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Injection Molding, Packing Phase Analysis on Conformal and Traditional Cooling Channels

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Abstract: In injection molding cycle, packing phase predominate part quality and responsible for defect free part. The packing pressure, melt temperature, mould temperature, plastic materials, and the configuration of the runner and the gate are all factors that influence the production of components in injection moulding during the packing process. It's very tough only by trial and error to identify them. For packing analysis, Moldex3D is a valuable tool for dealing with this issue. Packing phase comprises different parameters which contribute in packing formation and part quality. These parameter has been studied and analyzed in conventional and conformal cooling channels so the effect of conformal cooling channels on packing parameter can be optimized and analyzed where ever it is needed.

Key Words: Injection Molding, Packing Phase, Packing Analysis, Conventional Cooling Channels, Conformal Cooling Channels, Packing Parameter.

1. INTRODUCTION

1.1 Injection Molding

Plastics can be shaped quickly because of their plasticity and ductility. Because of this, plastics are still widely used on a regular basis, making them an important part of society today. It is important processing methods for transforming plastics into products. The roots of plastic products derive from the consumer's "needs," which are further turned into "design concepts." Thermoplastic products are primarily injection moulded. [1]

1.2 Injection Molding Cycle

- **Closing of Mould:** First of all, clamping unit tightly closes the 2 halves (fixed and movable) of mould. One half of mould is attached with injection unit which is fixed half and other half is attached with clamping unit which is movable. The clamping unit forces the movable half for closing the mould tightly until the material is solidified.

- **Injection:** After closing the mould, the molten plastic, which is melted by heat and pressure, is injected into the mold cavity. The time of injection is hard to precisely measure because the flow of molten plastic is changing. However, injection power, injection pressure and shot volume can estimate injection time.
- **Cooling:** As plastics melt comes in contact with internal mould surface, it starts to cool. It would solidify into the wanted shape as melt cools. Shrinkage of the component may be occurred during the cooling. In injection process, material packing allows more material to pass through the mould and decreases the level of noticeable shrinkage. It is difficult to open the mould before the necessary cooling period has expired. From component's wall thickness and plastics properties, it is possible to estimate cooling time.

- **Ejection:** After solidifying the component, it is ejected from the mould by ejection system which is mounted on movable half. The pins force the component to release from the mould after the mould opens because the component adheres to mould during the process of cooling.

1.3 Packing Phase

As the mould cavities are nearly filled with molten plastic, Figure 1 indicates the packing process. For compensating the shrinkage, the packing pressures are added to continue delivering molten plastic in the mould cavities. As this compensated molten plastic reaches into the mould cavity, the pressure rises a little. Also, the molten plastic temperature inside the mould cavity drops and decreases to state (5) in Figure 2 because of the effect of cooling from the dispersion of heat of mould. [1]

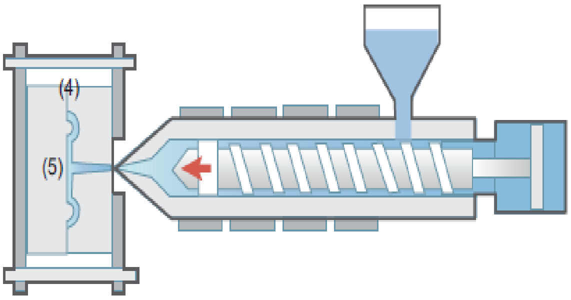


Figure 1: Packing Process [1]

In the PVT graph (Figure 2), including packing process, a specific Pressure is sustained or pressure rises in the starting, but the temperature decrease becomes higher as cooling time rises. The heat enters the mould is even lesser than the heat carried out by the cooling channels because there are no more melts carrying heat into mould cavity, and so temperature decreases rapidly. [1]

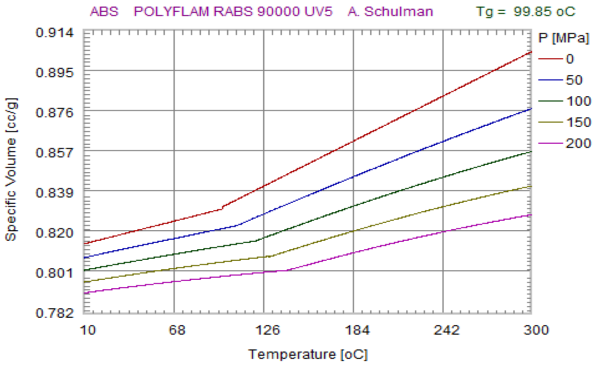


Figure 2: ABS PVT indicates stage of packing [1]

