Autodesk® Moldflow Insight 2024

Validation of Adjusting Constraint Positions According to Mold Shrinkage Allowance

Executive Summary

The Autodesk Moldflow Insight 2024 software release introduces a new feature that adjusts constraint positions in accordance with the mold shrinkage allowance used to scale up the mold. This allows the constraints to accurately represent the attachment points of the plastic part when mounted onto a rigid assembly. This report provides detailed information on the mathematical modeling underpinning this new feature. It also introduces the newly available solver options and showcases user workflow and new results. Additionally, it provides practical illustrations of how this feature can be used in a variety of verification and validation cases.

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Introduction

In industries such as automotive, aerospace, and home appliances, it's vital to adhere to strict dimensional tolerances once injection-molded components are incorporated into an assembly. Shrinkage and warpage, byproducts of the injection molding process, can cause the final product to deviate from its intended shape and size [1]. For flexible plastic parts, force can be applied during assembly to realign the connection points to their nominal positions.

Occasionally, the warpage issues of injection-molded components can be rectified once they are constrained in assemblies. Conversely, flat components may become distorted during assembly due to an unforeseen shrinkage magnitude from the injection molding process. Predicting the deformation of injection-molded components post-assembly can be an invaluable tool for designers, assisting in the identification of potential assembly issues and the optimization of the design.

Mold makers must consider the shrink factor of the material to be injection molded when creating the mold, to compensate for process-induced shrinkage. Typically, the material's nominal shrinkage is used to scale up the cavity size. This scaled-up model is often employed in injection molding simulations to verify the final part dimensions after shrinkage, relative to the intended part dimensions and tolerances.

In the Autodesk Moldflow Insight 2024 release, a new feature, "Adjust constraint positions according to mold shrinkage allowance," has been introduced. This option automatically adjusts the warp constraint positions according to a specified mold shrinkage allowance. This is necessary because fixed warp constraints do not account for the mold shrinkage allowance, potentially causing non-physical stresses to be generated between constraints. Available for Midplane, Dual Domain, and 3D mesh types, this feature calculates the final deformation of the injection-molded part post-assembly, and its deviation from the part design.

Mathematical Modeling

The final deformation of injection-molded components post-assembly includes both process-induced and assembly-induced deformation. This prediction typically involves a combination of warpage analysis, an interface between warpage and structural analysis, and a separate structural analysis. When flexible, thin-walled plastic components are mounted into high-modulus metal or rigid parts, only deformation analysis on the plastic part is required.

According to the superposition principle of the linear system, the deformation can be viewed as a linear combination of warpage analysis and a structural analysis with forced displacement. The automatically calculated imposed displacement at mounting nodes can be treated as a special loading case. As long as the deformation is within the linear range and the forced displacement is set up correctly, the combined deformation effects can be simulated in a single step.

Mold makers must consider the shrink factor of the material to be injection molded when creating the mold, to compensate for process-induced shrinkage. Typically, the material's nominal shrinkage is used to scale up the cavity size. This practice ensures that the final product adheres to the intended dimensions and tolerances, despite the inherent shrinkage that occurs during the injection molding process.

Given a mold that's scaled up using the material's nominal shrinkage S, the imposed displacement U at the mounting nodes can be calculated using the formula:

$$U = \frac{S}{1+S}(X' - C)$$

In this equation:

- U stands for the imposed displacement at the mounting nodes.
- X' represents the final position of the mounting nodes after the mold has been scaled.
- C refers to the coordinates of the reference origin for the cavity mesh scaling up.

This formula allows for the calculation of displacement at the mounting nodes due to the scaling of the mold based on the material's shrinkage. The algorithm has been implemented for the midplane solution, Dual Domain solution and 3D solution [2]. Both the small deflection analysis and buckling analysis are valid for the application.

Solver Options

In the Autodesk Moldflow Insight 2024 release, the new feature "Adjust constraint positions according to mold shrinkage allowance" is available, which can be found under the **Warp Analysis** tab in the **Thermoplastics injection molding solver parameters** dialog box, as shown in Figure 1, or in the **Process Settings Wizard – Warp Settings** dialog box, as shown in Figure 2.

