



Demonstration of an Effective Design Validation Tool for 3D Printed Injection Molds (3DPIM)

Injection molding, the process of injecting plastic material into a mold cavity where it cools and hardens to the configuration of the cavity, is one of the world's most popular manufacturing processes. It is best used to mass produce highly accurate, and often complex, end-user parts.

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To obtain a comprehensive and accurate assessment of a part's functional performance or to run the safety tests on electrical or mechanical components, injection molded parts must be produced using the actual materials and injection molding process of the final production part. Therefore, 3D printed injection molds (3DPIM) are increasingly adopted to create prototype parts to detect issues in the part's form, fit, function and validations (certificates) if needed.

These molds are far less expensive than their steel (hard) counterparts with shorter lead time, sometimes up to 90%, but dedicated analysis tools for 3DPIM are not yet available. Therefore, Stratasys and Moldex3D joined together to perfect 3DPIM solutions with upfront simulation predictions. Using both solutions, one can develop the production tool much more efficiently with better results. Furthermore, customers can increase the longevity of the printed tool, improve the design and understand the process better.

WHAT STRATASYS CAN DO

3DPIM are able to create a prototype for a fraction of the cost and a matter of days compared to the weeks-long lead time associated with traditional tooling processes. For example, the price to create a small, straight-pull mold ranges from \$2,500 to \$15,000 with delivery usually taking 10 days to four weeks. This is an investment that most companies find difficult to justify for a few dozen test parts. 3DPIM have the capability to produce five to 100 parts in the same thermoplastic as production parts. They can be constructed in one or two days for a fraction of the cost of soft metal or steel tooling. Currently, 3DPIM are mostly used with thermoplastics injected up to 300 °C, with some limitation on part geometries and size relative to traditional metal tools. However, they show great benefit to customers where this method can be applied.[1]



“Moldex3D is a powerful tool to help evaluate the moldability of 3D printed injection molds. Combining Stratasys with Moldex3D, customers have an enhanced solution for validating and testing the parts and molds for successful production.”

Nadav Sella, Director, Manufacturing Tools at Stratasys

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Benefits of Using 3DPIM:

- Average time savings of 50% - 90% for lead development
- Average cost savings of 50% - 70%
- Functional evaluation with production plastics
- Efficiency gains and automated tool-making with few steps
- Early validation on part performance, mold design and thermoplastic selection

The printed mold needs to bear the resin being injected at high temperature and high pressure. Moreover, high shear stress exists and can ruin the mold when ejecting the part. The quantity of successful shots depends on the injected material (flowability, viscosity and melting temperature) and the mold geometry. To optimize the performance of a particular mold geometry, it is recommended for users to follow the Stratasys design guidelines (TAG – Technical Application Guide [1]). This document information will help 3DPIM users to:

- Evaluate the mold with a printed replacement
- Revise the printed mold design such as the gate locations or number of gates
- Use metal inserts for critical features

WHAT MOLDEX3D CAN DO

Moldex3D is a process CAE (Computer Aided Engineering) simulator that evaluates the effect of material properties, process conditions and part/mold design on the process dynamics and part quality. The mold filling, packing, cooling and post-molding warpage analysis provide valuable information in the design phase as well as in the trouble-shooting of the existing process/design. Moldex3D also predicts the process characteristics during the injection molding cycle and shrinkage behavior of the molded part according to the selected material and process conditions. It helps to quickly evaluate, verify, and further optimize the design parameters (Fig. 1).

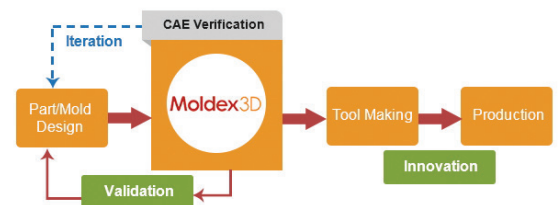


Fig. 1 - True 3D numerical simulation technology.

