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# CYCLE TIME REDUCTION IN INJECTION MOULDING WITH CONFORMAL COOLING CHANNELS

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## ABSTRACT

Cooling channel design in injection moulding is very important as it greatly affects the cycle time. Traditionally, cooling channels have been machined into mould components with gun-barrel drilling, with that only straight channels were possible to manufacture. An advanced method of cooling system that 'conforms' to the shape of the part in the core, cavity and strippers can be made possible with free form fabrication or 3D printing. This paper presents a study on optimized mould design of conformal cooling channel for a plastic part. Core and cavities have been designed using Pro/Molddesign and circular configurations of conformal cooling channels have been developed with Pro-Engineer software. The part cooling time has been optimized by using these conformal cooling channels and compared with straight channels in the mould using ANSYS thermal simulation software. Results are presented based on temperature distribution and cooling time using transient thermal analysis conditions. The results provide a reduction in cycle time for the plastic part, which will lead increase of production volume.

**Keywords:** Injection Moulding, conformal cooling channel, cooling time.

## 1. INTRODUCTION

Injection moulding is highly efficient means of producing plastic parts [1]. Its success depends on the optimum design of the mould and moulding process. The basic principle of injection moulding is that a solid polymer is molten and injected into a cavity inside a mould which is then cooled and the part is ejected from the machine. The main phases in an injection moulding process involve filling, cooling and ejection. The cost-effectiveness of the process is mainly dependent on the time spent on the moulding cycle which includes injection, cooling, plate movement and ejection. Among these, cooling phase is the most significant step. Time spent on cooling cycle determines the rate at which parts are produced. Since in most modern industries, time and costs are strongly linked, the longer is the time to produce parts the more are the costs. A reduction in the time spent on cooling the part would drastically increase the production rate as well as reduce costs. So it is important to understand and optimize the heat transfer process within a typical moulding process.

The rate of the heat exchange between the injected plastic and the mould is a decisive factor in the economical performance of an injection mould. Heat can to be taken away from the plastic material until a stable state has been reached, which permits demolding. The time needed to accomplish this is called cooling time. Proper design of cooling system is necessary for optimum heat transfer process between the melted plastic material and the mould. Historically, this has been achieved by creating several straight holes inside the mould core and cavity and then forcing a cooling fluid (i.e. water) to circulate and conduct the excess heat away from the molten plastic. The methods used for producing these holes rely on the conventional machining process such as straight drilling, which is incapable of producing complicated counter-like channels or anything vaguely in 3D space.

An alternative method of cooling system that conforms or fits to the shape of the cavity and core of the mould can provide better heat transfer in injection moulding process, and hence result in optimum cycle time. This alternative method uses contour-like channels of different cross-section, constructed as close as possible to the surface of the mould to increase the heat absorption away from the molten plastic. This ensures that the part is cooled uniformly as well as more efficiently. Now-a-days, with the advent of rapid prototyping technology (e.g. Direct Metal Deposition, Selective Laser Melting) and many advanced computer aided engineering (CAE) software, more efficient cooling channels can be designed and manufactured in the mould with many complex layout and cross-sections. Most of the researches on conventional cooling systems for injection moulding have been directed toward optimal cooling system design to improve the effectiveness and efficiency of cooling. K. M. Au [2] presented a scaffolding architecture for conformal cooling design for rapid plastic injection moulding. Tang et. al. [3] have developed a methodology for optimal design of cooling channels for multi-cavity injection mould in terms of channel size, location and coolant flow rate using finite element analysis for solving the transient heat conduction problem. Li [4] has described a feature based design synthesis approach to develop cooling system design by first decomposing complex part shape into simpler shape elements and then developing an algorithm to generate cooling channels.

Research in conformal cooling system has mainly focused on fabrication and testing of prototype conformal cooling moulds using freeform fabrication techniques. Sach et al. [5] described the production of injection moulding tooling with conformal cooling channels using the Three Dimensional Printing (3DP) process. They compared the effectiveness of conformal cooling and conventional cooling of core and cavity by experimental testing and also by finite difference approach. They concluded that the conformal mould was able to maintain a more uniform temperature.