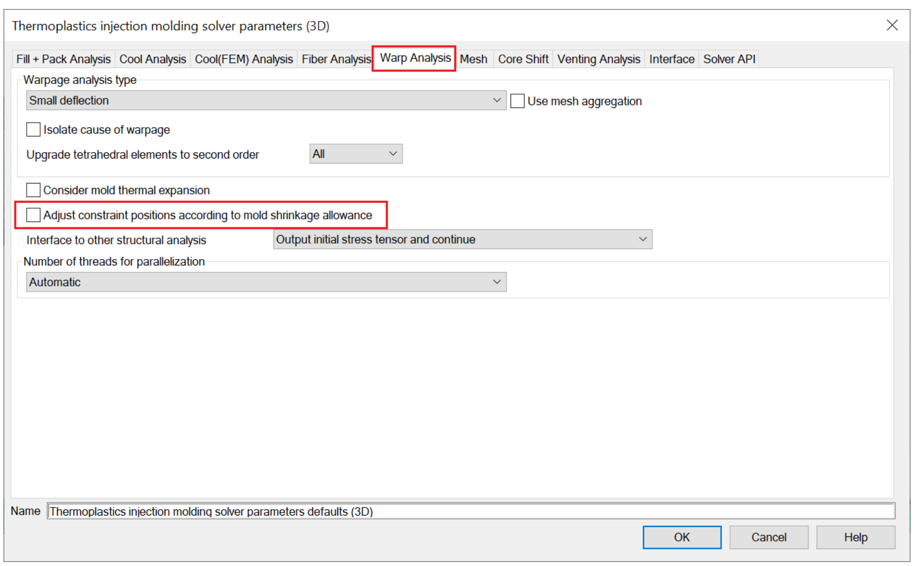

*Figure 1. Solver option of "Adjust constraint positions according to mold shrinkage allowance" under the **Warp Analysis** tab in the **Thermoplastics injection molding solver parameters** dialog box.*

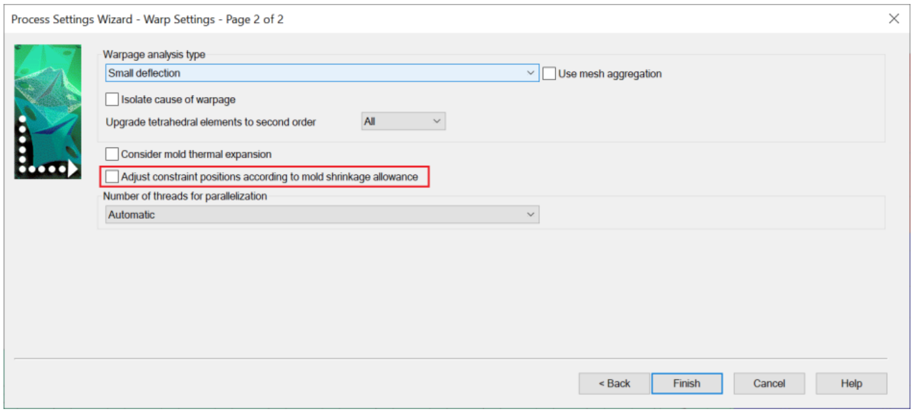

*Figure 2. Solver option of “Adjust constraint positions according to mold shrinkage allowance” in the **Process Settings Wizard – Warp Settings** dialog box.*

This feature causes the warp solver to adjust the position of constraints according to the scale-up factor of the mold shrinkage allowance. This results in the constrained nodes adopting the correct positions to represent attachment points of the plastic part onto a rigid assembly. The warp solver computes the final deformation of the injection-molded part after it’s been assembled, along with its deviation from the original part design.

By default, this option is unchecked. Warp constraints will not be adjusted unless nodal translations are manually specified.

User Workflow

To take into account the adjustments of constraint positions based on mold shrinkage allowance, users must first set up appropriate constraint for the mounting points and set “Use Constraint in” to “Warp Analysis” or “Stress and Warp Analysis”, as shown in Figure 3. A local coordinate system can be utilized if required. At a minimum, sufficient constraint must be applied to prevent rigid body motion.

