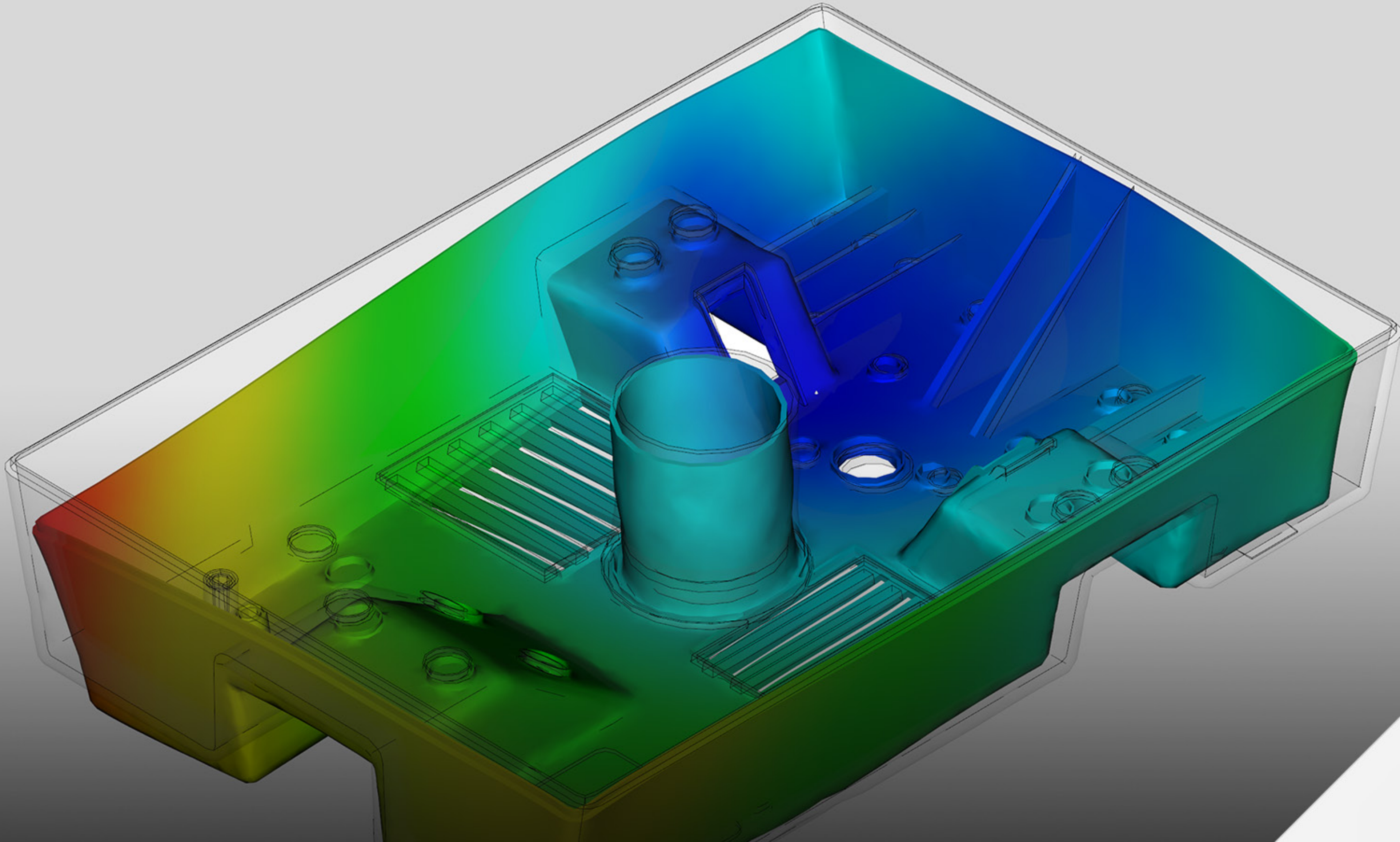

PREDICT AND PREVENT

WARPAGE

AUTODESK.

INTRODUCTION

A New Twist On Warpage

Nothing grinds a project to a halt like a warped part. Parts that are unexpectedly twisted out of alignment demand immediate attention and can seriously impact both the production schedule and the profitability of the run.

The good news is mold engineers don't have to settle for dealing with warpage when parts are getting ejected from the tool. Using simulation software, you can detect and mitigate the risk of warpage much earlier in the design process.

In fact, you can use simulation to understand how much warpage is likely to occur, what factors are causing the part to warp, and how best to change the part or the process (or both) to alleviate the issue and produce high-quality parts within the appropriate tolerances.

