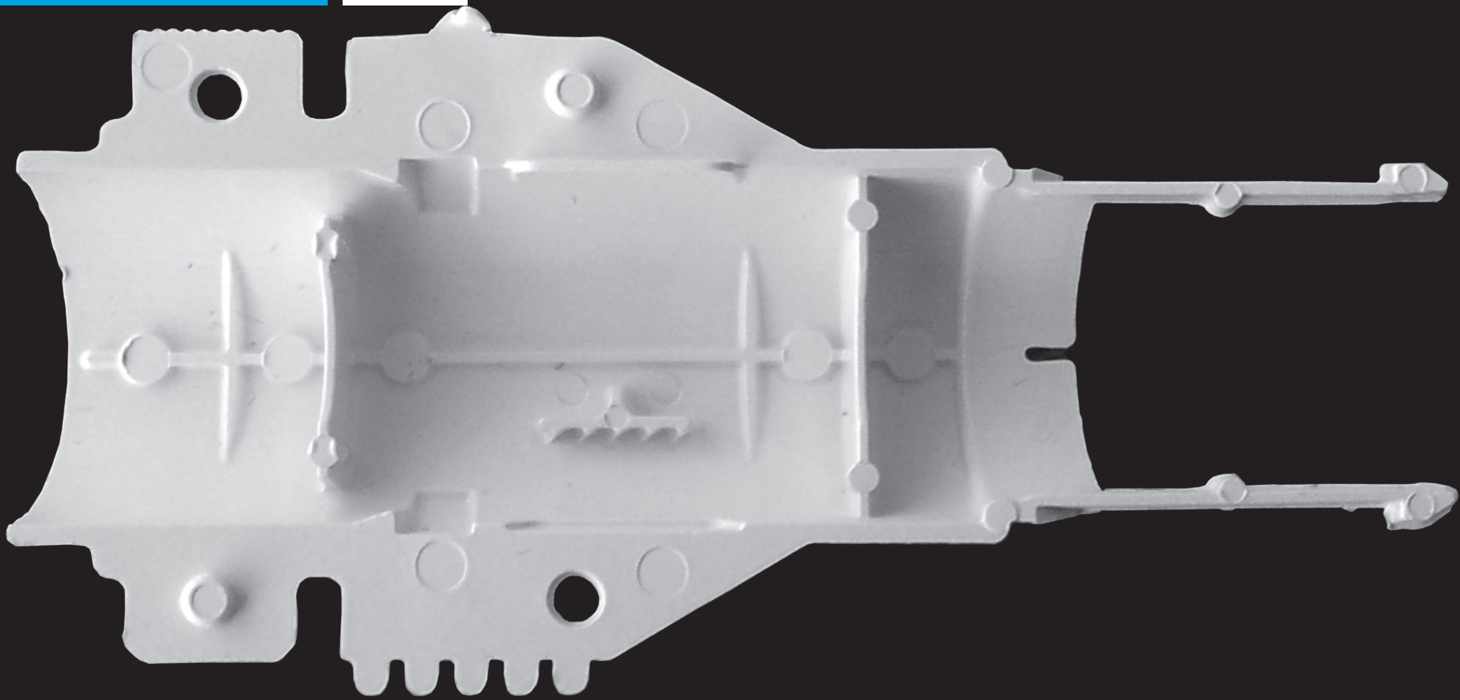

Precision Prototyping

THE ROLE OF 3D PRINTED MOLDS IN THE INJECTION MOLDING INDUSTRY

By Stratasys Mold Tooling Solutions Team

INTRODUCTION

Injection molding (IM) — the process of injecting plastic material into a mold cavity where it cools and hardens to the configuration of the cavity — is best used to mass-produce highly accurate, and often complex, three dimensional (3D) end-use parts and products. However, the development of molds for this process is often painstaking, highly expensive and time intensive.

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THE ROLE OF 3D PRINTED MOLDS IN THE INJECTION MOLDING INDUSTRY

Hard-tooling molds are usually made from tool steel with a CNC milling machine or via electrical discharge machining. When used in mass production, they can last for millions of cycles but cost hundreds of thousands of dollars. What's more, lead times to produce these molds are often measured in months rather than weeks or days.

