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ANALYSIS OF SHRINKAGE AND WARPAGE DISPLACEMENT USING CONFORMAL COOLING

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Abstract

This research paper presents a comprehensive comparison between conformal and conventional cooling channels in injection molding, focusing on geometric conformity, cooling performance, and part quality. The study demonstrates that conformal cooling channels offer a more compact design, with lower displacements in all directions. This enhanced geometric conformity leads to improved space utilization and better adaptation to complex part geometries. The cooling performance of conformal channels is found to be superior to conventional channels, with shorter cooling times and higher cooling efficiency. This results in increased productivity and reduced cycle times. Moreover, conformal cooling channels exhibit better thermal management, lower volumetric shrinkage, and improved flatness, contributing to higher part quality and reduced warpage. The research findings underline the potential of conformal cooling technology as a valuable solution for optimizing the injection molding process.

Keywords: conformal cooling channels, conventional cooling channels, cooling efficiency, flatness and volumetric shrinkage

Introduction

The article titled "Analysis of shrinkage and warpage displacement using conformal cooling" discusses the use of conformal cooling in injection molding processes to reduce shrinkage and warpage displacement. Shrinkage and warpage are common issues in injection molding, which can lead to dimensional inaccuracies and other defects in the molded products.

The article describes the methodology used to simulate the effects of conformal cooling on shrinkage and warpage displacement. The authors create a 3D model of the mold and simulate the injection molding process using finite element analysis software. They compare the results of simulations using conventional cooling channels versus simulations using conformal cooling channels.

The results of the study show that conformal cooling can significantly reduce the shrinkage and warpage displacement in injection-molded parts. The authors conclude that the use of conformal cooling can improve the dimensional accuracy and quality of injection-molded parts, resulting in cost savings for manufacturers.

Overall, this article highlights the importance of controlling shrinkage and warpage displacement in injection molding processes and the potential benefits of using conformal cooling to achieve this. It also underscores the value of simulation techniques in understanding the effects of process parameters on the quality of manufactured products.

Literature Review

Injection molding is a widely used manufacturing process for producing parts with complex shapes. However, the production process is often associated with challenges such as shrinkage and warpage. These issues can cause dimensional inaccuracies, reduced mechanical properties, and product defects[1]. Studies have investigated different methods to mitigate these problems, and one solution that has been explored is the use of conformal cooling. Conformal cooling is a technique that involves designing and manufacturing molds with cooling channels that conform to the shape of the part being produced, allowing for more uniform cooling[2]. It has been shown that shrinkage and warpage defects in injection-molded parts are significantly influenced by factors such as injection pressure, holds pressure, and cooling time [3].Studies such as Liao et al have investigated optimal process conditions for shrinkage and warpage in thin-wall parts. Other research, such as that by Doerffel et al, has studied the deformation of injection molded parts and validated the quality of plastic parts based on laminated sheet parts [4].Further research by Mlekusch has compared the corner-warpage of short fiber reinforced injection moldings versus non-reinforced systems, showing that fiber alignment can result in orthotropic effects that contribute to increased warpage [5].

According to Hu et al, FE modeling of the map-molding process was carried out for a map mold encapsulated with the epoxy system and the warpage [6] caused by the curing process and the subsequent cooling down stage was investigated. Additionally, studies have shown that the surface temperature of the mold is an essential factor in determining warpage [7].

Researchers, such as Yang et al, have evaluated the effectiveness of conformal cooling in reducing warpage and dimensional inaccuracies. Their results showed that conformal cooling can significantly improve the quality of injection-molded parts by reducing shrinkage and warpage [8].

However, while there have been many studies on the shrinkage and warpage of injection-molded parts, some aspects remain unexplored. For example, there is a lack of detailed research on the correlation optimization between volume shrinkage and warpage. Additionally, few studies have investigated the warpage of large-sized orthogonal stiffened plastic plates.More research is needed to fully understand and address these issues in injection molding. Nevertheless, current findings suggest that conformal cooling can be an effective solution for reducing shrinkage and warpage in injection-molded parts. By optimizing process parameters such as pressure, temperature, and cooling time while utilizing conform

Methodology

CAD Modelling

Creation of CAD Model by using CAD modelling tools in solidworks for creating the geometry of the part/assembly.

