injected with 3D printed molds such as PP, PE, TPE, TPU, POM, ABS, PC, ASA or PA. A low viscosity material will help reduce the pressure and extend the lifetime of the mold. Polypropylene and TPEs plastics are easy to process at a high amount of cycles. In contrast, higher melt index materials or filled plastics like PA will allow a lower number of runs. The handling of a release agent helps to separate the part from the mold, in particular for flexible materials such as TPUs.

The type of injection press does not have a significant influence on the process. If you are new to injection molding and are looking into testing it with limited investment, using a benchtop manual injection molding machine such as the Holipress or the Galomb Model-B100 could be a good option. Some of our customers have recommended systems from Minijector, Morgan or APSX as well. Automated small scale injection molding equipment such as the desktop machine Micromolder or the hydraulic machine Babyplast 10/12 are good alternatives for mass production of small parts.

DESIGN GUIDELINES

When designing an injection mold that is to be 3D printed, common design for manufacturing principles should be followed. It is good practice to adhere to the rules of design for additive manufacturing as well as the general rules for injection mold design, such as including two to five degrees of draft angles, maintaining a uniform wall thickness across the part or rounding up the edges. 3D printed molds can incorporate the same components as metal molds including mold halves, runner systems, inserts, and ejector pins. Here are a few helpful advice from users and experts, specific to polymer printed molds:

To optimize dimensional accuracy:

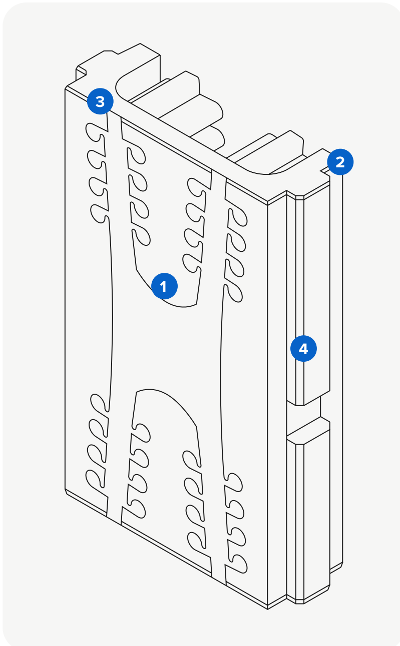
- Plan stock allowance on the mold to post-process and adjust sizes.
- Print one set of the mold prior to production to understand dimensional deviations. Edit your CAD model to account for these deviations in your mold design.

To extend the lifetime of the mold:

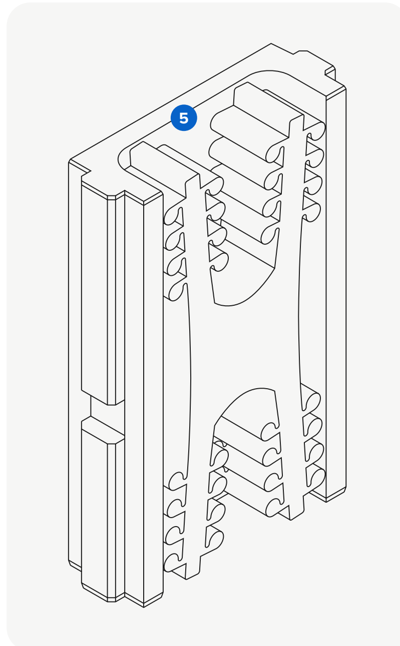
1. Open up the gate to reduce the pressure inside the cavity.
2. When possible, design one side of the stack flat while the other side carries the design. This will lessen the chance of misalignment during mold clamping and reduce the risk of flashing.
3. Include large air vents (0.05mm depth) from the edge of the cavity to the edge of the mold to allow the air to escape. This yields a better flow into the mold, minimizes pressure and alleviates flashing in the gate area to decrease cycle time.
4. Avoid thin cross-sections: surface thickness less than 1-2 mm may deform with heat. Negative features smaller than 0.5 mm can be challenging to get a good definition on, while standing features smaller than 0.1 mm can be prone to break off.

To optimize the print:

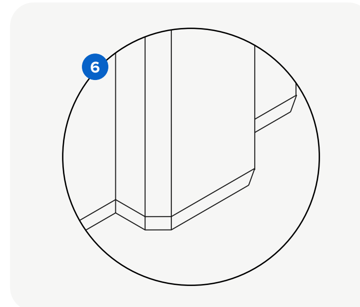
5. Adjust the back of the mold to minimize material: reduce the cross section in areas that are not supporting the cavity. It will save costs in resin and diminish risks of print failure or warpage.
6. Add chamfer to help to remove the piece from the build platform.
7. Add centering pins at the corners to align both prints.

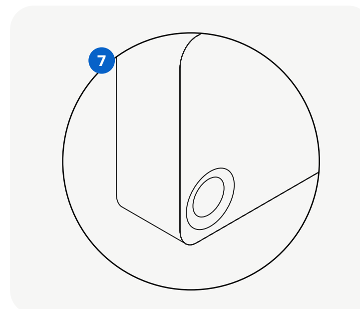


Front of the mold



Back of the mold





OTHER BEST PRACTICES

To optimize dimensional accuracy:

- Print molds flat, directly on the build platform without support to reduce warpage whenever possible. Eliminating supports also saves printing time, labor, and resin.
  - Select a base surface that will minimize overhangs.
  - If your design does require support, avoid contact on molding faces to improve surface quality.
- Post-process the printed mold: desktop milling, drilling or hand-sanding will help to fit both halves of the mold together and avoid flashing.

