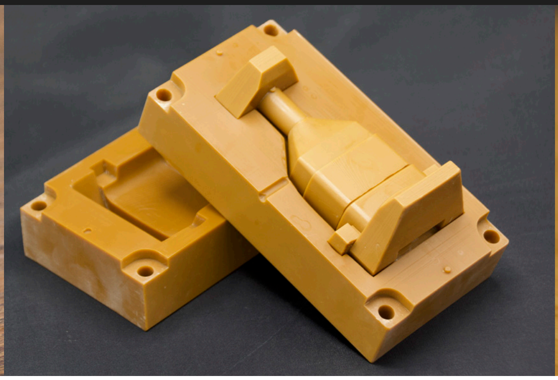
FORTIFY



3D PRINTED MOLD TOOLING

THE FAST, INEXPENSIVE SOLUTION FOR PROTOTYPE & LOW VOLUME MOLDING

WHITE PAPER

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INTRODUCTION

Injection molding has become the go-to manufacturing solution for plastic components. Used in a variety of industries, the injection molding market is poised for continued aggressive growth driven by trends such as the need for light-weighting and electrification, where plastics are trending to replace metals and alloys with injection molded parts.

The economics behind injection molding parts is advantageous for molders, especially when the required part quantity is greater than 100,000. Though the dominant cost of injection molding is the high capital investment of a machined metal mold, once this mold is made, the cost of producing parts are minimal.

Machining metal tools for prototyping can be prohibitive as lead times are lengthy and cost of machining is high. Engineers often have to wait 6-8 weeks to procure parts molded on a metal tool, slowing down design cycles. Prototyping mold tools becomes impractical for many molders.

Designers are forced to rely on sub-par rapid prototyped parts to make design decisions, or skip the prototype phase altogether. This often leads to rework later on in the project, wasting time and money.

Finding solutions to quickly and cost-effectively procure tools that produce parts that meet quality standards is essential to bridging prototype to production for injection molders.

3D PRINTING USE CASES AT THE PROTOTYPE STAGE

DIRECT 3D PRINTING OF PROTOTYPES

Direct 3D printed fabrication of prototype parts has become a fast and easy process. Early in the design process these models have huge value in validating form and fit of new designs. As technology options have exploded over the past decades, access to 3D printed prototypes has become commonplace across industries. The material properties, cost, and turnaround times to access this technology have all improved dramatically, furthering the acceptance of these models.

As new product designs move into the functional testing phase, 3D printed models are often no longer adequate. Product testing needs to be performed using parts made with the end-use material and the actual production process to get an accurate representation of capabilities. At this point, designers and engineers are faced with a difficult decision. How can they produce a small set of parts to continue their testing when faced with tight timelines and budgets?

The whole concept of functional testing implies that some further refinement of design details may be needed, so releasing tooling at this stage of a design cycle is risky from both a cost and scheduling standpoint.

3D PRINTING MOLD TOOLS FOR PROTOTYPING

The scenario described above opens the door for 3D printed injection mold tooling. This approach leverages the access and speed of 3D printing while providing parts in the actual engineering thermoplastics required by the final design. These tools serve as a bridge between prototyping and manufacturing.

This concept has been interesting to engineers since 3D printing first came into practical use. The savings in time and money are just too compelling to ignore. Early attempts were often met with frustration as 3D print materials available at the time were far to weak to withstand the injection molding process.

Over the past 20 years, however, the window of performance has steadily opened to enable longer tool life and higher performance materials. Innovations in materials science and printing technology has allowed for the development of higher performing materials for use in 3D printed tooling, widening the aperture of opportunity.

THE BUSINESS CASE FOR 3D PRINTED MOLD TOOLING

TIME AND MONEY. These are the two big reasons molders invest in 3D printing technology for mold tools. What are the actual numbers behind lead time and dollar savings that make this technology so compelling?

The straight cost savings of a $600 3D printed tool versus a $6,000 machined tool is easy to calculate. However, this is just one piece of the puzzle.

In many cases, the bigger motivation is TIME. To make good business decisions, we need to tie actual dollars to time saved.

