Thermal analysis of conformal cooling channel in injection molding

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Abstract Injection molding is a typical method for producing plastic goods because of its high productivity, efficiency, and capacity to be molded into a broad range of things. Using numerical simulation, this study examines how using conformal cooling channels in plastic injection molds differs from using conventional cooling channel. The purpose of this comparison is to look into the benefits and drawbacks of using conformal cooling channels. Thus, this study aims to utilize the flexibility and reduced constraints of additive manufacturing (AM) to develop a novel method of cooling. Step one in the process involves revamping the cooling system used in a mold for an automobile component (used by a company that collaborates in the present study). The most notable results include a decrease of about 10.6 % % in the amount of cooling time required to reach the extraction temperature; a decrease of about 23.3 % in the temperature of the part; and a decrease of about 26.1 % in the temperature of the mold.

Keywords: Injection mold. Plastic injection moulding. Conformal cooling channel. Additive manufacturing.

1. Introduction

Injection molding technology is the most popular method of plastics processing for mass production. The injection cycle time is an essential indicator of the energy efficiency of the injection moulding process. Injection mould processes are divided into four stages – filling, pressurization, cooling and ejection. The longest of these processes takes cooling, and the shortening and overall optimization of this process is the focus of this diploma thesis. The cooling process affects the quality of the manufactured component, as the uneven cooling of the component causes different shrinkage and residual stress in the parts of the product, therefore the cooling channels have a very an essential role in injection mould.

Cooling optimization in this work is done by comparing conventional methods such as simpler bored channels versus contour and conformal cooling systems. For optimal design, an injection mold including 3D model and drawing documentation is designed. Conformal cooling technology potentially achieves a uniform distribution of heat in the mold , reducing cooling time while ensuring high quality of the finished part .

Optimization of the cooling process is performed using CAE simulations in Autodesk Moldflow 2016. Cooling efficiency and manufacturability are included in the analysis. The analysis aims to compare conformal cooling technology to conventional methods. [1], [11], [9]

Injection Cycle

The injection cycle consists of several sequential processes.

- **Filling and plasticization:** The material in the form of powder or granulate is fed into the hopper of the injection molding machine, where it is gradually heated to form a viscous melt. Before injection into the mold cavity, the melt has a uniform composition, density, viscosity and temperature.
- **Injection:** Under the influence of high pressure, the melt is fed into the mold cavity through the inlet system and through the nozzle of the injection molding machine.
- **packing:** After a certain filling of the mold cavity, there is pressure when the screw of the injection molding machine moves slowly forward and exerts pressure on the melt in order to subsequently replenish the mold and reduce shrinkage injection molded product.
- **Cooling:** The injected product is cooled in the mold cavity to obtain the necessary hardness and rigidity and can be successfully thrown out of the mold by the ejection system.
- **Ejection** : When the ejection temperature of the product is reached, the ejection system takes the product out of the mold.

II. Literature Review

Heat dissipation and temperature control system requirements

The heat transfer from the melt to the injection mold cavity is dependent on the thermal conductivity of the material used in the manufacture of the mold parts. Materials, such as. Copper and its alloys have many times higher thermal conductivity than steels and are therefore able to dissipate heat many times faster. A temperature gradient is required for heat transfer, which practically means that the heat transfer rate can be increased by placing the tempering channels closer to the mold cavity surface. However, the investment associated with the use of highly thermally conductive materials may not always be an effective solution. The reason is that heat transfer is not so limited by the conduction of heat through the form, but especially by the low thermal conductivity of the plastic and the limited ability of the tempering medium to hold a certain amount heat. The use of highly thermally conductive materials is in some cases efficient and relatively easy to machine, but it cannot be said that they are universal the best solution. More complex tempering channel systems require more complex machining methods, more complex procedures, sealing and maintenance. The design choice therefore remains whether investing in a more complex and expensive system is effective or whether a simpler solution is sufficient for the application [1]

Temperature control unit

Closed-circuit cooling and heating are controlled by temperature control devices with pumps with the possibility of power regulation. The pump output must be sufficient to ensure turbulent water flow in the injection mold channels [2]

The water temperature control system is pressure-free at temperatures up to 95°C or overpressure at temperatures up to 400°C . [2]

Temperature medium

Water , air, oil, glycols or steam are used as heat transfer medium. These tempering media flow through the formed channels in the form. They temper both parts of the mould (movable and immobile) as needed. [3]

Spiral Baffle system

The system of spiral partitions works on the same principle, but the secondary temperature control channel is divided into two turns. At the end of the partition, the temperature medium stream changes its direction and continues with a second thread back to the main tempering channel. By using a spiral partition, an almost homogeneous temperature field is achieved in the adjacent area tempered by this system. The limiting factor is the size of the secondary temperature duct and manufacturers recommend not choosing a system with a diameter smaller than 6 mm.