To extend the lifetime of the mold:

- Keep the injection pressure and speed low.
- Support all free-hanging cores, in particular small diameter cores.
- Place the printed mold inside a metallic frame or print the insert and machine the outside of the mold to provide support against the downward pressure and heat of the injection nozzle. Standard aluminium frames are readily available from injection molder manufacturers. Another option could be to use a metallic modular mold base system, such as the Master Unit Die Quick-Change or similar solutions, allowing you to quickly switch and replace printed mold inserts.

To facilitate the demolding process and reduce cycle time:

- Employ interchangeable stacks to run new cycles while the other sets cool in order to decrease the cooling time, which compensates for the low thermal-conductivity of a plastic mold.

- Cooling can be accelerated by applying compressed air to cool the mold.
- Apply a release agent for some technical thermoplastics. Mold release is widely available and silicone mold release, are compatible with Formlabs Grey Pro Resin, High Temp Resin, and Rigid 10K Resin. Novus Applications uses solutions from Slide and Braskem uses the MR303 silicone food grade release agent from Sprayon.
- Print at a small layer height as the smooth surface helps to separate the plastic part from the mold—50 microns or even 25 microns on High Temp Resin if the model presents very fine details. It will also improve dimensional accuracy.
- View the molding conditions used by our customers.

CHOOSING THE RIGHT RESIN

Injection molds need to withstand clamping pressures, injection pressures, injection temperatures, and any coolants or mold release agents that may be used. Doing so ensures the mold can be repeatedly used overtime and consistently produce parts true to the original design. Formlabs offers a range of materials that meet these requirements and are capable of replacing aluminum molds for low-volume manufacturing.

- The combination of strength, stiffness, and thermal resistance makes Rigid 10K Resin an ideal material for injection molds. The advanced strength ensures a mold made from Rigid 10K Resin can withstand the clamping and injection pressures without breaking, while the high stiffness enables the mold to maintain its shape under these pressures and produce accurate parts.
- High Temp Resin is an alternative material that can be considered when clamping and injection pressures are not too high and Rigid 10K Resin cannot meet the required injection temperatures.
- Grey Pro Resin should be chosen when pressures and temperatures are low and dimensional accuracy of your molded part is less critical. Molds made from Grey Pro Resin will bend before breaking, potentially increasing longevity, but potentially worsening accuracy over time as the mold is used

This is summarized in the below table where more stars indicates better performance under that condition..

CRITERIA	RIGID 10K RESIN	HIGH TEMP RESIN	GREY PRO RESIN
High molding temperature	••	•••	•
Shorter cooling time	••	•••	•
High pressure	•••	•	••
Increase cycle number for complex geometries	•••	•	••

CASE STUDIES

In this section, we will go through the case studies from Novus Applications, Holimaker and Braskem. See how 3D printed injection molds were used on both benchtop and industrial machines to efficiently and affordably produce hundreds to thousands of functional prototypes, parts for pilot production, or end-use parts.

Novus Applications Injection Mold Hundreds of Threaded Caps With a Rigid 10K Three-Part Mold

This case investigates the behavior of Formlabs latest engineering material, Rigid 10K Resin. Thanks to its high stiffness and temperature resistance, Rigid 10K Resin will expand the longevity of more intricate molds undergoing high pressure and temperature.

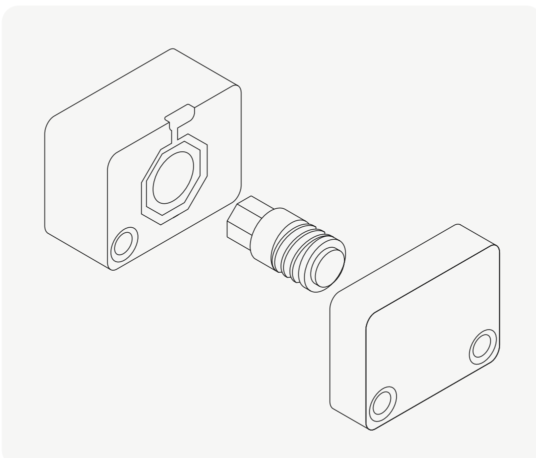
The printed three-part mold with the caps injected in polyethylene.

