Autodesk® Moldflow Insight 2027

Validation of the Cooling Channel Optimization for drill and plug applications

Executive Summary

This report validates the extension of Autodesk® Moldflow Insight 2027 cooling optimization to traditional drill and plug mold designs. While additive manufacturing enables conformal cooling, most injection molds continue to rely on drill and plug manufacturing due to its cost efficiency, durability, and widespread adoption.

Building on proven additive cooling optimization technology, Moldflow Insight 2027 now optimizes drill and plug cooling layouts within strict manufacturability and clearance constraints. Cooling channels are automatically repositioned, and baffles or bubblers are intelligently introduced to eliminate localized hot spots and improve heat removal.

Validation results show that optimized drill and plug cooling layouts deliver performance approaching that of additively manufactured molds, with significant reductions in average mold temperature, temperature variation, cycle time, and temperature-induced warpage. These results confirm that manufacturers can achieve advanced cooling performance using conventional mold construction methods, improving part quality and productivity without the cost or risk of additive manufacturing.

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Introduction

Plastic-injection molding is best suited to mass production. Initial injection molding equipment and mold tooling costs can only be recovered through the volume of plastic products manufactured. To be competitive, the manufacture of each component must be done as efficiently as possible. The component needs to be manufactured as fast as possible to an acceptable level of quality for its intended purpose.

Heat goes into the polymer during injection molding, to be shaped into its final component form. Once the polymer is in its final component form this heat must be removed quickly in a uniform way. The quicker the heat is removed, the lower the cycle time, and the lower the production costs. In-molded residual stresses can be reduced by removing heat from the mold uniformly. As polymers cool and solidify, they contract significantly. If certain regions freeze after other regions, internal residual stresses are frozen-in at these interfaces. When the part is ejected, these frozen-in stresses cause the part to warp toward the regions that froze last. Generally, the cooling phase accounts for two-thirds of the cycle time. [1] As the cooling phase accounts for the bulk of the cycle time, it accounts for the bulk of the production costs. Hence by optimizing the cooling channel layout, cycle times can be significantly reduced, and large gains in production costs can be made. [1]

The drill and plug method is by far the most common approach for creating cooling channels in plastic injection molds. In this process, straight channels are drilled through the mold block from one face to the opposite face. Additional cross-drilled passages from adjacent faces intersect the main channels, allowing the coolant flow to be directed as needed. Threaded or pressed plugs are placed at the ends of drilled channels where flow is not desired, ensuring proper control of coolant movement throughout the mold.