This paper presents an investigation on the effects of conformal cooling channel layouts and conventional cooling in an injection mould using the Pro/Engineer, Pro/Molddesign and ANSYS thermal simulation software and determining which one offers the most effective heat removal.

## 2 DESIGN OF MOULDS AND COOLING CHANNELS

The part chosen for this study is an injection moulded plastic canister made in polypropylene thermoplastic, as shown in Fig 1. The mould of this plastic part consists of a cavity, a core and base plate. Analysis of the complete mould assembly has been done by ANSYS.

Fig 1: 3D model of canister designed by Pro-E.

The CAD modeling of the mould has been done with the Pro/Molddesign module of the Pro/Engineer system using this model as a work piece. After getting core and cavity from Pro/Molddesign (Fig 2) cooling channels and additional devices of the mould has bee developed by Pro-Engineer software. Cooling channels in the mould has been designed with sweep-cut option of Pro-E software. Cooling channels have been designed keeping the design rule of minimum distance between cooling channels and core-cavity surface that is in contact with melting plastic as well as channels itself. Cooling channels diameter was 12mm.

Fig 4 shows the complete assembly model of core, cavity and base insert with conformal cooling channels. Conformal cooling channels that conforms to the shape of the part makes the mould design simple, consequently reducing the cost of the mould manufacturing. Conformal cooling channels also increase the heat transfer process faster as it is conform to the shape of part, especially in the curve areas of the mould that has to be designed according to the shape of the manufactured plastic part.

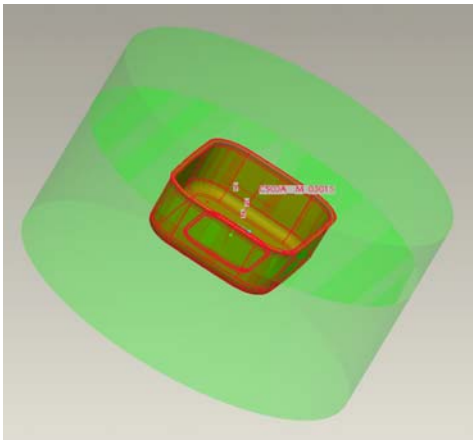

Fig 2: Core, cavity and part in Pro/Molddesign system for conformal cooling channels

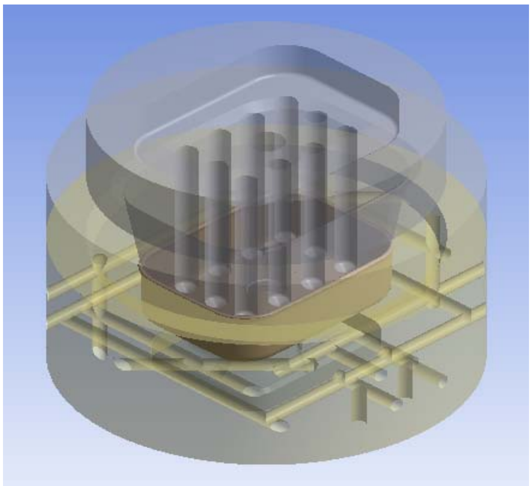

Fig 3: Assembly model of mould with straight cooling channel.

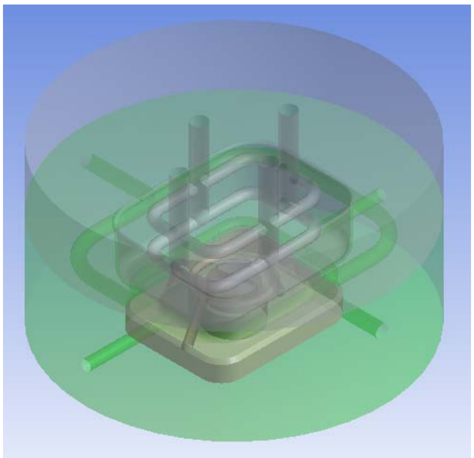

Fig 4: Assembly model of mould with conformal cooling channels.