BACKGROUND AND CHALLENGE

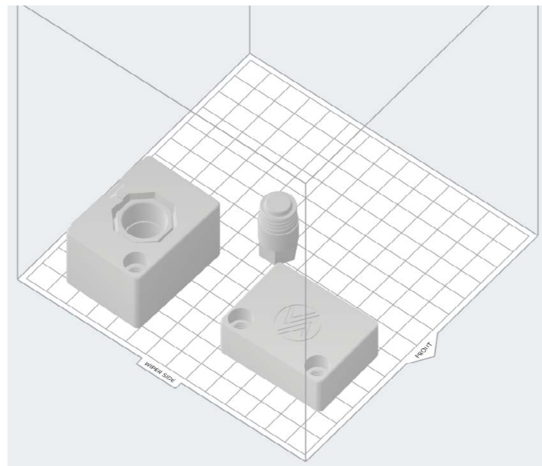
Novus Applications is a product development company focusing on consumer goods. Experienced in injection molding and 3D printing, they run design for manufacturing and moldability studies for their customers. Speed is crucial for the team as they need to quickly deliver low-volume series of prototypes. They conducted an internal study to test the viability of using a 3D printed mold in the injection molding process to fabricate a small batch of caps. They were specifically looking at the dimensional stability and longevity of the printed molds; how it would behave under the heat and pressure of the process and how many injection cycles they could expect from one mold.

THE DESIGN PROCESS

Mark Bartlett, the founder and president of Novus Applications, wanted his team to create a generic cap with an internal thread which was applicable for both tubes and bottles. It requires a complex, three-part stack with a dynamic threaded core, which can used to help validate future complicated injection molding projects. Bartlett followed the usual recommendations for designing a mold for injection molding. Specifically, he included draft angles to facilitate the demolding process, supported all free-hanging cores where possible, and avoided very thin cross-sections. In an effort to reduce the pressure in the cavity, he drew large gates and incorporated venting to release the gas from the mold. Finally, some extra material was included in order to groom the blocks in a post-processing step.



This is a three-part mold with a moving B side cavity (left), a threaded side-action core (middle) and stationary A side (right).



The CAD file of the mold loaded into Formlabs PreForm software for print preparation.

THE PRINTING PROCESS

Bartlett was looking for a 3D printing material stiff enough to withstand the pressure of the process while able to render the fine details of the design. Having used FDM printing technology before, he needed the higher resolution that SLA technology can offer. He opted for Formlabs Rigid 10K Resin as it is an extremely stiff material with high tensile strength and tensile modulus, and great dimensional stability. Formlabs High Temp Resin was also considered but did not perform as well on small features. Bartlett needed the mechanical properties that Rigid 10K Resin offers rather than the thermal properties of High Temp Resin.

The molds were printed overnight on the Form 3 3D printer with Rigid 10K Resin at 50 micron layer height. They printed extra side-action cores in case of failure during demolding. They were subsequently washed in IPA twice for 10 minutes and post-cured. It is recommended to post-cure Rigid 10K Resin parts in Form Cure for 60 minutes at 70°C and then heat the part at 125°C for 90 minutes for a higher HDT. The parts were then post-processed to match the desired sizes. Mark designed the molds with additional stock allowances in mind so that the mold's key surfaces and features could be fine-tuned in post-processing operations, allowing him to achieve a perfect fit inside the press. Common post-processing operations include drilling out or reaming holes and sanding or milling faces to achieve the tight tolerances necessary to reduce print defects.

THE MOLDING PROCESS

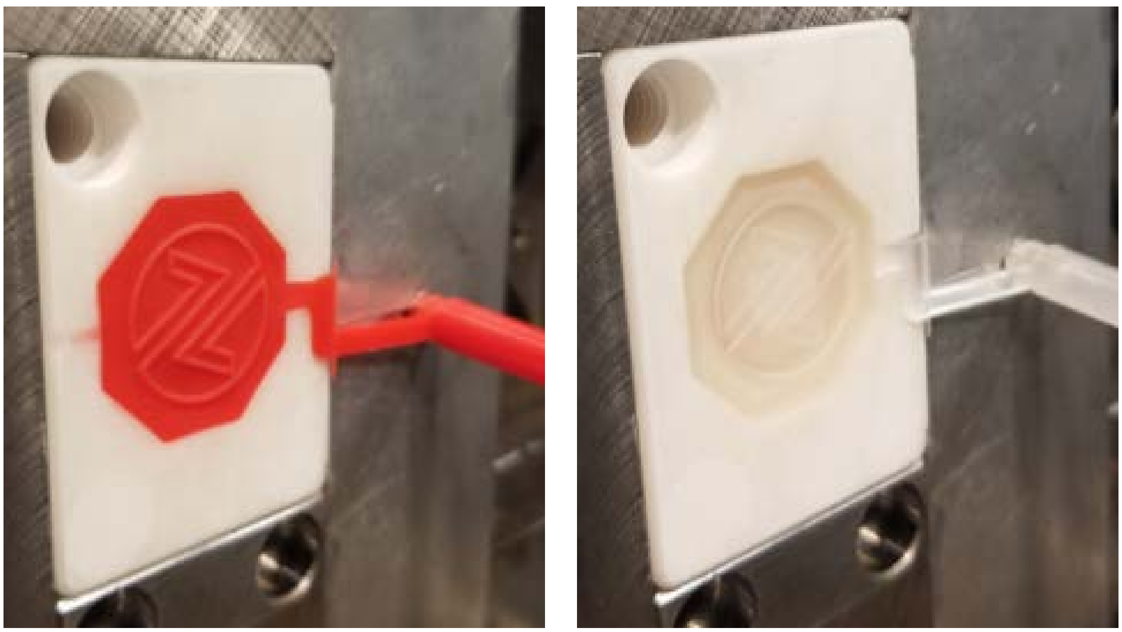
The printed molds were placed into a metallic frame before injection. The side-action core went inside the B side (left) which was clamped to the stationary A side (right).