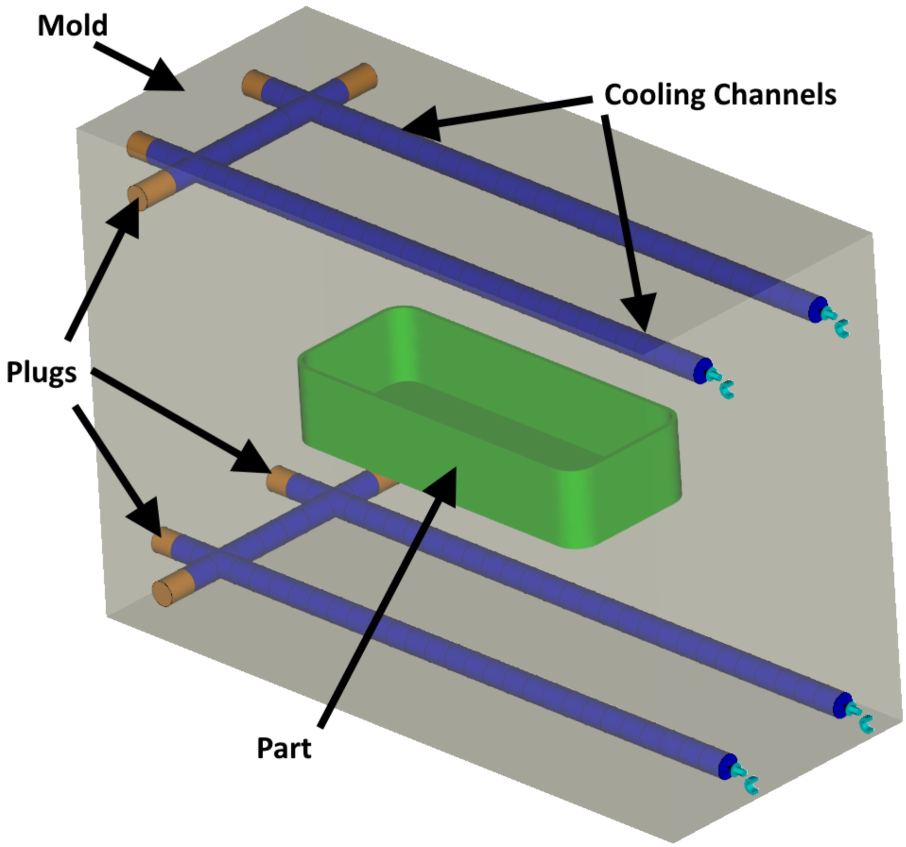

Figure 1: Schematic showing a drill and plug layout

In drill and plug cooling systems, the mold designer typically positions the main straight cooling channel in a location that removes the greatest amount of heat from areas close to the molded part—usually beneath the hottest region of the mold surface. The effectiveness of this main channel can be improved by adding baffles or bubblers. These are created by drilling a hole of the same diameter perpendicular to the main cooling channel and toward the hottest area of the mold. A baffle is formed by inserting a thin metal strip, equal in width to the hole diameter, into this cross-drilled hole and plugging its base. This forces coolant to flow up one side of the hole and down the other, directing circulation toward the hot zone. Bubblers are made in a similar way, but instead of a metal strip, a thin metal tube is inserted into the cross-drilled hole. Bubblers typically use a lower cross-channel to supply coolant upward through the tube and a higher, parallel channel to return it. Figure 2 illustrates the schematics of a baffle and a bubbler. Bubblers are preferred if the length of the hole is very long, more than 15 times the diameter of the hole, as thin metal strips lose rigidity when very long.

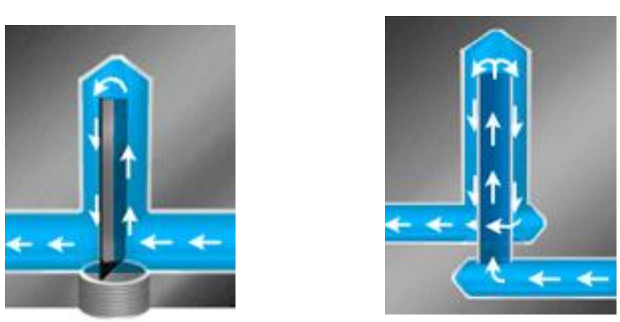

Figure 2: Baffle and bubbler layout

Drill and plug mold manufacturing is the traditional method for creating cooling channels in injection molds. In contrast, modern mold-making techniques such as metal additive manufacturing (e.g., 3D metal printing) are far less constrained by straight-line drilling and allow cylindrical cooling channels to closely follow the geometry of the molded part while maintaining a round cross section. Although these additive techniques can be more thermally efficient than drill and plug designs, they also have notable disadvantages. Additively manufactured molds are significantly more expensive to produce and can be structurally weaker when subjected to the high forces of plastic injection molding. In addition, they tend to be more susceptible to corrosion, and their cooling channels are more prone to sediment buildup and blockage over time.

Optimization techniques have been developed to improve the placement of cooling channels in additively manufactured molds by repositioning initial channel layouts to achieve optimal cooling performance. While these methods are effective, most injection molds in use today are still produced using traditional drill and plug manufacturing techniques. As a result, there remains a clear need for optimization methods specifically tailored to cooling channel placement in drill and plug mold designs.

Cooling layout optimization of the mold

The purpose of optimizing the cooling layout of the mold is to produce an acceptable part quality with a minimal cycle time**.** The part quality and the cycle time are directly related to the average mold-part surface contact temperature. Generally, a higher mold temperature leads to a lower cooling rate and thermal imbalances, resulting in more stress relief and less temperature difference induced warpage. Residual stresses and thermal bending are minimized through a higher mold temperature. However, a higher mold temperature results in a longer cooling time and total cycle time, resulting in higher production costs. The goal of cooling layout optimization is to reach the perfect balance between the part quality and cycle time objectives.

Simulation technologies

Traditional injection molding design aims to maintain the mold at a constant temperature for the entire injection molding cycle. To achieve this, coolant is pumped through mold cooling channels with constant set inlet temperatures. For conventional designs, this mold cooling process can be simulated sufficiently accurately by a steady-state solution of the cycle-average mold temperature. This means that an average temperature during the molding cycle is calculated for each location throughout the mold. It is assumed that during a single injection molding cycle, the mold temperatures in contact with the part only deviate slightly from the steady-state cycle averaged temperature at each location. It is the variation of the steady-state cycle averaged temperatures across the cavity surface of the mold that is the important cause of temperature difference induced part warpage.

To optimize a cooling channel layout and to ensure good numerical performance, a simulation using the boundary element solution (BEM) best meets these needs. The mold need only be represented by the outer boundaries of the mold, the surface mesh of the part and the cooling channel layout in the mold for a full steady-state 3D temperature representation inside the mold to be obtained. By using this method, the internal representation of the mold does not need to be re-meshed after each optimization, and the new cooling channel layout can be derived from the results of the previous layout. When the boundary element method is applied to the Laplace equation which describes the steady-state heat transfer equation, the internal representation of the mold is not required, [3]. However, with the boundary element method, every element in the domain is dependent upon every other element in the domain. This means that the resulting system matrix is a fully populated matrix and is computationally intensive. This type of system matrix cannot be banded to save memory, and basic iterative matrix solvers are used to solve it. For very large models the full system matrix cannot be stored in volatile memory and so “out of core” solvers are used.

When using such a boundary element solver to optimize the cooling channel layout, the relationships between all the elements in the model need to be re-calculated as these depend upon their spatial positions within the mold. However, the results from the previous optimization can be used as initial conditions for the new analysis, as these would not change much between optimizations. The connectivity between all the elements remains the same, with only their positions changing. When the connectivities do not have to be re-calculated, and existing results are used as the initial solution estimate, a substantial speed-up in the solution can be achieved. A literature survey showed that the boundary element method for channel optimization has been used previously [2].