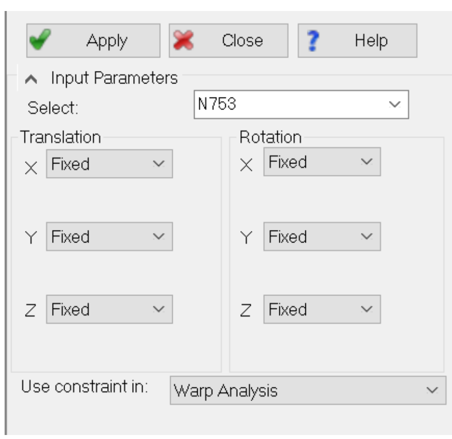

Figure 3 Setting up constraints for “Adjust constraint positions according to mold shrinkage allowance” option.

The next step for the user is to activate the "Adjust constraint positions according to mold shrinkage allowance" option. When this checkbox is selected in the warp analysis, an input box titled "Mold shrinkage allowance" will appear. This input box allows users to specify the mold shrinkage allowance used to scale up the mold cavity, as shown in Figure 4.

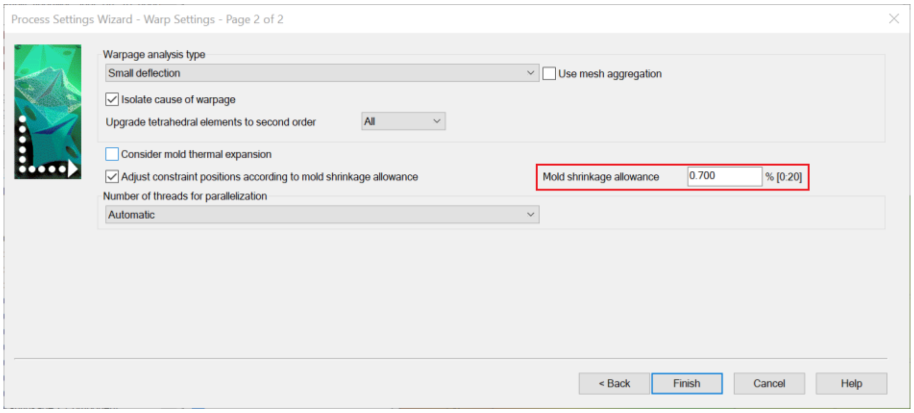

*Figure 4. "Mold shrinkage allowance" specified in the **Process Settings Wizard – Warp Settings** dialog box.*

Once the settings mentioned above are in place, the user can execute either the Cool+Fill+Pack+Warp or Fill+Pack+Warp analysis.

Results

The deflection result produced by the Warp solver will incorporate adjustments of constraint positions according to the mold shrinkage allowance if this option is enabled in the analysis. If the "Isolate cause of warpage" option is enabled along with the option to "Adjust constraint positions according to mold shrinkage allowance", then a new "**Deflection, constraint effects**" result is produced which shows the deflection solely due to the movement of the constraints. Note that the deflection results due to other causes of warpage include the effect of the constraints in their positions in the scaled-up mold (without the movement of constraint positions).

Furthermore, a new result titled **Deviation from part design** will be generated, as shown in Figure 5. This result illustrates the geometric deviation between the final mounted part and the original part design (geometry prior to scaling up to compensate for molding shrinkage). This additional output provides a quantifiable measure of the deviation from the original design, offering valuable insights for design optimization and potential adjustments to the injection molding process.