The team operated an all-electric Sumitomo 50 ton press. The printed molds were placed into a prefabricated metallic mold frame inside the machine. They injected three different materials; a low melt polypropylene (PP) (P5M6K-048 Red), high melt polypropylene (PP) (PP1013H1 White), and high melt polyethylene (PE) (Marlex 9018 HDPE). Polypropylene is quite easy to process and does not require very high pressure. The table below shows the injection conditions used for one printed mold.

INJECTED MATERIAL	P5M6K-048 RED	PP1013H1 WHITE	MARLEX 9018 HDPE
Melt index	35	7.5	20
Nozzle temperature	390°F, 199°C	410°F, 210°C	400°F, 204°C
Injected pressure	6,800 PSI	9,500 PSI	7,200 PSI
Cycle time	48 sec	50 sec	68 sec
Number of injection cycles	30	30	30
Pressure to failure		11,500 PSI	

Cycle times were slower than in a traditional injection molding process, including the injection, cooling, and manual demolding. The injection speed was reduced in order to keep the pressure low. To shorten the cooling time of the plastic mold, Bartlett printed multiple cores and was not running consecutively on the same core in order to leave the ones cooling on the side. There were no water cooling channels available but the aluminium frame did absorb some of the temperature. The demolding process is a sensitive step as the mold can be damaged during the operation. The team was ejecting and unscrewing the part from the side-action core manually, and had to pay attention to not break the core during the separation. They first applied a release agent to facilitate it, but it turned out not to be necessary as the draft angles were sufficient. They did not notice any chemical reaction between the printed resin and the injected materials.

RESULTS



The mold cavity after the injection of P5M6K-048 Red (left) and PP1013H1 White (right) materials.

With maintaining the injection pressure under 11,500 PSI, the team operated about a hundred of injection cycles for one mold. The lead time of this project was about two days, from idea to production. The team designed the mold in a few hours, printed it overnight, needed half a day to prepare and assemble the mold and another half a day to mold the parts. They used only one CAD model, however, more complicated parts would require a few more days for design iterations.

The next table displays measurements on the final part injected in three different materials. For each, the team measured 20 diameters of the inside of the threaded cap to assess the repeatability of this process. We can observe an average deviation from the mean diameter of ±0.0 4mm over these 60 caps, reflecting a good dimensional stability.

MATERIAL	P5M6K-048 RED		PP1013H1 WHITE		MARLEX 9018 HDPE	
Mean	0.515 in	13.072 mm	0.520 in	13.207 mm	0.517 in	13.134 mm
Cycle number	Deviation (in)	Deviation (mm)	Deviation (in)	Deviation (mm)	Deviation (in)	Deviation (mm)
1	0.000	0.009	0.002	0.052	0.000	-0.003
2	0.002	0.060	0.001	0.027	0.002	0.048
3	0.001	0.034	0.000	0.001	-0.002	-0.053
4	0.005	0.136	0.001	0.027	0.004	0.099
5	0.000	0.009	-0.001	-0.024	0.003	0.074
6	-0.001	-0.017	-0.001	-0.024	0.000	-0.003
7	-0.001	-0.017	-0.004	-0.100	-0.001	-0.028
8	-0.002	-0.042	0.002	0.052	-0.001	-0.028
9	-0.002	-0.042	-0.002	-0.050	0.000	-0.003
10	0.000	0.009	-0.003	-0.075	0.001	0.023
11	0.000	0.009	0.004	0.103	-0.001	-0.028
12	-0.003	-0.067	0.001	0.027	-0.001	-0.028
13	0.000	0.009	-0.001	-0.024	0.002	0.048
14	-0.002	-0.042	-0.001	-0.024	0.002	0.048
15	0.003	0.085	0.003	0.077	-0.002	-0.053
16	0.000	0.009	0.002	0.052	-0.001	-0.028
17	-0.002	-0.042	-0.002	-0.050	-0.002	-0.053
18	-0.003	-0.067	-0.003	-0.075	0.001	0.023
19	0.000	0.009	0.002	0.052	0.000	-0.003
20	-0.002	-0.042	-0.001	-0.024	-0.002	-0.053
Average from absolute deviation	0.001	0.038	0.002	0.047	0.001	0.036

COSTS ANALYSIS

> *"If my customer only needs 20 parts why would I need an aluminum mold? With 3D printing technology, the team shows a much faster learning curve, the production is more unattended—specifically thanks to the Form 3's ease-of-use."*
>
> **Mark Bartlett**

With this workflow, Novus Application saved a lot of time and simplified a previously complex process. Normally, they would have machined the mold in-house out of a block of steel or aluminum, which would be far more labor-intensive. It would take a few more days and require high-end software with highly trained operators. Due to the more expensive equipment and materials, both machine time and the production cost of the mold would have been substantially higher. For this project, Bartlett estimates that 3D printing the mold cost less than half of machining it in house.