Governing Equation

In this study, the fluids are considered to be incompressible, Newtonian (for water) or generalized Newtonian (for polymer melt). The governing equations for 3D transient non-isothermal motion are:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = 0$$

$$\frac{\partial}{\partial t}(\rho \mathbf{u}) + \nabla \cdot (\rho \mathbf{u}\mathbf{u} + \tau) = -\nabla p + \rho \mathbf{g}$$

$$\rho C_P\left(\frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T\right) = \nabla(\mathbf{k}\nabla T) + \eta\dot{\gamma}^2$$

where **u** is velocity vector, T is temperature, t is time, p is pressure, τ is stress tensor, ρ is density, η is viscosity, k is thermal conductivity, Cp is specific heat & is shear rate. For the polymer melt, the stress tensor can be expressed as:

$$\tau = -\eta\left(\nabla \mathbf{u} + \nabla \mathbf{u}^T\right)$$

The modified-Cross model with Arrhenius temperature dependence is employed to describe the viscosity of polymer melt:

$$\eta(T, \dot{\gamma}) = \frac{\eta_o(T)}{1 + \left(\eta_o \dot{\gamma}/\tau^*\right)^{1-n}}$$

$$\eta_o(T) = BExp\left(\frac{T_b}{T}\right)$$

where n is the power law index, is the zero shear viscosity,* is the parameter that describes the transition region between zero shear rate and the power law region of the viscosity curve.

The total element number is from to the numerical schemes, Moldex3D uses a hybrid finite-difference/control volume/finite element method. Time step selection has an important effect on accuracy and calculating speed. An internal parameter was carefully chosen to have a good balance on accuracy and efficiency”.

Pre-Processing

- **Import part/ insert geometry:** import a CAD model for mould analysis.

- **Meshing:** Cross section is a basic operation in molding process. In this operation, the CAD geometry is discretized into expansive quantities of little Element and hubs. The game plan of hubs and component in space in a legitimate way is called network. The examination exactness and term relies on upon the cross section size and introductions. With the expansion in cross section size (expanding no. of component) the CFD examination speed diminish however the precision increment.

- **Type of Wizard:**

  1. **Gate wizard:** choose best gate location for filling of material
  2. **Runner wizard:** choose the type of runner for moulding process
- **Boundary Condition:** Define the desired boundary condition for the problem by choose moldbase wizard

- **Cooling Channel:** design the cooling channel for cooling the part in moulding process

- **Selection of inlet and outlet section in cooling channel:** Selecting the section from where the fluid is enter and exit in cooling channel.

- **Generate meshing:** by generating mesh the file is ready to execute.

Post Processing

- **Material Property**: Choose the Material property for molding process.
- **Processing:** For viewing and interpretation of Result. The result can be viewed in various formats: graph, value, animation etc.

Model Details

Table 1: Model details

S. No.	Parameter	
1	Material	ABS (CYCOLACBDT5510)
2	Part Thickness	1.8mm
3	Length	820mm
4	Breadth	299mm
5	Hieght	250mm

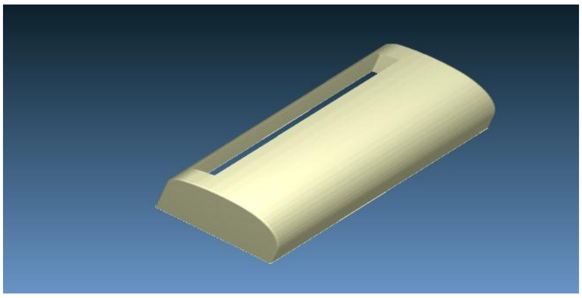


Figure 1: CAD Model Side View

Table 2: Model Geometry Channel detail

Parameter	dimension
Diameter of conformal cooling	8 mm
Distance between centre to centre of conformal pine	34 mm
Distance between outer diameter of conformal cooling and AC Cover	16 mm

