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Comparative Thermal Analysis of Circular and Profiled Cooling Channels for Injection Mold Tools

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Abstract: Injection Mold Thermal Management is a critical issue in plastic injection molding process and has major effects on production cycle times that is directly linked with cost and also has effects on part quality. For this reason, cooling system design has great significance for plastic products industry by injection molding. It is crucial not only to reduce molding cycle time but also it considerably affects the productivity and quality of the product. The cooling channels in injection molding have circular cross section due to the conventional manufacturing technique of drilling. In Rapid Prototyping and Tooling techniques of fabricating conformal cooling channels, the channel cross section is again circular. In circular channel, there can be a problem that the distance from the edges of channel to the cavity is not constant and it is variable even for conformal channels. This can give problem of not having even heat dissipation. In this study, injection mold designing and thermal simulations were performed and comparison is presented between molds having cooling channels of circular cross section with mold with profiled cross section channels. Thermal analysis and simulations can effectively predict the performance of circular channels as compared to profiled channels. Some concepts are also presented for the manufacturing of molds with circular and profiled channels with the use of metal filled epoxies.

Key words: Profiled channels, thermal management, injection molding, conformal cooling channels, aluminum filled epoxy

INTRODUCTION

Injection Molding (IM) is a common plastic processing method and is a vast business in the worldwide plastics industry (Rosato *et al*., 2003). Process cycle time is the key factor in IM affecting the productivity of the process. The process cycle time in injection moulding process depends greatly on the cooling time of the plastic part, which is facilitated by the cooling channels in the injection mould. Conventional cooling channels are normally fabricated with straight drilled holes in the mould, which have geometric and cooling fluid mobility limitations. The technique of conformal cooling is being introduced as effective alternatives to conventional cooling (Saifullah and Masood 2007).

The cross section of conventional cooling channels is circular due to the manufacturing technique of drilling. In conformal channels fabricated with Rapid Prototyping (RP) and Rapid Tooling (RT) technologies, the geometry is again circular. Thermal management of injection mold tools is very much enhanced with the application of conformal cooling channels as compared with conventional method of cooling with straight drilled holes. The concept of conformal cooling channels is shown in Fig. 1 and 2.

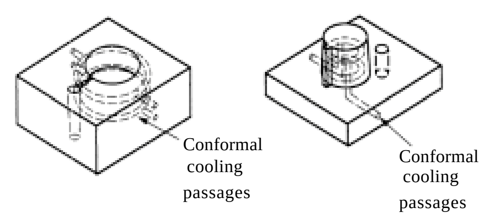

Fig. 1: Conformal cooling passages (Sachs *et al*., 2000)

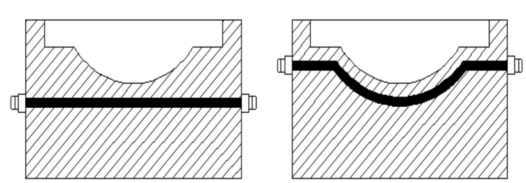

Fig. 2: Conventional and conformal cooling channels

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One problem might arise in the cooling channels with circular geometry that the distance between the edges of cooling channel and the edges of cavity in mold cannot be constant due to the geometric constraints. This distance is variable even in the case of conformal channels which conform to the shape of the cavity but have a circular cross section. If the cross section of the cooling channel is so designed that not only it conforms to the cavity but the side of the channel facing the cavity is following the profile of the cavity side. This concept can be called as a Profiled Cooling Channel (PCC). This concept can add further improvements in the field of conformal cooling, enhance the injection molding process and reduce the cooling cycle time.

The use of analysis tools for the simulation of the molding process is a neglected area amongst many manufactures of plastic products. Mostly, the design and the choice of different process parameters are based on the experience of mold designers and other engineers. Studies have shown that costs up to 50% can be cut for mold modifications and up to 15% for cycle time when using simulation(Saifullah and Masood, 2007). Thermal analysis is done with different profiles of cooling channels and cavity geometries to compare the results of circular and profiled cooling channels.

For the fabrication of IM tools, Rapid tooling is a technology for either indirectly utilizing a rapid prototype as a tooling pattern for the purposes of molding production materials, or directly producing a tool with a rapid prototyping system. Manufacturing of aluminium filled epoxy molds are reasonably quicker in comparison with machined molds. It is a relatively inexpensive and quick way to create prototype and production tools. If the molds are designed properly, they can withstand the injection or the compression pressures with the use of aluminium frames. But the process cycle time is higher due to poor thermal conductivity of the material (Kovacs and Bercsey, 2005).

