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Choosing the Right Material for Injection Molds

AN EVALUATION OF VARIOUS 3D PRINTING TECHNIQUES

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by Thorsten Brorson Otte, Grundfos A/S, and Stratasys

Proper material selection is a critical success factor when creating injection molds. Realizing their own need for fast, production-ready injection mold prototypes, pump manufacturer Grundfos conducted several tests to determine its ideal substance. With the optimal material, it found that manufacturers can leverage the best 3D printing has to offer making complex molds inexpensively.

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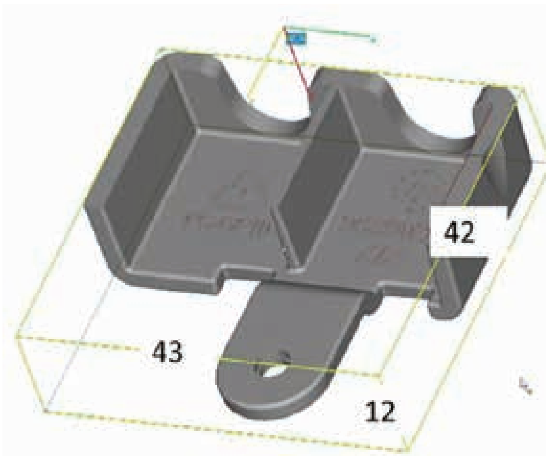

Figure 1. The part selected for initial evaluation of polymer-based 3D printed mold inserts

Grundfos, headquartered in Bjerringbro, Denmark, is the world's largest circulator pump manufacturer with an annual production of 16 million units. Its circulator pumps are commonly used for heating and air conditioning; whereas its centrifugal pumps are most often used for water supply, sewage and dosing needs.

Mass producing pumps involves a series of processes, like injection molding its plastic components. Because pumps often operate in high-temperature, fluid-rich environments, Grundfos uses rugged thermoplastic components such as glass-reinforced PA, PC, PPS and POM. As part of the pump assembly quality inspection, components must withstand working conditions of the pump. Specifically, plastic parts must pass burning, functionality, geometry, hydraulic and electric testing.

Therefore, while still in the development stage of new components, it is crucial to prototype with the same material as the manufacturing process. This way, manufacturers can qualify both the specific design and material combination.

Grundfos evaluated several polymer-based 3D printing technologies for 3D printing mold inserts. For the initial tests, a simple geometry was selected with general dimensions of 42 x 43 x 12 mm (Figure 1) and with the functionality to cover cables in a control box (Figure 5). Due to certain functionality requirements – for instance, the control box would be under water – Grundfos could not compromise on the material and production process.

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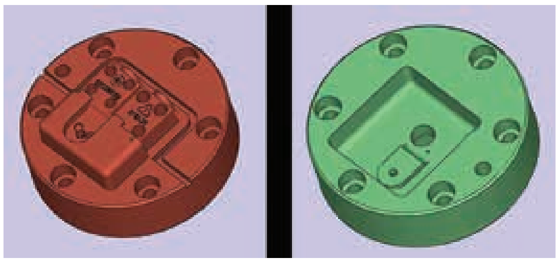

Figure 2. Core (left) and cavity (right) inserts. The six holes on the periphery are intended to receive standard bolts to secure the printed inserts into a mold base

MOLD #1 TESTING

To determine its optimal mold material, Grundfos devised trials for two different injection molds – one of va two-part standard mold and one of a more complex, nine-part design. Grundfos designed the molds for the first part with two main parts, core and cavity, seen in Figure 2.

Grundfos designed a mold base (Figure 4) to facilitate the assembly of the printed mold inserts (Figure 3). The printed mold insert is mounted to the mold base using standard bolts. In the core side of the mold, ejector pins were added to facilitate part ejection automatically. The pins are designed to be flat with the core surface and they have a tight fit in the printed ejector pin holes.

An important design feature is the insertion of a metal sprue bushing (marked in a white arrow in Figure 4) in the printed sprue hole. The sprue bushing is also an important design feature in the traditional manufacturing process using metal molds; in that process and here, it serves as a direct gate to the part cavity from the hot nozzle. The large gate that is strategically located at the top of the part, called the sprue gate, facilitates even filling of the cavity, while reducing the pressure and shear heating. In fact, this key factor enables Grundfos to mold aggressive thermoplastics with high viscosities in the printed mold.

Testing Mold #1

Grundfos wanted to compare how the materials from different 3D printing technologies functioned in injection molding, so the company selected four materials-based polymers for 3D printing the core and cavity mold: Transparent (RGD720) and Digital ABS™ that run on PolyJet™ technology, and PA2200 and PA3200 with glass fibers that run on SLS technology. After 3D printing the different

Figure 3. The 3D printed inserts include, on the left, Digital ABS (green) and Transparent (yellowish), and on the right, PA12 (with glass fiber, gray) and PA (without glass fiber, white).