"It always depends on the part that you are working on—I can print complex parts accurately way faster than I am going to machine them," said Bartlett.

	IN-HOUSE MACHINED METAL MOLD	IN-HOUSE 3D PRINTED MOLD
Equipment	CNC machine and software Injection molding machine PP, HDPE	Form 3 printer Rigid 10K Resin Injection molding machine PP, HDPE
Mold production time	Two days	One day
Mold production cost	2X	<1X

Holimaker Produces 100s of Prototypes and Pre-Production Parts With 3D Printed Molds in Grey Pro Resin

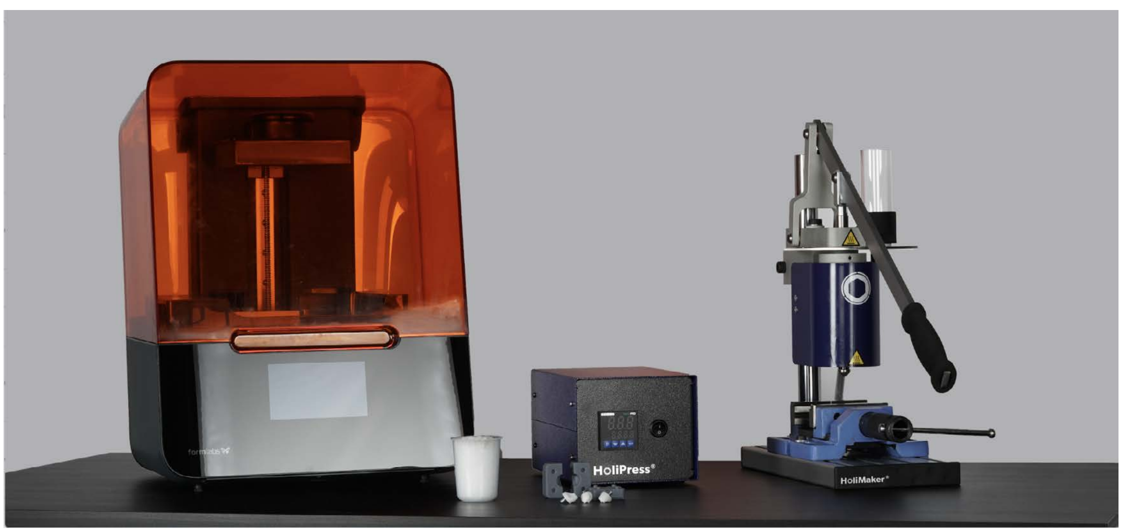
This case shows how Grey Pro Resin can be an alternative to High Temp Resin to augment mold longevity if cooling time is not a priority.

BACKGROUND AND CHALLENGE

French startup Holimaker aspires to make plastic manufacturing accessible by fabricating micro-industry tools for plastic processing. Their core product, the Holipress, is a manual injection molding machine that enables engineers and product designers to process plastic parts on their desktop in low quantities for prototypes, pilot-production, or even limited series of end-use parts.

Holimaker offers feasibility studies for their customers, using 3D printed molds for fast and affordable turnaround. This allows their clients to quickly and affordably prototype designs and validate final manufacturing conditions during the pilot production phase of new product introduction. By using the same manufacturing method including mold design and materials, these parts can be tested in the field and ensure the designs are ready to be produced at scale. The 3D printed mold designs can then be easily adapted for tool-grade steel during mass production.

Holimaker uses 3D printed injection molds in 80% to 90% of their projects today. We met with the managing director Aurélien Stoky and the marketing director Vivien Salamone to understand how they combine both technologies.



The Holipress next to the Form 3 printer

"The blocker in injection molding is to manufacture the mold. In order to democratize injection molding and make it accessible to everyone, we had to find a complementary technology to produce our mold. Desktop printing was a perfect fit for this. We combine the flexibility of 3D printing with the productivity and quality of injection-molded plastic," Stoky and Salamone said.

Holimaker has looked into alternative ways for mold making. For orders over a thousand parts, they would employ a machined aluminum mold, but for smaller quantities, they run the press on 3D printed molds. In some cases they combine both in a similar way as Braskem: for large volumes with demanding geometries, they machine the outside of the mold and 3D print the insert, which is replaced over time.

DESIGN PROCESS

Usually, the team iterates on three to four models per project in order to optimize the design. They follow the general molding and design for manufacturing recommendations, such as including draft angles. They mostly work on small parts, and add 0.1 mm vents and 0.5 mm runners.

In addition, they respect a few 3D printing rules such as including chamfers to help to remove the part from the build platform, including centering pins to align the mold halves, and adding notches to assist opening the mold with a screwdriver. They usually use 10 mm thick molds and avoid thin cross-sections. Parts that are only 1-2 mm thick cannot endure the high temperatures.

Transitioning from a 3D printed mold for low-volume production to a machined metal mold for mass-production is seamless. Simple modifications to draft angles, gates, and air vent dimensions may be needed.

3D PRINTING PROCESS

Holimaker's team prints the molds, directly on the build platform at a 50 microns layer height. This orientation saves printing time and resin by not using support structures; the team also observed better dimensional accuracy on the mold surfaces after curing. If dimensional errors occur, it is usually on the outside of the block that they post-process with hand sanding to fit in standard metal frames that provide added support.