When tens of thousands of injection molded parts are needed, soft-tooling is an option. Made in aluminum, these molds are less expensive (typically $2,500 - $25,000) and faster to produce (2 - 6 weeks).

Unfortunately, the cost and time of tooling molds is often compounded by factors like design mistakes that require the mold be remade correctly or the need to create multiple iterations before the final part design and quality are achieved. It is with these issues in mind that manufacturers have begun to embrace the use of 3D printed molds to create functional IM prototypes.

POLYJET 3D PRINTED MOLDS: THE MODERN ALTERNATIVE

PolyJet technology is an exclusive method of 3D printing offered by Objet™ 3D Printers from Stratasys that gives companies the ability to build injection molds in-house, quickly and easily.

PolyJet printing creates 3D objects by positioning successive layers of liquid photopolymer into desired configurations. The plastic is then cured (solidified) with UV light. Once fully cured, molds can immediately be placed into IM equipment and used to create prototypes from the same material that is specified for use in the final product. These precision prototypes give manufacturers the ability to create realistic, finished-product examples that can then be used to gather true-to-life, performance data.

PolyJet injection molds are not intended to be replacements for soft or hard tools used in mid- and high volume production. Rather, they are intended to fill the gap between soft tool molds and 3D printed prototypes. The following chart (Figure 1) illustrates the niche PolyJet technology fills in the prototype development process.

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METHODS OF PRODUCING PROTOTYPES	*Optimal Quantity of Parts*	*Material Used to Produce Prototype*	*Average Mold Cost*	*Average Cost/Part*	*Average Cost/Part*
3D Printing*	1-10	FDM® or PolyJet Plastic	N/A	High	High
Machine Milling	1 – 100	Thermoplastic	N/A	High	Medium
Silicone Molding	5 – 100	Thermoset	Low	Medium	High
Injection molding using PolyJet 3D printed mold	10 – 100	Thermoplastic	Low	Medium	Medium
Injection molding using Soft Tools	100 – 20,000+	Thermoplastic	High	Low	Very Low

Figure 1: The characteristics of PolyJet printing versus traditional prototype production methods.

** Although FDM and laser-sintered processes use thermoplastics to create prototypes, the mechanical properties will not match those of an actual injection molded part because a) the processes used to create the prototypes will be different, and b) the materials used to create FDM and laser-sintered prototypes are not generally the same as those materials used to injection mold final parts*

Key points related to PolyJet molds:

- The initial cost of creating a PolyJet mold is

  relatively low. However, PolyJet molds are best suited for runs ranging up to 100 parts depending on the type of thermoplastic used and mold complexity. As a result, the cost per part is medium.
- Building a PolyJet mold is relatively quick; a mold can be built within a few hours as compared to days or weeks to create traditional molds.
- In cases where design changes are required, a new iteration of the mold can be created in-house at minimal cost. This, combined with the speed of PolyJet 3D printing, allows designers and engineers greater design freedom.
- Molds created in Digital ABS™ material can be precisely built in 30 micron layers, with accuracy as high as 0.1 mm. These production features create a smooth surface finish so postprocessing is not needed in most cases.
- Complex geometries, thin walls, and fine details can easily be programmed into the mold design. What's more, these molds cost no more to make than simpler molds.
- No pre-programming is needed to create PolyJet molds. Also, once the CAD design files are loaded, the 3D printing process can run without manual intervention.
- The manufacturing time to injection mold a part using a PolyJet mold is relatively low, although not as low as conventional molding.

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MATERIAL SELECTION

Proper material selection is important for success when injection molding using PolyJet molds.

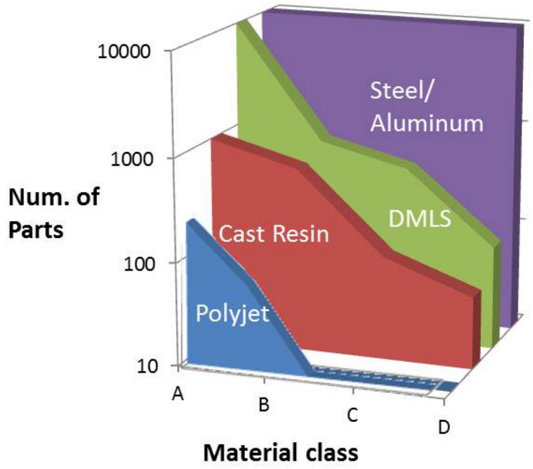
Digital ABS is the best choice for printing IM molds; it combines strength and toughness together with high temperature resistance. Other PolyJet materials like rigid FullCure®720 and Vero™ also perform well as IM molds. However, when used to create parts with complex geometries, molds made from these materials will have shorter lives than those made with Digital ABS.