MATERIALS AND METHODS

The objective of the current research is to design an experimental mold for analyzing the concept of Profiled Conformal Cooling Channels for injection mold tooling. The cooling stage is the most time taking stage (about 70%) (Villalon, 2005) during injection molding process cycle. The cross sectional geometry of conventional and conformal cooling channels in injection molding is circular. In the current research, design and modeling of molds will be done with circular and profiled channels and thermal analysis and comparison was done to simulate the heat dissipation in injection molds and using different geometries of cooling channels (Fig. 3).

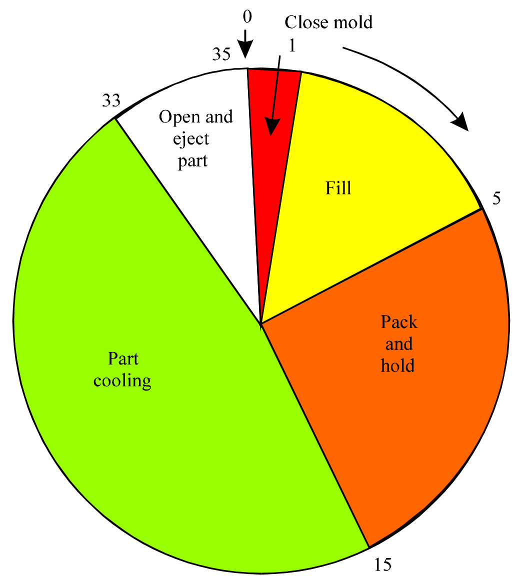

Fig. 3: Cycle time in injection moulding (Saifullah and Masood, 2007)

The design and modeling of mold cavity and cooling channel was done using CAD solid modeling software. The three dimensional CAD model is imported into ANSYS Workbench environment for thermal simulation. Initial and boundary condition and thermal loads are applied to the model.

Following molds were designed and thermally analyzed.

- Mold with Circular Conformal Channels (Fig. 4)
- Mold with Profiled Conformal Channels (Fig. 5)

The diameter of the circular channel in the mold is taken as 10mm with an area of 78.5mm^2. The cross sectional area of the profiled cooling channel used in the mold is also same as the cross sectional area of a circular channel of diameter 10 mm. This area for profiled channel is designed as 78.5mm^2. The mold dimensions are 125 mm (W), 140 mm (L) and 61 mm (H). The convection value for cooling water is taken as 5000 W/m^{2}K and for air 20 W/m^{2}K.

A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component. Engineer/analysts often perform a steady-state analysis before doing a transient thermal analysis, to help establish initial conditions. A steady-state analysis also can be the last step of a transient thermal analysis, performed after all transient effects have diminished (Sadegh *et al*., 2009).

Transient thermal analysis determines temperatures and other thermal quantities that vary over time.

Engineers commonly use temperatures that a transient thermal analysis calculates as input to structural analyses for thermal stress evaluations. Many heat transfer applications- heat treatment problems, nozzles, engine blocks, piping systems, pressure vessels, etc. involve transient thermal analyses. A transient thermal analysis follows basically the same procedures as a steady-state thermal analysis. The main difference is that most applied loads in a transient analysis are functions of time (Sadegh *et al*., 2009).

The channel geometry which is dissipating heat more will have the effect of having more heat flow at the cavity side. The cumulative heat flow rate will be determined on the cavity side of the mold, done with Ansys simulations. For determining the results of simulations, Ansys uses different types of probes. These probes can be structural, thermal and magnetostatic. For the current work, thermal probes were used in the Ansys simulations. For determining heat flow, Reaction Probe was applied on the cavity planes (Fig. 6). The reaction probe calculates the heat flow respective to each time interval set in the Ansys analysis settings.

