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ANALYSIS OF THERMALLY INDUCED RESIDUAL STRESSES USING CONFORMAL COOLING

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Abstract

In this research paper, we explore the impact of conformal and conventional cooling channels on thermally induced residual stress components in injection molding. The study reveals that conformal cooling channels experience lower stress components across all directions (X, Y, and Z) compared to conventional channels, indicating better dimensional stability and reduced warpage. Additionally, conformal cooling channels exhibit lower shear stress values in the XY, YZ, and ZX planes, which may result in improved part quality and reduced susceptibility to defects caused by high shear stresses. The Von Mises stress, an indicator of the overall stress experienced by the material, is also found to be lower for conformal cooling channels, suggesting better stress management and enhanced part quality compared to conventional cooling channels. The research findings emphasize the importance of conformal cooling technology in addressing stress-related challenges in injection molding.

Key word: conventional channels, stress components, injection molding, conformal cooling, shear stresses and Von Mises stress

Introdution

The article titled "Analysis of thermally induced residual stresses using conformal cooling" explores the use of conformal cooling in injection molding processes to reduce the residual stresses that can occur during cooling. Residual stresses can cause warping, cracking, and other defects in the molded product, which can lead to costly production problems and reduced product quality.

The article discusses the methodology used to simulate the effects of conformal cooling on residual stresses. 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 demonstrate that conformal cooling can significantly reduce the residual stresses in injection-molded parts. The authors conclude that the use of conformal cooling can improve the quality and reliability of injection-molded parts, resulting in cost savings for manufacturers.

Overall, this article highlights the importance of controlling residual stresses 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

Thermally-induced residual stresses are a major concern in the manufacturing industry, particularly in metal casting and molding processes. Residual stresses are caused by several factors, including shrinkage during solidification, thermal expansion and contraction, and inhomogeneous cooling rates. These stresses can result in a variety of detrimental effects, such as warping, cracking, and reduced mechanical strength. [1]

One effective method of reducing thermally-induced residual stresses is through the use of conformal cooling. Conformal cooling involves the placement of cooling channels in a mold or casting that matches the shape of the object being produced. Studies have shown that this method significantly reduces thermal gradients, thereby reducing the magnitude of residual stresses. [2]

As an example, the use of a conformal cooling system in a pressure mold for casting Zn alloys resulted in a reduction in solidification phase time by 1 second, as reported by authors in a study. [3]

In addition, shot peening or dynamic surface treatment can be used to introduce compressive residual stresses in metallic glasses. Direct casting processes have limitations due to the conflicting requirements for mold filling and vitrification, restricting the shapes that can be produced. However, by carefully balancing processing parameters, limited shapes can be produced. [4] High thermal conductivity steels have also proven effective in reducing thermally-induced stresses. [5]

It has been observed that high levels of residual stresses are commonly detected in large cast components with intricate geometry, particularly when parts have low thermal conductivity and cooling rates are non-uniform. [6] The semi-solid casting process has emerged as a popular metal-forming method due to its ability to produce high-quality components with superior mechanical properties. [7] Simulation is a key tool for understanding and minimizing thermally-induced residual stresses in casting processes. The use of trial-and-error practices for optimal process parameters is both expensive and time-consuming. [8]

In conclusion, the analysis of thermally-induced residual stresses in metal forming processes is a complex and challenging task. The use of conformal cooling systems has been identified as an effective method for reducing these stresses. Additionally, shot peening or dynamic surface treatment can also be used to introduce compressive residual stresses in metallic glasses. Direct casting processes have limitations but can be optimized through careful balancing of processing parameters. High thermal conductivity steels have shown promise in reducing thermally-induced stresses. Lastly, simulations provide a valuable tool for minimizing residual stresses while optimizing process parameters more efficiently and cost-effectively than traditional trial-and-error methods.