Solver implementation

This optimization method is implemented within the existing Autodesk Moldflow Boundary Element Method (BEM) Cool solver. The solver first performs an initial cooling analysis, followed by the optimization procedure. After each optimization step, the positions of the cooling channels are updated, and each subsequent iteration is based on the channel positions obtained in the previous step.

Because the model geometry from the prior iteration has already been solved—and most components, such as the molded part and the outer mold boundaries, remain unchanged—the connectivity matrices associated with these elements do not need to be recomputed. However, as noted earlier, the boundary element method requires a fully populated system matrix in which every element influences every other element. Since the cooling channel elements change position during each iteration, all rows and columns of the system matrix associated with these channels must be updated. Consequently, the boundary integrals that define the interactions between all elements must be recalculated. The analysis continues iteratively until either the maximum number of user-specified iterations is reached or no further improvement in cooling performance is achieved.

An optimization algorithm for additively manufactured molds was introduced in Autodesk Moldflow Insight 2025 [3]. The algorithm optimizes cooling performance by repositioning cooling channels within the constraints of additive manufacturing. It provides clear guidance on optimal one-dimensional channel placement and quantifies the resulting performance gains. Detailed derivations of the underlying algorithms are presented in the Moldflow Insight 2025 cooling optimization validation report [3].

Despite these advances, most injection molds are still manufactured using traditional drill and plug techniques, which retain advantages over additive manufacturing, particularly in terms of cost and structural durability. To address this, the existing additive manufacturing optimization algorithm was adapted to support drill and plug mold designs, provided that the user supplies an initial cooling layout that is manufacturable using drill and plug methods.

The adapted optimization algorithm relocates drill and plug cooling channels to their optimal positions while enforcing manufacturability constraints in the same manner as for additive manufacturing. Once the cooling channels have been positioned optimally, further improvements are achieved by targeting localized hot spots in the mold regions in contact with the part through the addition of baffles or bubblers. Users may choose whether to include baffles or bubblers in the design. In general, bubblers are preferred for long drilled holes, as the metal strip used in a baffle can lose rigidity over extended lengths. The software allows users to automatically switch from baffles to bubblers once a specified channel length threshold is exceeded.

The drill and plug optimization algorithm is fundamentally based on the additive manufacturing algorithm. However, prior to each optimization iteration, each drill and plug cooling channel is decomposed into individual straight sections that are manufacturable by drilling. After an iteration of the additive manufacturing optimization, the algorithm identifies the cooling channel section that requires the greatest displacement from its original position to improve cooling performance. That entire section is then moved by the computed distance.

The algorithm subsequently checks for collisions between the repositioned cooling channel sections and other mold components, including the part, existing cooling channels, ejector pins, and inserts. If collisions are detected, the algorithm determines the minimum retreat distance required to eliminate the interference and moves the affected sections back toward their original positions until all collisions are resolved.

Once all cooling channel sections have reached their optimal, collision-free positions, the algorithm identifies remaining hot spots in mold regions in contact with the part. These hot spots commonly occur in internal cavities of hollow parts or at the bases of bosses. The algorithm then targets these regions by strategically placing baffles or bubblers from the nearest cooling channels. With each subsequent iteration, additional baffles or bubblers are introduced until their inclusion no longer results in a meaningful improvement in cooling efficiency, based on the user-defined analysis objectives.

Metrics for measuring optimization.

With the objectives of the cooling optimization being to reduce the cooling time and to minimize the temperature difference across the surface of the mold in contact with the part, two metrics are defined.

The first metric is the normalized average mold temperature in contact with the part. The average surface temperature of the mold in contact with the part is dictated by the molding resin. Certain resins such as nylons or polycarbonates require a very high mold temperature, whereas polypropylenes or polystyrenes require cooler mold temperatures. The coolant temperatures are set accordingly to achieve these desired mold temperatures. The first metric is defined as the average temperature metric. T_m

$$T_m = \frac{T_{average_{iteration}}}{T_{average_{initial}}} \quad [1]$$

Equation [1] states that the average mold-part surface contact temperature is normalized with respect to the initial mold's average temperature result. If the average mold temperature in contact with the part decreases with subsequent analyses, the metric is a fraction smaller than 1.0, showing that the mold is colder. If the metric increases, the subsequent design is hotter than the previous one.

If there are vast improvements in this metric during optimization, the user should then recalculate the cycle time on the final design iteration to ensure that the final mold temperature meets the polymer's requirements. This analysis will raise the final mold temperature by shortening the cycle time, satisfying the first goal.

To meet the second objective to minimize the temperature difference across the surface of the mold in contact with the part, the temperature variance results will be used. The temperature variance result is defined as

$$T_{variance\ i} = T_i - T_{ave} \qquad [2]$$

Where the area-weighted average mold-part surface contact temperature is subtracted from the temperature of the mold in contact with the part. Hence, if an element is hotter than the average temperature, the metric will be positive, or if it is cooler, the metric will be negative. The goal of the optimization is to get as many elements as possible to have a low magnitude of temperature variance (close to zero). To achieve this, the standard deviation of the temperature variance will be minimized. A low standard deviation indicates that the values tend to be close to the mean of the set, while a high standard deviation indicates that the values are spread out over a broader range.