Moldex3D simulates the entire injection molding process using true 3D solvers; thus, there is no need to manually simplify geometry models for the simulation. For 3DPIM users the “Moldex3D Professional Package” or “Moldex3D Advanced

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Package” is the most suitable package for 3DPIM defect prediction and design optimization (Fig. 2).

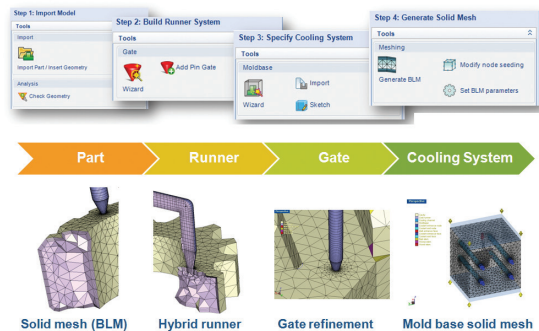


Fig. 2 - The simulation process of Moldex3D.

Moldex3D can generate full 3D solid mesh with enough boundary layers, intuitively, to guarantee prediction accuracy. After solid mesh generation, users can easily define process conditions and follow the basic operation procedures to perform the analysis. According to the analysis results, part/mold dimensions and layout can be optimized considering the rheological, thermal, and mechanical properties.

USING MOLDEX3D TO DETECT POTENTIAL 3DPIM DEFECTS

The product in this showcase is a test part designed by Stratasys® to test several common design features that appear in injection molded

parts while using a printed mold, (i.e., 3DPIM process). Past experience indicates feature cracking is a critical issue which has to be avoided to ensure product quality and prototype mold life requirements. Stratasys applied Moldex3D to predict potential flow-induced defects and cracking. This showcase demonstrated the value of early defect diagnosis for improving 3DPIM performance (Fig. 3).

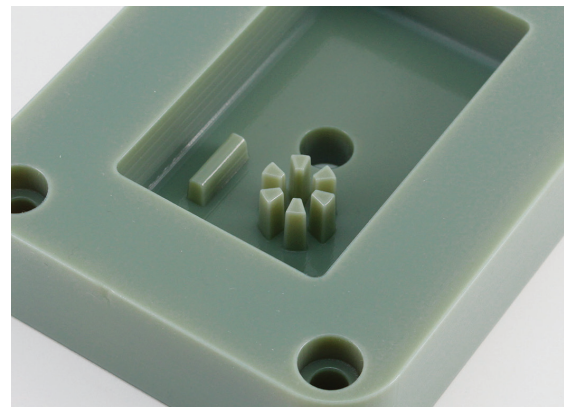


Fig. 3 - The 3DPIM with towers

Challenges

- The towers are heated and softened due to low thermal resistance, and tend to break during injection or ejection (Fig. 4).
- The mold surface temperature of the specific area is significantly higher after part ejection.

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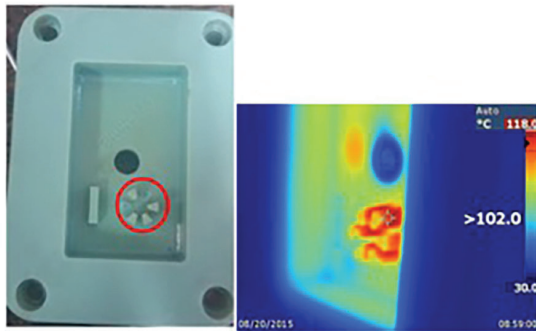


Fig. 4 - The towers tend to break off after 2 to 6 shots.

Solutions

Moldex3D Designer BLM (boundary layer mesh) and MCM (multiple component molding) analysis technologies are utilized to observe the flow behavior and deformation of 3DPIM. In this case, the 3DPIM of core and cavity molds are set as two “inserts” of a plastic mold in Moldex3D analysis (Fig. 5). We then can apply Moldex3D Core Shift analysis to predict the insert deflection and stress results caused by non-uniform pressure distribution during the filling stage (Fig. 6).