The best materials for creating injection molded parts are those that have reasonable molding temperatures (< 570 °F / 300 °C) and good flow behavior. Ideal candidates are:

- Polyethylene (PE)
- Polypropylene (PP)
- Polystyrene (PS)
- Acrylonitrile Butadiene Styrene (ABS)
- Thermoplastic elastomer (TPE)
- Polyamide (PA)
- Polyoxymethylene or Acetal (POM)
- Polycarbonate-ABS blend (PC-ABS)
- Glass-filled polypropylene or glass-filled resin (G)

Plastics requiring processing temperatures of 250 °C (480 °F) and higher, or those that have high viscosity at their processing temperature, will shorten the life of the mold, and in some cases, the quality of the finished part.

Figure 2 below outlines the relative number of parts that are typically produced using the different tooling methods.



Polyethylene (PE)
Polypropylene (PP)
Polystyrene (PS)
Acrylonitrile Butadiene Styrene (ABS)
Thermoplastic elastomer (TPE)

Glass-filled Polypropylene (PP+G)
Polyamide (PA)
Acetal (Polyoxymethylene [POM])
Polycarbonate-ABS blend (PC+ABS)

Glass-filled Polyamide (PA+G)
Polycarbonate (PC)
Glass-filled Acetal (POM+G)

Glass-filled Polycarbonate (PC+G)
Polyphenylene Oxide (PPO)
Polyphenylene Sulfide (PPS)

Figure 2: Anticipated Number of Parts by Material Class*
* Numbers will change depending on geometries and sizes of IM parts.

Steinwall, Inc., a leading Midwestern injection molder, compiled data on Digital ABS mold tool life for several thermoplastics. The results are shown in Figure 2B.

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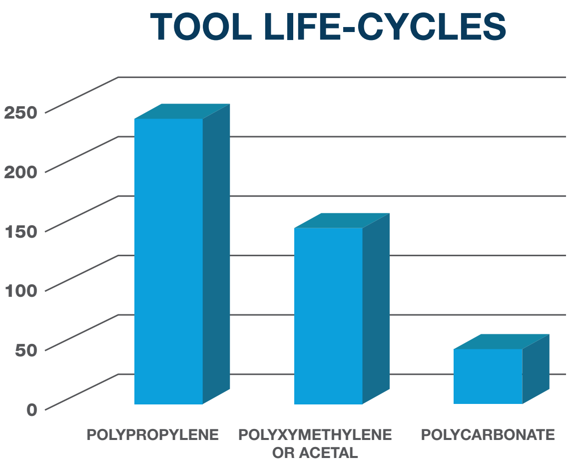


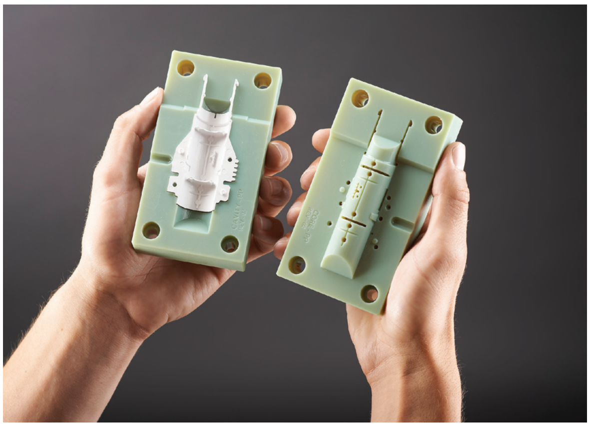
Figure 2B – Tool Life Cycles (Data provided by Steinwall, Inc.)

METHODS OF USE

3D printed molds are just as versatile as their metal counterparts and can be used in a variety of use cases.