The minimization of the standard deviation of the temperature variance will be used to achieve the second objective of the cooling channel optimization. The standard deviation of the temperature variance is given by equation [3]

$$\sigma = \sqrt[2]{\frac{\int_S \left(T_{variance\ i}\right)^2 dS}{\int_S dS}} \qquad [3]$$

While one of the aims of the optimization is to minimize the standard deviation of the temperature variance in the mold, the other objective is to minimize the average mold-part surface contact temperature. To minimize average mold temperatures, the cooling channel elements may move very close to the part. This could give rise to cold spots on the surface of the part. These cold spots increase the temperature variance in these positions, which increases the standard deviation. The standard deviation metric is normalized as:

$$std_m = \frac{\sigma_{iteration}}{\sigma_{initial}} \qquad [4]$$

If this standard deviation metric decreases, it means that the individual cavity surface temperature values are closer to the average mold temperature in contact with the part.

Application of the optimization metrics

Equations [1] and [4] are used to normalize the metrics for optimizing the cooling channel locations. A weighted sum method is chosen to deal with the dual objectives of the cooling analysis. The user can set objectives by setting the relative importance of reducing the cycle time versus reducing the temperature induced warpage. These two user inputs are normalized to a single factor α.

$$\alpha = \frac{Relative\ importance\ of\ Cycle\ Time}{(Relative\ importance\ of\ Cycle\ Time + Relative\ importance\ of\ Warpage)} \qquad [5]$$

The default relative importance of cycle time is set to 1.0 and the default relative importance of warpage is 0.0. Therefore, the default parameter values will optimize the cooling channels to achieve a reduced cycle-time without considering the part warpage. If the two user inputs have the same value, the factor of α will equal 0.5. This means that both average mold temperature (which reduces cycle time), and temperature difference (which reduces temperature induced warpage), have equal weighting during optimization. The final weighted metric is given by:

$$Metric = \alpha T_m + (1.0 - \alpha) std_m \quad [6]$$

The aim of the cooling channel layout optimization analysis is to minimize this metric equation [6].

During optimization, the solver will update the positions of the cooling channels while maintaining their drill and plug nature and do a full cooling analysis on the updated cooling layout. At each iteration, the solver recalculates the average part temperature in contact with the mold, the standard deviation of the temperature variance, equation [3], together with their respective equations [1], [4], and the metric equation [6]. Once the metric in [6] has reached its minimum, the optimal cooling channel layout has been achieved.

Results and discussion

To demonstrate the cooling channel optimization a simple box model is used, Figure 3. The initial model is a box with 4 drill and plug cooling channels located far from the part in both the fixed and moving halves of the mold.

A cooling channel optimization is performed on this model using both the additive manufacturing solver and the drill and plug solver. The objectives for both analyses are the same. The results of both optimizations are reported and documented here.