How much is one week of saved lead time worth to you, your operations, and your customers?

Fortify has developed an interactive Business Case ROI (Return on Investment) calculator to help molders better understand the financial impact of Fortify's technology at different phases of the product and customer life cycle.

The calculator is available at www.3dfortify.com/roi-calculator/ and explores the combined effects of four different use cases.

THE 4 KEY BUSINESS CASES

CASE #1

USING 3D PRINTED MOLD TOOLS INSTEAD OF CNC TOOLS

Offsetting the upfront cost and time of CNCs prototype tooling by using 3D printed tooling. This is the most common calculation used across industries.

CASE #2

VALIDATE DESIGNS WITH 3D PRINTED MOLDS TO REDUCE SCALE-UP RISK

Investing a small amount of time and money upfront to ensure your designs are correct **BEFORE** investing in hard tooling makes good sense. Mold rework costs plus delayed product launches can be devastating. Run these numbers for yourself and see.

CASE #3

INCREMENTAL PROFIT STREAM FROM SELLING QUICK TURN MOLDING

Custom molders can create a new revenue stream around quick turn prototype tooling. This generates immediate cash flow and attracts new customers to your business. This activity leads directly to case 4.

CASE #4

LIFETIME VALUE OF NEW CUSTOMER ACQUIRED THROUGH QUICK TURN MOLDING

Once a new customer has a good experience with your services, you are in a great position to expand the relationship. What is your average order size from ongoing customers?

A Fortify representative will be happy to work with you to calculate inputs for the model and explore different ROI scenarios. We can help you head to the corner office with confidence.

SAMPLE

Below is AN EXAMPLE* of the calculator with average numbers used as inputs. Fortify encourages you to use your own numbers to give a more representative number of the true time and savings realized with these tools in your shop.

CASE #1 3D PRINTED MOLD TOOLS INSTEAD OF CNC TOOLS	
Number of times used (annually)	8
Cost savings each time	$6,100
Savings/year ($)	$48,000
Savings/year (lead time)	56 weeks

CASE #2 VALIDATE DESIGNS WITH 3D PRINTED MOLDS INSTEAD OF "GUESSING"	
Number of times used (annually)	15
% of times you find a problem	50%
Printed mold stack cost (print and run cost)	$1,400
Cost to add prototype step (annually)	$21,000
Number of times you require CNC work	7.5
Cost of CNC work	$3,750
Total tool rework cost (annually)	$28,125
Time lost to each rework (weeks)	12 weeks
Net hard cost benefit (annually)	$7,125.00
Net time saved (annually)	90 weeks

Figure 1. Sample numbers used in Fortify's ROI calculator tool. Visit www.3dfortify.com/roi-calculator/ to get more accurate data

FIBER REINFORCED PHOTOPOLYMERS = BETTER TOOL PERFORMANCE

Fortify is enabling a step-change in 3D printed tool performance, allowing for more shots in more challenging materials.

This is done with Fortify's Digital Tooling material that is printed on the FLUX ONE printer. The printers allow for functional additives to be incorporated into the photopolymers, enhancing material properties of the resultant 3D printed part.

Fiber and particle additives have been used to enhance polymer performance and functionality in the injection molding industry for decades. Fortify is the first company to implement these reinforcing techniques with 3D printed photopolymers. The FLUX ONE printer features several proprietary mechanisms that allow for fibers to be homogeneously distributed and aligned in printed tools.

The end result is a fiber-reinforced polymer tool that has improved strength, stiffness, and heat deflection temperature.