Straight-Pull Molds

These molds consist of an A and B side with an internal cavity that forms the part. PolyJet molds are capable of handling thermoplastic materials typically used in production (thermoplastic polyolefins, ABS, thermoplastic elastomers, etc.).



Straight-pull PolyJet injection mold.

It is also useful to take a look at the following cost benefit analysis to understand how the use of injection molding with a PolyJet mold compares to injection molding with an aluminum mold.

As can be seen in the table below (Figure 3), the time savings were highly significant, ranging between a few days and several weeks. Additionally, the cost to produce the molds was generally 40% - 75% cheaper.

	TRADITIONAL MOLDS		DIGITAL ABS MOLDS	
	Cost	*Lead Time*	*Cost*	*Lead Time*
Berker	$22,350	28 days	$3,800	3 days
Arad Group	$5,000	4 weeks	$2,000	10 hours
Grundfos	(not specified)	5 weeks	(not specified)	10 days

Figure 3: Cost benefit analysis in terms of construction time and cost (comparison with aluminum molds)

** Printing cost was calculated in the following manner: material cost + printing time x hourly printing cost per system used. Hourly printing cost was calculated based on average of 17 machine working hours per day.*

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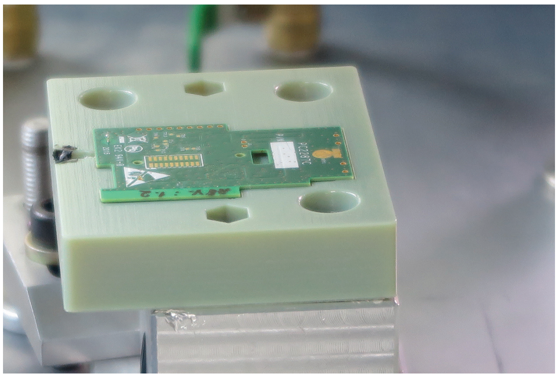
Low-Pressure Injection Molding / Molded Cable Assemblies

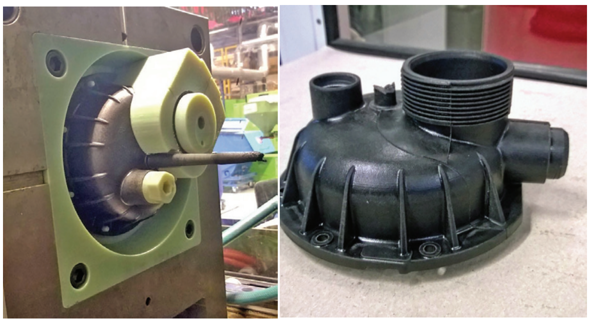
PolyJet 3D printed molds can be used for overmolding printed circuit boards, cables and other electronic components.



An example of a PolyJet low-pressure injection mold.

Insert Molding

3D printed mold inserts allow creative design for challenging geometries. They also improve mold longevity since they can be economically replaced as needed to prevent replacement of the entire mold.



Mold inserts (left) and the final injection-molded part (right).

FIELD TESTING

Stratasys along with Nypro Healthcare, a global manufacturer of precision plastic products for the health care and packaging industries located in Bray, Ireland, conducted a series of tests to assess the performance of rapid prototyped cores and cavities with critical features that included:

- Gears
- Ratchets
- Interlocking legs
- Catch features

During one of the many tests conducted, sample ABS parts were injection molded into a single PolyJet mold made from Digital ABS. Parameters such as maximum pressure, cushion, and core and cavity temperatures were tracked.

Figure 4 presents the injection molding parameters that were used for the first 25 shots after the mold had been optimized.

Upon completion of the tests, the mold was deemed to be stable as indicated by a constant injection pressure and cushion, and that by using the recommended procedure for mold cooling, the temperature in the core and cavity did not exceed 58° C. What's more, the quality of the injection molded prototypes was deemed by Nypro to be "good."