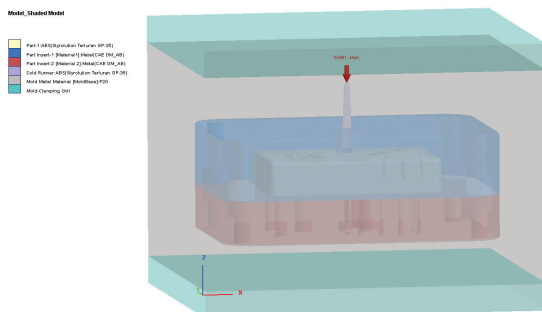


Fig. 5 - BLM model created in Moldex3D.

The molding condition data are provided as follows:

Part material	ABS Terluran GP-35	
3DPIM material	Digital ABS	
CUSTOMIZED 3DPIM MATERIAL PROPERTIES		
Maximum machine pressure	80 MPa	Packing pressure: 20 MPa
Filling time	2.4 seconds	Cooling time: 70 seconds
Packing time	2.5 seconds	Mold-open time: 100 seconds
VP switch	98%	

Results

The comparison of simulated melt front and a short shot sample from real molding at 1.24sec (Fig. 7) demonstrates the feasibility of using Moldex3D to evaluate flow behavior inside a 3DPIM. The tower roots are under higher von Mises stress by the unbalanced flow fronts around the towers, implying greater stress subsection which may easily lead to fracture. We can clearly observe the towers broke off at the same locations in real molding (Fig. 8).

Comparison of the simulated mold temperature distribution and thermal image from the real molding further validates the accuracy of Moldex3D thermal analysis. The red area indicates elevated 3DPIM surface temperature which prohibits efficient cooling and may induce excessive thermal stress (Fig. 9).

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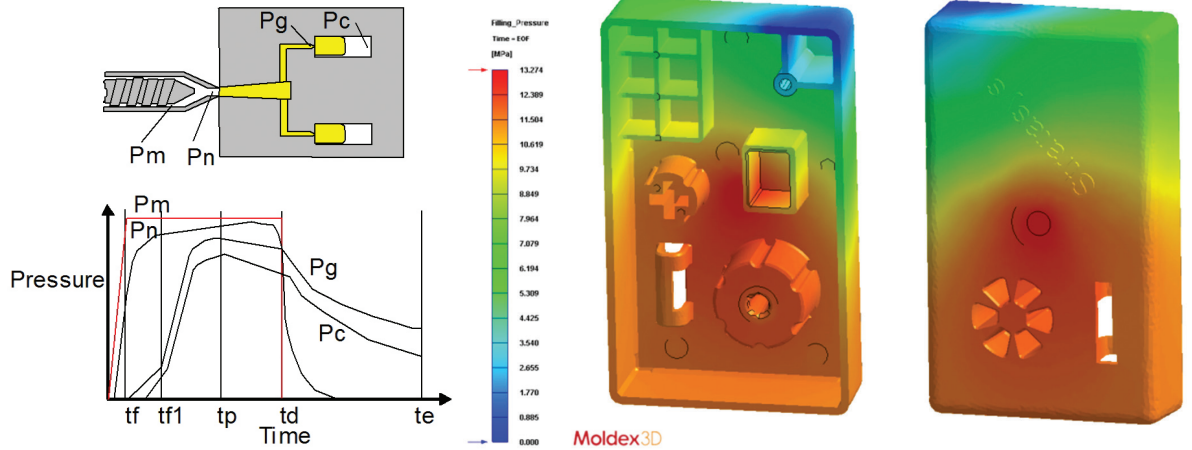


Fig. 6 - The pressure in the injection molding process at different locations.

Because the 3DPIM typically has no cooling system the mold temperature will be elevated after several shots. The Moldex3D Transient Cool analysis capability enables users to create several analysis runs to simulate the thermal results after a series of shots. By referring to the previous shot temperature results, the current analysis

can consider the residual thermal conditions from previous shots. Users can visualize the mold temperature distribution and how the mold temperature is elevated over shots (Fig. 10).