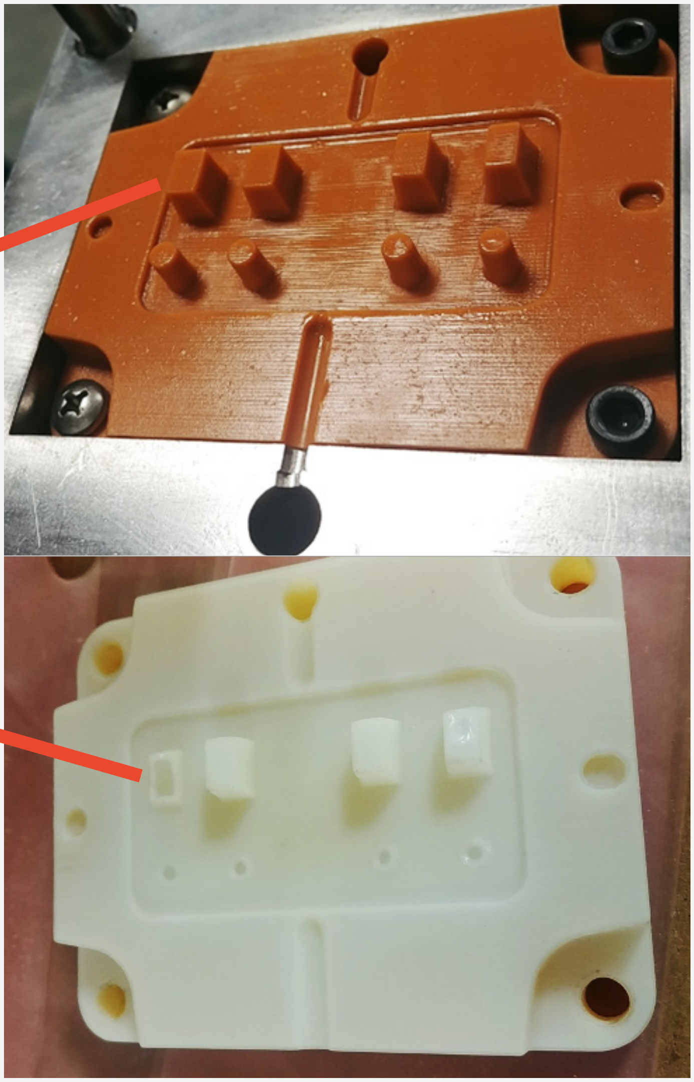
Learn more about Fortify's unique technology platform at www.3dfortify.com/process

Key Material Properties are 2-3X Higher than prior generation of materials

MECHANICAL PROPERTY	METRIC	METHOD
Ultimate Tensile Strength (MPa)	95	ASTM D638
Young' Modulus (GPa)	5.6	ASTM D638
Strain (%)	3.0	ASTM D638
Heat Deflection temperature (°C) @ 0.45 MPa	260	ASTM D648
Flexural Strength (MPa)	150	ASTM D790
Flexural Modulus (GPa)	6.3	ASTM D790
Shrinkage After Post-Cure (%)	<1	
CTE (μm/m/ °C)	50	
Smallest Printable Feature (μm)	100	

FIGURE 2. Fortify Digital Tooling Specifications

FIGURE 3.
Fiber Reinforced 3D Printed Tool vs. Neat Polymer Tool



FORTIFY TOOL, 3D PRINTED WITH CERAMIC REINFORCEMENT

High aspect ratio extruded features stable after 100 shots

COMPETITOR'S 3D PRINTED TOOL

Extruded features failed on first shot

MECHANICAL PROPERTY	FORTIFY DIGITAL TOOLING RESIN	COMPETITIVE 3D PRINTED MATERIAL A	COMPETITIVE 3D PRINTED MATERIAL B
Tensile Strength (MPa)	95	55-60	48.7
Flexural Strength (MPa)	150	65-75	94.5
Flexural Modulus (GPa)	6.3	1.7 - 2.2	2.8
Heat Deflection temperature (°C) @ 0.45 MPa	260	92 - 95	238

FIGURE 4. Mechanical Property comparison of 3D printed materials. All competitive data taken from public resources online

DESIGN GUIDELINES OVERVIEW

Although Fortify has implemented significant improvements to material properties, some planning is still required to get great results from 3D printed tooling, as the tools do not behave exactly like traditional metal tooling made of steel or aluminum.

To help understand these differences, Fortify's applications engineering team developed a set of guidelines and best practices available for download on Fortify's website. An overview of these best practices is presented here. For full details, download the guidelines here.