Holimaker favors Grey Pro Resin for most of their studies. This material has lower temperature resistance than High Temp Resin but it is less brittle and allows for a higher number of cycles for difficult geometries. Grey Pro Resin can also be drilled and handled repeatedly, and can be employed in a standard injection press.

MOLDING PROCESS

The team uses the Holipress injection molding machine in all their studies. It is a small manual press, easy to use, and available at a tenth of the cost of an industrial press. The molds are placed into a prefabricated aluminum frame which holds the pressure better and ensures that the injection nozzle is not in direct contact with the printed mold.

With Formlabs printed molds, Holimaker injects a broad range of thermoplastics with different levels of hardness from Shore 40A to 90A, at a three to five minutes cycle time. The number of cycles per mold varies from about 10 parts for a PA injected at 270°C to 100s of parts for a PP, TPE, or POM injected at lower temperatures. Holimaker is developing an integrated cooling system to help reduce the cooling time before demolding.

POM football cleats injected in the Holipress from molds printed with Grey Pro Resin.

RESULTS

The team chose SLA 3D printing from Formlabs for its part quality and ease-of-use. "The quality of our injected parts is very good because of the high quality molds. And when I start a print in the evening, I am almost sure to have a good mold ready the following day" they said.

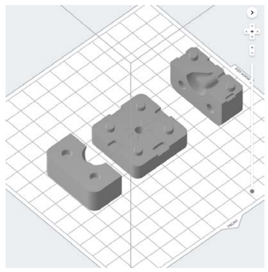
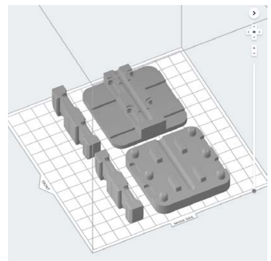
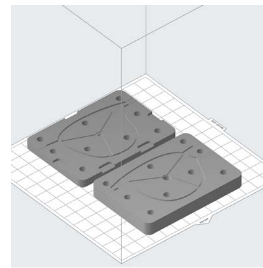
Stoky and Salamone had used another desktop printing technology before, but observed too much deformation on the prints even prior to injection.

“Formlabs parts offer great dimensional accuracy and surface finish, If there is a dimensional error, it is very minor, and it is uniform on the three axes, therefore we can predict it and post-process it. With other desktop printers, we could not control the deformation," said Stoky.

The team also appreciates the simple workflow that is easy to learn and operate, including the Form Wash and Form Cure which totally automate the washing and curing process. They can go from design to molded parts within a working day and then also iterate the design to optimize the model.

> *"We often design the mold in the morning, print it during the day and we can test the injection in the afternoon to modify the CAD model and start a second print overnight, "*
>
> **Aurélien Stoky**

Holimaker shared a few cases from their customers to give a better understanding of the part, molding conditions, and results of their feasibility studies.

COMPANY	SMART POWER	FERME 3D	EYEWEAR MANUFACTURER
Product	Football cleat	Face shield clip	Eyewear frame
Need	Pre-production prototypes in different thermoplastics, to test on the field and select the final material for mass production.	Test a solution to produce a series of 10,000s of parts in a short time.	Test compatibility of eyewear materials with printed molds to produce a series of 200 frames.
Mold CAD			
Injected part			
Materials injected	POM (180°C), PA 6.6 (270°C), PP (210°C)	PP (food-grade, 220°C)	ASA (240°C), PA (240°C)
Number of parts for one mold	60	100	70
Cycle time	Two minutes	Two minutes	Two minutes
Project lead time	One week	One week	Two weeks

COSTS ANALYSIS

	OUTSOURCE MACHINED METAL MOLD	IN-HOUSE 3D PRINTED MOLD
Equipment	Holipress, thermoplastics	Holipress, thermoplastics, Form 3 printer, Grey Pro Resin
Mold production time	Three to five weeks	One week
Mold production costs	4-5X	1X

Braskem Fabricated Thousands of Mask Straps in a Week with Molds 3D Printed in High Temp Resin

This case is an example of a very simple geometry, flat with no fine features, where reducing cooling time was critical to produce thousands of polypropylene (PP) parts in a short time.