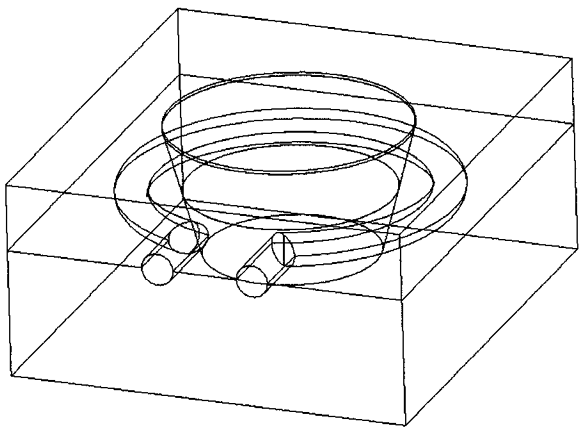

Fig. 4: Mold with circular conformal channels

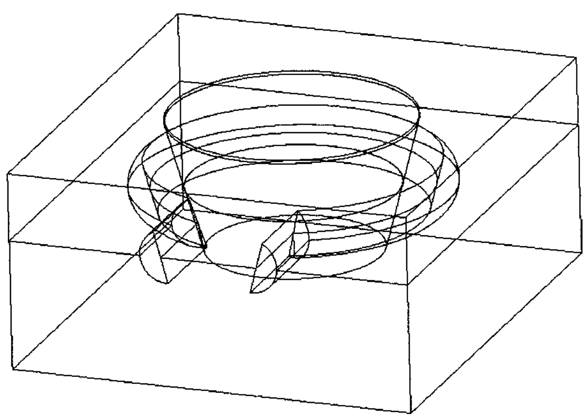

Fig. 5: Mold with profiled conformal channel

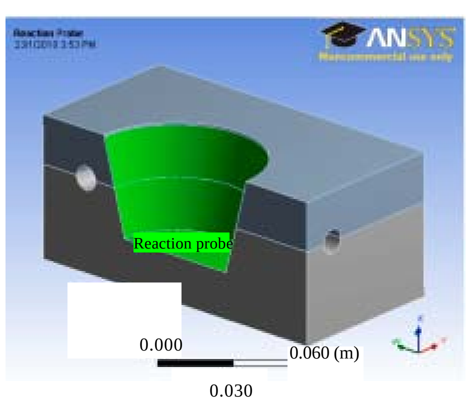

Fig. 6: Reaction probe in ansys

RESULTS AND DISCUSSION

A Profiled channel was designed, modeled and simulated to give a comparison between conventional circular channels with profiled channels.

Steady state thermal analysis was performed for molds with different configurations of circular and profiled channel geometries. Heat flow was measured for all mold configurations channels geometries by placing a reaction probe on the cavity side (Fig. 6). The channel geometry which is giving more heat at the cavity end is dissipating more heat and therefore has faster cooling which can result in lesser cooling time.

The results for the two channel type's i-e circular and profiled are given in Fig. 7.

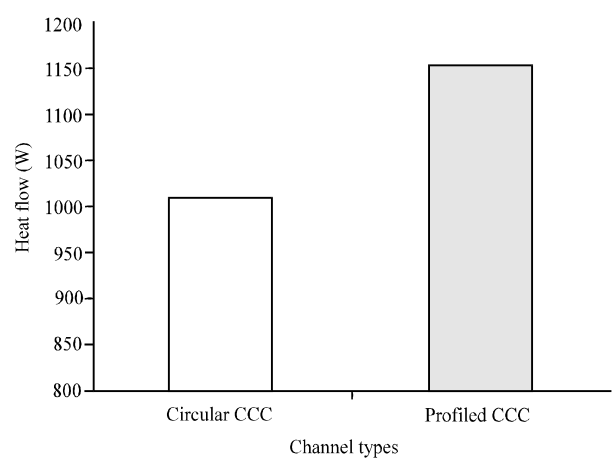

Fig. 7: Heat flow - circular vs. profiled

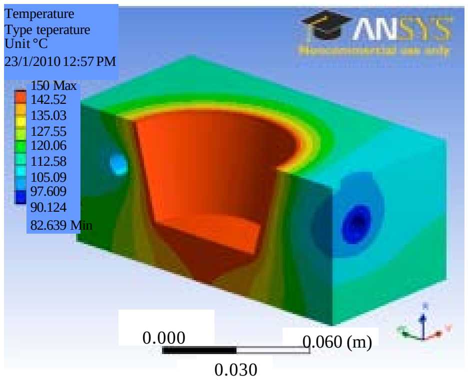

Fig. 8: Temperature distribution in circular conformal channel

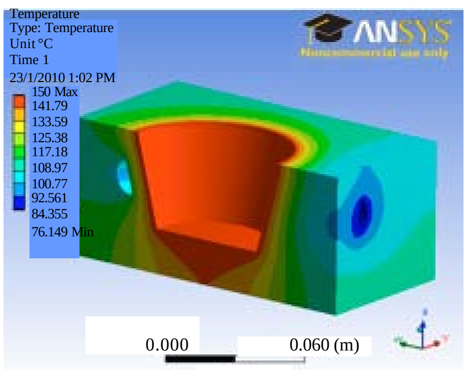

Fig. 9: Temperature distribution in profiled conformal channel

The Ansys simulated analysis results showed that the profile channel give more heat flow at the cavity side which results in shorter cooling times for injection mold process (Fig. 8).

The percentage increase in the heat flow value was about 14.6% for the profiled channel over circular channel (Fig. 9).

CONCLUSION

The current research has shown that the concept of Profiled Conformal Cooling Channels (PCCC) removes heat faster resulting in more heat flow at the cavity side of the mold. The cooling phase in injection molding process is the most important and crucial part as it directly links with cycle time and part quality. This concept can be utilized in injection molding process for better heat dissipation which can lead to improved cycle times and part quality. A Profiled channel was designed, modeled and simulated to give a comparison between conventional circular channels with profiled channels. The Ansys simulated analysis results showed that the profile channel give more heat flow at the cavity side which results in shorter cooling times for injection mold process.

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