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ADVANCEMENTS IN DESIGN AND FABRICATION OF CONFORMAL COOLING CHANNELS FOR IMPROVEMENT IN PLASTIC INJECTION MOLDING PROCESS

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ABSTRACT:

Conventional cooling channels give uneven cooling due to variation in distance of the cooling channel from the mold surface which contributes to defects like warpage, sink marks and thermal residual stresses and hence longer cycle time. With non-conventional machining techniques, channels can be formed that conform to the shape of product. Reducing the cycle time is most important parameter in injection molding process. Thus, using conformal cooling technique, the cooling time can be significantly reduced. There are various other factors that should also be considered like cooling channel design for mold and cavity melt temperature, injection pressure, mold temperature, coolant temperature, method of ejection from mold etc. so that quality of the product can be improved. Hence there is need to enhance the cooling performance. To improve the quality of cooling, conformal cooling channels are the newest and better approach. Recent advancements in the fabrication of a cooling channel has helped in the easy fabrication. This paper gives an overview about the recent advancements in increasing the efficiency of cooling channel and non-conventional manufacturing processes for fabrication of conformal cooling channels in the injection molding process.

KEYWORDS: Conformal cooling channels, temperature distribution, cooling efficiency, advanced manufacturing techniques

1. INTRODUCTION

Injection molding is one of the most important manufacturing processes available in plastic manufacturing industries. Various researches have been done on injection molding process so that cycle time of production can be minimized. Since cooling of the injection mold takes most of cycle time, reduced or minimum cooling time leads to increase in the productivity, so the literatures reviewed are mostly based on reducing the cooling time. So to optimize cycle time is important. As the cycle time is reduced the productivity of the plant increases. The cooling system design comprises of the design of the cooling channel. The straight drilled cooling channel is the most common because of its simplicity in design and manufacturing. It is the cheapest type of cooling channel. It can be manufactured by drilling or boring operations. The methodology involves optimum design of the cooling channel in terms of cooling time, number of cooling channels, size of cooling channels, location of cooling channels, coolant temperature, convective heat transfer between coolant and the wall. Due to non-uniformity in cooling stage, defects like shrinkage and warpage may occur. Thus the design of conformal channels is such that it conforms to the shape of molded part keeping in view that the distance between the cooling channels and mold surface is uniform. This paper gives an overview of the major work that has been done by the researchers in improving the quality of product and reducing the cycle time.

2. LITERATURE REVIEW

Altaf et al. (2012) [1] did research on prototype production of profiled conformal cooling of injection mold using epoxy. As the distance between the circular cooling channels and mold

cavity is not constant because of circular profile of cooling channels. A new method of design of conformal cooling channel is proposed called profiled conformal cooling channel in which channel were created with flat face, facing the mold cavity. Mold core and cavity were created by creating wax pattern in aluminium flame and then epoxy is poured in the frame. For cooling time analysis of both circular cooling channel and profiled cooling channel, they used CAD software. They found that profiled conformal cooling channel mold takes 176s less time to reach ejection temperature of 35°C, so heat transferred rate is faster and this increases the cycle time.

Agazzi et al. (2013) [2] proposed a methodology for optimal cooling system. In this they have taken a T-shaped component for design of effective cooling system. Seven cooling channels were created for cooling of the mould. initial boundary conditions were $w=0.75$, fluid temperature is 303K, fluid flow rate is 364 cubic centimeter per sec, cooling time is 23.5s, finite element method is used for computation and they found, temperature distribution is more uniform.

Dalgarno and T D Stewart (2001) [3] stated in their article about integration of conformal cooling channel. The cooling channels were created by CNC and EDM machine. The channels created by these conventional machining methods did not give uniform cooling as it did not had the capability to reach near mold cavity. With the advancement in computer technology leads to generation of various rapid tooling processes like laser generating process, three dimensional printing process and selective laser sintering (SLS). It was found SLS is the most appropriate to create conformal cooling channels. These channels conforms the shape of the mold and provide uniform cooling. Moldflow software was used to analyze, screen and

wheel, two different components. Using Moldflow, they found conformal cooling is more efficient than conventional cooling. In this study, they also found shot efficiency of conformal cooled mold is very high.

Dang and Park (2011) [4] proposed a U-shaped groove channels for conformal cooling. They created milled groove in cope and drag of the mold and inserts are used to form cooling channels. These channels were created by CNC milling machine. Design of experiment (DOE) and 3D CAE simulation were used for design parameter and cooling time analysis. Response surface method was used to optimize the behavior of the mold surface temperature. Molding parameter was melt temperature 305°C, ejection temperature 247°C, average mold temperature was 100°C. After optimization they found average temperature of the mold was 100°C and 15.7% less warpage as compared to conventional straight drilled cooling channels.

Dimla (2015) [5] did research on design parameters that should be considered while designing conformal cooling channels for injection mold. Temperature of the plastic, cooling time and thermal properties of materials used for mold and cooling channels are the most important parameters. For analysis he has chosen a dog bowl as a part. Moldflow and solidworks software have used for analysis. Straight drilled channel and conformal cooling channel were created for a dog bowl. One and four injection points were taken for uniform injection of melt into the mold. Cooling channels have created 1mm closer to the mold cavity and having pitch of 17mm. It was observed that by conformal cooling heat transfer between melt and mold is more uniform and cooling time gets reduced.