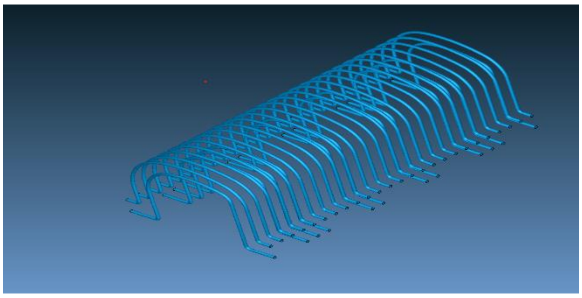


Figure 2: conformal cooling design isomatric view

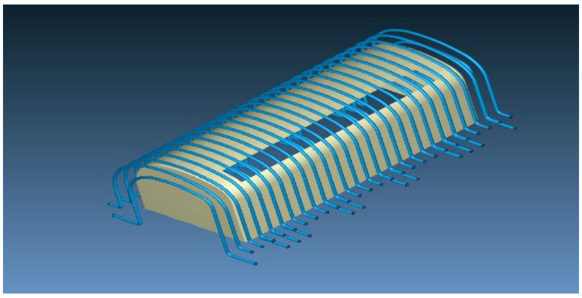


Figure 3: CAD Model with conformal cooling side view

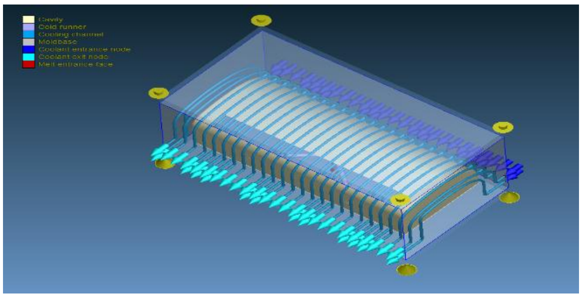
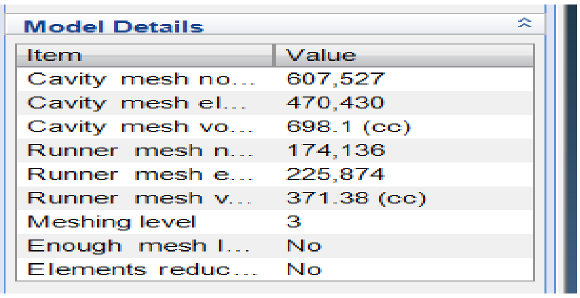


Figure 4: CAD Model and conformal cooling in mould



Model Details

Item	Value
Cavity mesh no...	607,527
Cavity mesh el...	470,430
Cavity mesh vo...	698.1 (cc)
Runner mesh n...	174,136
Runner mesh e...	225,874
Runner mesh v...	371.38 (cc)
Meshing level	3
Enough mesh l...	No
Elements reduc...	No

