Intelligent Mold Tooling Design with Plastic Injection, CFD and Structural Simulation

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***Abstract**: Mold Cooling channel design directly impacts the cooling efficiency, temperature uniformity, and cycle time, and is also one of the key factors which influences the overall quality of injection molded plastic products. In this paper, we describe a project involving the mold cooling design optimization for the Impeller of a HVAC blower unit. Conventional cooling channel design is compared and contrasted with a conformal cooling channel design. Conventional cooling channels have straight-line channels which can easily be drilled. However, with increasing complexity of plastic part designs, these conventional channels are too inefficient and can result in long cycle times or worse inferior part quality by increasing part warpage. Conformal cooling uses channels that closely follow the contour of the part geometry and therefore can provide highly effective and uniform cooling throughout the part. The complexity of machining the channels is solved thanks to Additive Manufacturing (AM) techniques including laser sintering. Finally, the same blower design is included in the whole HVAC product assembly and then validated by a frequency analysis.*

***Keywords:** Tooling design; Topology optimization; Additive manufacturing; Conformal cooling channel; Frequency analysis; **3D**EXPERIENCE*

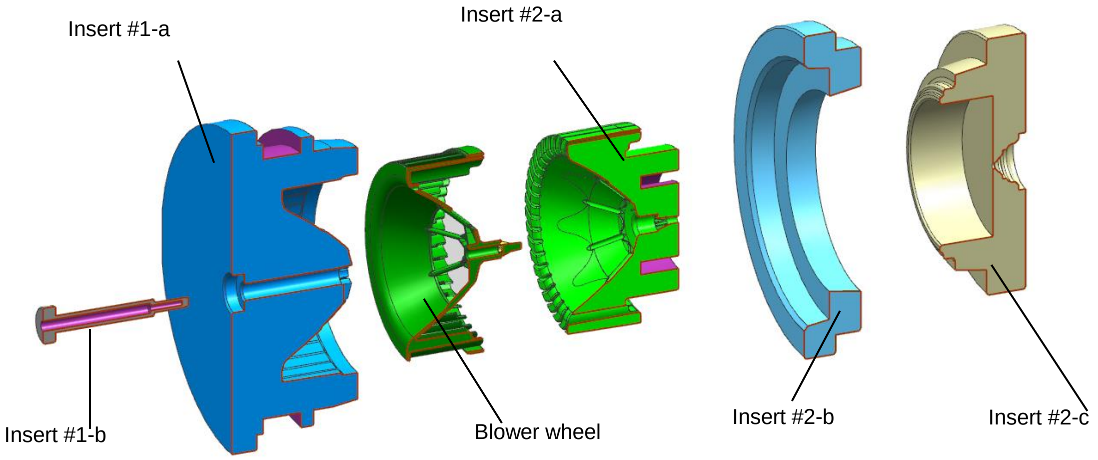
1. Introduction

Injection molding is a widely used and accepted manufacturing process in the production of plastic parts (Suchana and Hazim, 2016). Filling, packing, cooling and ejection are the main phases. Cooling phase is a significant step among the three because it greatly affects the production rate and molding quality (Hong-Seok, 2017). Design of mold cooling channel for plastic injection is of critical importance for cooling efficiency, temperature uniformity and cycle time, and is also one of the key factors for the quality of the product. With the rising competition worldwide in automobile industry, cycle time reduction in plastic injection molding is attracting more and more attention. Conventional cooling channels with straight drilled lines always manufactured by CNC are far from being efficient and result in longer cooling cycle. At present, additive manufacturing (AM) can provide an opportunity to manufacture intelligent mold tooling with conformal cooling channels that closely conform to the contour of the part geometry. Conformal cooling channel made by additive manufacturing can provide uniform cooling, highly cooling efficiency and reduce amount of warping (Lawrence, 2014). Additive manufacturing as a revolutionary technology also can provide economic manufacturing at very low volumes and highly complexity geometry parts (Matrin, 2014), for example aerospace (Brandt, 2013), high-value jet engine (Halchak, 2012), and automotive components that are incompatible with traditional manufacturing methods (Cooper, 2012).