## 3 THERMAL ANALYSIS FOR COOLING CHANNELS

ANSYS simulation software has been used for the analysis of the parts. By using ANSYS, engineers can easily evaluate product performance by simulating the behaviors of parts and assembly product in thermal loading condition. ANSYS simulation module can perform steady state and transient analysis of a thermal problem. The steady state thermal analysis is used to calculate thermal response to heat loads subject to prescribed temperatures and/or convection conditions. Steady thermal analyses assume a steady state for all thermal loads and boundary conditions. This characteristic is used to test the temperature distribution on the mould surface. Transient thermal analysis is used to calculate thermal responses over the period of time and therefore it is used to estimate the cooling time. After designing cooling channel systems for the injection mould, they need to be evaluated for the efficiency in terms of temperature distribution and cooling time. In this investigation, the thermal analysis for the complete assembly of the conformal and straight cooling channels mould has been done.

Both steady-state and transient analysis have been investigated but only transient analysis has been discussed as it gives better range of result than steady-state. In the transient analysis, required parameters are temperature of the mould surface which was 230-225 °C. Five different temperature zones have been considered as a boundary condition and corresponding heat flow has been put as a boundary condition. Equation (1) has been used as heat flow[6 ].

$$Q_{hf} = m_t C_p \Delta T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where,

$Q_{hf}$ =Heat flow
$m_t$ =flow rate of the plastic
$C_p$ = Specific heat of plastic
$\Delta T$ = difference of temperature between melting surface and cooling medium

The convection condition is applied to the water lines, and therefore; the convection coefficient was calculated in advance. The heat convection coefficient calculation was based on Dittus-Boetler [8] correction equation (2) for forced convective heat transfer by turbulent flow in a circular pipe and was found to be 5927 Watt/m$^2$ °C.

$$h_c = 0.023 \frac{k}{D} Re^{0.8} Pr^{0.4} \quad \ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

$h_c$ = heat transfer co-efficient
k = thermal conductivity of coolant (water)
D = Diameter of the cooling channels
Re = Reynolds Number
Pr = Prandtl Number

Boundary conditions of the conformal cooling channel mould have been shown in Fig 5; same boundary conditions have been applied for straight cooling channel mould also.

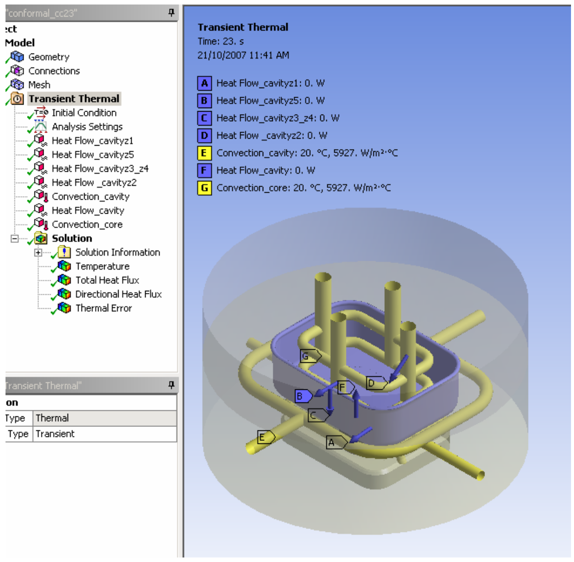


Fig 5: Boundary conditions that have been applied for transient analysis in ANSYS.

The result has been shown by a fringe diagram of temperature distribution of different region of the mould and temperature–time graph obtained from transient analysis using ANSYS Thermal simulation software.

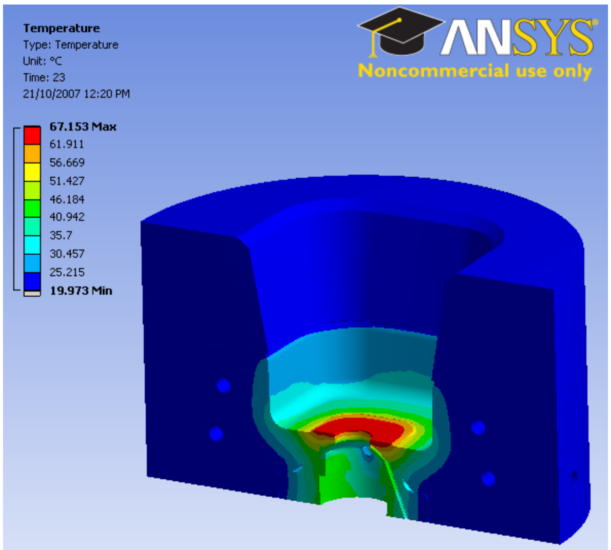


Fig 6: Temperature distribution at 23 second in the conventional cooling channel mould.