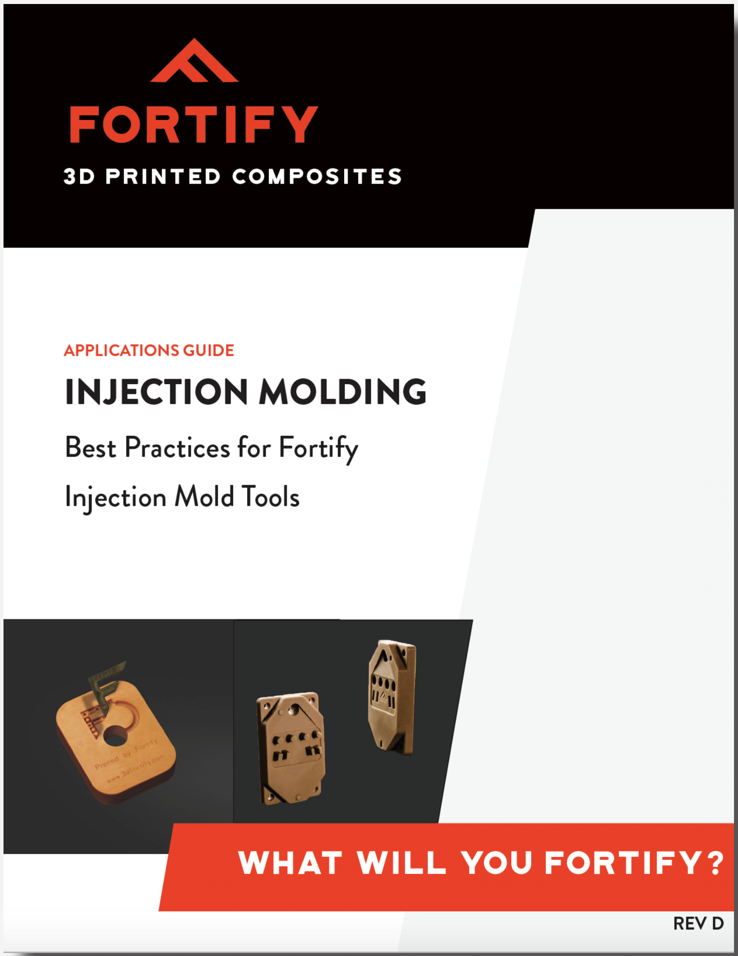


Figure 5.
Fortify's Injection Molding Applications Guide for Best Practices on Designing, Running, and Machining 3D Printed Tools

MOLDED MATERIAL SELECTION

	MATERIAL	# OF SHOTS
EASY MATERIALS	TPU	100s
	TPR	100s
	TPE	100s
	PVC	100s
	Acetal	100s
	ABS	100s
MODERATELY CHALLENGING	Nylon	50-100+
	PC/ABS	50-100+
	Polycarbonate	50-100+
MOST CHALLENGING	GF Nylon	20-50+
	PBT	20-50+
	Ultem	20-50+

FIGURE 6. Estimated number of shots in a given material with Fortify's tools

DRAFT ANGLES / SHUTOFFS

Draft angles should typically be 3 degrees. For certain features such as part outer walls and very low aspect ratio features (less than 1:1) a smaller angle is allowed. For higher aspect ratio extrusions (beyond 3:1), greater than 3 degrees is preferred. For high aspect ratio core pins, one way to maintain a low draft angle is to design this pin as a metal core pin.

Shutoff angles should be a minimum of 5 degrees. Greater than 10 degrees is preferred.

A good mindset to have when designing for these angles is to think what is the largest angle I can use rather than what is the minimum angle I need.

Inner corners that are 100 degrees or sharper should have fillets of a minimum 0.1mm radius.

VENTING

- Design inserts with more venting opportunities than with an aluminum tool. In some cases, it is acceptable to deal with a small amount of flash at the vent locations to ensure proper filling of the cavity at lower pressures.
- Vent holes should be a minimum of 0.4mm in diameter.
- Surface venting should be 0.1mm in depth.
- Ejector pins and any inserts will also act as venting opportunities.
- Use of mold flow software is beneficial to identify areas of air buildup and the end of the fill. Both of these locations are key areas that need extra venting.