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

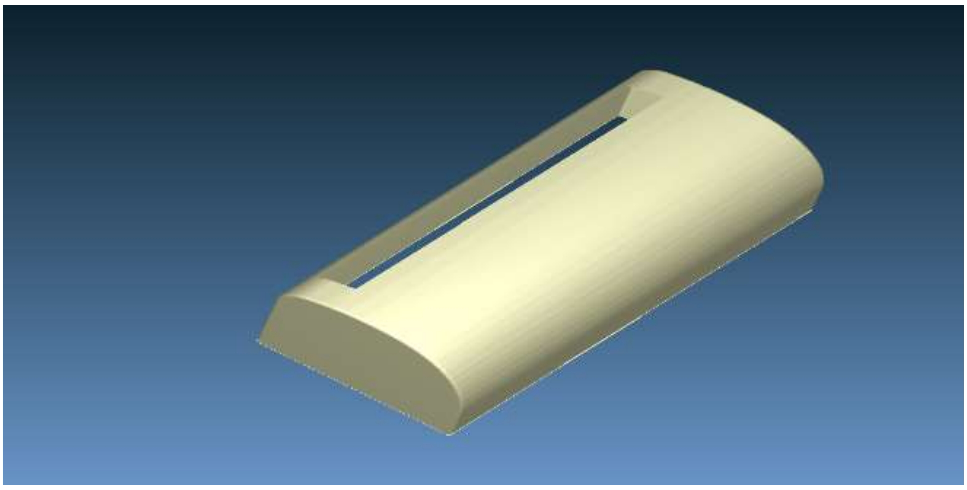


Figure 1: CAD Model Side View

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

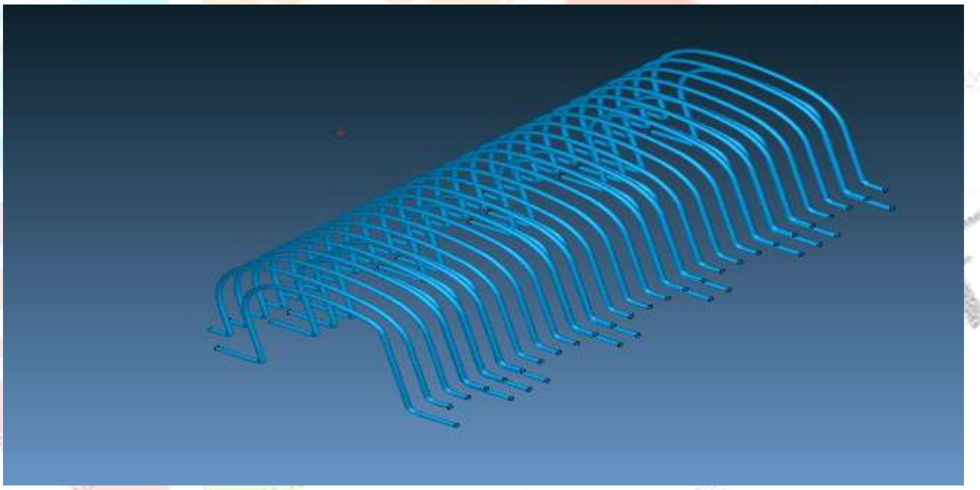


Figure 2: conformal cooling design isomatric view

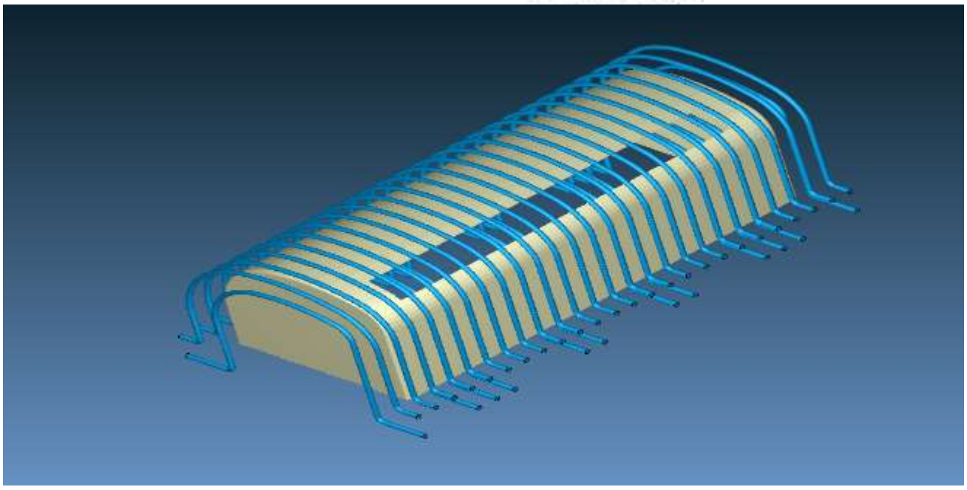


Figure 3: CAD Model with conformal cooling side view

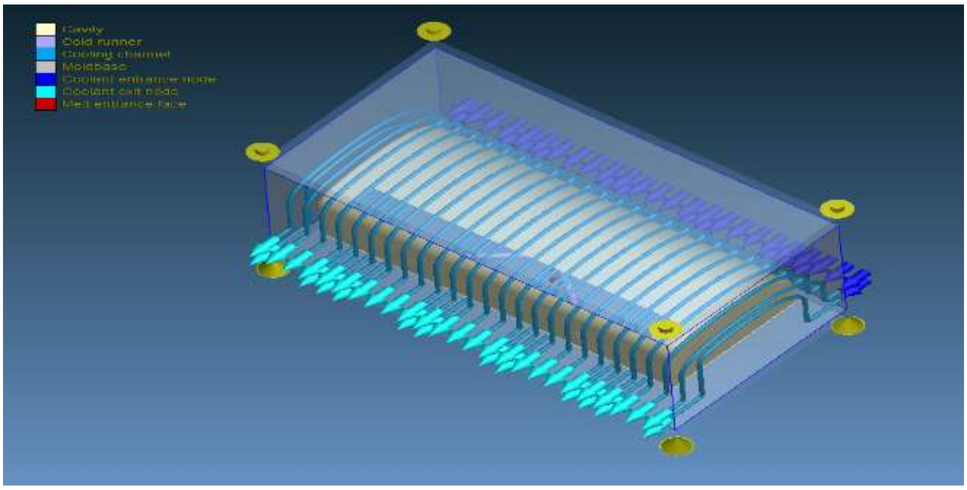
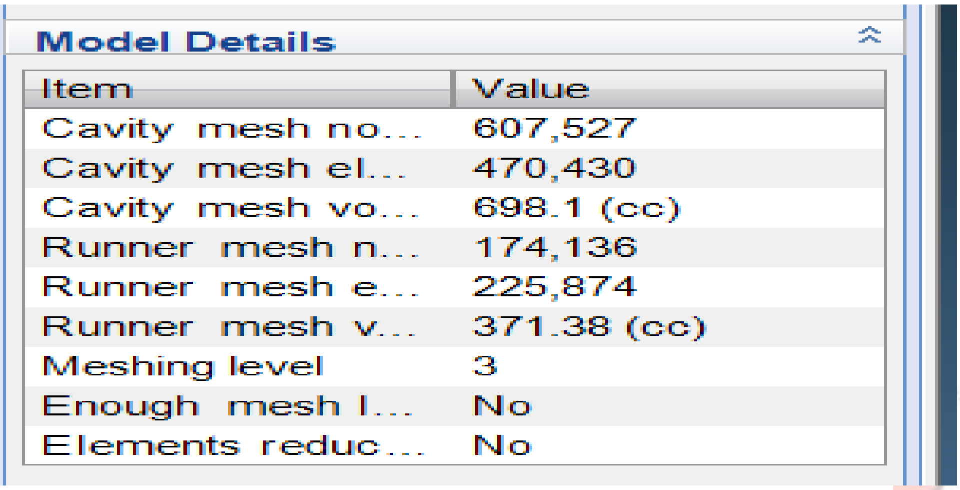