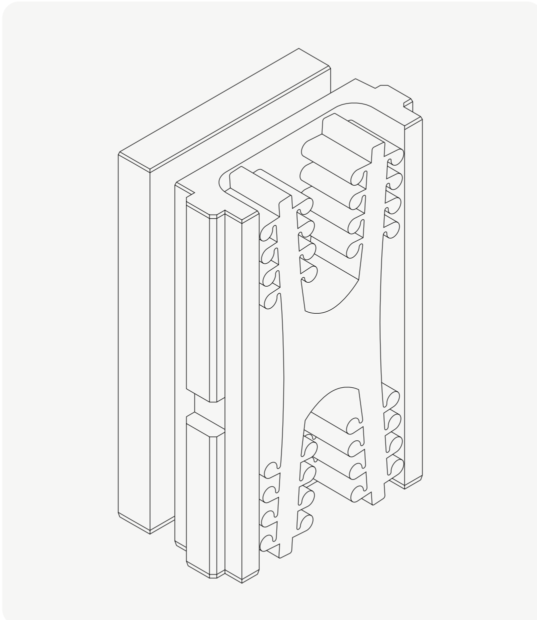
BACKGROUND AND CHALLENGE

Being one of the world's leading petrochemical companies, Braskem is well experienced in injection molding. Michelle Sing, Jake Fallon, Collins Azinger, and Fabio Lamon work on exploring opportunities with additive manufacturing for Braskem's customers. One particular interest is to help their community gain access to temporary tools and gain flexibility in production with rapid tooling. The urgent need for masks during the COVID-19 crisis led them to test the viability of using a 3D printed mold with injection molding. They needed to design and produce thousands of masks straps within a week to distribute to Braskem employees. After initially considering directly 3D printing the straps with with FDM printers and machining a traditional mold out of tooling metal, they ultimately landed on 3D printed injection molds to reduce costs and turnaround time.

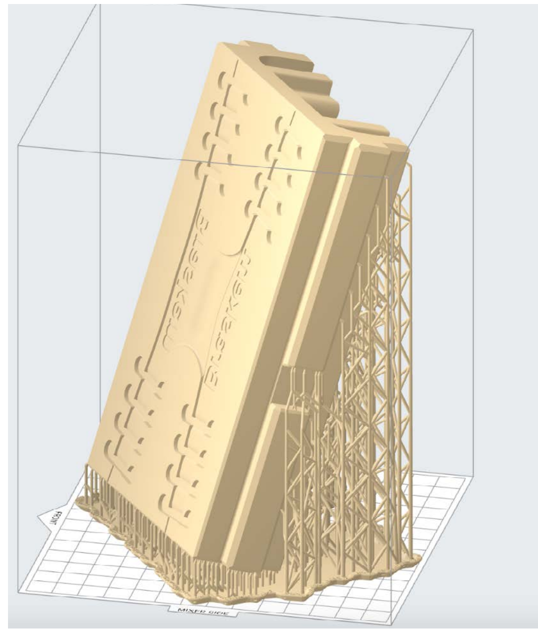
DESIGN PROCESS

Fallon went through three design iterations in order to increase the number of cycles before breakage, lessen flashing to shorten demolding time, and save resin. Here is an overview of the modifications:

	MOLD V1	MOLD V2	MOLD V3
Design features	Added draft angles	Added draft angles Enlarged gate	Added draft angles Enlarged gate Added large vents (against flashing) Reduced the cross-section in some areas
Results	500 cycles	1500 cycles	2500 cycles Alleviated flashing 28% in resin savings



The one-side mold directly locked to a metallic plaque.



The final CAD file of mold loaded into Formlabs PreForm print preparation software. The part was printed tilted with supports. Smaller molds can also be printed directly on the build platform to minimize post processing time.