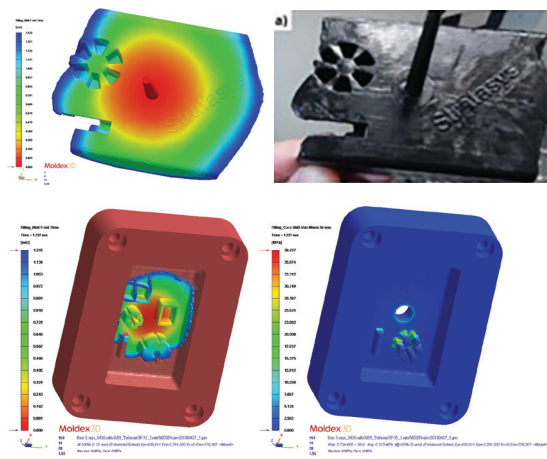


Fig.7 - The flow behavior indicates unbalanced flow around the towers and leads to the corresponding von Mises stress result.

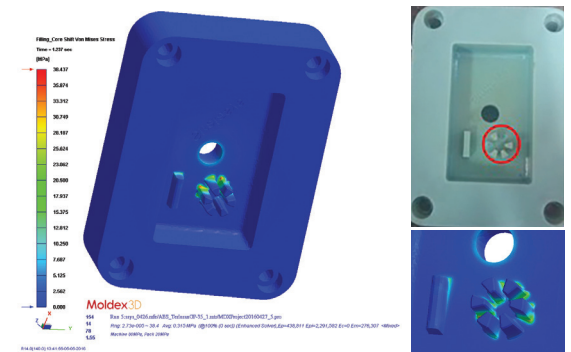


Fig. 8 - The towers show greater stress in two roots that may cause break-off in the real part.

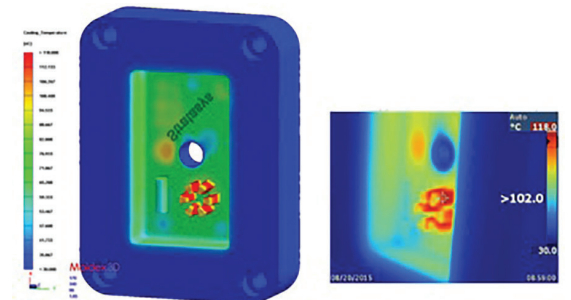


Fig. 9 - Temperature comparison at the end of cooling (mold just open).

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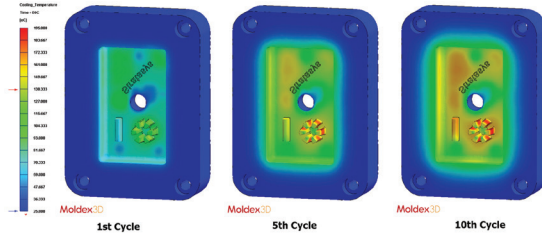


Fig.10 - Temperature comparison and accumulation at the 1st, 5th and 10th shot.

How Can the User Modify/ Improve the Design Based on the Simulation Results?

Moldex3D provides high-fidelity simulation results of flow-front animation, mold temperature variation and distribution, and stress concentration of 3DPIM. Based on the original simulation results, users can redesign and optimize the product process condition, materials (if allowed), and modify the mold and part design to use 3DPIM to produce prototype parts effectively. For example, the gate number and location(s) can be revised to reduce the stress applied to the towers.

The following table has three main sections, Process, Material, and Redesign, for 3DPIM users to improve or optimize the product evaluation and development.