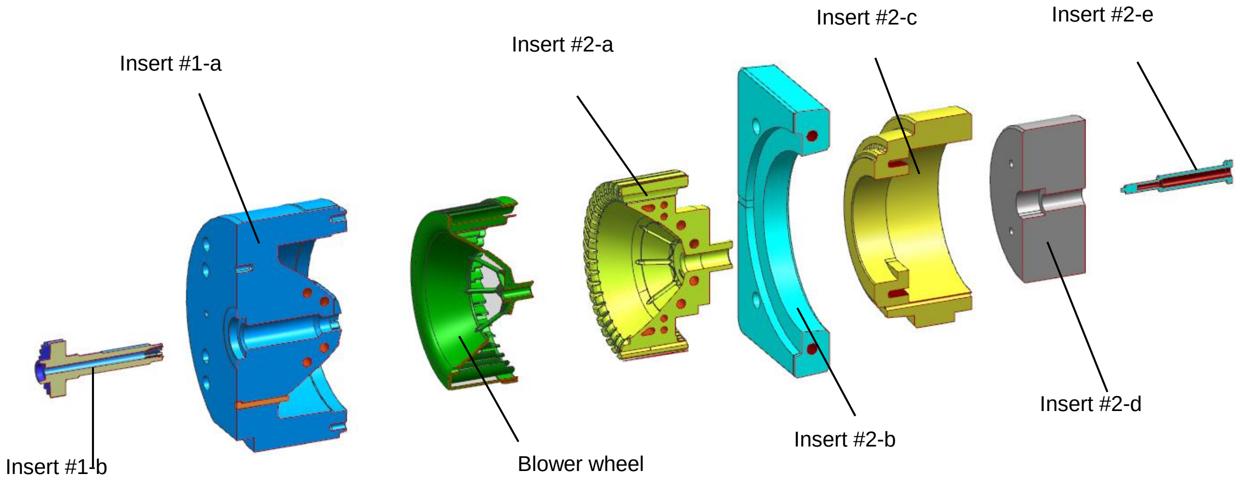
The current work is concentrated on developing intelligent mold tooling insert with conformal cooling channels for the impeller of a HVAC blower unit. The proposed conformal cooling channel design has been validated and compared with conventional cooling channel design using two simulation products developed by Dassault Systemes on **3D**EXPERIENCE Platform – Plastic Injection Mold Engineer (IME) and Fluid Mechanics Analyst (FLA). With FLA, a conjugate heat transfer CFD simulation was performed to determine optimal coolant flow conditions (flow rate, temperature). The results of FLA were then used to setup injection molding simulation in IME to validate the temperature uniformity and part quality (warpage, volumetric shrinkage, pressure, etc.) aspects of the conventional and conformal cooling channel designs.

With the assistance of Dassault Systemes **3D**EXPERIENCE Functional Generative Designer (GDE) role, for the impeller project, we were able to obtain a topologically optimized conformal cooling channel design. Topology optimization refers to the search for geometry that optimizes an objective function, such as minimal mass or cost, subject to associated boundary conditions and constraints, such as applied loads, allowable spatial envelope or maximum allowable stress (Sigmund, 2000).

2. Design and simulation



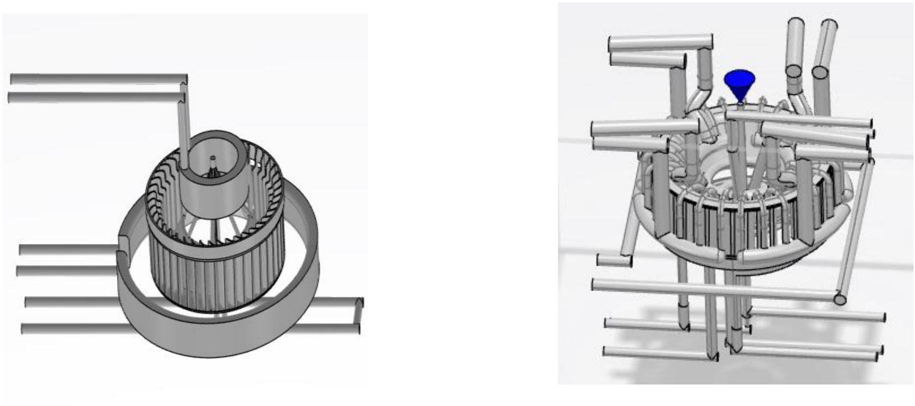
(a) Milling (traditional)



(b) 3D printing (conformal)

Fig.1 (a) CAD model with traditional cooling channel for traditional tooling; (b) CAD model with conformal cooling channel for 3D printing

Injection molding is a popular method that is used to make plastic product due to high productivity. Fig.1 shows the injection molding system with traditional cooling channel and conformal cooling channel for the impeller of a HVAC blower unit. Traditional cooling channel is straight drilled lines manufactured by CNC shown in Fig.2 (a). Conformal cooling channel is produced by 3D printing in Fig.2(b). All cooling channels are Φ8 mm. Steel is used for part-forming components of molds. Water is selected as the coolant and its temperature at inlet is about 25℃. The loop operates at an average flow rate of 15 L/min.