1.4 Molding Simulation

CAE (Computer Aided Engineering) is a software and technologies that uses analysis and simulation to facilitate the production and diagnosis of difficult injection moulding process. CAE allows to integrate the complex mechanical, rheological and thermal properties of materials, and allows engineers and designers to do quantitative and qualitative diagnosis and research for mould development and also diagnosis and research for establishing moulds and operational Parameters. [1]

Designers can examine the sources of complications that emerge from CAE analysis outcomes and evaluate numerous design improvements for identifying the best suitable approach that isn't feasible by the conventional trial and error process. In addition, if design improvement includes component or mould modification, machine, expenses of time, material, labour and resources is also beyond calculation by repetitive mould modification and test. Therefore, during the period of development, it is basic to apply CAE for verifying the design. [1]

1.5 Governing Equation

CAE is, from scientific perspective, a numerical method for solution of physical system's conceptual perspective. As a consequence, the degree of emulation in conceptual model, the convergence and accuracy of numerical system used, and the mesh model being used for analysis are linked to the reliability and precision of analysis. [1]

In conservation laws, conservation of energy, mass, and momentum are the basic governing equation of moulding system, which can be calculated, by using conservation of control volume that is smallest unit in system. The amount of change of physical unit over time can be calculated, as seen in Figure 3 , by considering amount of physical quantity which come in, go out and created in an extremely small part. The total calculation of macroscopic structure is achieved by adding value of all tiny space together. [1]

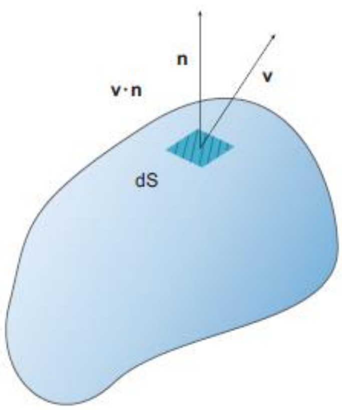


Figure 3 : Controlled volume [1]

In Figure 3, the universal controlled volume is defined by shaded area within fluid. The outer surface normal vector n, velocity vector field v and differential surface area factor is dS. One should turn to ref.[1] for derivation information of laws of conservation.

1. Equation of continuity

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{v}) = \mathbf{0}$$

Where,
ρ : density
t : time
v : velocity vector
Above equation is standard equation of continuity

2. Equation of momentum

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

Where,
g : gravity
τ : shear stress

3. Equation of energy

$$\frac{\partial}{\partial t}(\rho C_p T) + \nabla \cdot (\rho C_p \mathbf{v} T - k \nabla T) = \eta \dot{\gamma}^2 + \Delta H$$

Where,
T : temperature field
Cp : heat capacity,
K : coefficient of thermal conductivity
H : viscosity of fluid
Γ : shear rate
ΔH : heat of generation.

2. LITERATURE REVIEW

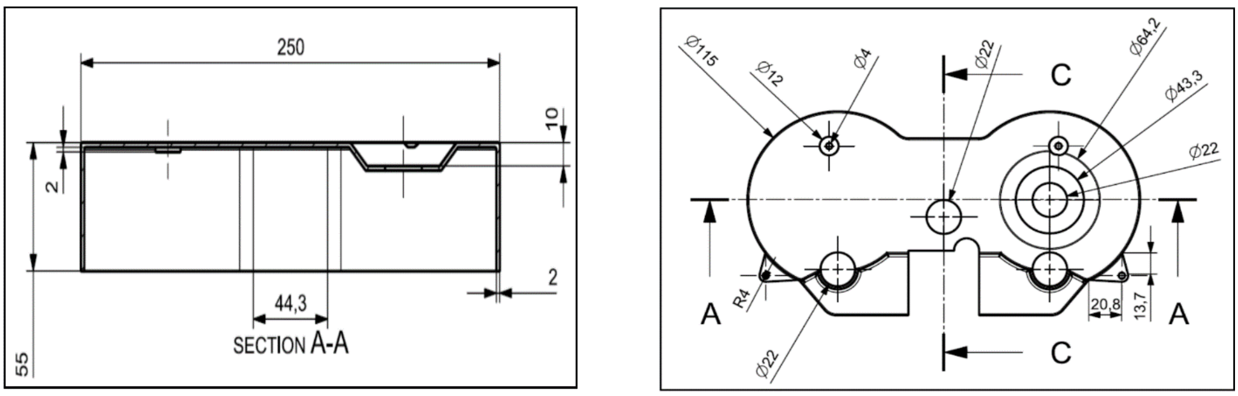
2.1 **S. Ahn, S. T. Chung, S. V. Atre, S. J. Park & R. M. German (2008):** Due to difficulty of PIM systems, trial and error approaches are also commonly used to address design issues. With the assistance of a computer aided engineering (CAE) modelling method for PIM, analytical approach to finding thess causal relation between control parameters such as processing condition and viscosity of feedstock, and their effect on mold filling behavior, defect creation, and stability of dimension can be significantly reduced. [3]