Figure 6.7: CAD Model and conformal cooling Meshing Details

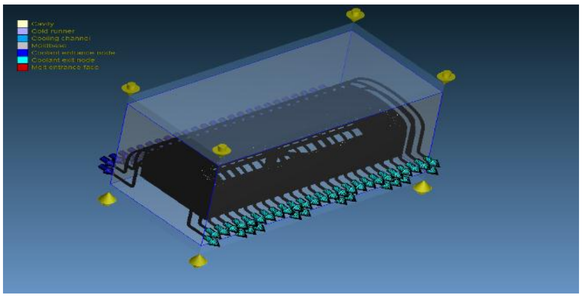


Figure 5: CAD Model and conformal cooling in mould after Meshing

Result

- **Conventional Cooling**

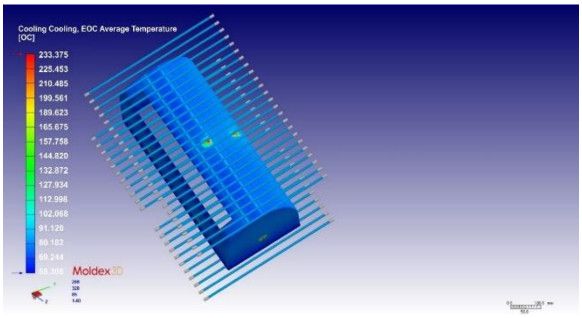


Figure 6: Average Temperature of Conventional Cooling

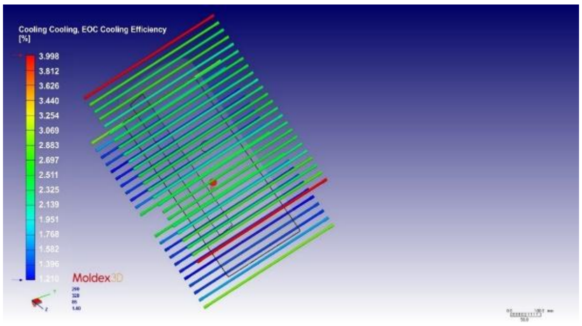


Figure 7: Cooling Efficiency of Conventional Cooling

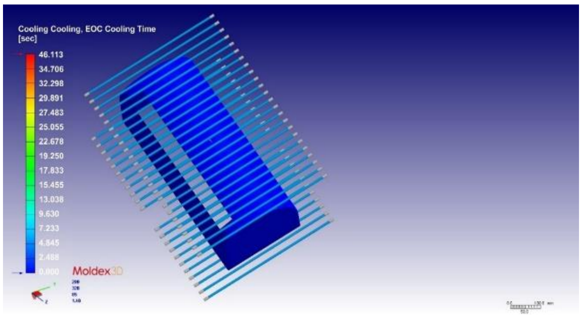


Figure 8: Cooling Time of Conventional Cooling

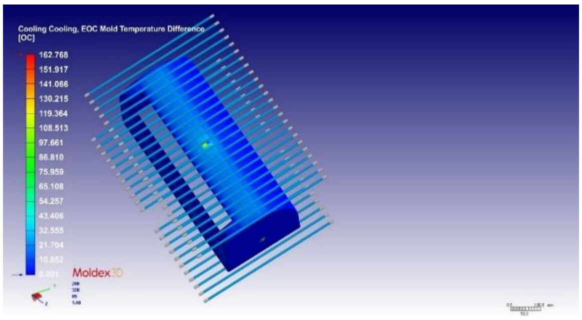


Figure 9: Mold Temperature Difference of Conventional Cooling

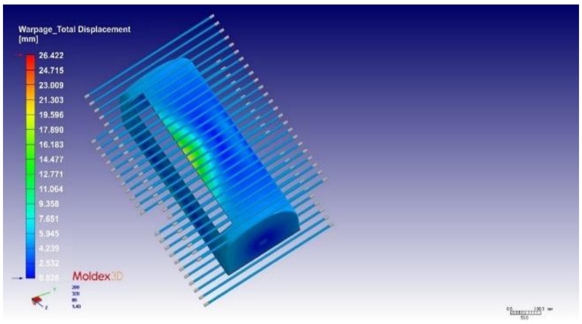


Figure 10: Total Displacement of Conventional Cooling

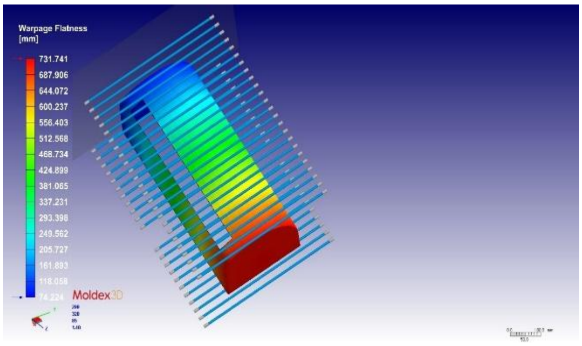


Figure 11: Warpages Flatness of Conventional Cooling

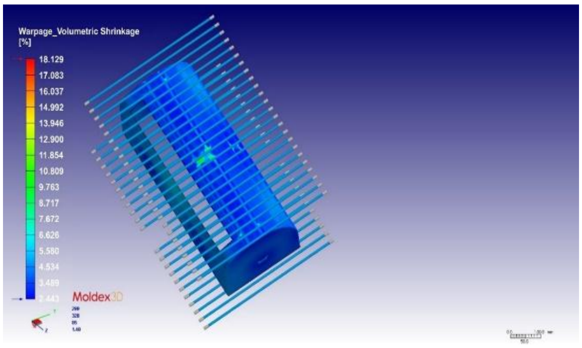


Figure 12: Volumetric Shrinkage of Conventional Cooling

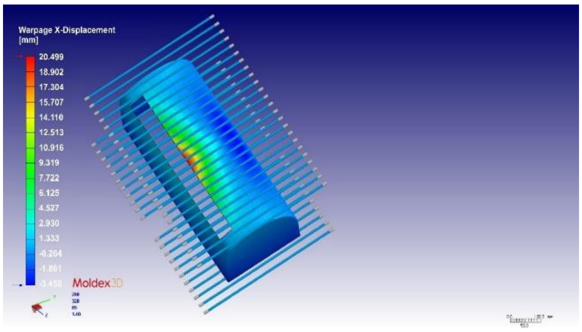


Figure 13: X-Displacement of Conventional Cooling

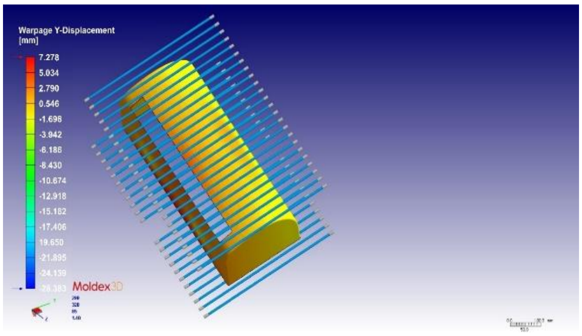


Figure 14: Y-Displacement of Conventional Cooling