III. 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:

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.

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.

IV. Model Details

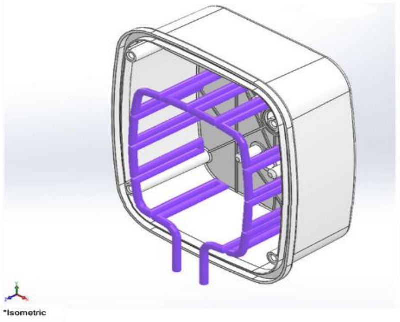


Figure 5.1: Representation of the part with conventional cooling channels

Table 5.1: Conventional design dimensions

Conventional design dimensions	
Channel diameter	10 mm
Distance between channel centers	25 mm
Distance between the center of the holes and the cavity	18 mm

V. Results

Part Cooling Time

The results of the simulations of the cooling time of the part are shown in Figures 4.1 and 4.2, for the conventional system and conformal cooling, respectively. It is observed that the cooling time was shortened in the cooling model, conformal cooling.

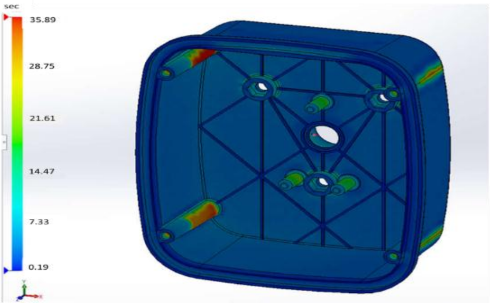


Figure 6.1: conventional cooling time

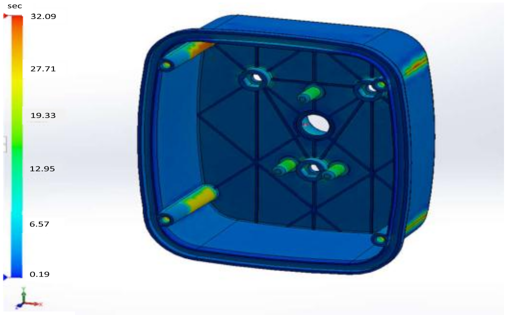
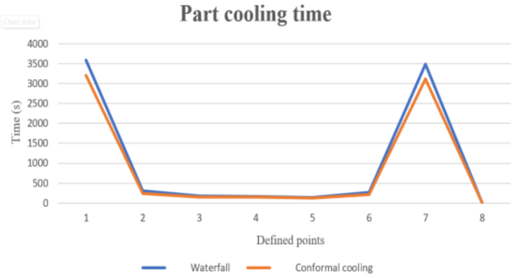


Figure 6.2: Conformal cooling time

Observing Figures 4.1 and 4.2 , it is observed that the part cooled by the conventional system presented the total cooling time of 35.89 seconds and for the part cooled by the conformal cooling system, presented the total cooling time cooling rate of 32.09 seconds, a reduction of 10.59%. The points shown by the closest color to red, are the points that took the longest cooling time. Figure 4.3 shows 8 points selected to establish a comparative analysis between the two cooling projects.



Defined points	conventional cooling	Conformal cooling
1	35.89 sec	32.09 sec
2	3.02 sec	2.36 sec
3	1.74 sec	1.45 sec
4	1.61 sec	1.47 sec
5	1.42 sec	1.21 sec
6	2.66 sec	2.12 sec
7	34.89 sec	31.19 sec
8	0.68 sec	0.61 sec

Figure 6.4: Cooling time for the 8 part points selected (conventional conventional versus conformal cooling)

In both cooling systems, the heating points with the long greatest cooling times are the same as expected due to the geometry of the part and the configuration of the projected cooling channels.