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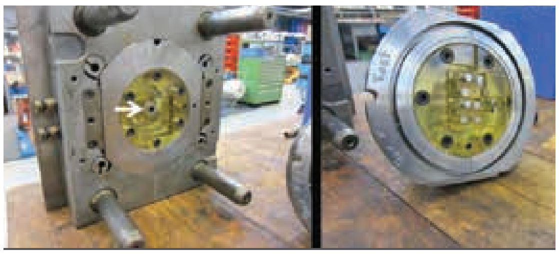

Figure 4. Cavity and core side of the mold. The arrow indicates the sprue bushing, an important design feature.

molds on its Objet500 Connex3™ 3D Production System, Grundfos checked each mold capability by injecting various materials. General properties of the four molds materials can be found in Table 1.

Grundfos tested the four types of mold with a range of materials. Grundfos injected different types of material into each mold: POM, Noryl with 20% glass fiber component, polycarbonate with 10 percent glass, PPS that is 40 percent glass-filled (GF) and PA66 30GF (30-percent glass-filled). The glass-reinforced PPS and PA materials proved the most challenging in regard to working temperature, viscosity and abrasiveness due to the high loading of glass fibers.

The testing results can be seen in Table 2. The most comprehensive evaluation for surface smoothness was made using the glass-reinforced PPS and PA. Both SLS mold types provided unsatisfactory surface quality. The molds were injected with PPS with 40% glass fiber, a challenging resin with a relatively high abrasiveness due to the glass fibers. The PolyJet molds' surface smoothness was so satisfactory that Grundfos decided to stop testing the SLS molds and to test the remaining materials only with the PolyJet molds.

The main problems that Grundfos encountered were with the surface roughness of the molded parts. The SLS molds failed to eject the parts due to the injected material shrinking to the rough mold surface, then pulling it apart during ejection of the solidified part. The PolyJet inserts, on the other hand, provided a huge advantage with smooth surfaces straight out of the printer. This reduced the shear stress the printed mold is subjected to during part ejection.

Both the Transparent and Digital ABS molds passed visual inspection and functional tests, even with glass-filled PPS. Grundfos concluded that when molding relatively simple geometries, Transparent and Digital ABS gave similar results and each produced 20 usable parts.

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TABLE 1. GENERAL MATERIAL PROPERTIES

	SHORE D HARDNESS	MELTING POINT	SOFTENING TEMPERATURE
Transparent (PolyJet)	83	No melting point	48.7° C
Digital ABS (PolyJet)	85-87	No melting point	58-68° C
PA2200 (SLS)	75 ± 2	172-180° C	163° C
PA3200 (SLS)	80	172-180° C	166° C

TABLE 2. THE TEST RESULTS

MATERIAL	MELTING TEMP	TRANSPARENT	DIGITAL ABS	SLS WITHOUT GLASS	SLS WITH GLASS
POM	190° C	✔	Not tested	Not tested	Not tested
Noryl 20% glass	280° C	✔	Not tested	Not tested	Not tested
Polycarbonate 10%	310° C	✔	Not tested	Not tested	Not tested
PPS-40 GF	340° C	✔	✔	×	×
PA66 30 GF	300° C	✔	✔	×	×

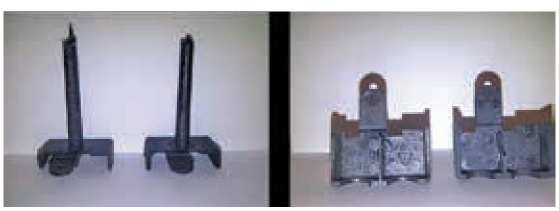

Figure 5. Injected cover cables prototype (left) and injected cover cables prototype, bottom view (right).

This initial test convinced Grundfos that PolyJet molds are capable of molding a limited quantity of parts for functional testing during the development stage. After the parts passed the functionality and geometric measurement tests, they were used to validate the functionality of the part, as well as its form and material selection for specific applications.

MOLD #2

Once Grundfos was satisfied with a material choice for its injection mold, the company decided to put it to a new kind of test. In the second phase of its evaluation, Grundfos attempted to mold a larger, more complex part, seen in Figure 6. The ambitious prototype design required a nine-part injection mold for the complex part with both threads and many ribs. The company estimated that using the printed PolyJet molds to create

Figure 6. Top and back views of the part as it came out of the printed core and cavity. Notice the complex ribbed sections in the right picture. The part's dimensions are 160 mm (diameter) and 70 mm (height).

these prototypes would save 50 percent in costs and 70 percent in lead time compared to the alternative molds in traditional aluminum.