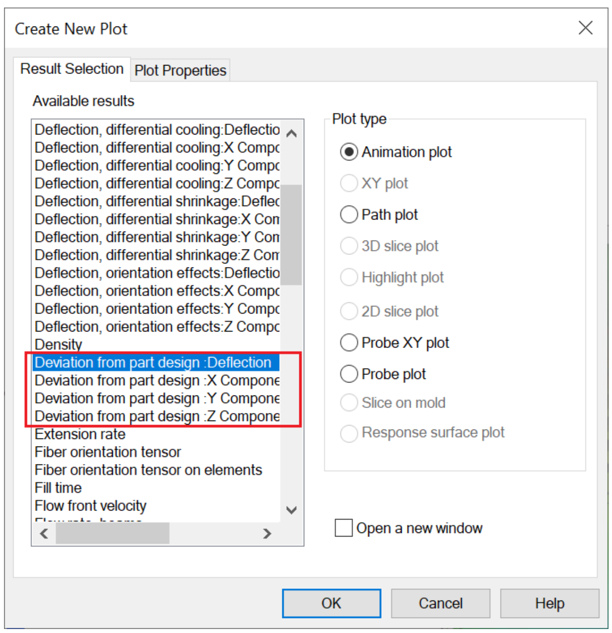

*Figure 5 New result **Deviation from part design: Deflection**.*

When no warp constraints are applied, this result is similar to adjusting for the mold shrinkage allowance by using the "shrinkage compensation" option in the plot properties of a regular "Deflection" result. However, the "shrinkage compensation" plot property should not be used if constraints which influence of the final part shape are present. This is because that plot property cannot account for the movement of the constraint positions in scaling from mold to part design dimensions. If the "Adjust constraint positions according to mold shrinkage allowance" option is not selected, the Warp solver will not generate the **Deviation from part design** result.

Verification and Validation

Two examples are provided to illustrate the effectiveness of the newly introduced feature "Adjust constraint positions according to mold shrinkage allowance" in this validation report. The uncorrected residual stress model is used in both examples.

Molded Square Plate Fastened to Mounting Positions at Four Corners

This particular case is utilized to demonstrate various scenarios in assembly simulation. The part under consideration has been designed with dimensions of $40mm \times 40mm \times 2mm$ and is modeled using a midplane shell mesh. The chosen material for this part is a PA6: Tarnamid T-27 natural from Azoty Tarnow. The processing conditions for this case are detailed in Table 1.

Table 1: Processing conditions of a square plate.

Mold Temperature	80 °C
Melt Temperature	270 °C
Injection Time	1 second
Packing Time	10 seconds
Packing Pressure	10 MPa

To offset the shrinkage that occurs during the injection molding process, the mold cavity is scaled up by the material’s nominal shrinkage. Shrinkage simulation suggests that the plate will undergo a shrinkage of approximately 1.64%. If we use this 1.64% as the material’s nominal shrinkage for cavity scaling-up, we can produce a molded part that closely matches the intended size.

Using the proposed approach, the predicted deformation after mounting the plate at four corners is depicted in Figure 6. The graphic reveals that the geometric deviation from the original design is virtually zero, demonstrating the effectiveness of using the correct shrinkage allowance.

Conversely, if 1% is used as the material’s nominal shrinkage for cavity scaling-up, the resulting molded part will be too small. When it’s forcefully mounted at the four corners, the molded plate is subjected to tension. The predicted deformation post-mounting is illustrated in Figure 7. The plate’s edges are shown to be slightly bowed inward, indicating that the smaller mold shrinkage allowance used in scaling up the cavity resulted in a part that deviates from the intended design.

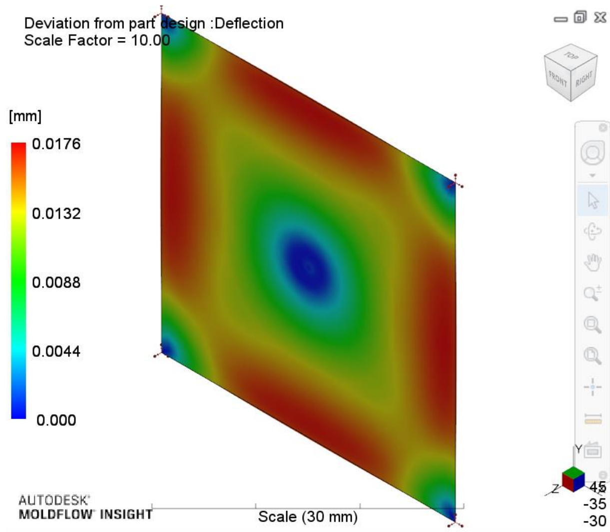

Figure 6 Deformation after mounting with 1.64% cavity scaling-up.