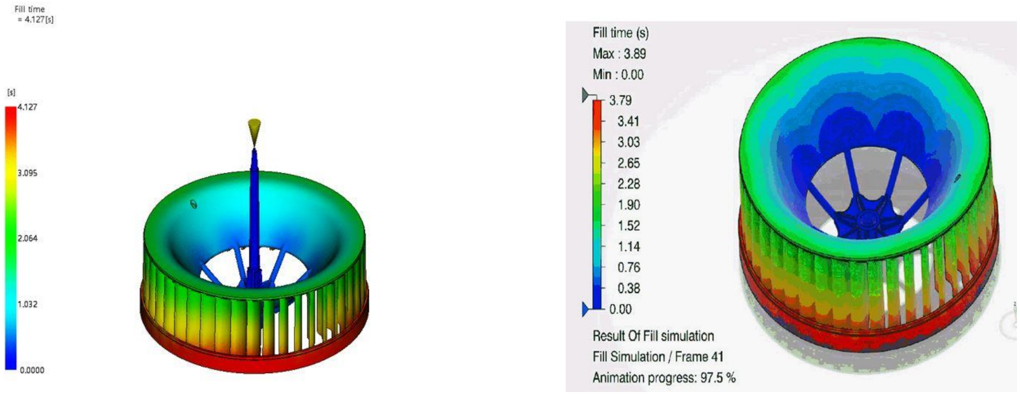


(a) (b)

Fig.2(a) traditional cooling circuits layout;(b) conformal cooling channel

2.1 Injection filling simulation

The injection molding process includes three significant stages: filling stage, cooling stage and ejection stage. Before we analyze the thermal performance of two cooling systems, filling simulation is carried out in Moldflow and Dassault Systemes' Plastic Injection Mold Engineer (IME) as the following pictures shown in Fig.3. It's clear that filling time is only about 4s, the melt temperature of material is 230 ℃. Material flow can be seen clearly during filling process. The filling time calculated by IME is similar to that calculated by Moldflow.