Figure 4: CAD Model and conformal cooling in mould



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

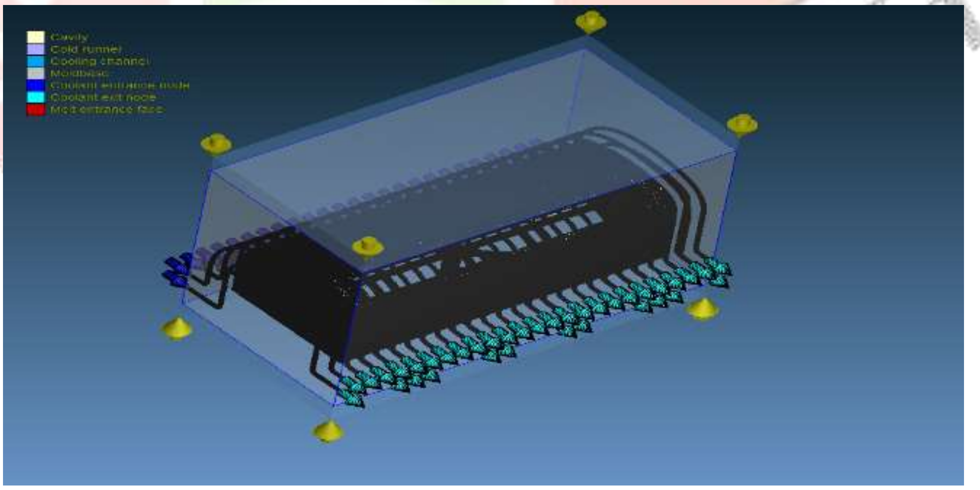


Figure 5: CAD Model and conformal cooling in mould after Meshing

Result

- **Conventional Cooling**

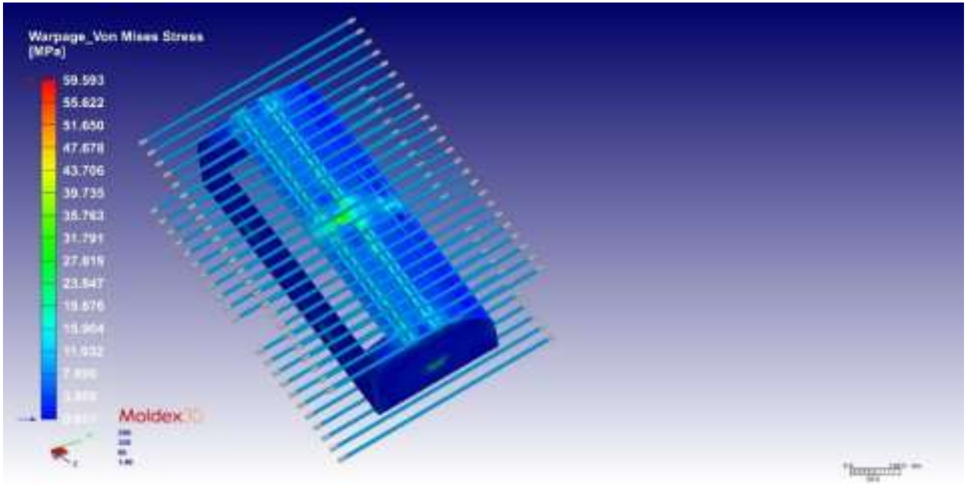


Figure 6: Von Mises Stress of Conventional Cooling

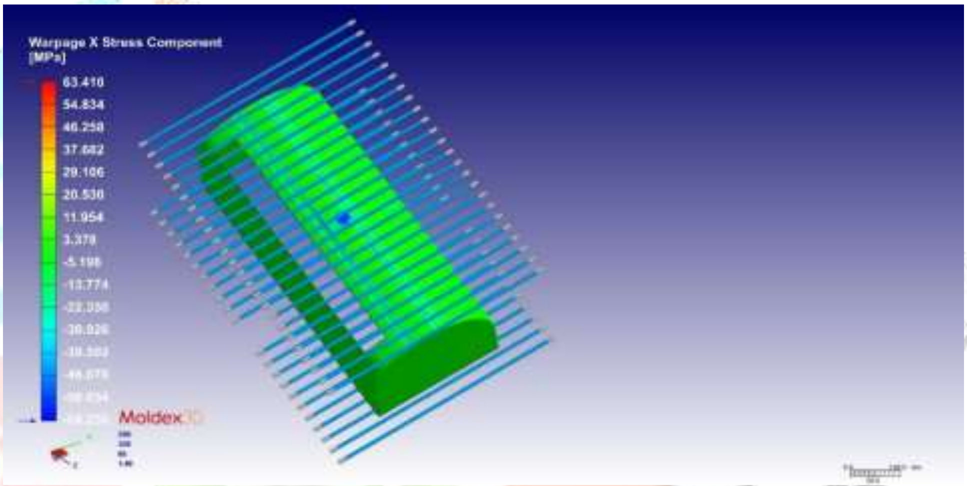


Figure 7: X Stress Component of Conventional Cooling

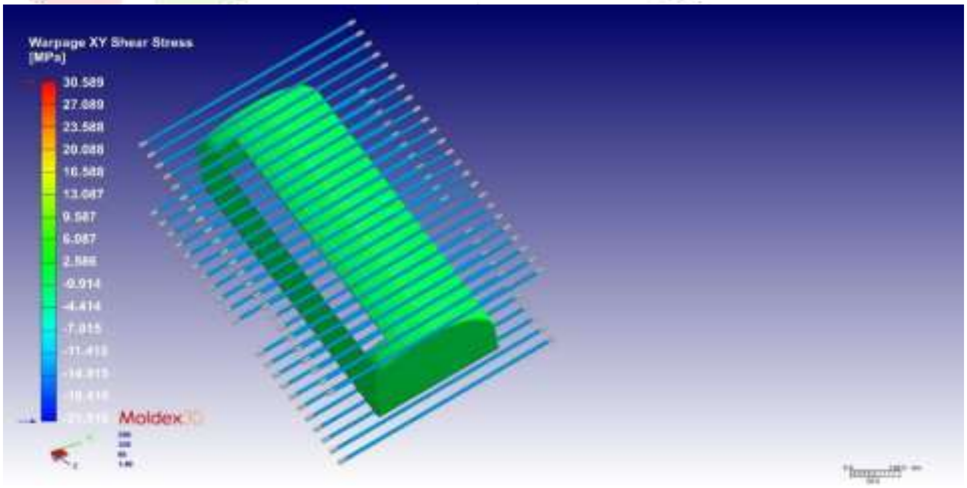


Figure 7: XY Shear Stress of Conventional Cooling

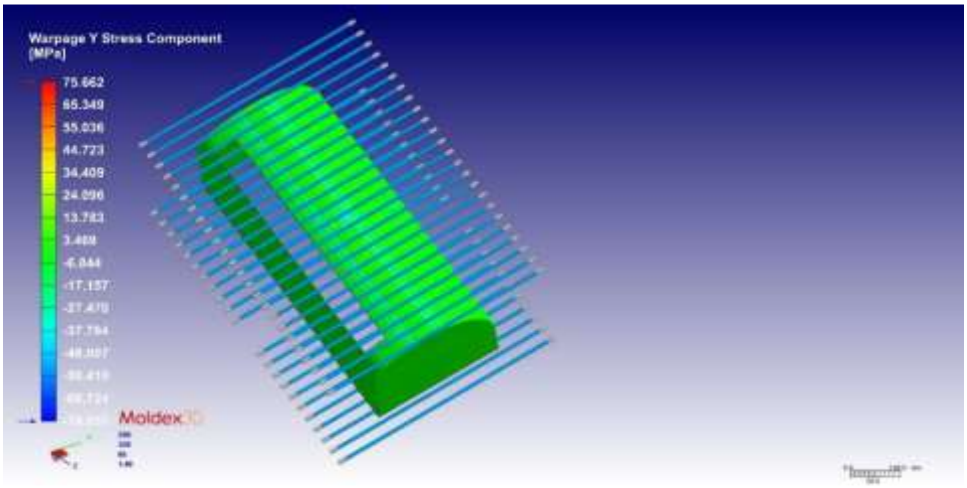


Figure 8: Y Stress Component of Conventional Cooling

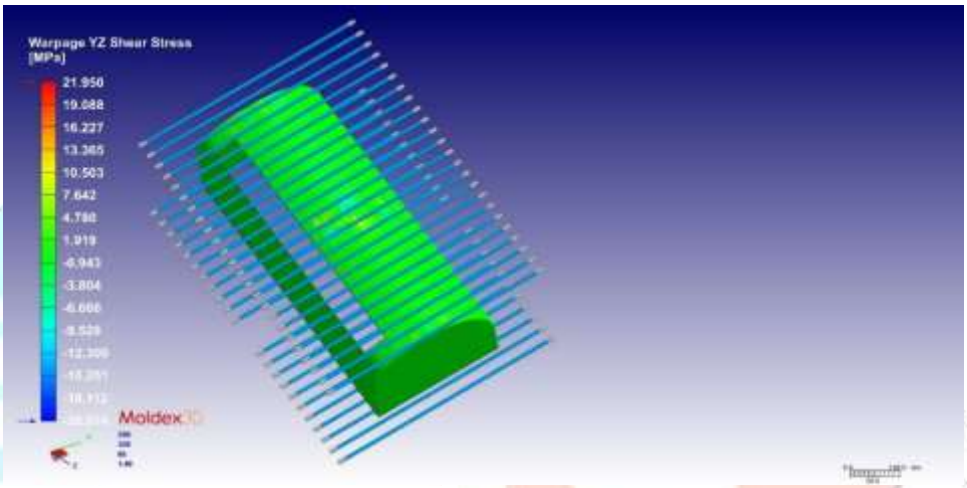


Figure 9: YX Shear Stress of Conventional Cooling

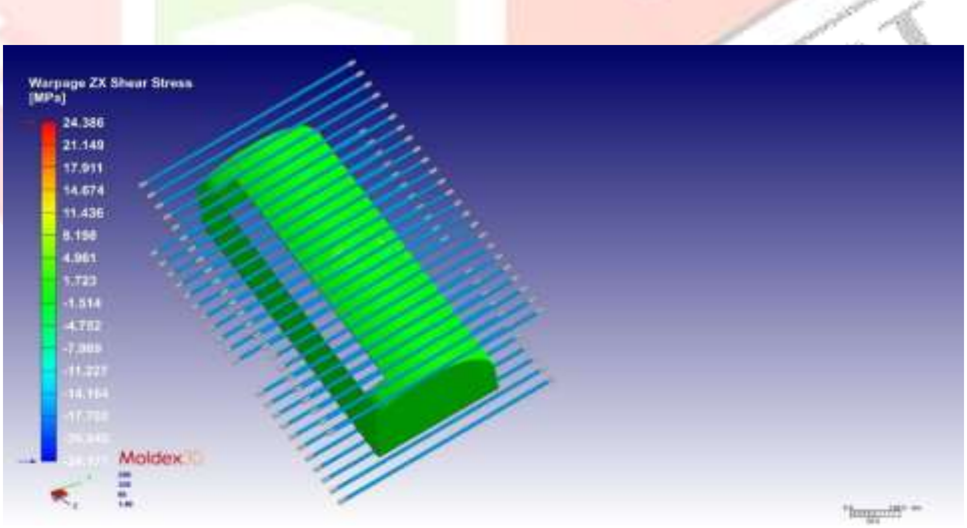


Figure 10: XZ Shear Stress of Conventional Cooling

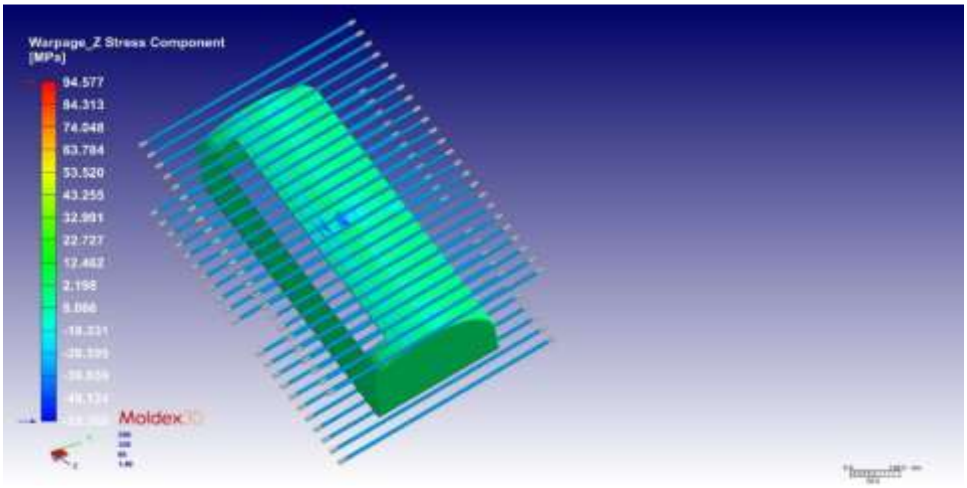