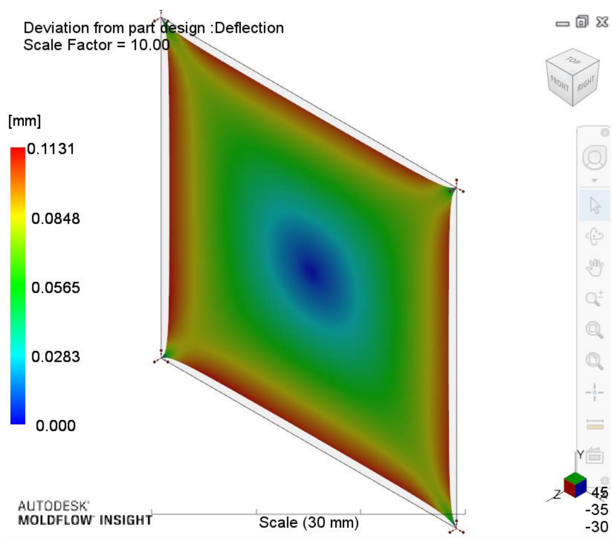

Figure 7 Deformation after mounting with 1.0% cavity scaling-up (midplane solution).

Alternatively, if 2% is used as the mold shrinkage allowance for cavity scaling-up, the resulting molded part will be too large. When this part is forcefully mounted at the four corners, the molded plate is subjected to compression. The predicted deformation following the mounting is illustrated in Figure 8. This shows the plate's edges slightly bowing outward, indicating that using a larger mold shrinkage allowance in scaling up the cavity results in an oversized part. Figure 9 demonstrates the predicted compressive stress level, providing further insight into the effects of using a larger mold shrinkage allowance on the final part characteristics.

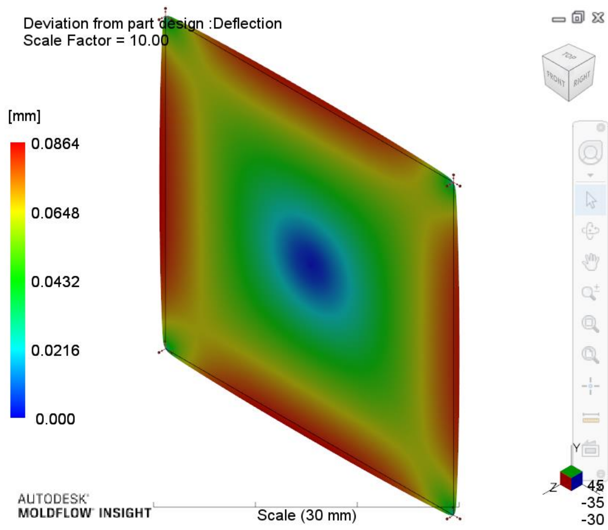

Figure 8 Deformation after mounting with 2.0% cavity scaling-up.

The compression stress induced by assembly could potentially cause buckling during the assembly process. A buckling analysis [3] indicates an eigenvalue of 2.375 from the compressive stress level depicted in Figure 9. This value suggests that buckling won't occur if the molded part is forcefully mounted at the four corners. The buckling mode, or the shape the plate will take upon buckling, is demonstrated in Figure 10.

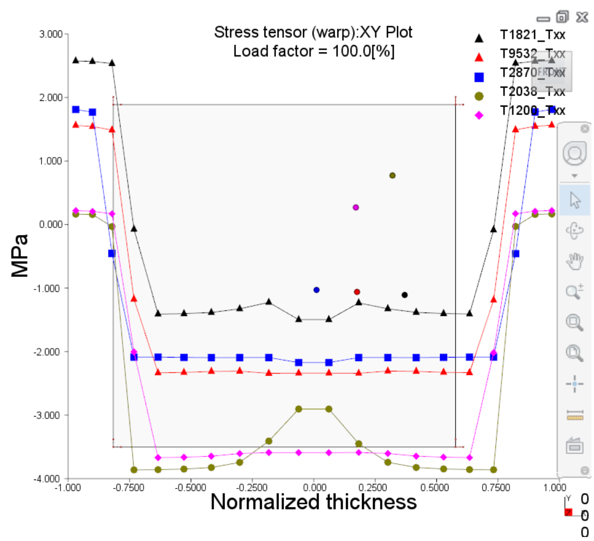

Figure 9 Compressive stress after mounting with 2.0% cavity scaling-up.