In a standard CAE modelling method, a significant no. of material variables are usually incorporated in predictive equation used in simulation procedures. It's crucial that CAE tool accurately captures the impact of process settings variation.

2.2 **Christoph Froehlich, Wolfgang Kemmetmuller & Andreas Kugi (2018):** A first principle design of injection machine are paired with conceptual design describe injection processes, which involves melt compression and polymer flows into mould. A proposed model designed for real time implementations and is an outstanding starting point for designing model based control approaches. A variety of experiments are used to show the effectiveness of proposed model. They state that model reliability is good over the entire operating spectrum for various mould geometry. [4]

3. PROBLEM FORMULATION

3.1 Model Geometry



(A) **(B)**

Figure 4 : CAD Model Drafting (A) Front View (B) Top View

3.2 Cooling Channel

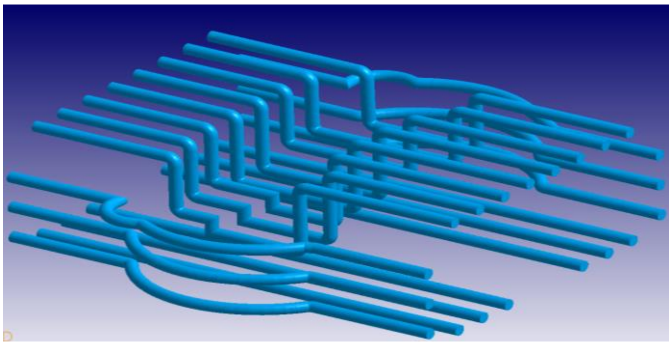


Figure 5: Conformal Cooling Channels Layout

Table 1: Cooling Channels Parameter

Property	Value
Diameter of pipe	8 mm
Distance between center to center of pipe	24 mm
Distance between part to center of pipe	16 mm

3.3 Processing Conditions

Table 2: Processing Parameter

Parameter	Values
Filling time	1.34 sec
Melt temperature	235 ^{O}C
Mold temperature	50 ^{O}C
Maximum injection pressure	400 MPa
Injection volume	112.241 cm^3
Packing time	5.34 sec
Maximum packing pressure	400 MPa
Cooling time	12.36 sec
Mold-open time	5 sec
Ejection temperature	99.85 ^{O}C
Air temperature	25 ^{O}C

3.4 Material Properties

Table 3: POLYFLAM® RABS 90000 UV5 - ABS

Property	Value
Melt volume-flow rate, MVR	30 cm^3/10min
Density	1200 kg/m^3
Temperature	220 ^{O}C
Load	10 kg
Tensile modulus	2200 MPa
Yield stress	42 MPa
Yield strain	3 %
Nominal strain at break	>50 %
Charpy impact strength, +23°C	80 KJ/m^2
Charpy impact strength, -30°C	45 KJ/m^2
Charpy notched impact strength, +23°C	10 KJ/m^2
Charpy notched impact strength, -30°C	5 KJ/m^2
Temp. of deflection under load, 1.80 MPa	80 ^{O}C
Temp. of deflection under load, 0.45 MPa	92 ^{O}C
Vicat softening temperature, 50°C/h 50N	96 ^{O}C

3.5 METHODOLOGY

3.5.1 Pre-processing:

Moldex3D studio is a powerful system for pre-processing. Two modes are available: eDesign mode, which uses eDesign meshing technique, and BLM mode, which uses BLM meshing techniques.