Figure 11: Z Stress Component of Conventional Cooling

- **Conformal Cooling**

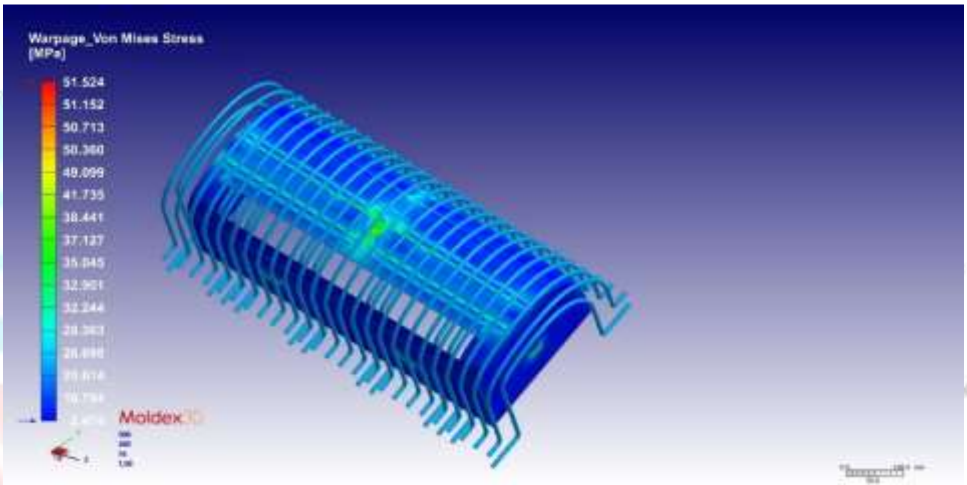


Figure 12: Von Mises Stress of Conformal Cooling

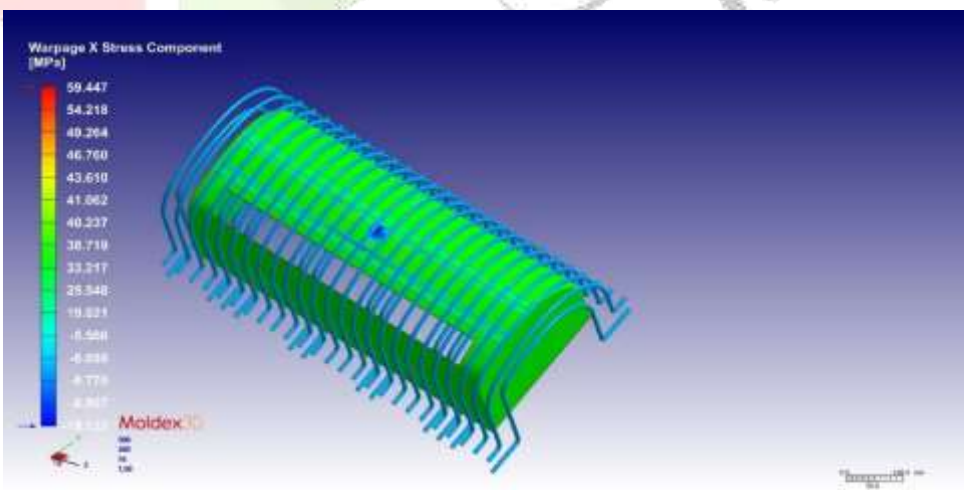


Figure 12: X Stress Component of Conformal Cooling

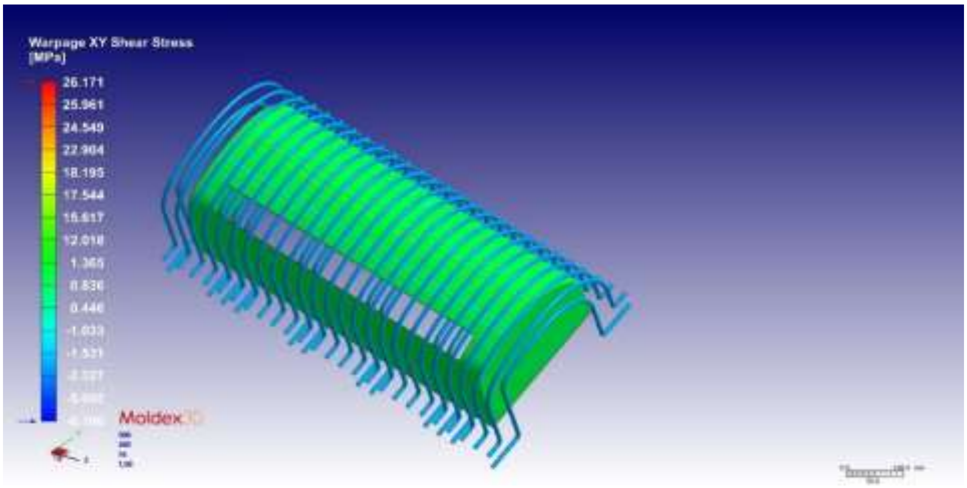


Figure 13: XY Shear Stress of Conformal Cooling

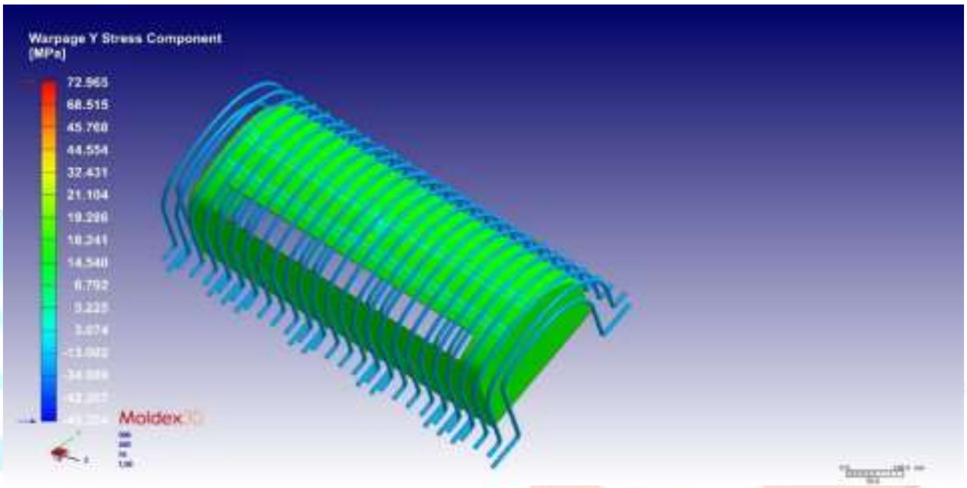


Figure 14: Y Stress Component of Conformal Cooling

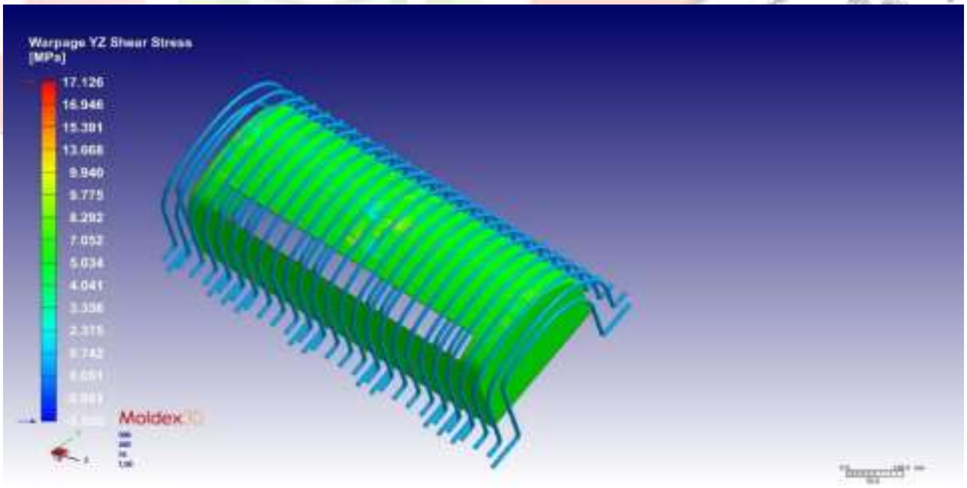


Figure 15: YX Shear Stress of Conformal Cooling

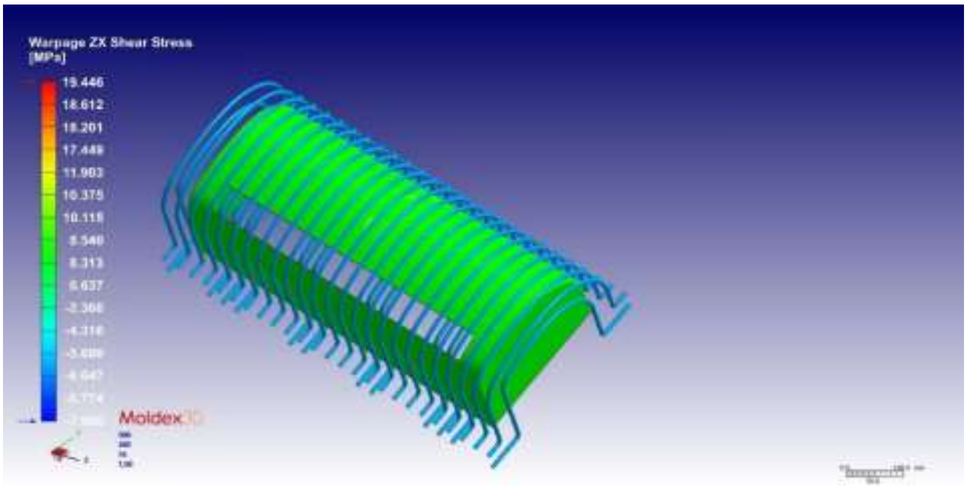


Figure 16: XZ Shear Stress of Conformal Cooling

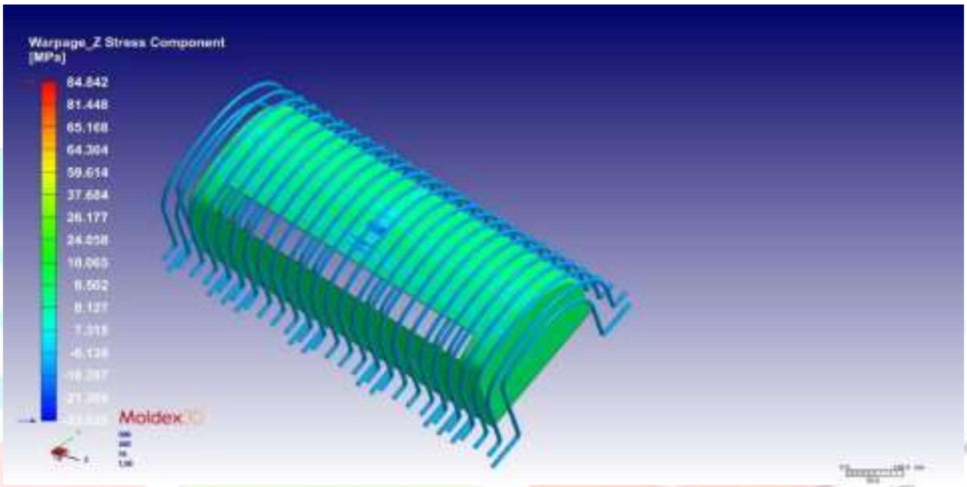


Figure 17: Z Stress Component of Conformal Cooling

Table 3: Comparison Between Conventional and Conformal Cooling

Parameter	**Convectional Cooling**	**Conformal Cooling**