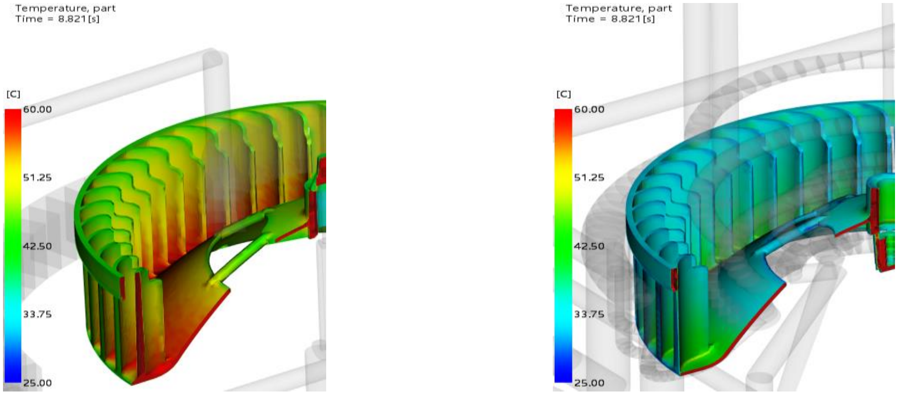


(a) Filling results from Moldflow (b) Filling reults from IME

Fig.3 Filling simulation:(a) results from Moldflow; (b) results from 3DE IME

2.2 Temperature distribution

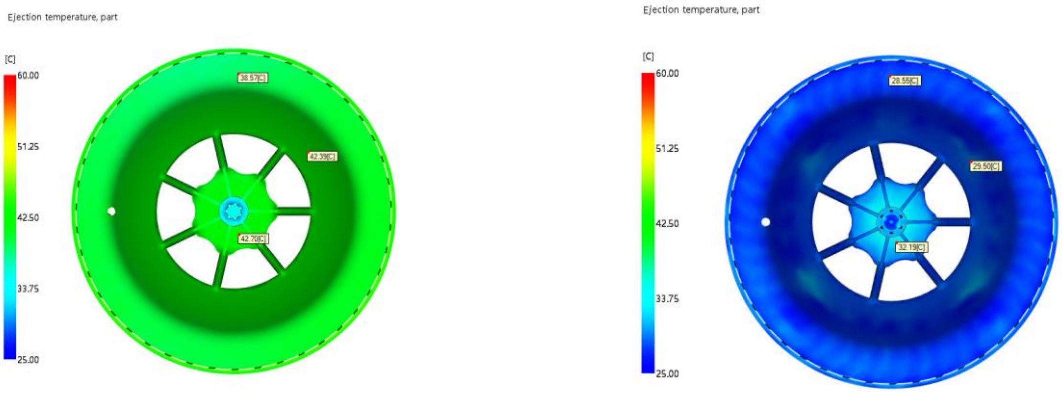
Transient cooling simulation is carried out to analyze the thermal performance of the two cooling systems. The part temperature distribution of them is shown in Fig.4. As the pictures show that part cooled by conformal cooling channel provides better temperature distribution at the same cooling moment. It can be concluded that conformal cooling channel provides higher cooling efficiency than traditional cooling channel. Higher cooling efficiency always results in shorter cooling time (t=8.821s).



(a) traditional (b) conformal cooling channel

Fig.4. Comparison of part temperature distribution:(a) traditional and (b) conformal cooling channel

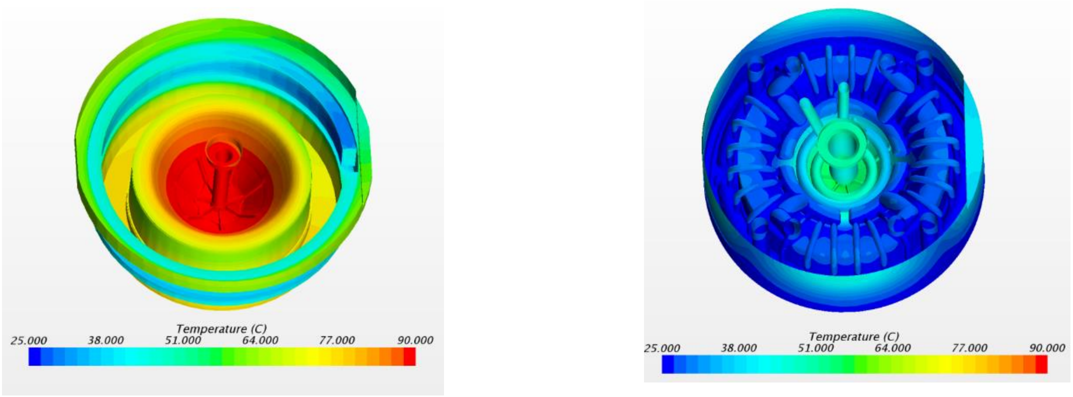
Fig.5 shows the part ejection temperature distribution of two cooling systems calculated by MoldFlow. From the following pictures, part ejection temperature distribution is more uniform, and its maximum temperature is much lower cooled by conformal cooling channel than that cooled by traditional cooling channel. It also shows that conformal cooling channel is more efficient.



(a) Conventional (b) 3D printing

Fig.5 Part ejection temperature distribution (a) conventional tooling systems; (b) 3D printing tooling systems

After checking part temperature distribution of two cooling systems, we also checked the mold temperature distribution of the two systems in STAR-CCM+, Moldflow and **3D**EXPERIENCE Plastic Injection Mold Engineer (IME). Fig.6 shows the mold temperature distribution from STAR-CCM+, it's clear that mold with conformal cooling channel gives better temperature distribution. The temperature at traditional mold center is almost unchanged after 60s cooling. It can be concluded that conformal cooling channel provides better mold cooling