This ebook provides a practical approach to reducing warpage in injection molded parts using three case studies based on actual Autodesk customer experiences.

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ENSURING ACCURACY

Generating meaningful, useful results from simulation requires careful setup.

Ensuring Accuracy

Predicting warpage correctly with simulation software depends on the accuracy of the inputs. In this context, accuracy refers to how closely the inputs match real-world conditions. If the initial inputs are not closely aligned with reality, the results of the analysis may be unknowingly incorrect, resulting in the risk of making significant, irreversible decisions based on flawed data.

THE FOUR INPUTS TO FOCUS ON INCLUDE:

- Final part geometry
- Complete mold geometry, including feed system and cooling channel designs
- Expected process settings
- Complete material characterization

Of these four, material characterization is the most critical simply due to the complex nature of plastics and how differently they behave in varying conditions – even within the same family. While mold engineers typically have a great deal of control over the first three inputs, material data is often a separate entity. Validating it may require a separate conversation with material manufacturers or the simulation software provider.

One important note:

Up-front analysis of warpage does not have to be done with extreme precision if the intent is to gain initial guidance rather than drive more rigorous optimization.

In other words, if the part is still early in its development, design teams can use less detailed inputs to gain a rough idea of how much the part may warp and in what direction. This work may be done, for example, before the cooling channels have been designed. At this point, simply knowing the part's warpage tendencies makes it easier to "design out" the problem, add strengthening features to minimize it, or investigate various mold types or processing conditions to mitigate it.

RUNNING THE ANALYSIS

Optimizing warpage usually follows a number of other optimization efforts.

Running The Analysis

Minimizing warpage with simulation software is inherently an iterative process. Each outcome depends on many variables related to the part, the mold, and the process, and each layer of analysis builds on the results from the previous one. This is why warpage optimization is typically the last major step performed in the part optimization process.

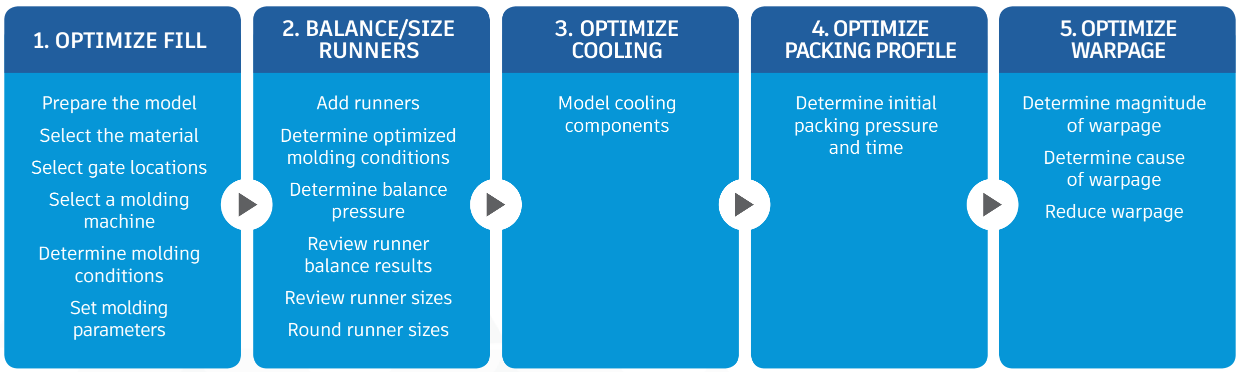


Figure 1: Because it depends so heavily on many other factors, optimizing warpage should be performed last after other steps have been perfected.

Optimizing warpage essentially encompasses the outcomes of all the preceding steps, and so the decisions made during these steps will influence the results of the warpage analysis. By the same token, the solution for reducing warpage may require you to revisit one or more of the previous steps. On the plus side, however, completing these steps in order validates that the simulated results will more closely match the molded components, giving you the best possible chance of mitigating shrinkage.

Running The Analysis

Of course, you can always run an analysis to get a baseline measurement of warpage based on how the part has been designed to date. But before you begin the real work of optimizing warpage, the first four steps (see Figure 1) should be completed. At this point, the software typically requires no additional information or modeling to simulate the warpage of the part accurately.

When you generate results from the first warpage optimization analysis, you will have two objectives. First, determine the magnitude of warpage. Is it within tolerance? Second, identify why the part is deflecting. Depending on the cause, you will have multiple options for resolving it.