- Import model
- Build runner system
- Specify cooling system
- Generate solid mesh
- Export mesh mode

3.5.2 Preparation of Analysis

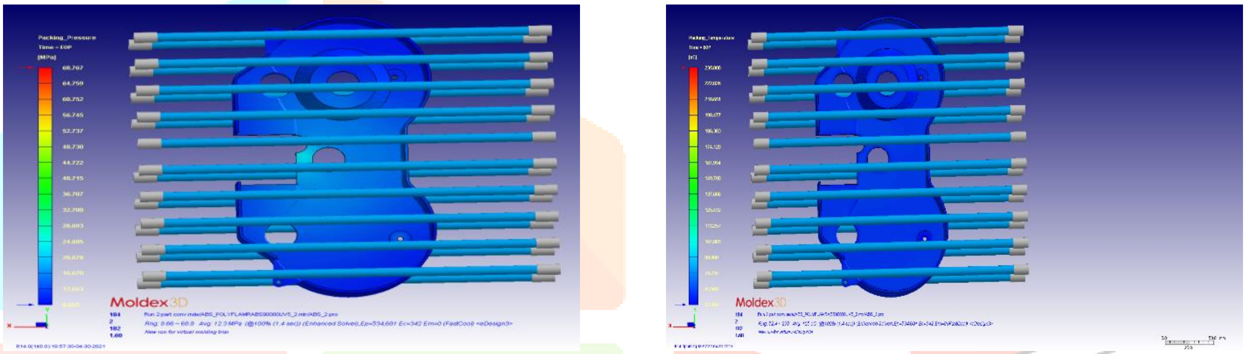
- Preparation of analysis in Moldex3D Project
- Preparation of analysis in Moldex3D Studio
- Material Wizard
- Process Wizard
- Computation Parameter

3.5.3 Post- processing.

- Post processing
- Result Interpretation
- Warning and error Messages
- Viewer

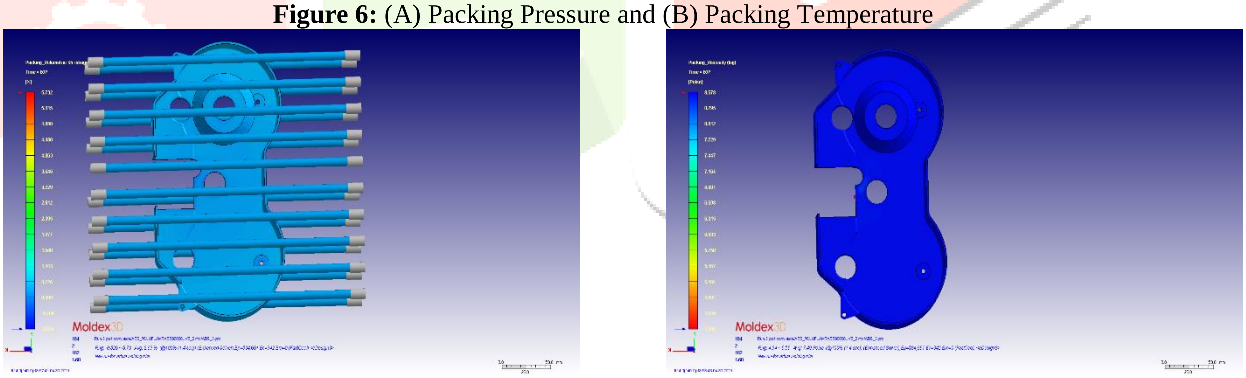
4. RESULTS

4.1 Conventional Cooling Result



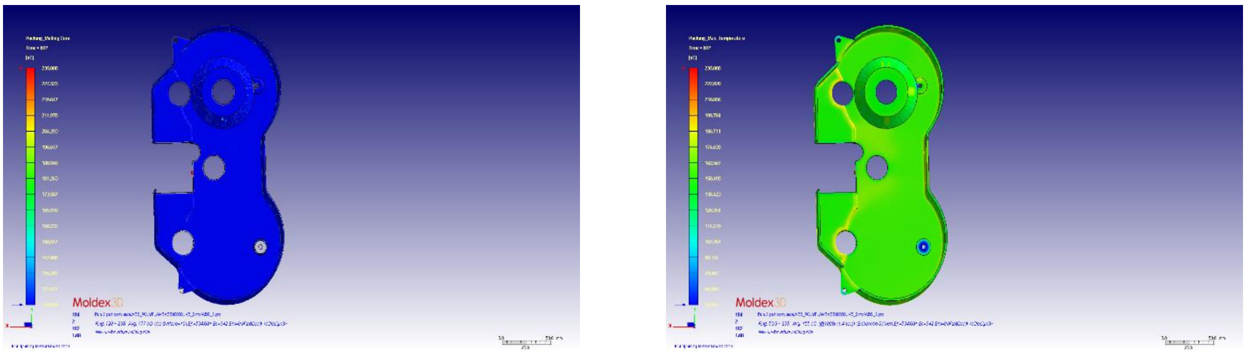
(A) (B)