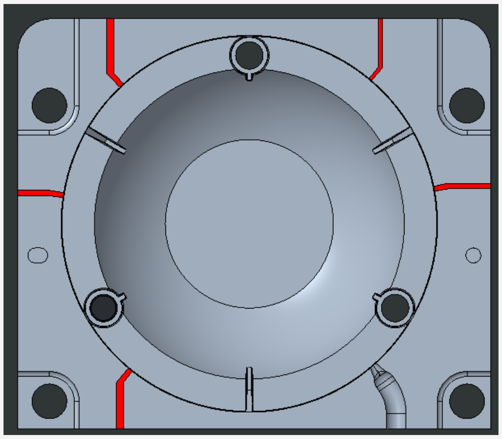


Figure 7.
Surface vents on a CAD drawing of a mold tool

FIGURE 8.
Nozzle blowing compressed air on 3D printed mold tool

TOOL COOLING

- Fortify tools have a lower heat transfer coefficient than metal tools, therefore the heat stays near the surface of the tools and needs to be removed between shots.
- Molds are cooled with a compressed air knife/nozzle(s) positioned to cool the A and B mold halves consistently after each shot. The compressed air setup should be firmly affixed to the molder with on/off tied into the molder auto-cycle control system for consistent results. Hand held compressed air can be used effectively for very short runs.
- Water cooling has not been shown to have a meaningful impact on cycle times or mold life with Fortify tools. Cooling does not harm the tool or molded parts.

MOLDING PARAMETERS GUIDELINES

PARAMETER	IMPERIAL	METRIC
Clamping Tonnage	5 - 20 tons	5 - 20 tons
Injection Pressure	2000 - 6000 psi	14 - 40 MPa
Injection Speed	0.2 - 1.2 in/s	5 - 30 mm/s
Pack Pressure	1000 - 2000 psi	6 -14 MPa
Cooling Time	120 - 30 s	120 - 30 s

FIGURE 9. Molding parameters used for molding with Fortify's 3D printed tools

CASE STUDIES

The following cases used tools that were printed with Digital Tooling on the FLUX ONE printer. The end result for all of these cases showed significant cost and time savings, while incorporating difficult to machine features. In these cases Fortify engineers worked hand in hand with customers to transfer the knowledge required to achieve success.

CASE STUDY: INDUSTRIAL

Fortify's Digital Tooling gave Catalysis Additive Tooling the ability to create quick-turn injection mold tools at a fraction of the cost and time. Because the molds produced using Fortify's materials and systems are fiber-reinforced, the tools function much better than traditional 3D printed injection mold tools while eliminating the need to wait weeks for an aluminum tool.

PROCESS

Customer / Catalaysis

Industry / Industrial

Material / Polypropylene

Catalysis ran the mold shown to produce 200 parts using polypropylene to meet their customers requirements. To further test the tool, an additional 200 shots were run with Nylon 6. At that time the test was halted as the tool showed no appreciable wear from the combined 400 shots. The tool is available for additional parts as needed.

RESULTS

	FORTIFY TOOL	METAL TOOL
COST:	$1,300	$2,000
PROCUREMENT TIME:	3 Days	28 Days
# OF PARTS:	400+	thousands

CASE STUDY: AUTOMOTIVE

The customer needed to test a new design where fast iteration of injection molds and short run production was needed. High HDT & toughness were critical requirements to meet thermal cycling specifications.

Fortify's printer (with patented magnetic 3D Printing process) can enable the production of composite parts in a DLP process, with glass filled resins (up to 15%).