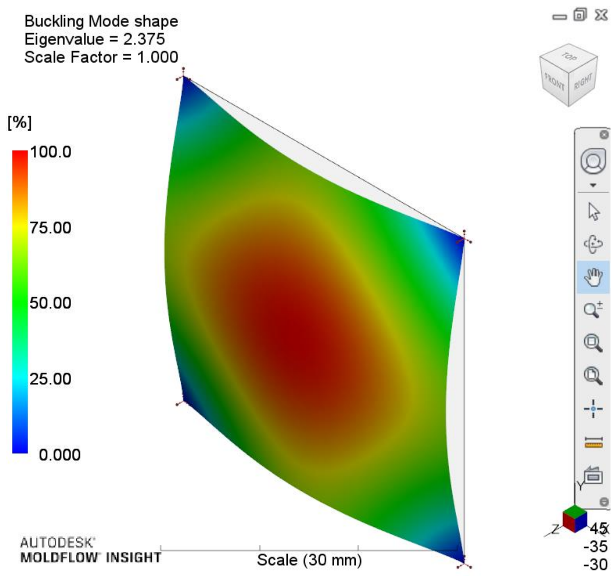

Figure 10 Buckling analysis after mounting with 2.0% cavity scaling-up.

While these analyses have been conducted on a midplane model, the approach is also implemented for the Dual Domain mesh type and 3D meshes for injection molding. Figure 11 and Figure 12 display the deformation results using the Dual Domain mesh technology and 3D mesh technology after mounting with a 1.0% cavity scale-up, respectively. These results are akin to the results obtained from the midplane mesh, as shown Figure 7.

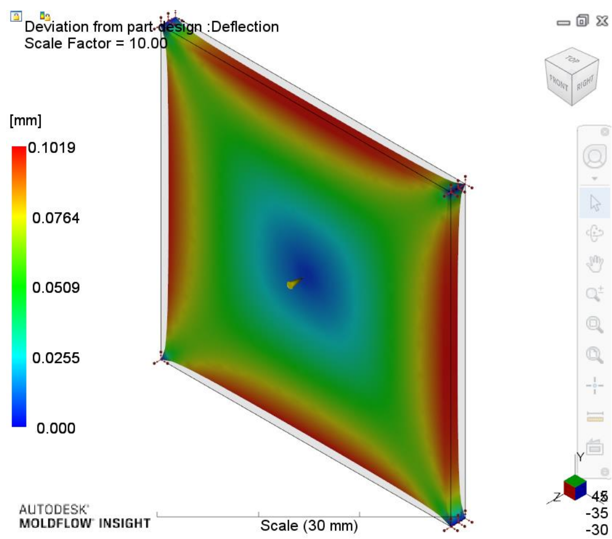

Figure 11 Deformation after mounting with 1.0% cavity scaling-up (Dual Domain solution).

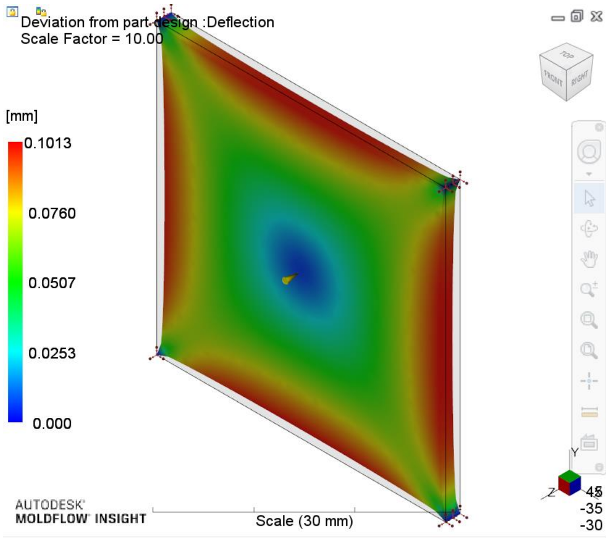

Figure 12 Deformation after mounting with 1.0% cavity scaling-up (3D solution).