This part posed several challenges, including material selection, overall part size and elaborate design features such as threaded features, pickouts and a ribbed section. Due to part functionality, it was crucial to obtain molded prototypes in the final thermoplastic, the 30-percent glass-filled Noryl (PPE-PS-GF30).

Mold Design

Since only several parts were required and cycle time was not a concern for this part, many of the mold features were designed to be manually removed after each injection and placed back in the mold. This way, Grundfos could mold complex features and undercuts without having to invest in automated core side actions.

The printed parts were designed with no gap between the adjacent surfaces. The printer tolerance was ±0.2 mm. (Grundfos could grind off any excess manually.) A printed insert was 0.7 mm too large in the one side, and 0.2 mm too small in the other side. Grundfos decided that the assembly parts should be designed undersized to fit against another part in 0.05 to 0.1 mm space between the parts.

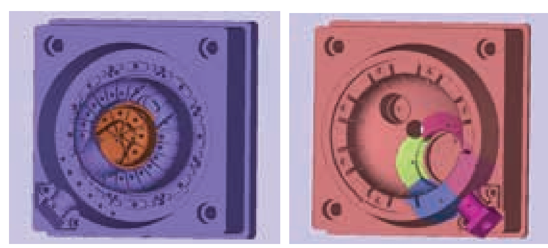

Figure 7. The mold design. The different colors depict the nine components that make up the mold assembly..

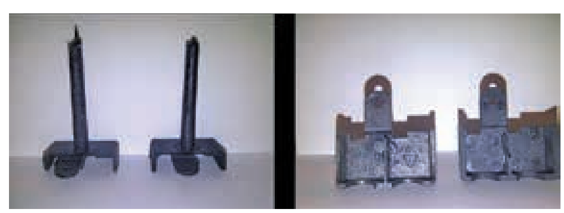

Figure 8. Printed mold components in Digital ABS. The metal sprue bushing will insert into the hole in the mold part on the far right.

The hole where the metal sprue bushing was inserted can be seen in Figure 7's right image.

A large center gate was designed from the sprue into the part to reduce the pressure, shear heating and promote even filling of the mold cavity.

Mold Printing

The mold contained nine parts. The molds' parts were printed in Digital ABS and Transparent. Grundfos' main consideration with orientation was to achieve maximum glossy surfaces in the locations that are exposed to the injected polymer. For example, the build orientation for the threads ensured that they would not be built with support material, enhancing the strength of the mold component and the appearance of the molded part. Figure 9 shows the tray orientation in Digital ABS; the same tray setting was used for the Transparent part.

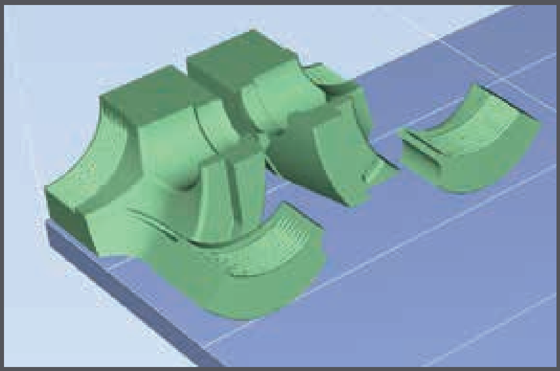

Figure 9. The correct orientation of mold components.

Figure 10. The core (left) and cavity (right) inserts assembled onto 200 x 200 mm insert mold base.

Mold Assembly

The printed parts were sanded a bit in key areas to fit in the assembly. The parts were 0.2 to 0.3 mm out of tolerance and required slight modification. Grundfos selected a mold base with inserts of 200 x 200 mm to fit the printed inserts, shown in Figure 10.

Injection Process

Grundfos used a 200-ton 3K ENGEL for the injection molding. The machine used an open-cylinder nozzle, a 50-mm screw, a R40 nozzle tip and standard 8-mm diameter hole.

The material used for the test was 30% glass-filled Noryl (PPE-PS-GF30%). Injection parameters were originally set with minimum volume and pressure. Afterward, these parameters were increased in every shot until a satisfactory and fully molded part was produced. A satisfactory part with the right parameters was produced in the sixth shot.

On the Transparent mold, injected material caused tears and cracks (Figure 11). The tears and cracks increased shot by shot; after the seventh shot, Grundfos stopped using this mold.

The Digital ABS mold replaced the Transparent mold using the same injection parameters. The resulting parts had a nice surface quality and the mold did not tear in the same way. Grundfos created 20 satisfactory parts before stopping so the mold could still be used for more tests.

Due to the long cooling time, some of the material in the cylinder was overheated and burned. Therefore, every injection cycle started by purging the burned material from the cylinder to prevent burned material being injected into the mold.