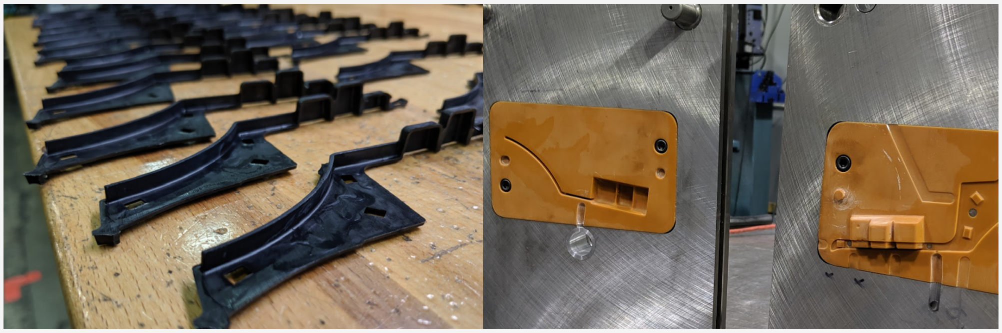
PROCESS

- Customer target was 25 shots of 35% GF Nylon
- Prior attempts with 3D printed tooling has yielded good shots

Customer / Henkel

Industry / Automotive

Material / Nylon 6 & GF Nylon 6 (35%)



RESULTS

	FORTIFY TOOL	METAL TOOL
COST:	$500	$8,000
PROCUREMENT TIME:	5 Days	8 Weeks
# OF PARTS:	50 Nylon 6 50 Nylon 6 (35% GF)	thousands

CASE STUDY: MEDICAL

RAPID MEDICAL DEVICE VALIDATION

Ventilator Project was on a mission to provide ventilators to clinicians and hospitals in need to meet high demand due to COVID-19. They sourced thousands of sleep apnea machines (such as CPAP and BiPAP) to serve as supplementary equipment to hospitals. The Ventilator Project designed a T-splitter component to house the alarm, a critical feature to alert clinicians if airflow to the patient is interrupted. This new design would need to be tested in an oxygen rich environment in order to receive FDA approval. This became a materials problem, where Ventilator Project needed to test the part and in the end-use manufacturing material (polypropylene) to conduct efficacy and safety validation testing to scale up for full scale manufacturing.

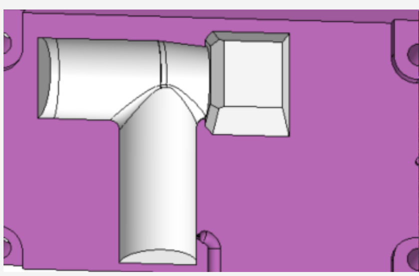
PROCESS

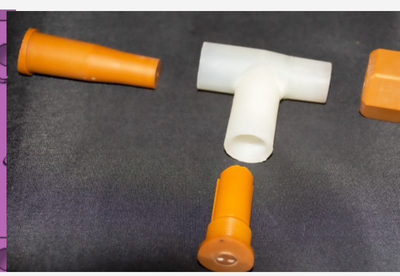
- Designed mold to fit mold frame pocket
- Confirmed part matched design guidelines
- Created inserts around base part
- Modeled geometry into mold halves
- Reviewed mold assembly to confirm fit of inserts and placement of ancillary features
- Released designs for printing

Customer / Ventilator Project

Industry / Medical

Material / Polypropylene





RESULTS

Fortify used 3D printed tooling to get two designs printed for the customer's engineering team. Fortify delivered a set of injection molded polypropylene T-splitter components which met the fit, form, and function quality requirements - but more critically enabled the Ventilator Project team to perform validation testing using injection molded polypropylene.