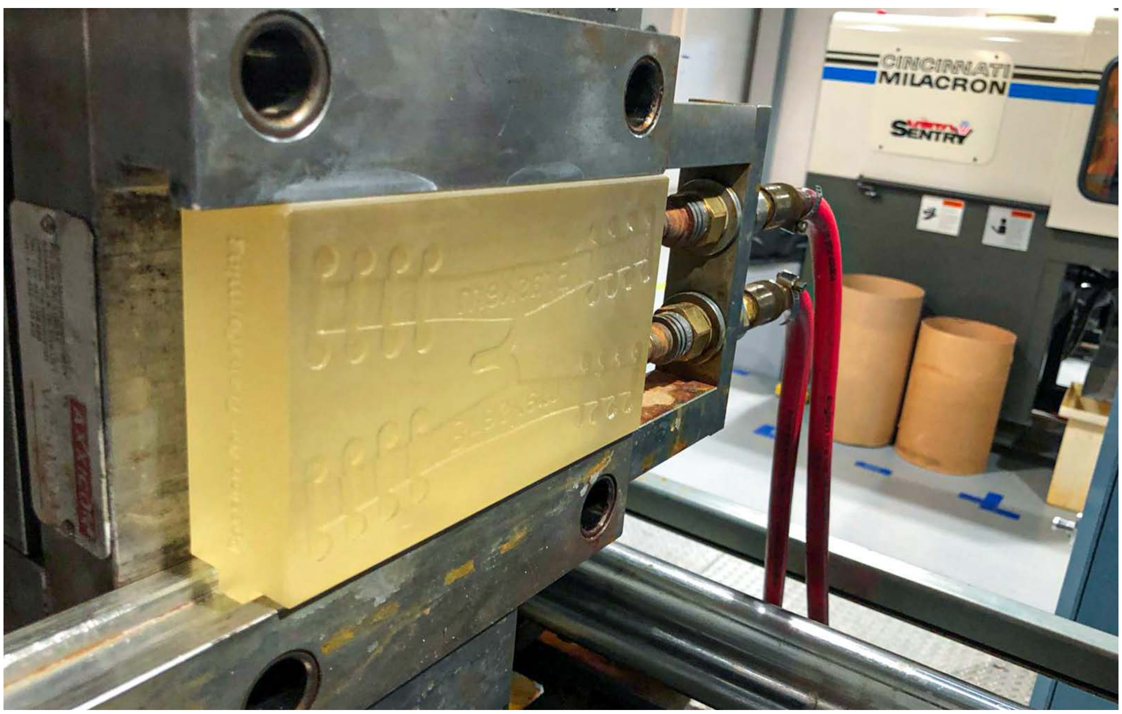
PRINTING PROCESS

The team printed on the Form 3 with High Temp Resin. Thanks to the Form 3's Remote Printing feature, Fallon could work on the CAD file from home and start the print remotely, so that the part would be printed by the time he arrived back to the office in the morning. He opted for a 50 micron layer height in order to balance time to reduce print times while ensuring a good surface finish to improve demolding. This resin was chosen because of its high Heat Deflection Temperature (HDT) that could handle an average molding temperature of 230°C with a short cooling time. Formlabs Rigid 10K Resin could also bear this temperature for such a short exposure, however, the cooling time would be slightly longer. It took about 24 hours to print the part. They were subsequently washed in IPA for six minutes, post-cured for 120 minutes at 80°C, thermally post-cured for three hours at 160°C and then hand sanded to fit inside the system.

MOLDING PROCESS

The team operated an all-electric press Cincinnati Milacron 110 Ton Roboshot. Braskem was using a one-sided printed mold, slid into the system and directly locked to a metallic plaque, which helped to hold at high pressure. They injected generic polypropylene (PP), which has good flexibility and toughness. They chose a higher melt flow PP for low viscosity in order to minimize the injection pressure, extend the lifetime of the mold, and avoid flashing. To minimize the injection pressure they kept the temperature in the barrel higher to reduce the viscosity of the melted plastic. Some of the molding conditions were: 5-ton clamping pressure, 30 second cycle time, injection speed of 0.5 in/s, and hold pressure of 5000 psi for ~8 seconds.

Cincinnati Milacron Roboshot.



The one-sided printed mold (V1) slided in the injection molding machine

The demolding process was quite labor-intensive. The team trimmed the gate and purged the vents manually. They applied the MR303 silicone food grade release agent from Sprayon to facilitate the separation, spraying after every 50 to 60 shots. There were no ejection pins or cooling system. However, they managed to reach an average total cycle time of 30 seconds, including cooling and manual separation.

RESULTS

The team ran 1500 injection cycles with one printed mold before breakage. Producing four straps per minute, they used two molds for the total production and more than 8000 mask straps that were distributed to Braskem team members in the USA, Mexico, and Brazil. The high number of cycles is largely the result of the structural simplicity of this insert—flat with a large gate, no intricate features, and held inside a metallic frame. For this project, Braskem went from idea to production within a week.

The mold printed with High Temp Resin next to the two-straps injected in polypropylene

COSTS ANALYSIS

Braskem considered three possibilities to produce these masks. Given that they only had a week to deliver the masks, reducing the overall project time was a crucial requirement. Therefore they included the mold fabrication time and costs when comparing each method. By choosing injection molding with in-house 3D printed mold they obtained 90-94% time saving and 80-97% cost saving compared to the alternatives.

	IN-HOUSE DIRECT 3D PRINTING	INJECTION MOLDING WITH OUTSOURCED METALLIC MOLD	INJECTION MOLDING WITH IN-HOUSE 3D PRINTED MOLD
Equipment	FDM printer	Injection molding machine, PP	Form 3 printer, High Temp Resin, Injection molding machine, PP
Mold production time	Zero	30 days	One day
Mold production costs	Zero	$10,000-15,000	$200
Total project time, including mold fabrication and 8000 straps production	72 days (13 minutes / strap)	32 days	3 days
Total project costs, including mold fabrication and 8000 straps production	$2080	$10160 - $15160	$360

Conclusion

The conversation around 3D printing and injection molding is often oppositional, but it's not always a question of one versus the other. By directly 3D printing parts or using alternative workflows such as 3D printing injection molds for prototyping and low-volume production, your company can leverage the benefits of both technologies. This will make your manufacturing process more time- and cost-efficient and allow you to bring products to market faster. With rapid tooling for injection molding, it is possible to shorten the time from concept to production while delivering a series of parts in traditional thermoplastics.

With the recent release of the Form 3L, Formlabs' large format SLA 3D printer, you can scale this process to large molds and tackle even more applications. Users are also exploring techniques such as electroplating or assembling a multi-material printed stack to expand the capabilities of short-run molds.

The cost and lead time of producing parts in limited volume can often be a barrier to introducing a new product. With 3D printed injection molds, engineers, manufacturers, and product designers can reduce costs, shorten lead times, and bring better products to market. 3D printed injection molds are a great option for those looking to design functional prototypes with end-use materials, fabricate a series of identical pre-production prototypes, or even manufacture custom or limited series of end-use parts. Whether you are looking for a desktop solution or something to implement on the factory floor, Formlabs complete, easy-to-use 3D printing ecosystem can seamlessly be integrated into any injection molding workflow.

Do you have questions about using an SLA printer for injection molding or other engineering and manufacturing applications? Reach out to our solutions specialists or request a free sample of one of the three materials showcased in this white paper.