Figure 6: (A) Packing Pressure and (B) Packing Temperature



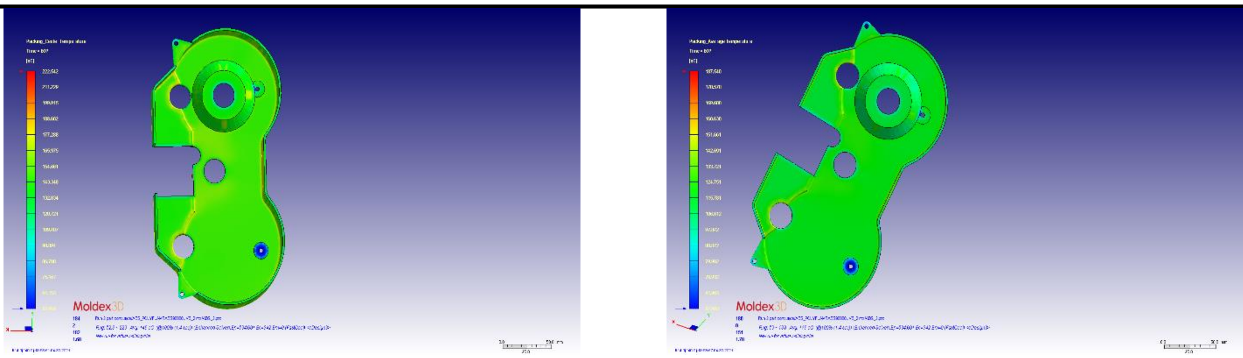
(A) (B)

Figure 7: (A) Packing Volumetric Shrinkage & (B) Vector & Packing viscosity (log)



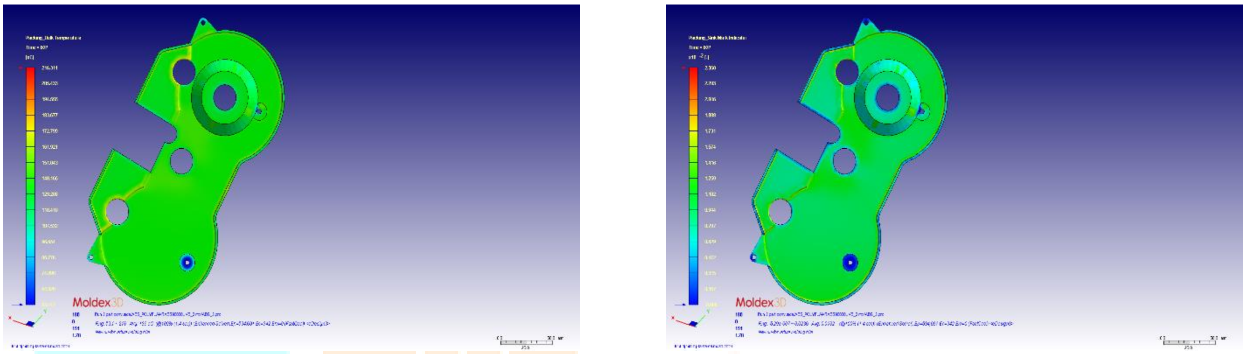
(A) (B)