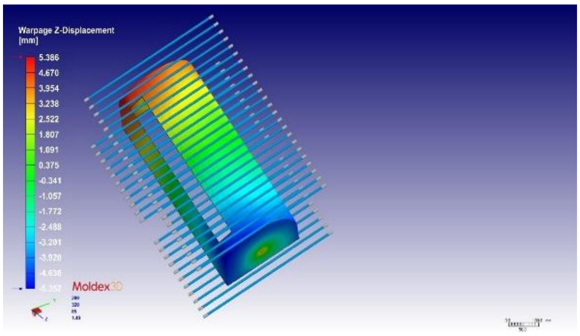


Figure 15: Z-Displacement of Conventional Cooling

- **Conformal Cooling**

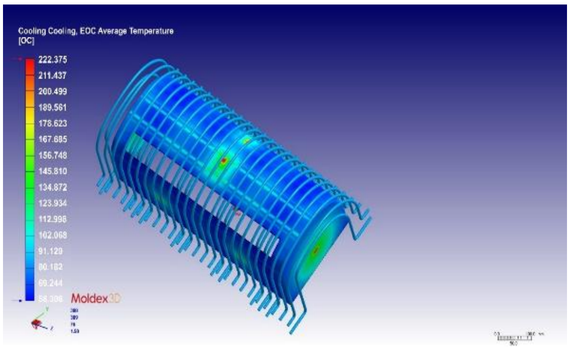


Figure 15: Average Temperature of Conformal Cooling

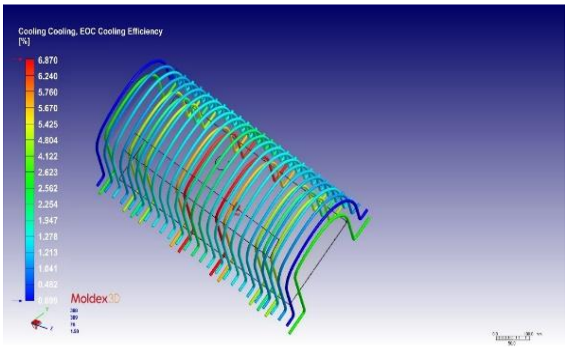


Figure 16: Cooling Efficiency of Conformal Cooling

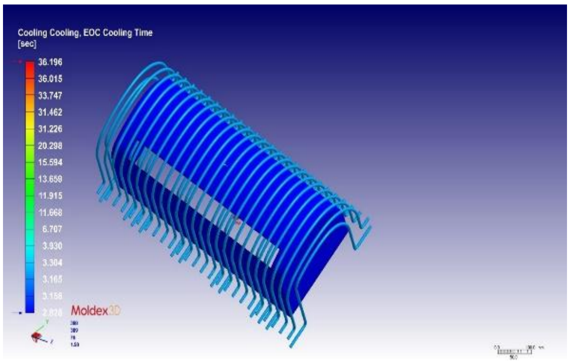


Figure 17: Cooling Time of Conformal Cooling

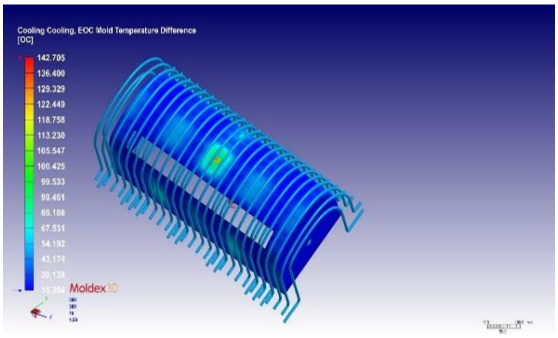


Figure 18: Mold Temperature Difference of Conformal Cooling

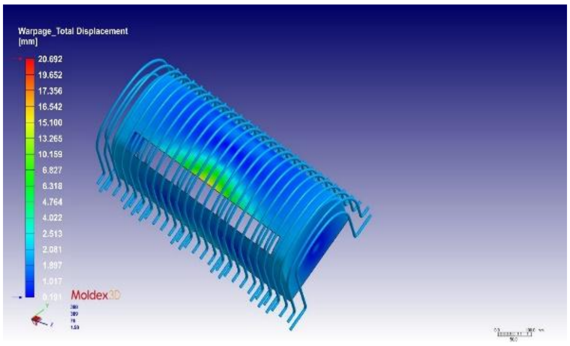


Figure 19: Total Displacement of Conformal Cooling

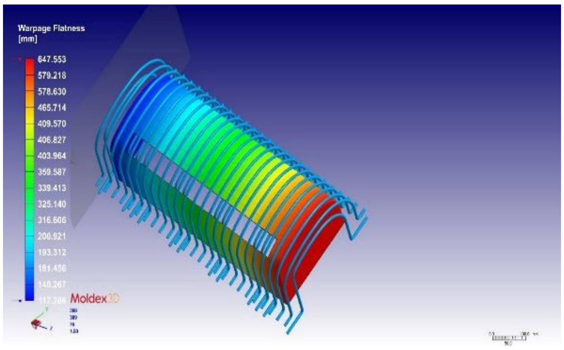


Figure 19: Warpages Flatness of Conformal Cooling

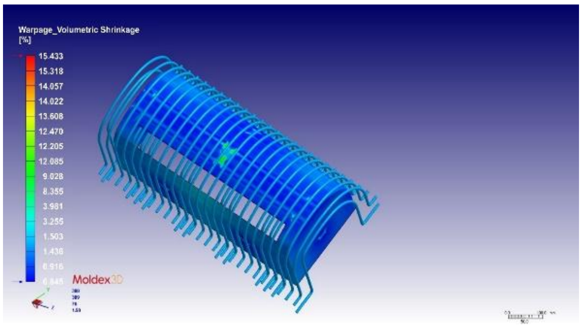


Figure 20: Volumetric Shrinkage of Conformal Cooling

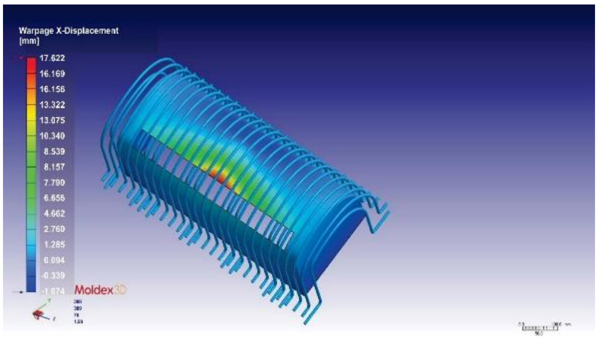


Figure 21: X-Displacement of Conformal Cooling

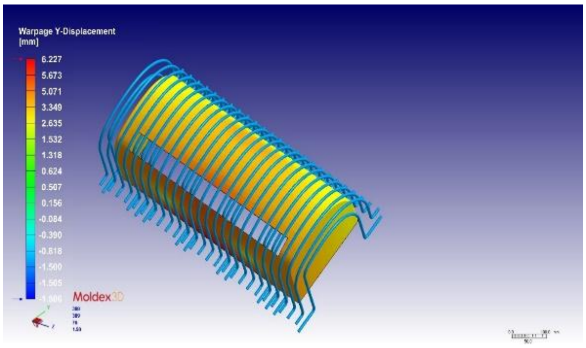


Figure 22: Y-Displacement of Conformal Cooling

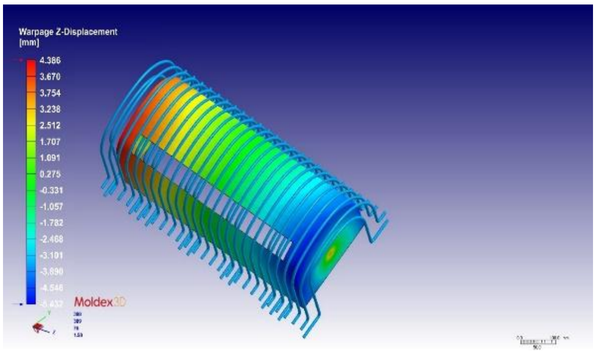


Figure 23: Z-Displacement of Conformal Cooling

Table 3: Comparison Between Conventional and Conformal Cooling