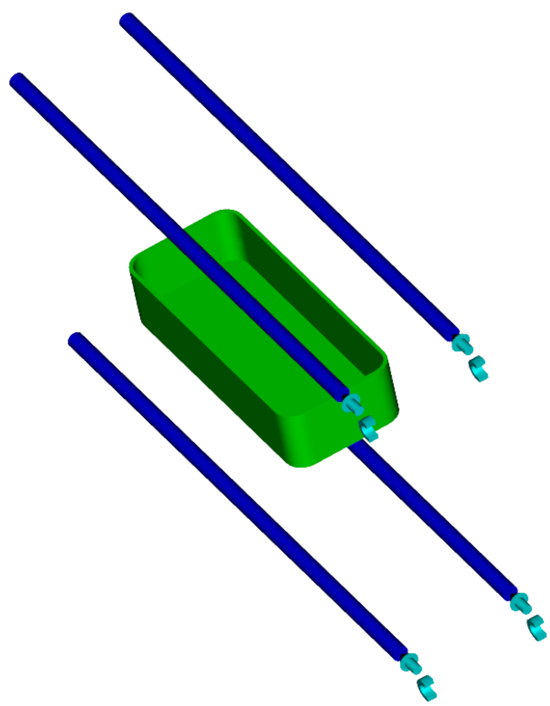

Figure 3: Box model with 4 initial cooling channel layout

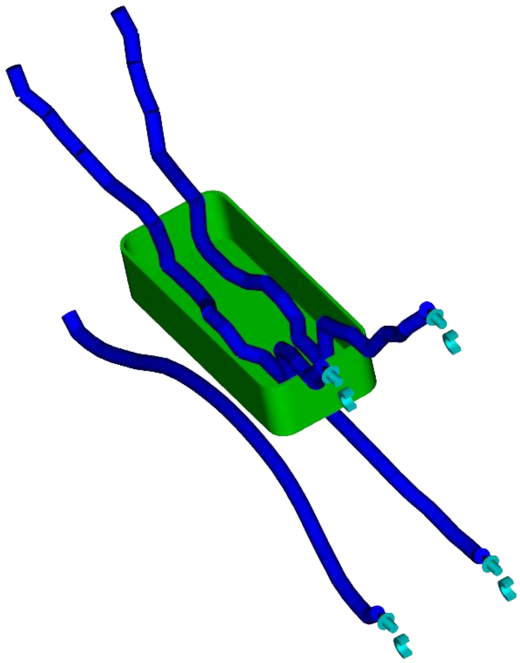

Figure 4: Optimized box model cooling channel layout for additive manufacturing

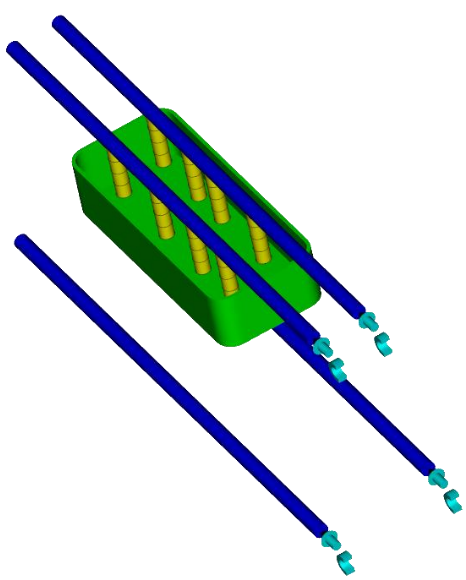

Figure 5: Optimized box model cooling channel layout for drill and plug manufacturing

Figure 4 is the optimal cooling channel layout of the model presented in Figure 3 using the existing additive manufacturing restrictions. Figure 5 shows the optimal layout after optimization for the cooling channels presented in Figure 3 using the drill and plug restrictions.

Table 1 shows the results of the optimized cooling layout from additive and drill and plug, compared to the initial layout.

Model	Initial	Additive	Drill Plug
Overall Metric	1.0	0.48	0.52
Average mold temperature in contact with the part (Tavg) °C	53.42	37.10	38.15
Standard deviation of temperature variance (std) °C	9.6	2.6	3.15
Temperature range of mold temperature in contact with the part	26.0	15.14	16.34
Temperature metric (Tavg Mold current / Tavg Mold initial)	1.0	0.70	0.71
Standard deviation metric (Metric std current / Metric std initial)	1.0	0.267	0.33

Table 1: Initial and optimized results with α = 0.5

Table 1 shows a:

- Drill and plug show a 48% improvement of “Metric” with the optimized cooling channel layout, whereas additive shows 52% improvement.
- Drill and plug show a 15.27° C reduction in average mold-part surface contact temperature, T_{avg} , whereas the additive shows a 16.32° C reduction
- Drill and plug show a 6.45° C reduction in the standard deviation of the temperature variance, σ, and a 7.0° C reduction for additive
- Drill and plug show 16.34° C reduction in the overall temperature range of the mold in contact with the part, T_{range} , and a 15.14° C reduction for additive
- 29% improvement in the Average temperature metric. T_m for drill and plug and a 30% improvement for Additive.
- 66% improvement in the standard deviation of the temperature variances, std_m, for drill and plug and 73.3% improvement for additive.

Therefore, the components produced with the optimized cooling channel layout will require less cycle time because the average surface temperature is cooler and will be of higher quality because there is less temperature variation across the surface of the part. It is noted that the optimization tailored toward additive produced layouts marginally more efficient than those manufactured using drill and plug. However, when considering that most molds manufactured use drill and plug, the results from table 1 prove that molds manufactured using traditional techniques can be optimized to produce molds that are almost as efficient as those manufactured using additive techniques, providing they get optimized correctly.

Figures 4 and 5 show the cooling channels maintain at least a single channel diameter from the part and other cooling channels, as seen on the inside of the box. Comparing Figures 4 and 5 shows that the cooling channels are moved closer to the part and into the hollow section of the box for the additive case and that for the drill and plug model 8 baffles are inserted into the corresponding region, this area is an enclosed area that naturally traps heat. Symmetry is maintained during optimization for the additive case, left and right or top and bottom channels are drawn in toward the part by equal amounts from either side.

For drill and plug symmetry is maintained while the individual sections of the cooling channel are moved into their optimum positions. However, during the baffle or bubbler insertion phase of the analysis, symmetry is not maintained, and the baffles and bubblers are not inserted in a symmetrical fashion. The algorithm will target the hottest hot spot first with a baffle and will try to place the baffle centrally so that it has the chance of cooling down the largest region. Then after this has been inserted, the next iteration will target the next hottest hot spot and so forth. Doing this will result in the most efficient mold when it comes to heat removal but may not guarantee symmetry of the cooling channels.