Figure 8: (A) Packing Molten Core & (B) Packing Max. Temperature



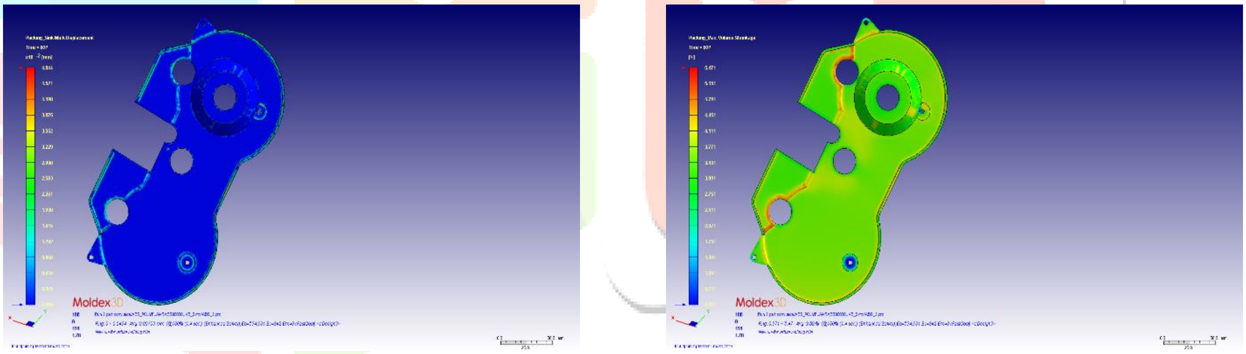
(A) **(B)**

Figure 9: (A) Packing Centre Temperature & (B) Packing Average Temperature



(A) **(B)**

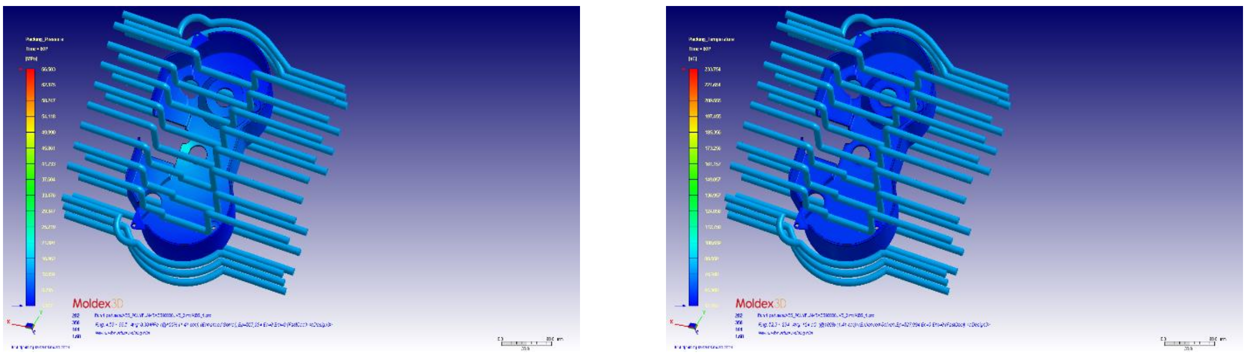
Figure 10: (A) Packing Bulk Temperature & (B) Packing Sink Mark Indicator



(A) **(B)**

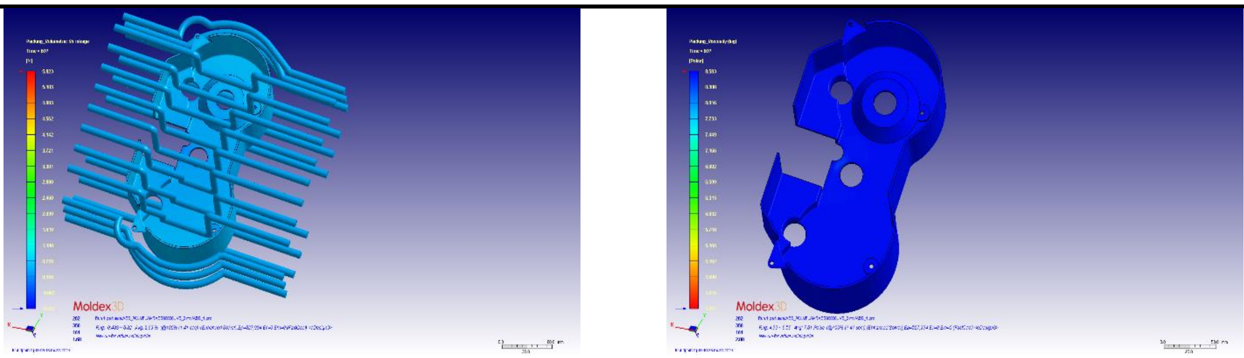
Figure 11: Packing Sink Mark Displacement &(B) Packing Max. Volume Shrinkage