X Stress Component	63.41 MPa	59.44 MPa
Y Stress Component	75.66 MPa	72.96 MPa
Z Stress Component	94.57 MPa	84.84 MPa
XY Shear Stress	30.58 MPa	26.17 MPa
YZ Shear Stress	21.95 MPa	17.12 MPa
ZX Shear Stress	24.38 MPa	19.44 MPa
Von Mises Stress	59.59 MPa	51.52 MPa

Conclusion

conformal cooling channels exhibit lower stress components across all directions (X, Y, and Z) compared to conventional cooling channels. Specifically, the X, Y, and Z stress components for conformal channels are 59.447, 72.965, and 84.842, respectively, while for conventional channels, they are 63.410, 75.662, and 94.577. This suggests that conformal cooling channels experience reduced stress in all directions, potentially leading to better dimensional stability and reduced warpage.

Additionally, the table highlights that conformal cooling channels have lower shear stress values in the XY, YZ, and ZX planes, with 26.171, 17.126, and 19.446 respectively, compared to conventional cooling channels at 30.589, 21.950, and 24.386. Lower shear stress values may result in improved part quality and reduced susceptibility to defects caused by high shear stresses.Furthermore, the Von Mises stress, which is an indicator of the overall stress experienced by the material, is lower for conformal cooling channels at 51.524 compared to conventional cooling channels at 59.593. This reduced overall stress implies that conformal cooling channels may offer better stress management and improved part quality compared to conventional cooling channels.

References

Sellitto, Andrea et al. (2020, March 10). Numerical-Experimental Investigation into the Tensile Behavior of a Hybrid Metallic–CFRP Stiffened Aeronautical Panel. Applied Sciences, 10(5), 1880. https://doi.org/10.3390/app10051880