	FORTIFY TOOL	METAL TOOL
COST:	$700	$4,000
PROCUREMENT TIME:	7 Days	3-6 Weeks

CASE STUDY: CONSUMER

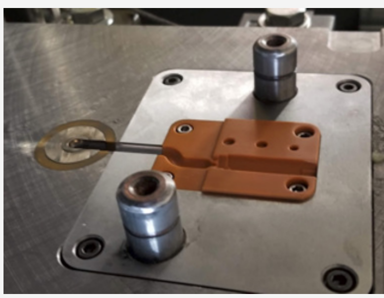
PROTOTYPING MIM WITH 3D PRINTED TOOLS

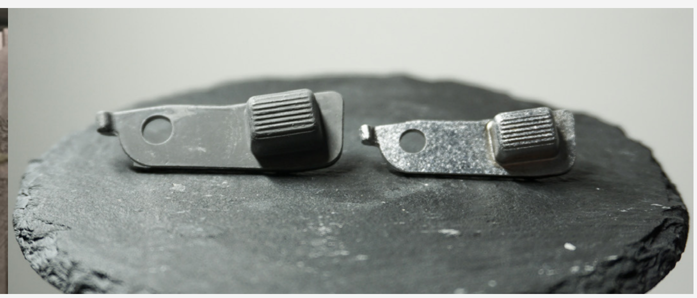
Justifying the economics to prototype metal injection molding (MIM) tools is as challenging as it is timely and costly to produce these tools. 3D printed tools save molders time and money, but traditionally have not been able to perform with the MIM feedstock - an abrasive/polymer slurry. In MIM, after parts are molded on a press, the green body is sintered to obtain pure metal parts.

Alpha Precision Group (APG), a leading service provider of highly-engineered metal fabrication, offers MIM services to meet many customer needs. APG was looking to incorporate prototyping as a part of the process for their customers to better design for production MIM. 3D printed tools provided the fast and economic value that customers were looking for but failed during the molding process.

PROCESS

Fortify was able to supply APG with a tool that met the economic and time benefits of 3D printing and also met the process demands of the MIM process - producing the number of parts needed to validate the components. Fortify's tools are printed on the FLUX ONE printer, which incorporates proprietary hardware components that allow fiber to be reinforced and aligned throughout the tool, resulting in higher performing tools.





RESULTS

	FORTIFY TOOL	METAL TOOL
COST:	$250	$4,000
PROCUREMENT TIME:	4-6 Days	4-6 Weeks
# OF PARTS:	Dozens needed for prototype validation	Thousands (production)

A NOTE ON METAL 3D PRINTING

FORTIFY

POLYMER VS METAL

3D PRINTED TOOLS

WHICH IS BETTER?

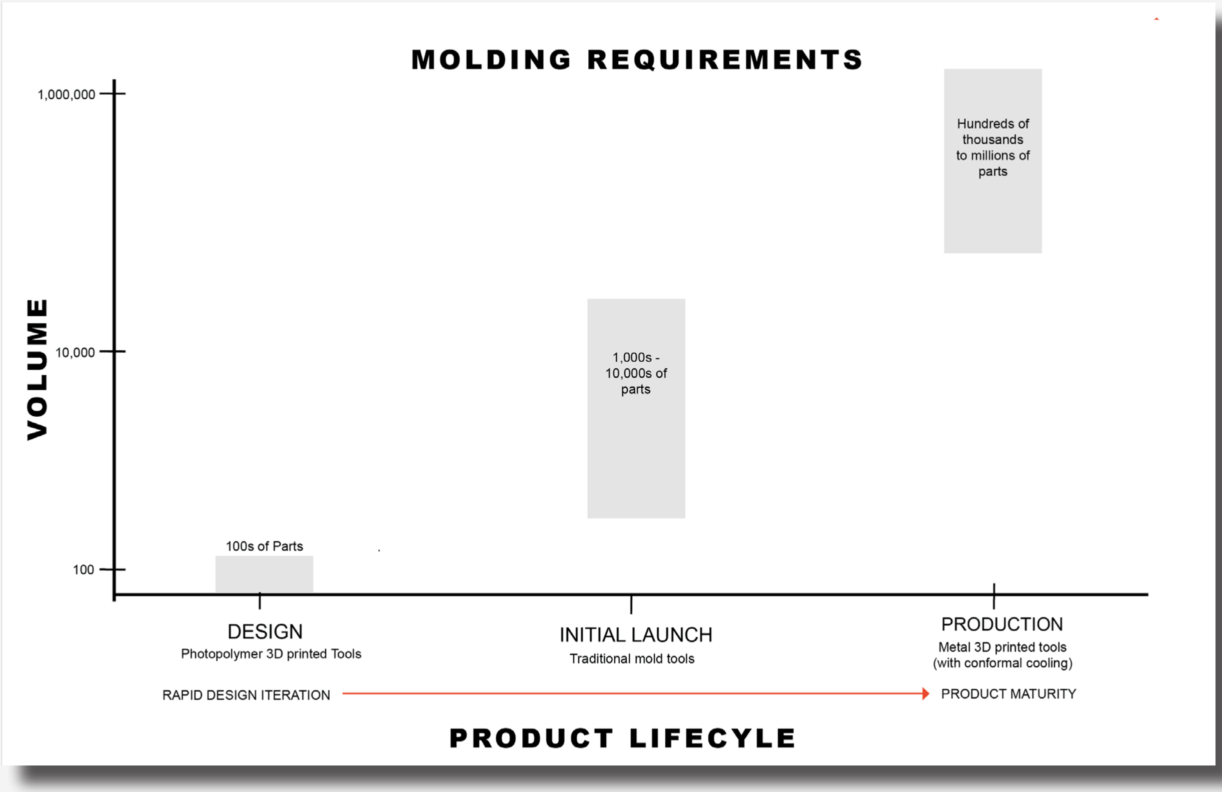
3D PRINTED MATERIAL	TIME	COST
POLYMER 3D PRINTED TOOLS	**PRO** • Fastest method to get first shots in hand • No added time for custom threads, patterns, textures or complex design elements • Reduces time from 3-6 weeks to 3-6 days **CON** • Longer cycle time	**PRO** • Polymer tools cost a few hundred dollars vs. $3-6K for aluminum or steel tools. • More complex tools with side action and hand loads add minimal cost **CON** • Tool life is limited to prototyping and low volume • Some jobs may require multiple mold sets
METAL 3D PRINTED TOOLS with conformal cooling	**PRO** • Faster cycle time once a tool is up and running **CON** • Requires upfront time in mold building • Machining is still required to prep molds for use	**PRO** • Faster cycle times allows more output from mold presses **CON** • Typically costs more and requires specialized knowledge to design