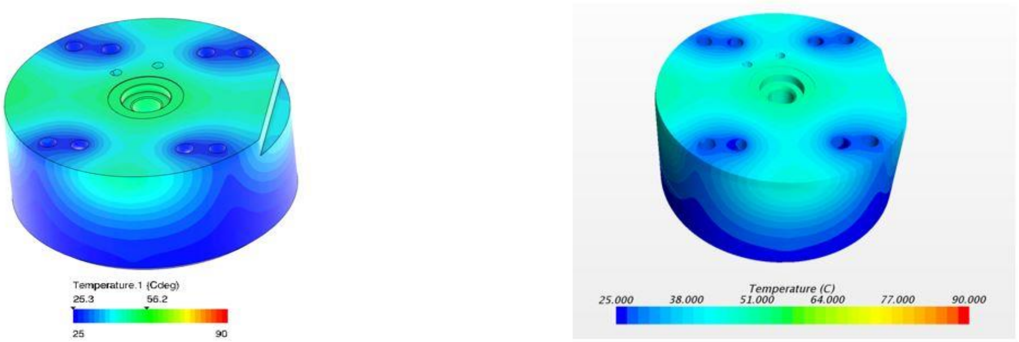
(a) conventional (b) 3D printing

Fig.6 Mold temperature distribution (a) traditional mold with straight line; (b) 3D Printing mold with conformal cooling channel

2.3 Coolant flow simulation

Coolant flow simulation was conducted using Fluid Mechanics Analyst (FLA) role on **3D**EXEPRIENCE to validate thermal performance of the conformal cooling channel system. The CFD results from Fluid Mechanics Analyst were benchmarked with Star-CCM+, and were found to be equally accurate. The initial temperature of mold is set to 90°C and the coolant is 25°C. The loop is used with an average flow rate of 15L/min, and the Reynolds number of coolant water is 10000.

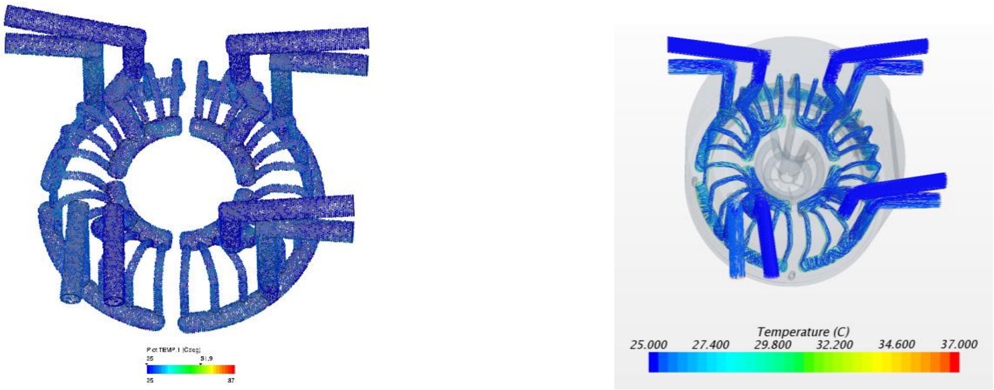
Mold temperature distribution is shown in Fig.7. As shown in the images below, result from Fluid Mechanics Analyst is very similar to that of STAR-CCM+ at 60s.



(a) 3DEXPERIENCE Fluid Mechanics Analyst (b) STAR-CCM+

Fig.7 Mold temperature distribution at 60s: (a) 3DEXPERIENCE Fluid Analyst; (b) STAR-CCM+

Similarly, the coolant temperature is shown in Fig.8. It also shows that coolant temperature distribution from Fluid Mechanics Analyst is very similar to that of STAR-CCM+ at 60s. It can be inferred that CFD simulation results from Fluid Mechanics Analyst are comparable to that of STAR-CCM+.

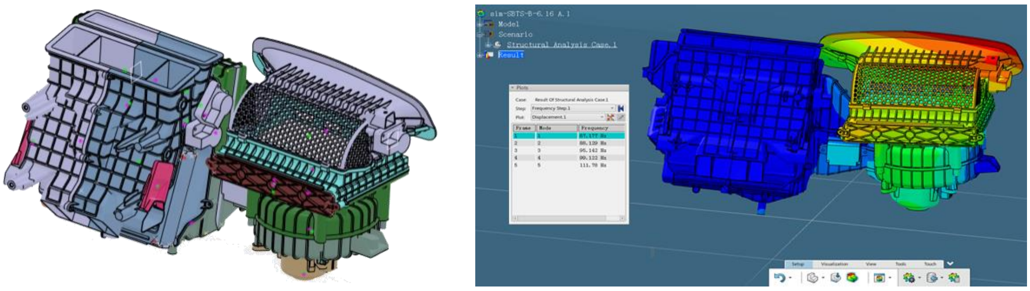


(a) 3DEXPERIENCE Fluid Mechanics Analyst (b) STAR-CCM+

Fig.8 Coolant temperature distribution at 60s: (a) FLA on 3DEXPERIENCE; (b) STAR-CCM+