PROCESS CONDITION	TARGET
Filling rate	<ul style="list-style-type: none"> Determine flow rate profile to ensure smooth filling Change Melt Temperature for easy filling and less residual stress Achieve optimized flow rate profile <ul style="list-style-type: none"> Lower filling pressure Lower clamping force
Temperature	
MATERIAL VARIATIONS	TARGET
Melt material	<ul style="list-style-type: none"> The number and location of gates based on the flow length capabilities of material Filling time, packing time, cooling time, melt temperature and mold temperature will vary with material Fiber-reinforced material to enhance the mechanical properties of the part
Metal/printed mold inserts	<ul style="list-style-type: none"> The effect on the radiating speed by heat conductivity and thermal translation Metal mold insert can be used for the weak feature for higher stiffness
Metal sprue bushing	
MODEL REDESIGN	TARGET
Gate size	<ul style="list-style-type: none"> To ensure balanced filling and packing To avoid problems due to filling and packing To ensure enough pressure to counteract high back pressure To ensure more melt filling to compensate for shrinkage
Gate location	
Gate type	
Aspect ratio	<ul style="list-style-type: none"> Core pins for features with aspect ratio variation, resulting in different shear and von Mises stress distribution

REDESIGN 3DPIM

There are several ways to redesign 3DPIM. The quickest improvement is made by incorporating the tower feature as a separate insert assembled into the mold (Fig. 11). The tower insert material may be high-hardness plastic or steel. However, the material price and tooling time will be more than a one-piece process.

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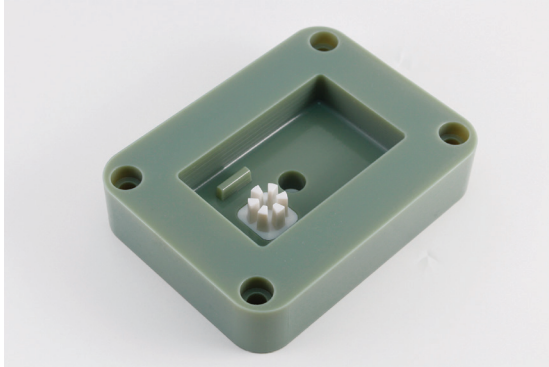


Fig. 11 - Tower-insert assembly.

CHANGING THE PROCESS CONDITION

While considering the disadvantage of the tower-insert assembly, modifying the process condition can be a good choice to solve the break-off issue.

The melt temperature is changed in this case. The original melt temperature is 220 °C. Based on the work range suggestion of ABS Terluran GP-35, another two melt temperatures, 180 °C and 260 °C, are used to evaluate the von Mises Stress during the filling stages.

Based on the same filling stage of these three temperatures, the higher melt temperature may reduce von Mises Stress on the feature roots. When using 260 °C, the von Mises Stress is 17.66 MPa less than half of the original stress (Fig. 12). Therefore, the melt temperature increase helps

solve the broken tower problem, and the 3DPIM can be used for more injections. But the melt temperature is much higher; it needs to spend more time for cooling the part and mold.

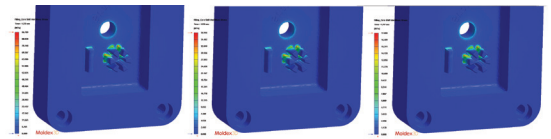


Fig. 12 - The von Mises Stress comparing three melt temperatures.

MELT TEMPERATURE (°C)	VON MISES STRESS (MPA)
180	89.71
220	36.95
260	17.66

REFERENCE

1. http://usglobalimages.stratasys.com/Main/Files/Technical%20Application%20Guides_TAG/TAG_PJ_InjectionMolding.pdf?v=635923370695739650

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HEADQUARTERS

7665 Commerce Way, Eden Prairie, MN 55344
+1 800 801 6491 (US Toll Free)
+1 952 937 3000 (Intl)
+1 952 937 0070 (Fax)

2 Holtzman St., Science Park, PO Box 2496
Rehovot 76124, Israel
+972 74 745 4000
+972 74 745 5000 (Fax)

Moldex3D

M O L D I N G I N N O V A T I O N

CoreTech System Co., Ltd.
mail@moldex3d.com
For more information, please visit www.moldex3d.com

stratasys

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