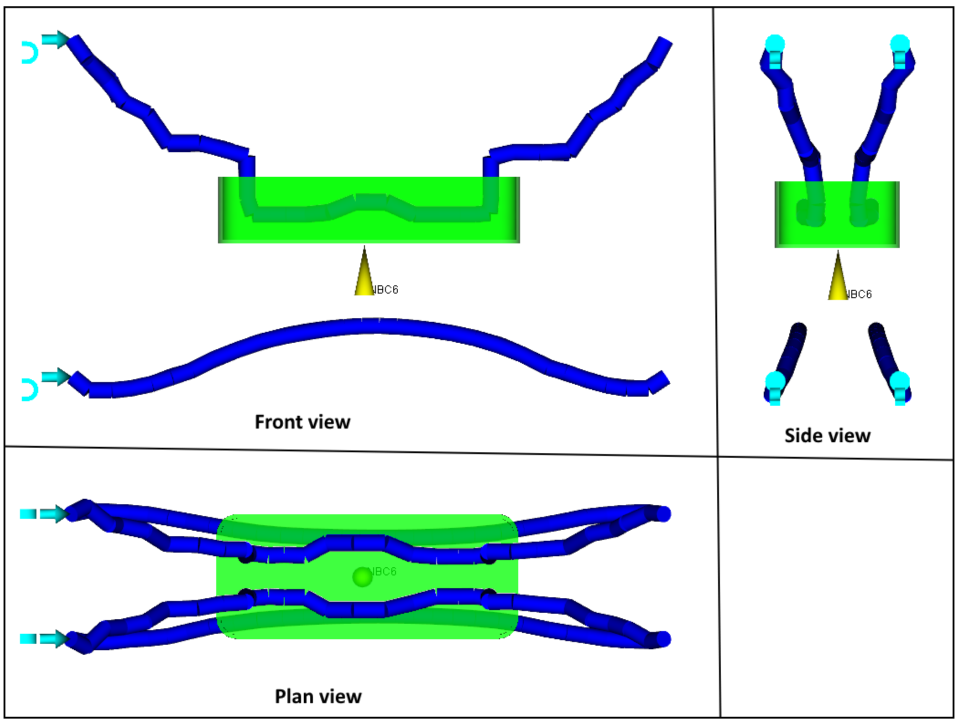

Figure 6: Front, plan, and side views of the optimized additive layout

Figures 6 and 7 show the front plan and side views of the cooling channels relative to the part and other cooling channels in the mold. From figures 6 and 7 it can be seen that the cooling channels and the baffles for the drill and plug case maintain a specified distance from each other and the part. Figure 7 also clearly shows that its layout can be manufactured using the drill and plug method.