2.4. Structural Validation

The same blower unit design has been included in the whole HVAC product assembly and a frequency analysis is carried out using Structural Analysis Engineer (DRD) role (Figure 9). The model preparation time is largely reduced thanks to the automatic solid meshing and automatic detecting capability for creating tie connections. And, blower design changes can be revalidated easily simply by replacing the old geometry with the new ones.



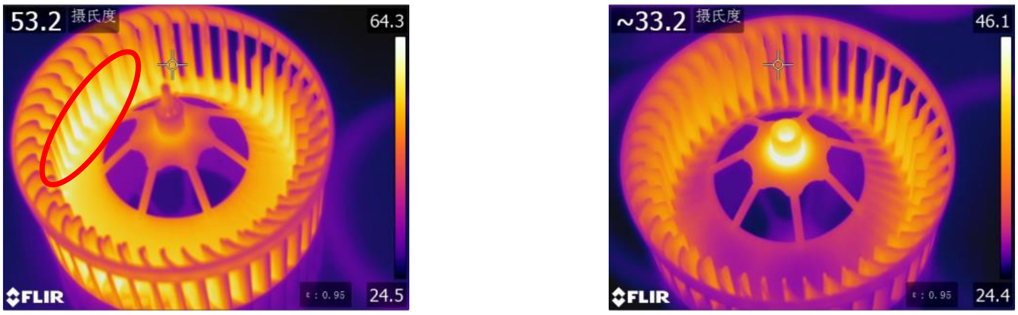
Case: Result Of Structural Analysis Case.1
Step: Frequency Step.1
Plot: Displacement.1

Frame	Mode	Frequency
1	1	87.177 Hz
2	2	88.139 Hz
3	3	95.142 Hz
4	4	99.122 Hz
5	5	111.78 Hz

Fig. 9 (a) HVAC assembly (b) Frequency analysis results

3. Thermal imager check

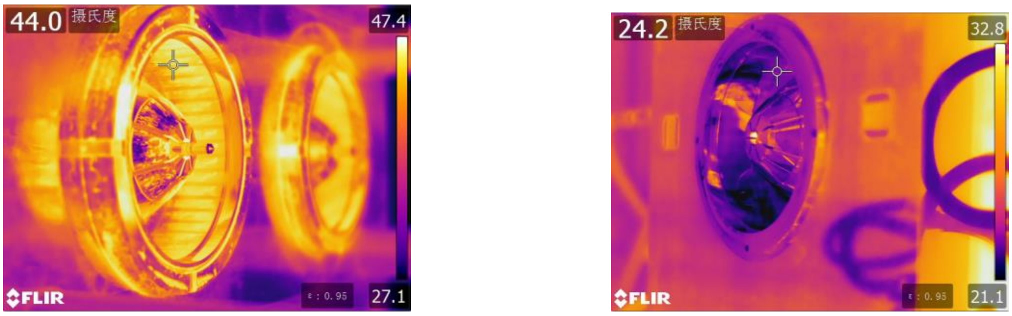
After running simulation to check part and mold temperature distribution of two cooling systems, thermal imager is used to check the temperature distribution of real part and real mold. Fig.10 (a) and (b) show the temperature distribution of products after ejection by thermal imager of traditional and 3D printing injection systems. The impeller of a HVAC blower unit manufactured by intelligent mold tooling system is cooled more uniform and efficiency. The maximum ejection temperature of impeller can be reduced from 53 ℃ to 33 ℃ with conformal cooling channel. Highlight areas by traditional cooling process have impact on dynamic unbalance behaviour and uneven cooling effects may cause appearance problems.