## 4 RESULTS AND DISCUSSION

Fig 6 and Fig 7 show the fringe diagram of comparative temperature distributions of the analysis result of moulds with conventional and conformal cooling channels. From the conventional cooling channel mould it can be seen that maximum temperature of the cavity surface is around 68 °C at 23 second, which is the actual cycle time of the process, whereas from conformal cooling channel mould it is 47°C and also temperature distribution is more uniform in conformal cooling channel mould. So it concludes that using conformal cooling channel 21°C temperature is reduced at the same cycle time and more uniform and fine temperature distribution can be possible which is very much necessary for quality product.

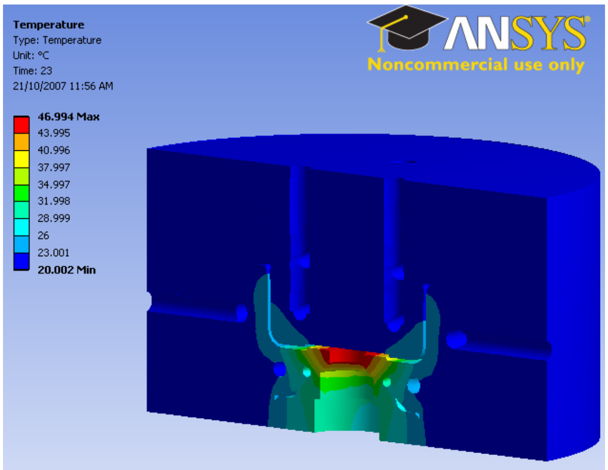


Fig 7: Temperature distribution at 23 second in the conformal cooling channel mould.

Another significant result obtained in this study was the cooling time calculation. Comperative result has been shown in Figure 8.

From Fig 8, it can be seen that conformal cooling channels give better cooling time than conventional channels. For this particular plastic part, de-moulding temperature is around 80 °C. Cooling time or time required for molten plastic to reach 80°C from 230 °C, for the conventional channel mould is 19 second but in case of conformal channel it is 11 second. So, 8 second of cooling time or the cycle time has been saved using conformal cooling channels which is 35% of the total cycle time.

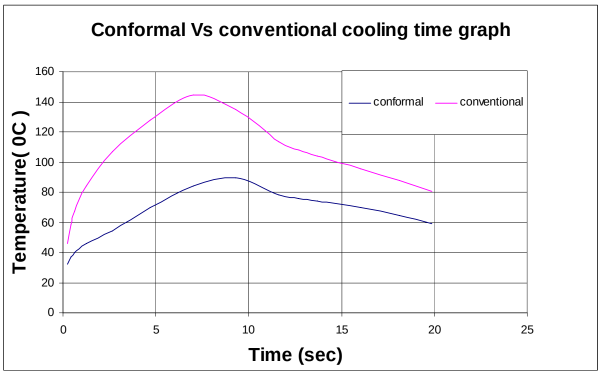


Fig 8: Comparative cooling time plot of conformal and conventional cooling channels mould.

## 5. CONCLUSIONS

The cooling process is one of the most important sub processes in injection moulding because it normally accounts for approximately half of the total cycle time and affects directly the shrinkage, bend and warpage of the moulded plastic product. Therefore, designing a good cooling channel system in the mould is crucial since it influences the production rate and quality. The results of ANSYS thermal simulation have shown that with proper geometry sections and proper layout designs, the conformal cooling channels can obtain up to 40% reduction in cooling time and 35% of the total cycle time thus greatly improving the production rate and the production quality of injection moulded parts

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