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THE ROLE OF 3D PRINTED MOLDS IN THE INJECTION MOLDING INDUSTRY

ABS – PROCESS PARAMETERS

SHOT #	F/H TEMP (°C)	F/H TEMP (°C)	M/H TEMP (°C)	CUSHION (MM)
1	54.3	59	880	9.19
2	18.1	38.1	887	9.12
3	51.2	42	892	9.21
4	48.4	37.9	894	9.2
5	49.0	40.5	896	9.18
6	49.6	38.2	894	9.24
7	49.6	39.8	897	9.25
8	50.9	37.6	891	9.15
9	53.9	38.1	894	9.17
10	53.6	40.2	884	9.14
11	54.8	44.0	890	9.27
12	53.3	40.8	882	9.26
13	55.1	41.8	884	9.24
14	53.1	41.7	884	9.07
15	57.0	42.1	897	9.22
16	48.2	43.7	893	9.19
17	52.7	41.9	891	9.22
18	55.4	42.3	882	9.15
19	55.7	42.9	884	9.2
20	56.3	47.9	884	9.26
21	57.3	46.8	886	9.29
22	55.1	47.6	882	9.23
23	56.2	43.6	885	9.23
24	55.1	45.2	884	9.19
25	57.5	47.1	882	9.22

Figure 4: ABS test data for Nypro injection molded parts.

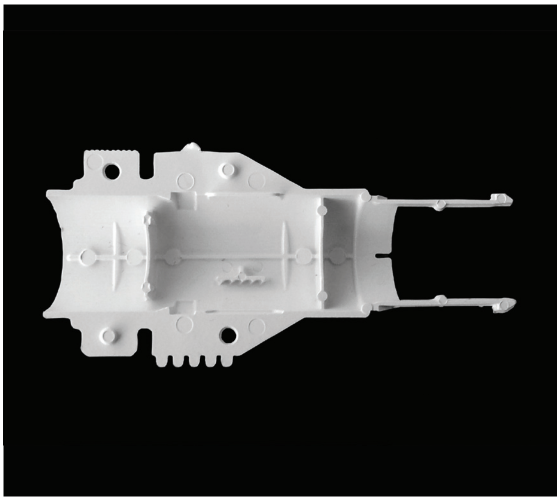

Figure 5 : Component part created by Nypro to test injection molded parts using a PolyJet mold.

Figure 6 : Finished sample part.

BEST FIT PARAMETERS

PolyJet molds are a best fit for the application when working with:

Thermoplastics:
- Reasonable molding temperatures < 300° C (570° F)
- Good flow behavior
- Candidates:

--Polyethylene (PE)
--Polypropylene (PP)
--Polystyrene (PS)
--Acrylonitrile Butadiene Styrene (ABS)
--Thermoplastic elastomer (TPE)
--Polyamide (PA)
--Polyoxymethylene or Acetal (POM)
--Polycarbonate - ABS blend (PC-ABS)
--Glass-filled resins

- Low quantities (5 to 100)

Size:
- Mid-sized parts <165 cm3 (10 in3)
- 50 to 80-ton molding machines
- Manual hand presses can also be used.

Design:
- Multiple design iterations are required.

Testing:
- Functionality confirmation is required.
- Compliance testing (e.g., UL or CE) is required.

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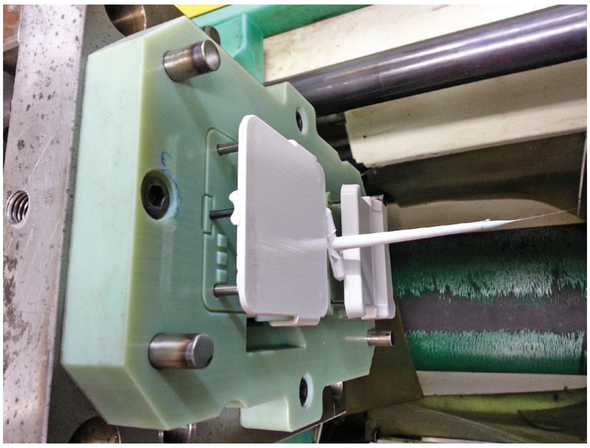
Nypro offered the following analysis of the tests: “It can be concluded that the injection molding trials were very successful… the process of printing cores and cavities can be considered an advantage in terms of time, initial functionality evaluations and reduced tooling cost.”

REAL-WORLD PERFORMANCE

The capability of 3D printed injection molds is best represented by the customers that use them, demonstrated by the reduction of product development costs and the time to bring those products to market. A key advantage that’s common throughout the following examples is the ability to use production material in the 3D printed molds, a necessity for functional prototyping and short-run/low-volume production.