Causes of warpage

There are two typical causes of warpage:

1. NON-UNIFORM COOLING
Temperature differences from one side of the mold to the other can lead to layers freezing and shrinking at different times, which generates internal stresses.

2. INCONSISTENT SHRINKAGE
This may be the result of material variations in moisture content, melt consistency, pigmentation, or other properties. It may happen due to process variations, such as inconsistent packing or varying mold and melt temperatures, as well as machine variations, such as a damaged check ring or unstable controller. It may also be a result of part geometry, such as variations in wall thickness.

CAUSE:
DIFFERENTIAL COOLING

A manufacturer redesigns a cooling system to reduce a core-to-cavity temperature differential.

Cause: Differential Cooling

The customer in the first example designs, engineers, and manufactures components and systems for virtually every vehicle manufacturer worldwide. One engineering center in particular caters to products for climate control, electronics, and interior products.

While working for a leading automotive OEM, this engineering center faced a challenge during the development of a rear AC cover. The interior part was warping, causing a large gap between where the part was supposed to sit and where it actually sat in the final assembly. Specifically, warpage exceeded 5mm, resulting in low dimensional accuracy and complete failure during component assembly.

During the initial phase of investigation, the customer's engineering team attempted to find the causes of warpage using an iterative test-design process. The feed system and cooling channels were modeled with actual tool data, and the input processing parameters were set.

The first iteration revealed warpage between 2.3 and 5.7mm in the fitment area as well as a temperature of 83.94° C in the core side compared to 79.87° C in the cavity side.

As a result, the team modified the cooling circuits in the mold design, increasing both channel diameter and baffle height, but these changes did not resolve the temperature differential.

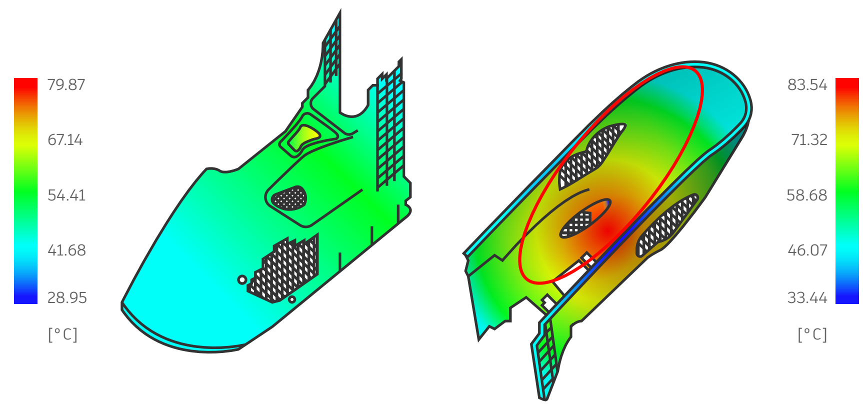
In the next phase of analysis, the customer's engineering team further revised the design of the mold, making three major changes. The cooling channel's hole length in the lifters was increased, one baffle was added, and two existing baffles were extended to be closer to the part cavity.

Cause: Differential Cooling

Further simulations revealed that these changes brought down the core side temperature from 83.94°C to 69.89°C, adequately reducing deflection in the fitment area from the initial range of 2.3 to 5.7mm to a new range of 1.7 to 3.0mm, allowing successful assembly.

SUMMARY

Part: Rear AC cover
Cause of warpage: Differential cooling
Simulation approach: Multi-stage cooling system redesign
Solution: Cooling hole length increased, one baffle added, two baffles extended



Cavity side temperature
Temperature of part in cavity side: 79.87°C

Core side temperature
Temperature of part in core side: 83.94°C

Figure 2: The warpage of the AC cover was caused by a temperature differential between the core and cavity side of the mold, as shown here.

CAUSE: ORIENTATION EFFECTS

When glass fibers in a resin result in unexpected warpage, a manufacturer uses a DOE to find the fastest way to resolve the issue.

Cause: Orientation Effects

In the second example, the customer is a material supplier that works with a wide range of automotive manufacturers. In this case, the parts were a pair of structural components that provided support to the top shoulder in the luggage compartment of an SUV.

The initial mold-filling analysis was conducted on a prototype-level design using various materials in order to check the filling pressure and balance filling from multiple gates. Based on the analysis results and initial mold trials, a PC/PBT blend produced the best dimensional properties.