Automotive Component

An automotive component is depicted in Figure 13. For the analysis, a 33% glass fiber filled PA66 material is used, specifically Zytel 70G33L NC010, manufactured by DuPont Performance Polymers. The specific process conditions used for this analysis are provided in Table 2.

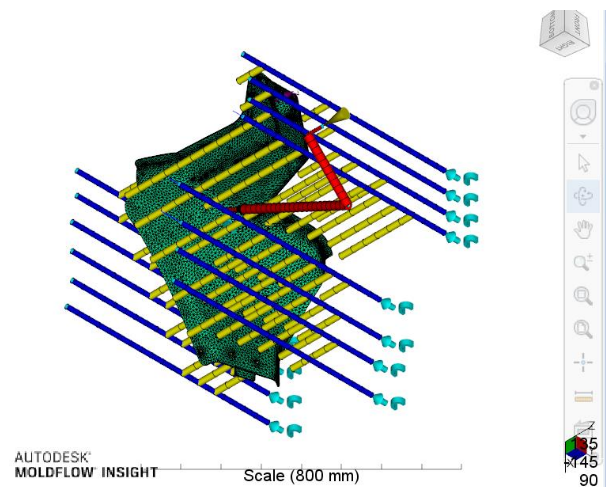

Figure 13 Model and cooling configuration details of an automotive component.

Table 2: Processing conditions of an automotive component.

Melt Temperature	295.5 °C
Injection Time	3.5 second
Packing Time	10 seconds
Packing Pressure	21 MPa
Cooling time	6.5 seconds

The cooling, filling, packing, fiber orientation, residual stress, and warpage analyses were performed on a 3D model. The average fiber orientation results are depicted in Figure 14. For a standard warpage analysis including mounting constraints, but which does not consider adjusting the constraint positions according to mold shrinkage allowance, the predicted deformed shape is shown in Figure 15. The image reveals a significant distortion on the left side of the edge.

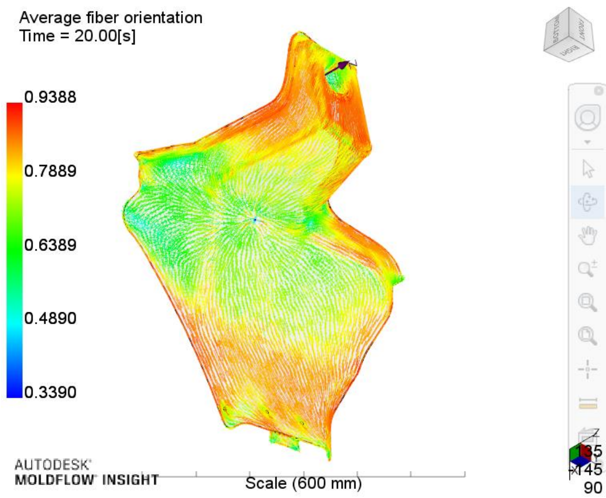

Figure 14 Predicted average fiber orientation.

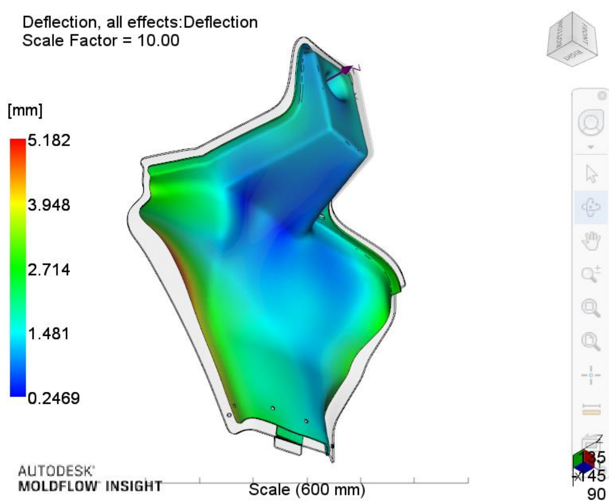

Figure 15 Warped shape without considering adjusted constraint positions according to mold shrinkage allowance in assembly.