Temperature at the end of the Cooling of the part

The results of the part temperature simulations at the end of the cooling cycle are shown in Figures 4.5 and 4.6 for the conventional system and conformal cooling, respectively. It is observed that the temperature presented greater uniformity in the refrigeration model, conformal cooling.

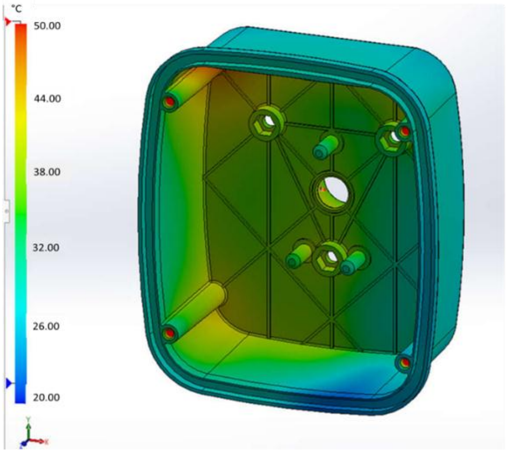


Figure 6.5: Temperature for the 8 stitches Selected on To final of thecooling of piece (conventional conventional)

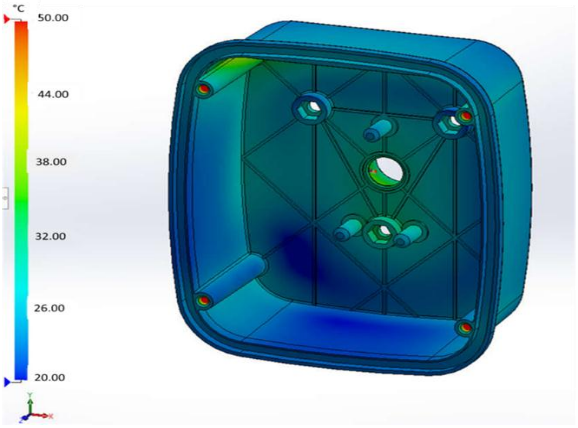
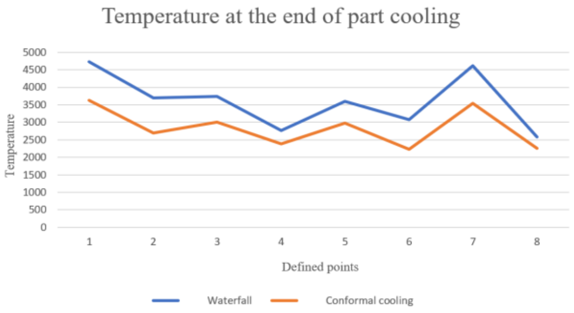


Figure 6.7: Temperature for the 8 points selected in end of the cooling of the part (conformal cooling)

The points shown by the closest color to red, are the points that had higher temperatures. It is noted that the part cooled by the conventional system presented a large area close to 50ºC (close to the yellow and red color), unlike the part cooled by the system which remained below 40ºC (close to blue).

The data of the simulations referring to the temperature in the part described through the 8 (eight) points identified in Figure 4.3 are compared using Figure 4.7.



Defined points	Conventional Cooling	Conformal cooling
1	47.26 °C	36.24 °C
2	36.95 °C	26.9 °C
3	37.41 °C	29.99 °C
4	27.72 °C	23.82 °C
5	35.95 °C	29.77 °C
6	30.73 °C	22.27 °C
7	46.19 °C	35.41 °C
8	25.79 °C	22.56 °C

Figure 6.8: Temperature for the 8 stitches Selected on To final of thecooling of piece (conventional conventional versus conformal cooling)

It is noted that the temperature magnitudes for the conformal cooling system were lower and greater temperature uniformity was obtained when compared to the conventional system due to uniformity, positioning and wider distribution area of refrigeration channels, as shown in Figure 4.7.

The temperature magnitude of the part was reduced considerably from the range of 25.79°C to 47.26°C in the conventional system, to 22.27°C to 36.24°C, in the conformal cooling system, a reduction in the highest value of 23.32%. The temperature variation in the part was also reduced, and in the conventional system the difference was 21.47°C, and in the conformal cooling system the difference was 13.97°C.