4.2 Conformal Cooling Result



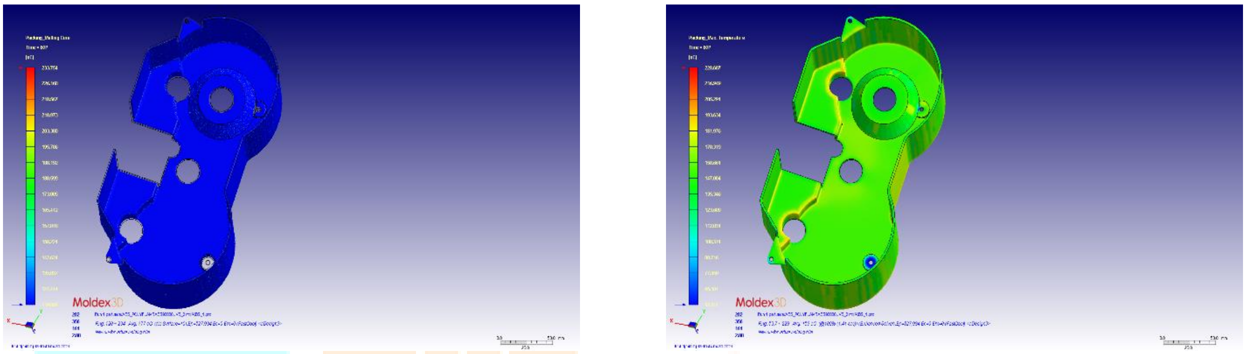
(A) **(B)**

Figure 12: (A) Packing Pressure and (B) Packing Temperature



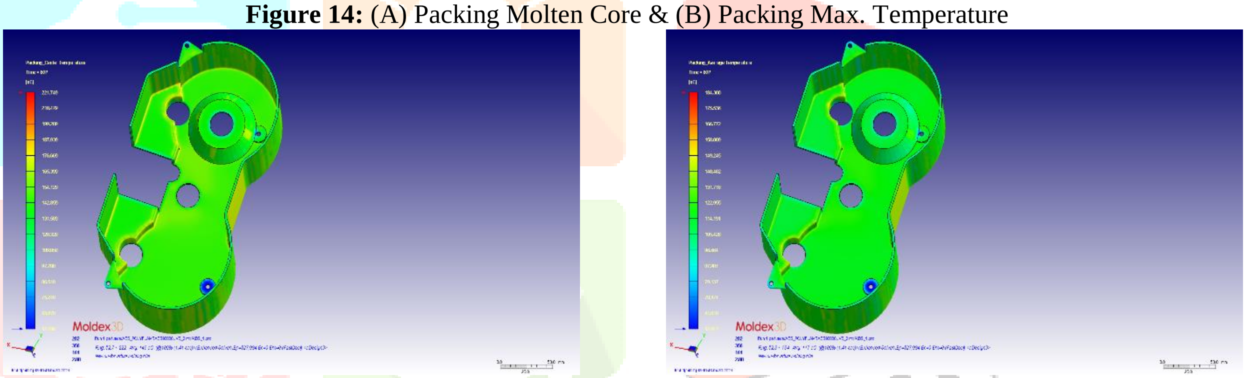
(A) **(B)**

Figure 13: (A) Packing Volumetric Shrinkage & (B) Vector & Packing viscosity (log)