In this study, the component is mounted into its designed position at six mounting points. The top mounting area serves as the anchor position where constraints are applied in all directions. In the other five mounting point, only the displacement out-of-plane is restricted.

It is assumed that 1% is used as mold shrinkage allowance for the cavity scaling-up. To calculate the final deformation after assembly, the imposed displacement is computed using the formula provided in the previous section. This is then automatically set up as a special loading case.

A warpage analysis, considering adjusted constraint positions according to mold shrinkage allowance, is performed. And the predicted deformed shape is shown in Figure 16. Interestingly, the distortion on the left side of the edge is actually reduced after assembly, demonstrating the impact of assembly constraints on the final component shape. The final deviation from the original design in terms of component shape and size is also predicted, as demonstrated in Figure 17.

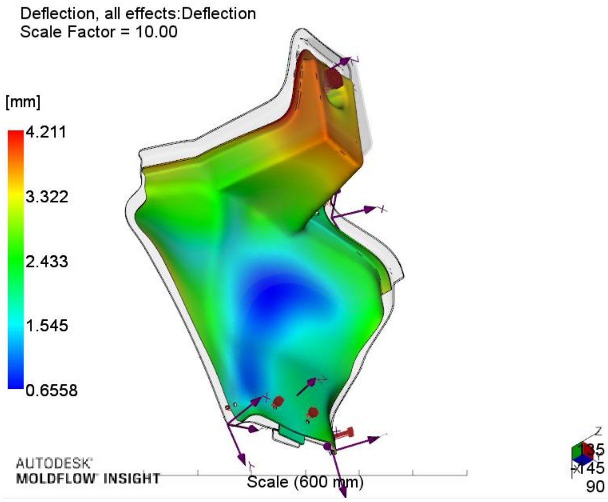

Figure 16 Warped shape considering adjusted constraint positions according to mold shrinkage allowance in assembly.

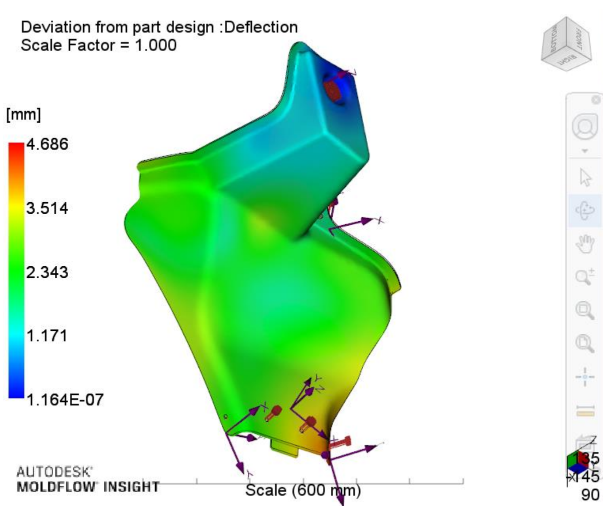

Figure 17 Final geometric deviation from designed shape and size considering adjusted constraint positions according to mold shrinkage allowance in assembly.

References

1. J. A. Camelio, S. J. Hu, S. P. Martin, Compliant Assembly Variation Analysis Using Component Geometric Covariance. Journal of Manufacturing Science and Engineering 126:355-380(2004)
2. Z. Fan, R. Speight, Deformation and stress prediction of injection molded components after being mounted into designed position. SPE ANTEC Proceedings, Orlando, Florida (2018).
3. Z. Fan, H. Yu, J. Xu and D. Astbury, Buckling prediction in 3D warpage simulation of injection molded plastics. Proc. Soc. Plastics Eng. Annual Technical Conference (ANTEC)(2013)