Unfortunately, its material properties were not suitable for production parts. Coordinate measuring machine (CMM) analysis of molded parts showed they were out of tolerance due to warpage. The spine of the part was arching while in the perpendicular cross-section the flanges were warping upward. These dynamics indicated that orientation effects caused by the glass fibers in the resin were to blame. Even worse, they were in a race against time to produce the final parts in a matter of weeks for the vehicle's debut at a major trade show.

To address the problem, the engineering team set up a Design of Experiments (DOE) with Moldflow Insight software. A DOE is a statistical tool that enables mold engineers to see how changing a processing variable affects the quality of the part. DOE analyses search for optimal processing conditions by automatically running a series of analyses while varying the values for selected processing conditions.

Cause: Orientation Effects

Typically, a DOE is run manually on a press. This is very time-consuming, because the parts need to be molded for each step of process variation, then measured for the specific quality criteria. Using Moldflow Insight eliminated the need to perform these steps manually. Essentially, simulation allows mold engineers to validate that the analysis matches the molded parts with fewer runs – or eliminate the need to perform this step entirely.

In the initial mold filling analysis, a model with two gates showed high curvature of the upper surface and high warpage of the flange, meaning that the DOE confirmed the original CMM results. So the engineering team effectively used the DOE to rule out their ability to mitigate warpage by changing processing conditions.

Next, the team considered three other ways to solve the problem. The first was replacing the material to achieve lower differential shrinkage, but the desired replacement material would have been too difficult to fully evaluate in the time allowed. The second option was redesigning the part to add or remove ribs to change its thickness and consequently the orientation effects. Simulation showed that this would have been impractical due to space restrictions.

This left the team with a third way: changing the gate sequencing. The gate location and number of gates were already set by the finished mold, and shutting off one gate entirely would make the part too difficult to fill. However, sequential valve gate timing was possible.

Cause: Orientation Effects

The first iterations in simulation showed that sequential valve gate timing produced a flatter part but it did not significantly affect flange warpage. The analysis continued and the team came up with a second idea. They observed that while a good alignment of fibers in the flange could be created during the filling phase using sequential valve gate timing, subsequent packing pressure disturbed this alignment, limiting the warpage reduction in the flange. Temporarily closing the valve gate at the end of filling – and then reopening the gate after a short pause to complete the packing – maintained good fiber alignment, reducing warpage.

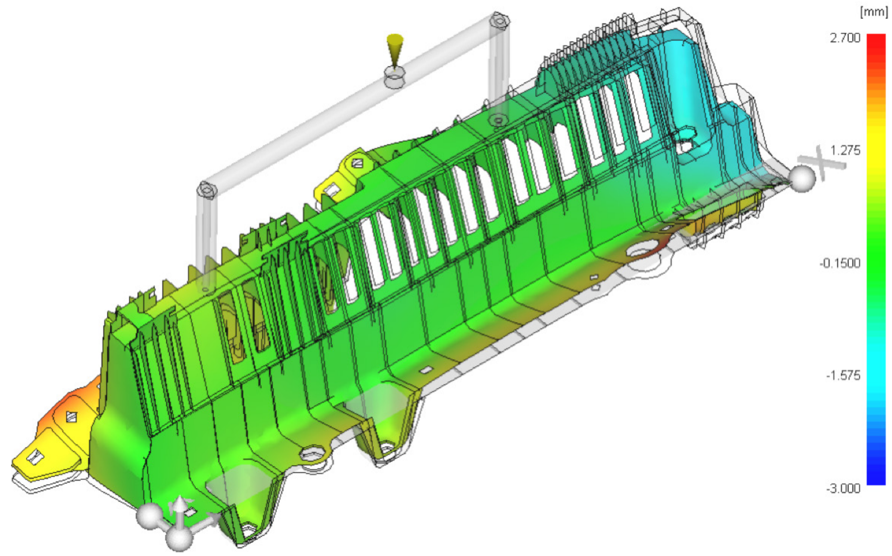


Figure 3: Using a DOE to eliminate options to change the process helped the engineering team quickly discover the use of sequencing valve gate openings to reduce the curvature of the upper surface of the part.

SUMMARY

Part: Top shoulder carrier
Cause of warpage: Orientation effects
Simulation approach: DOE
Solution: Sequential valve gating

CAUSE:
AREA SHRINKAGE

Deflection between a lid and base is resolved with an efficient parametric optimization process.

Cause: Area Shrinkage

The customer in the third example is a leader in engineering and design services for some of the world's largest automotive, aerospace and durable goods manufacturers.