Parameter	**Convectional Cooling**	**Conformal Cooling**
X-Displacement	20.49 mm	17.62 mm
Y-Displacement	7.27 mm	6.22 mm
Z-Displacement	5.38 mm	4.38 mm
Total Displacement	26.42 mm	20.69 mm
Volumetric Shrinkage	18.12 mm^3	15.43 mm^3
Flatness	731.74	647.55
Cooling Time	46.11 sec	36.19 sec
Cooling Efficiency	3.99 %	6.87 %
Mold Temperture Diffrence	162.76°C	142.70 °C
Avg Temperture	233.37 °C	222.37 °C

Conclusion

conformal cooling channels have a more compact design, with lower displacements in the X, Y, and Z directions (17.622, 6.227, and 4.386, respectively) compared to conventional cooling channels (20.499, 7.278, and 5.386, respectively). The total displacement is also lower for conformal cooling channels at 20.692, as opposed to 26.422 for conventional channels. This indicates that conformal cooling channels can provide better geometric conformity and space utilization. Moreover, conformal cooling channels showcase lower volumetric shrinkage (15.433) than conventional channels (18.129), which could potentially lead to better dimensional accuracy and reduced warpage. The flatness value is also lower for conformal channels (647.553) compared to conventional channels (731.741), suggesting improved surface quality.

In terms of cooling performance, conformal cooling channels significantly outperform conventional channels with a shorter cooling time (36.19 vs. 46.113) and higher cooling efficiency (6.870 vs. 3.998). This implies that conformal cooling channels can reduce cycle time and improve productivity. Additionally, conformal channels exhibit a lower mold temperature difference (142.705) compared to conventional channels (162.768), which could lead to more uniform cooling and reduced thermal stresses. The average temperature (Avg temp0) is also lower for conformal cooling channels (222.375) compared to conventional cooling channels (233.375), indicating better thermal management. Overall, conformal cooling channels offer several advantages over conventional cooling channels, including enhanced cooling performance, reduced cycle times, and improved part quality.

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