While both polymer and metal 3D printed mold tools offer significant COST and TIME advantages, the way these benefits are calculated is vastly different.

POLYMER 3D PRINTED MOLD TOOLS

Users of polymer based cores and cavities, focus on the TIME it takes to get first shots in hand. These molds can be printed and run within a few days. Multiple design iterations can be validated within a single week with this approach. Users can cut months of time from new product releases. One trade off to consider is polymer 3D printed tooling does run longer cycle times as the molds do not cool quickly.

The COST of polymer based 3D printed tooling also has important trade offs to consider. Polymer based tools can be printed for 60-90% less than metal (several hundred dollars or less versus $3,000 – $8,000 for metal). While these savings are compelling, tool lifetime needs to be factored in to get a true picture. Metal tools can be expected to last tens or hundreds of thousands of cycles while polymer tool life is typically measured in hundreds of shots.



METAL 3D PRINTED MOLD TOOLS

With 3D printed metal tooling, TIME advantages are focused on cycle time and productivity. The key attribute of the metal technology is the ability to fabricate molds with sophisticated conformal cooling channels that allow faster cycle times. This is a natural fit for high volume scenarios where cycle times are critical. Conformal cooling channels are simply not possible to manufacture with traditional machining techniques. Note that conformal cooling benefits do not translate to polymer based tools with their low heat transfer coefficient.

The COST savings associated with metal 3D printed tooling are typically realized on the production floor – not in the building of the tool itself. Metal 3D printers and materials are expensive, and the molds require significant post processing and machining before they can be put into production. Some exciting new technologies are available now that integrate additive and subtractive technologies and help close this gap. Material choices and quality levels of metal 3D printed molds are also trending upward making this option more attractive.

CONCLUSION

As the injection molding industry continues to grow, and 3D printing technologies continue to advance, the ability to leverage both technologies in tandem will give molders a competitive advantage.

Engineers and Product Developers can now prototype designs and validate parts in end use material with Digital Tooling on the FLUX ONE printer. The material combined with fiber-reinforcement gives these tools superior performance than other 3D printed tools on the market.

Tight deadlines and budgets can be mitigated with Fortify's fiber-reinforced 3D printed tools, printing at a fraction of the cost and in a quarter of the time it takes to source traditional metal tools.

Achieving the results indicated in this white paper is a practical goal for those innovators who are willing to invest the time and energy to learn the nuances of this exciting technology and develop a competitive advantage.

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