Figure 11. The injected part from the Transparent mold with the tears

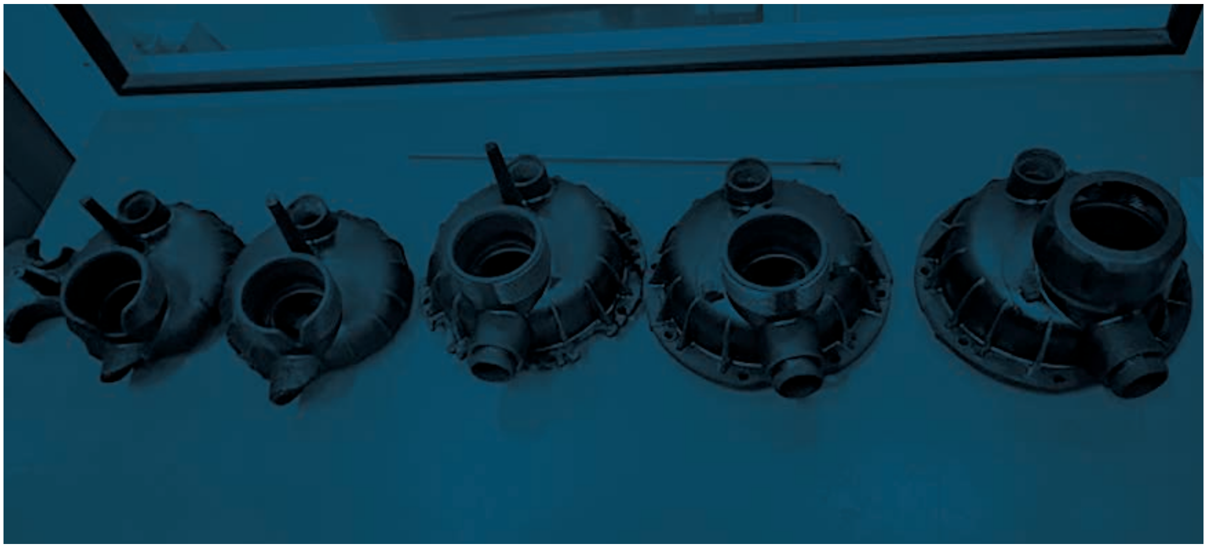

Figure 12. The first six parts using the Transparent mold.

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TABLE 3. PROCESSING PARAMETERS

MACHINE: ENGLE 200T	
Clamp force (KN)	500
Injection Pressure limit (bar)	500
Back Holding Pressure (bar)	50
Actual pressure at switchover position (bar)	360
Holding pressure (bar)	20
Holding time (sec)	25
Cooling time (sec)	110
Shot size (ccm)	330
Switch over point (ccm)	51.1
Temperature range (°C)	265 - 270

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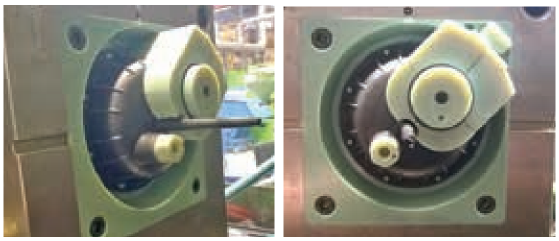

Figure 13. An injected part in the molds attached to the steel plates and to the injection machine

The molds were cooled with compressed air and by waiting till the mold reached to about 20°C.

Grundfos' production of the prototype was relatively quick, just 10 days from design to finish, compared to five weeks if the mold had been machined. The fast production of the prototype with the same end-use material (30% glass filled Noryl) and in the same process (injection molding) yielded great time savings. Additionally, Grundfos determined that Digital ABS was an ideal material for prototyping, and that it could create detailed, accurate injected parts with many complicated features. That helped Grundfos use the injected part for functionality tests and to evaluate their design.

Figure 14. A side view of the injected part with attached molds part and sprue

Figure 15. A side view of the injected part

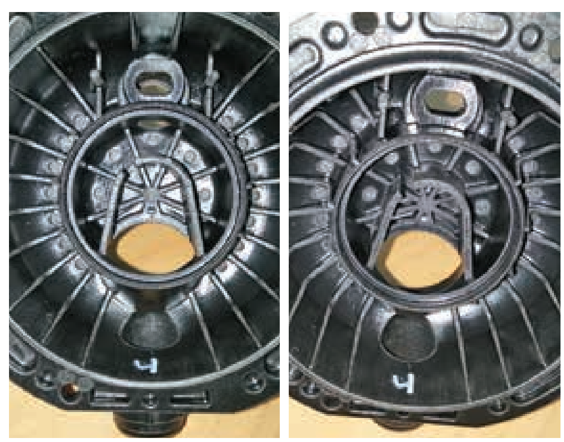

Figure 16. The bottom view of the injected part.

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