Injection-molded parts being ejected from a 3D printed mold.

Berker

Berker is a major producer of electronic switches used for intelligent building management systems whose products include injection molded parts. To reduce the time and cost of prototyping, Berker chose to use 3D printed injection molds. In Berker’s case, prototypes need to be made from production materials to validate required electrostatic discharge tests.

Berker leveraged the time and cost savings associated with 3D printed injection molds to make three molds to test several different thermoplastic materials in their design. Taking this same approach using conventional metal molds would have resulted in much higher cost and possibly months of lead time to procure the molds. More significantly, it gave Berker the ability to evaluate several different solutions at the same time, accelerating the R&D process.

The bottom-line impact for Berker was an 83% drop in cost per mold and an 85% reduction in production time. As a result, Berker adopted this approach across other product lines to create prototype and sample parts in production materials.

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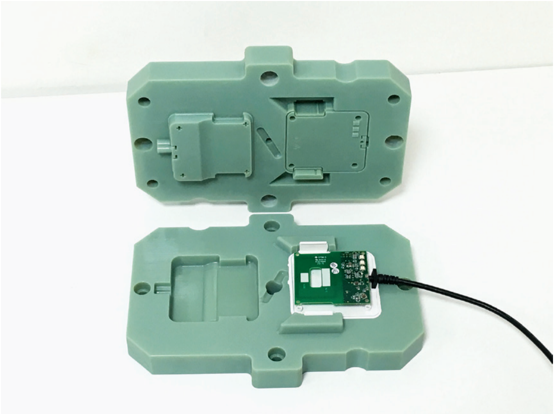
Arad Group

Arad Group specializes in developing products that measure the flow of water for residential and industrial applications, making over 500,000 units per year with production facilities that include injection molding. One application involves the use of injection molded parts that are ultrasonically welded together to provide a watertight seal around sensitive electronics.

Testing the integrity of these welds requires the parts be made in the final, production material. That's traditionally meant using metal molds that can take one to three months to produce. Any mold changes that are necessary as a result of testing drives increased expense and development delays.

As a solution, Arad embraced 3D printed injection molding for prototyping and functional testing using Digital ABS mold material. On one specific use case this strategy reduced mold production time for prototype testing from four weeks to 10 hours. This kind of efficiency lets Arad quickly produce functional prototypes that can be field-tested, ultimately reducing time to market in a competitive industry.



A 3D printed mold created in Digital ABS material by Arad Group.

Grundfos

For Grundfos, the world's largest pump manufacturer, it was a question of which 3D printing process and materials provide optimal results. Grundfos evaluated various polymer-based 3D printing methods to compare how the materials functioned in injection molding operations. Like Berker and Arad Group, Grundfos needed to use production materials for functional prototype testing.

Tests with PolyJet and SLS technologies revealed that surface roughness of SLS molded parts was unacceptable. The surface roughness of the SLS molds caused the injected material to adhere, causing problems with ejection and ultimately damaging the mold. In contrast, Grundfos found that the smoothness of the PolyJet molds provided an advantage during part ejection, reducing the shear stress on the mold.

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THE ROLE OF 3D PRINTED MOLDS IN THE INJECTION MOLDING INDUSTRY

Additional tests were accomplished to determine the effectiveness of PolyJet molds for larger, more complex parts. Even with challenging injection materials like glass-filled Noryl (PPE-PS GF 30%) Grundfos concluded that PolyJet Digital ABS is an excellent material for prototyping with 3D printed injection molds, capable of creating accurate parts for functional tests and design evaluation.

CONCLUSION

The use of PolyJet 3D printed molds allows manufacturers the ability to take functional testing to a new level, by creating product prototypes from the same IM process and materials that will be used to create the final product. With this technology, companies can generate superior performance data and validate certification confidence.

PolyJet molds are unique in that they perform in the same way as metal molds but are much cheaper, easier and faster to make. With PolyJet technology, manufacturers can produce prototypes at speeds and costs far below traditional methods. As a result, 3D printing allows manufacturers to easily evaluate the performance, fit and quality of potential products before mass production starts

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