One of the company's engineering teams encountered difficulty with the welded assembly of a reservoir, which consisted of a lid and a base. After the vibration welding of the parts, the lid was breaking into as many as four pieces due to assembly-level deflection. In addition, the team needed to use the existing molds for both parts due to budget constraints. And the material could not be changed due to shrinkage factors considered when cutting the tool.

To eliminate the deflection between two parts of the reservoir, the team used Moldflow Insight software to identify potential molding problems. This revealed that while the deflection in each of the individual parts did not exceed tolerance, the combined deflection caused substantial difficulty after assembly.

The team studied the base part first, checking several options for the gate location. However, changing the gate location did not have any direct impact on the deflection. This helped the engineers decide to keep the existing gate location.

The team then turned to the lid, which was experiencing comparatively more deflection than the base. Various gate locations and glass filler percentages (ranging from 30 to 35%) were simulated but had no effect on the deflection.

Cause: Area Shrinkage

Using the simulation software, the team then focused on part design. They ran a parametric optimization that encompassed 15 cases based on various constraints with a combination of different gate locations and ribs, flanges and patterns. Five different ribs and flange patterns were evaluated using Moldflow Insight to quickly analyze varying thickness and heights of added ribs, and flanges. The results of this effort showed that the additional stability from ribs, along with a slight modification to the gate geometry (edge gate), effectively reduced the deflection between the lid and base assembly from 3.5mm to 1.4mm, making it more stable and effectively resolving the warpage and breakage issue.

SUMMARY

Part: Reservoir lid and base
Cause of warpage: Area shrinkage
Simulation approach: Parametric optimization
Solution: Edge gate for the lid

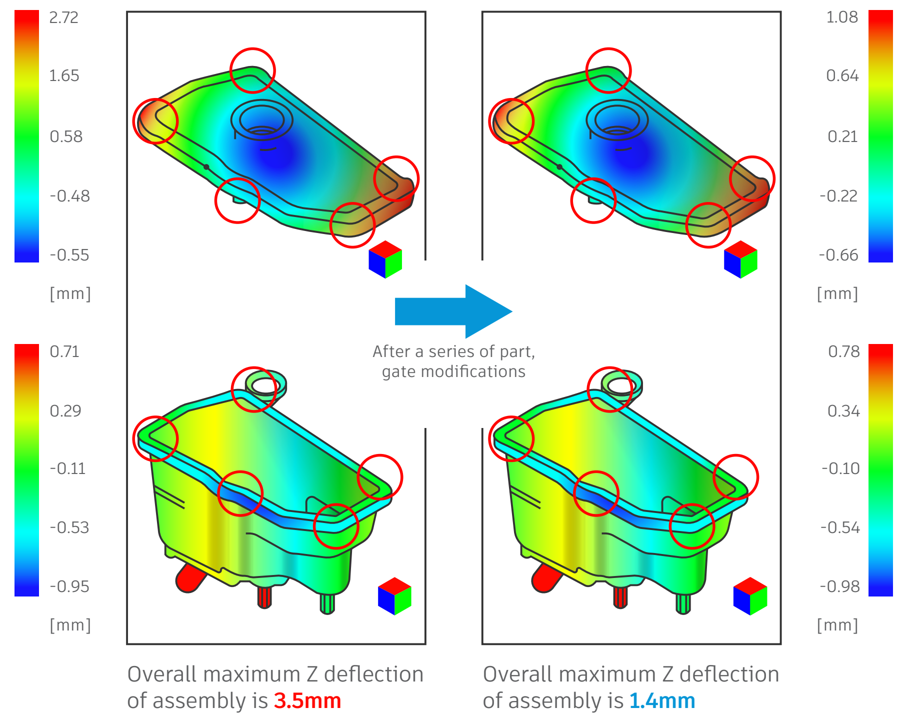


Figure 4: Parametric optimization allowed the team to evaluate 15 separate gate locations to identify the best solution.

CONCLUSION

Final thoughts on how to solve warpage through simulation.

Conclusion

There is no one “correct” approach to minimizing warpage. To find the right approach for your project, you need to first detect the potential for warpage through accurate simulation and identify the cause. Only with this knowledge can you determine how best to minimize warpage.

Simulation speeds this process along, whether you need to perform multiple mold design changes, evaluate a variety of part design combinations through DOE, or run a parametric optimization of process variables to fine-tune the part’s manufacture. In each case, using simulation software allows faster iteration of more ideas, giving engineers more ways to address the issue.

Get Started

To learn how simulation software can help you optimize warpage more efficiently, visit our injection molding resource center.

SOLUTION CENTER >