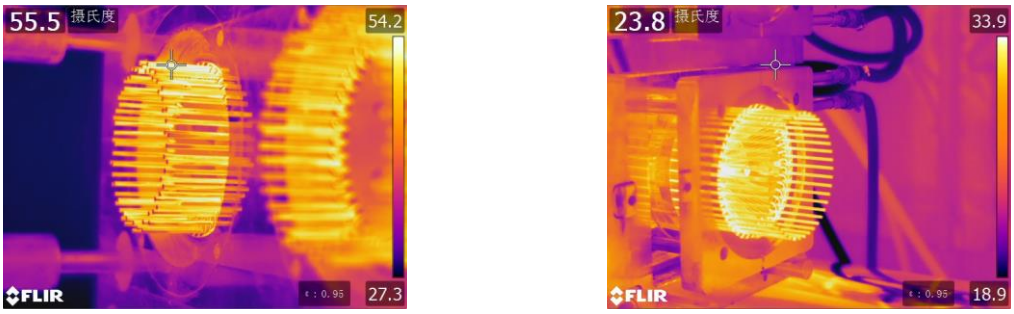
(a) Traditional(Product) (b) conformal cooling channel (Product)

Fig.10 Comparison of product temperature distribution after ejection by thermal imager

Similarly, Fig.11 (c)-(f) show the mold temperature distribution of traditional and 3D printing by thermal imager. The results show mold with conformal cooling channel gives better temperature distribution and its temperature difference is much smaller compared with that of traditional cooling channel. It also shows that conformal cooling channel requires less time to cooling down intelligent mold to ambient temperature.



(c) Traditional (Cavity) (d) conformal cooling channel (Cavity)



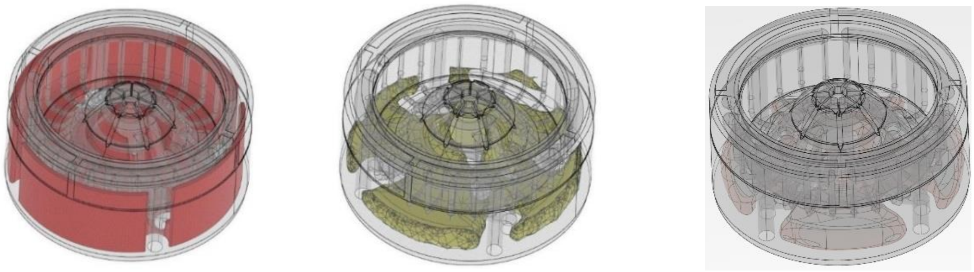
(e) Traditional (Core) (f) conformal cooling channel (Core)

Fig.11 Comparison of mold temperature distribution during cooling process by thermal imager

4. Topology optimization

From the above simulation and testing process, the desirable shape of an intelligent mold with conformal cooling channel has been confirmed. The intelligent mold can provide higher cooling efficiency and more uniform cooling. This section is to run topology optimization on it to minimize its weight in **3D**EXPERIENCE GDE. The original and optimized model is shown in Fig.12 (a) and (b), respective. After topology optimization the total mass reduction is about 20%.

The next is to perform CAD reconstruction which is a time-consuming job in the past. Now with the help of the integrated CATIA Bionic Molding tool, the smoothed model could be quickly built in less than one hour, showing in the following Fig.12 (c)



(a) Original model (b) Optimized model (c) smoothed model

Fig.12 Design created by 3DEXPERIENCE GDE: (a) original model; (b) optimized model before geometry reconstruction; (c) optimized model after smoothing geometry

5. Conclusion

Based on the completed process, an alternative method that provides a conformal cooling channel system has been proposed. 3D printing conformal channel ensures that the part is cooled more uniformly as well as more efficiently. The appearance and unbalance behavior of the injection part with conformal cooling channel is slight better. Topology optimization was carried out in **3D**EXPERIENCE Functional Generative Designer (GDE) to reduce the mass of the mold. In the traditional workflow, we designed the mold in Unigraphics and then transferred the data to STAR-CCM+, Moldflow and Tosca for one design cycle. The Tosca results were then converted to UG for iterative design. When several design and modify cycles are involved, this process is inherently inefficient and carries the risk of data corruption during the numerous data conversion steps. However, when deploying the same workflow on the **3D**EXPERIENCE Platform, there is almost no data conversion problem, access to state-of-the-art CAD-embedded-simulation tools and it's much more convenient to carry out iterative design while exploring multiple variants in a single collaborative platform. It's a powerful tool enabling faster design cycle, enhanced product quality, freedom to innovate, reduced protyping and significant reduction in the overall cost of the end product

6. Further work

To reduce repeated manual work during geometry reconstruction, we would like to have fully automated assistance. The thermal performance and structural strength of optimized conformal cooling channel need be validated.

Acknowledgements

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