Mold Temperature at the end of the cycle

The results of the mold temperature simulations at the end of the part cooling cycle are shown in Figures 4.8 and 4.9 for the system conventional and conformal cooling, respectively. It is observed that the temperature presented greater uniformity in the refrigeration model, conformal cooling.

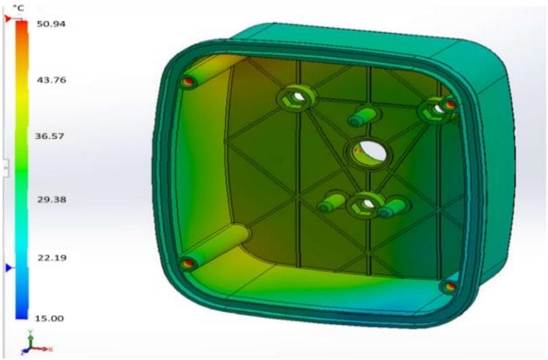


Figure 6.9: Mold temperature at the end of the cycle (conventional cooling)

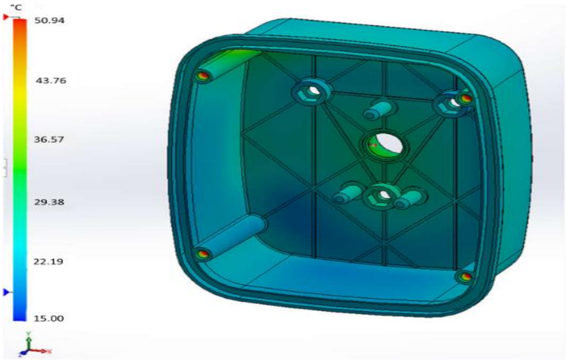
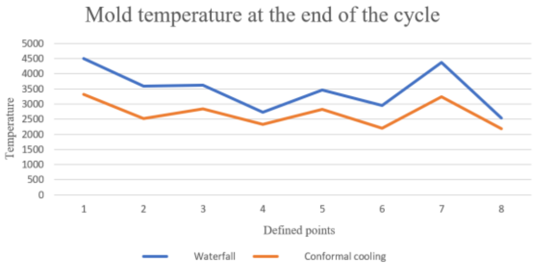


Figure 6.10: Temperature of the mold at the end of the cycle (conformal cooling)

The points shown by the closest color to red, are the points that had higher temperatures. It is noted that the part cooled by the conventional system presented a large area close to 50ºC (close to the yellow and red color), unlike the part cooled by the system which remained below 40ºC (close to blue).

The data of the temperature simulations in the mold described through the 8 (eight) points identified in Figure 4.3 are compared using Figure 4.10.



Defined points	Conventional	Conformal cooling
1	45.01 °C	33.24 °C
2	35.98 °C	25.21 °C
3	36.23 °C	28.44 °C
4	27.22 °C	23.21 °C
5	34.69 °C	28.21 °C
6	29.45 °C	22.07 °C
7	43.74 °C	32.39 °C
8	25.39 °C	21.8 °C

The temperature magnitude of the mold at the end of the cycle, as shown in Figure 4.10, was reduced from the range of 25.39°C to 45.01°C in the conventional system to 21.80°C to 33.24°C in the conformal cooling system, a reduction in the highest value of 26.14%. The temperature variation in the part was also reduced, and in the conventional system the difference was 19.62°C, and in the conformal cooling system the difference was 11.44°C.

VI Conclusion

Based on the results discussed in this study, we therefore have the following conclusions:

1. The injection mold with conformal cooling type channels provides significant cooling time savings of approximately 10.6% compared to the conventional drilling method studied.

2. The temperature of the part and mold were reduced by more than 23% in the proposed conformal cooling method. The most homogeneous distribution can also be observed in the part. These factors ensure better quality of the molded product and lower possibilities of any defects arising from improper refrigeration, especially in the case of crystalline plastics such as PP.

The proposed refrigeration system aiming at manufacturing possibilities through the MA, demonstrated according to numerical simulation that the conformal cooling can reduce the cycle time and lower the temperatures in the part and mold, proving the improved result of this refrigeration system.

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