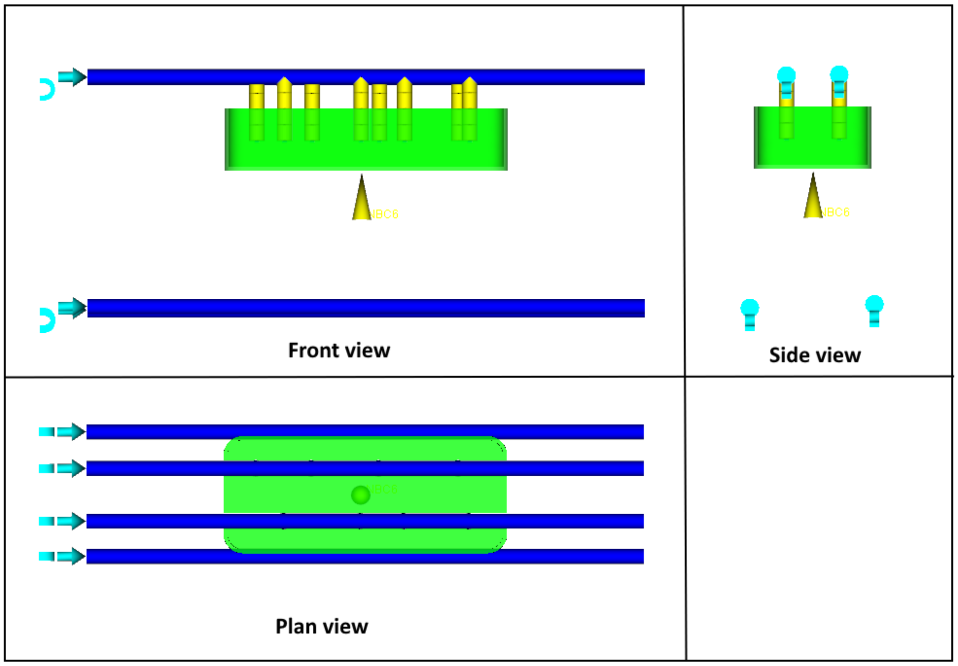

Figure 7: Front, plan and side views of optimized drill and plug layout

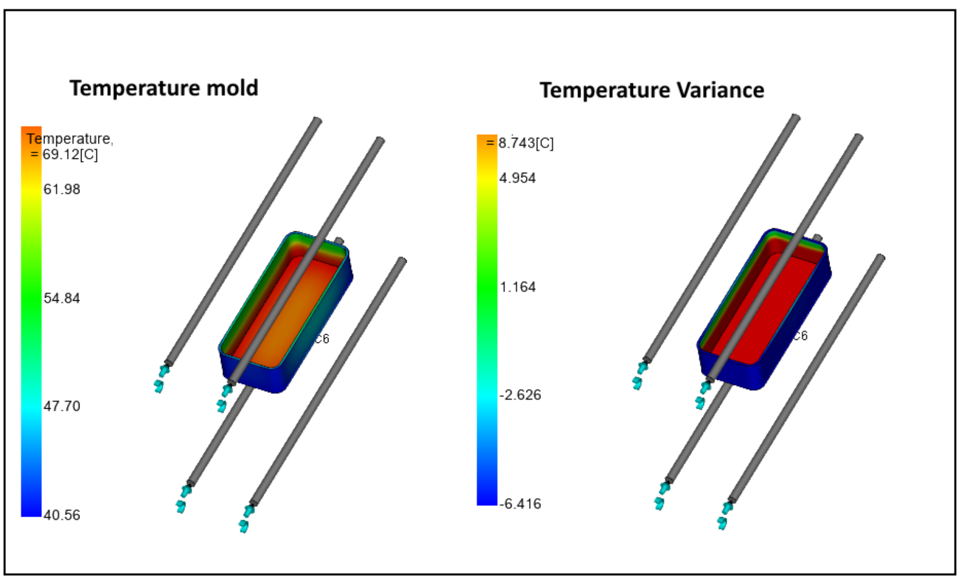

Figure 8: Temperature mold and Temperature variance of original model

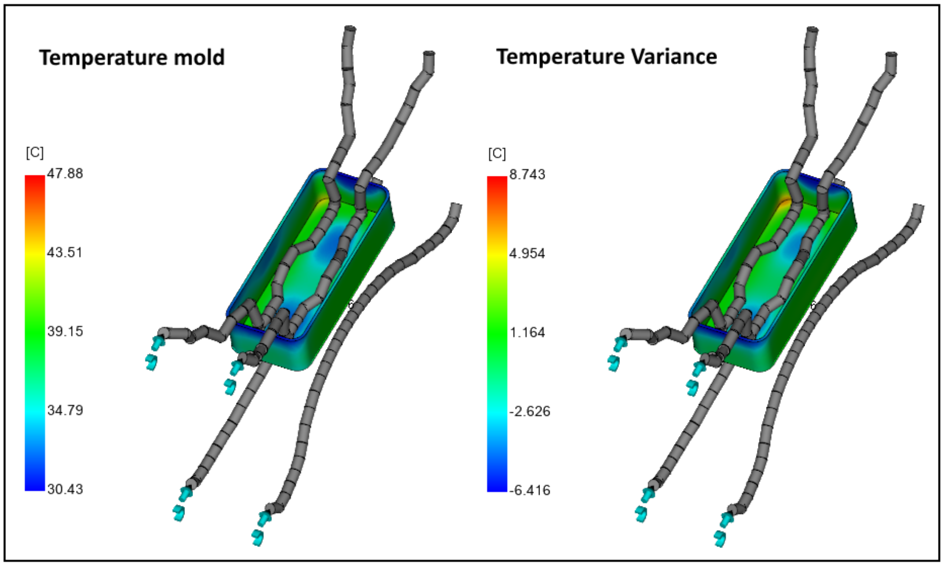

Figure 9: Temperature mold and Temperature variance of additive optimized model

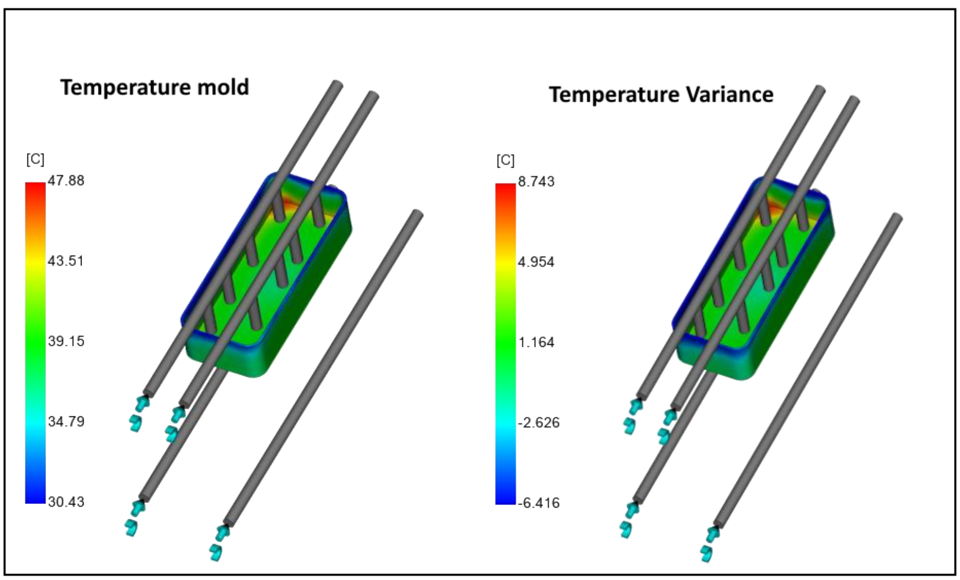

Figure 10: Temperature mold and Temperature variance of drill and plug optimized model

Figures 8, 9 and 10 show the temperature of the mold in contact with the part together with their temperature variance for the initial layout and for the additive and drill and plug optimized layouts. The figures confirm that the optimized layouts are much cooler than the original layout and the temperature variance across the surfaces of the mold in contact with the part is much less than what it is for the original model. The minimization in temperature variance should reduce the temperature induced warpage of the part. For the optimized cases these figures confirm that the optimized layouts are much cooler than the initial layout, and the temperature differences across the part surface are much smaller. Refer to table 1 for exact numbers.