Kuo, C., Nguyen, T., Zhu, Y., & Lin, S.. (2021, March 16). Rapid Development of an Injection Mold with High Cooling Performance Using Molding Simulation and Rapid Tooling Technology. Micromachines, 12(3), 311. https://doi.org/10.3390/mi12030311

Piekło, J., & Garbacz-Klempka, A.. (2020, December 4). Use of Maraging Steel 1.2709 for Implementing Parts of Pressure Mold Devices with Conformal Cooling System. Materials, 13(23), 5533. https://doi.org/10.3390/ma13235533

Investigation on Thermo-mechanical Behavior of Mold Corner for Continuous Casting Slab. (n.d). https://scite.ai/reports/10.2355/isijinternational.isijint-2015-230

Conradie, P. J. T., Oosthuizen, G. A., Dimitrov, D., & M, S.. (2015, November 30). EFFECT OF MILLING STRATEGY AND TOOL GEOMETRY ON MACHINING COST WHEN CUTTING TITANIUM ALLOYS. The South African Journal of Industrial Engineering, 26(3). https://doi.org/10.7166/26-3-1172

Selvaraj, Senthil et al. (2021, December 27). Recent Advancements in the Field of Ni-Based Superalloys. Advances in Materials Science and Engineering, 2021, 1-60. https://doi.org/10.1155/2021/9723450

Agunsoye, Olumuyiwa, Johnson et al. (2014, January 1). Effects of Graphite Additions and Heat Treatment on the Microstructure, Mechanical and Tribological Properties of 13% Chromium White Iron. Journal of Minerals and Materials Characterization and Engineering, 02(04), 270-285. https://doi.org/10.4236/jmmce.2014.24032

Pisarek, B., Kołakowski, D., & Pacyniak, T.. (2017, December 20). Simulation of Stress Distribution in a Thick- Walled Bushing Produced by Die-Casting. Archives of Foundry Engineering, 17(4), 127-132. https://doi.org/10.1515/afe-2017-0143