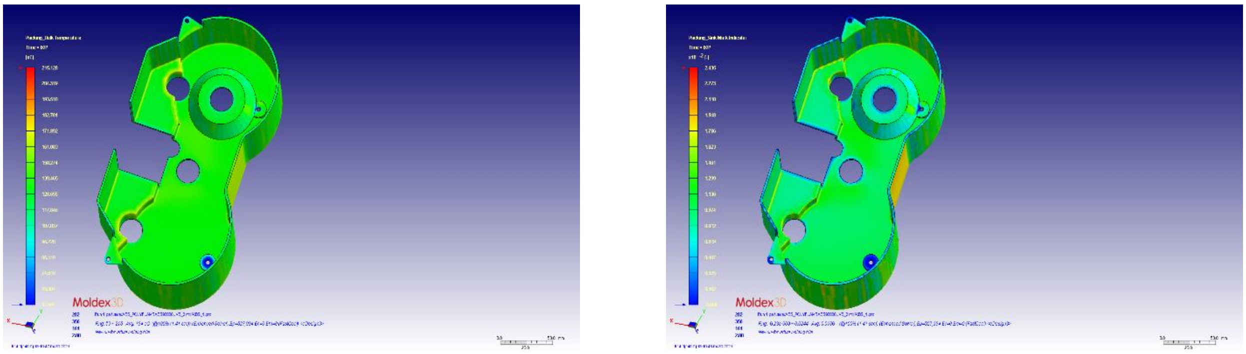
(A) **(B)**

Figure 14: (A) Packing Molten Core & (B) Packing Max. Temperature



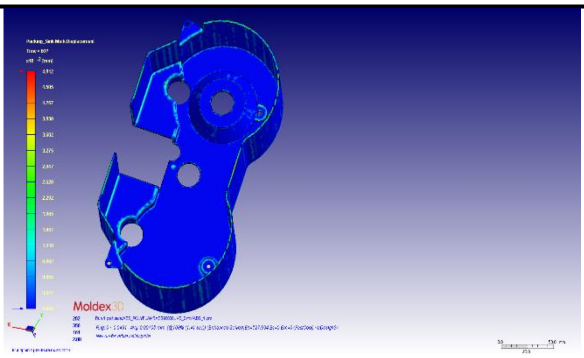
(A) **(B)**

Figure 15: (A) Packing Centre Temperature & (B) Packing Average Temperature



(A) **(B)**

Figure 16: (A) Packing Bulk Temperature & (B) Packing Sink Mark Indicator


(A)

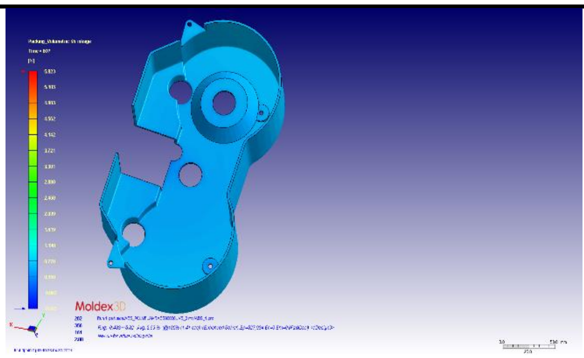

(B)

Figure 17: Packing Sink Mark Displacement & (B) Packing Max. Volume Shrinkage

Table 4: Comparison between Conventional and Conformal Cooling Result of Packing Phase

S No	Parameter	Conventional Cooling Result	Conformal Cooling Result
1	Packing Pressure	68.767 MPa	66.503 MPa
2	Packing Temperature	235.000 ^{0}C	233.754 ^{0}C
3	Packing Volumetric Shrinkage	5.732 %	5.823 %
4	Packing viscosity(log)	8.578 Poise	8.583 Poise
5	Packing Molten Core	235.000 ^{0}C	233.754 ^{0}C
6	Packing Max. Temperature	235 ^{0}C	228. 607 ^{0}C
7	Packing Centre Temperature	222.542 ^{0}C	221.749 ^{0}C
8	Packing Average Temperature	187.540 ^{0}C	184.300 ^{0}C
9	Packing Bulk Temperature	216.311 ^{0}C	215.128 ^{0}C
10	Packing Sink Mark Indicator	2.360 * 10^{-2} [-]	2.435 * 10^{-2} [-]
11	Packing Sink Mark Displacement	4.844 * 10^{-2} mm	4.912 * 10^{-2} mm
12	Packing Max. Volume Shrinkage	5.471 %	5.557

5. CONCLUSIONS

In conclusion, Moldex3D identify and optimized parameter by using conformal cooling channels. The results clearly indicated that the conformal cooling channels could effectively improve. Packing Pressure, Packing Volumetric Shrinkage, Packing Molten Core, Packing Max. Temperature, Packing Centre Temperature, Packing Average Temperature, Packing Max. Volume Shrinkage, Packing Temperature, Packing Bulk Temperature etc. Until the gate freezes, the polymer continues to fill the mould in thickness direction due to packing pressure. Mould-sticking, extreme residual stress, bleeding issues and flash are all common causes of extreme packing pressure. Inadequate packing pressure causes the element to shrink further and have more hollow spaces. The results verify that the conformal cooling channel could provide better packing phase than the conventional one.

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