The simple box model used for this demonstration shows that the channel optimization routine is working as expected and that optimized cooling channel layouts are possible when manufacturing methods are restricted to drill and plug. For this model, the initial channels were moved to positions that were more optimal to cool the part and maintain an even temperature distribution across surfaces of the part.

The predicted final part shape is shown in Figure 11 for both the initial channel layout and both the additive and drill and plug optimized channel layouts. In all cases, the shape deflection has been exaggerated to allow easier comparison. The color legend shows the actual predicted deflection values. This comparison shows that the optimized channel layouts, with the lower temperature variances across the surfaces of the part, result in less bowing of the side walls of the box. Therefore, the optimized layouts are expected to produce better-quality parts. In this instance the drill and plug layout resulted in slightly less thermal induced warpage than the additive.

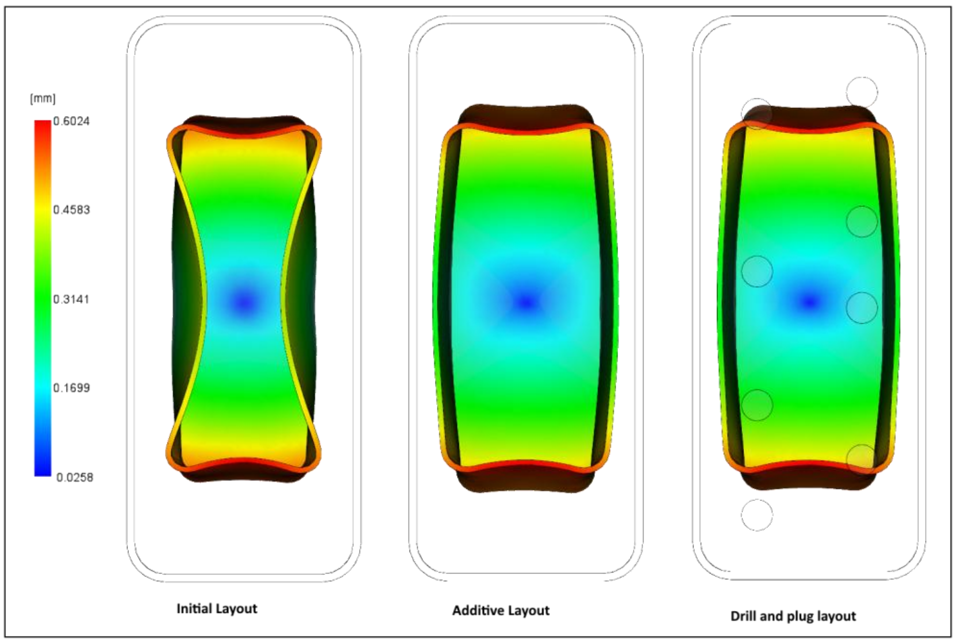

Figure 11: Warpage deflection for initial and optimized layouts

Conclusions

The cooling channel layouts generated by the drill and plug optimization algorithm achieve thermal performance that closely approaches that of additively manufactured molds. This is accomplished through the strategic placement of baffles and bubblers to target and eliminate hot spots in mold regions in contact with the part.

Compared with additive manufacturing, molds produced using traditional drill and plug techniques offer substantial advantages in terms of manufacturing cost and structural durability. The results presented in this report demonstrate that significant reductions in cycle time and temperature-induced warpage can be achieved by applying cooling channel optimization to drill and plug mold designs.

A representative example was presented in which cooling channels were optimized using both additive manufacturing and drill and plug approaches, and the results were directly compared. This example illustrates how optimization leads to improved cooling channel placement and enhanced part quality for both manufacturing methods.

The drill and plug optimization algorithm ensure that cooling channels maintain required clearances from critical mold features, including the molded part, parting planes, ejector pins, and other cooling channels, while remaining fully manufacturable using standard drilling and plugging techniques. These optimized layouts are further enhanced through the automated placement of baffles and bubblers.

As a result, the underlying cooling optimization framework can now be applied consistently across both additively manufactured molds and those produced using conventional drill and plug methods, enabling improved cooling performance regardless of the chosen manufacturing technology.

References

1. Jay Shoemaker, Moldflow Design Guide, A Resource for Plastics Engineers. Moldflow Corporation 2006.
2. Nicolas Pirc, Florian Bugarin, Fabrice Schmidt, Marcel Mongeau Cooling channel optimization for injection molding. NUMIFORM 07: Materials Processing and Design: Modeling, Simulation and Applications, Jun 2007, Porto, Portugal. p.525-530, 10.1063/1.2740864. hal-01354303
3. Autodesk Moldflow 2025 Cooling Optimization - Validation Report