Dimla et al. (2018) [6] designed and compared conventional cooling channel with the conformal one for a screw cap of non-constant thickness. They have compared the parameters like surface temperature of part, surface temperature of body, frozen layer percentage vs. time, mold temperature, volumetric shrinkage and warpage. The mold insert assembly consisted of core, cavity and ejector. Complete assembly consisted of 8 inserts and 8 parts and the injection was directed from hot runner. For conventional cooling, drilling was done for the coolant circulation and a conformal channel was a spiral contour. The channel diameter was kept 4 mm and the centerline distance between mold surface and channels was 4 mm. Polypropylene was taken as the material for the part with melting temperature of 260°C and ejection temperature as 105°C. Two materials were used for mold i.e. Steel P-20 for conventional channels and Maraging steel 1.2709 for conformal channels. The coolant used was water with inlet temperature 20°C and thermal conductivity 0.643W/m°C. The fluid flow rate for conformal was kept at 10L/min and was divided in 3 channels for conventional and 2 for conformal channels. Total cycle time was set at 14 sec. Simulation results indicate that part surface temperature was 18.8% less for same cycle time by using conformal method. Similarly part body temperature decreased by 3.9%. The material near thread was frozen and delayed ejection temperature. The maximum temperature of mold was reduced by 19.5% from 43.9°C to 35.2°C. Highest warpage was achieved in Y and Z axis. The author has also indicated that 3D printing techniques are more cost effective now and have a great future scope.

Liu et al. (2014) [7] proposed a rapid heat cycle molding (RHCM) in contrast to conventional injection molding process. In this they generated a cooling channel for mold cavity in two part; one is cavity plate another is cavity backing plate. For analysis they have taken a part named blue-tooth front shell having dimensions of 40mm×85mm×1.5mm. In this rapid heat cycle molding, mold is heated first to a temperature of 160°C in 6s and then injection of melt is allowed to inject in mold. For cooling of the mold water as a coolant is used to cool mold from 160°C to 80°C in 22s. Taguchi method is used to optimize boundary conditions of the mold. This RHCM process maintains productivity keeping cycle time low and reduces warpage, weld line, shrinkage etc.

O Gloinn et al. (2007) [8] introduced a comparative study of mold and core with no cooling channels, conventional cooling channels, and conformal cooling channels. They created a straight drilled channel for a mouse and found cooling time. The same was done using conformal cooling channels. By FEA analyst software it was found that with comparison of no cooling channels and conventional cooled, in the conformal cooled part, 21.7% lower temperature was lowered and there was a difference of 16% temperature difference between them.

Park and Dang (2010) [9] proposed a baffle based cooling channels to optimize the cooling time and temperature distribution on mold surface. Baffles provide cooling to small space which rarely gets cooling. Baffles can be normal or spiral based on the requirement. They used design of experiment (DOE), Moldflow for analyzing two different parts; one is plastic cover and other is automotive plastic part. The parameters like plastic material, mold material, part thickness, mold temperature, injection temperature are analyzed by response surface method (RSM) and Moldflow is used to simulate the results like temperature distribution and shrinkage, warpage and cooling time. For plastic cover they got average temperature of mold 51.4°C with respect to target 52°C and the temperature distribution on mold surface was 4.3°C as compared to conventional cooling system was 8.5°C. For automotive radiator grill, they got 49.1°C for 50°C target mold temperature.

Park and Pham (2009) [10] proposed a new method of cooling a mold. They developed a car part for analysis. They generated sub-cooling channels and optimize the cooling time for individual channels for efficient cooling of car part. To analyze moldflow software and CAE software are used. Three cooling channels were introduced; zigzag channel, parallel channel and spiral channel. 255°C Melt temperature, 85°C mold surface temperature, 0.9998 gram per cubic centimeter melt density, 0.25W/m.C thermal conductivity and 4400J/kg.C specific heat were taken as initial boundary conditions. The experimental analysis results indicated that the mold temperature difference between conventional and conformal cooling was 1.5°C which is significant. This leads to reduction in cycle time and increases productivity.

Saifullah et al. (2012) [11] introduced thermal analysis of cooling channels for injection mold. For analysis they have chosen plastic canister part made up of two different plastics polypropylene and acrylonitrile butadiene styrene having outer

dimensions of 160, 120 and 48 mm and thickness of 2 mm using Brass material due to its good thermal conductivity. Both straight drilled and conformal cooling channels were created and Ansys software is used for analysis. Autodesk Moldflow Insight (AMI) is used for simulation of injection molding process like cooling, packing, flow, and warpage analysis. AMI also gives boundary conditions like packing pressure, injection pressure, and mold temperature for thermal analysis. They found using bimetallic conformal cooling channel, 10°C temperature reduction compared to conventional cooling channel.

Shayfull et al. (2013) [12] did research on cooling of injection mold by creating milled grooved conformal cooling channels. For analysis, they have taken front panel housing as a part. They created two milled grooved square shaped cooling channels for analysis and ABS Cycloc MG47 thermoplastic material and mold is made up of steel. Pure water is taken as cooling fluid having 25°C temperature and Reynold's number 1000. Melt temperature is 238°C, ejection temperature is 81°C, packing time is 5s, filling time is 1.7s, coolant flow rate is 2.54 lit/min, packing pressure is 60Mpa. Autodesk Mouldflow Insight is used for analysis of cooling time of conventional and milled grooved square shaped channels. They found 6.57% and 8.05% reduction in ejection temperature.

Smith et al. (2008) [13] proposed a computational fluid dynamics approach to minimize the cooling time of the injection molding. They have developed a polypropylene tool and molded it using CAD software. For analysis, they used Ansys FLUENT 6.0. Tool temperature was set to 50°C and injection temperature 220°C as initial boundary condition. They found cooling time were 39s and 42s for experimental and computational respectively. Creating proper layout of cooling channels, appropriate size of cooling channels, it is possible to provide uniform cooling of mold where as conventional approach was limited to some location only. They also found that conventional cooling of mold leads to uneven cooling and cause defects like shrinkage and warpage of the molded part.

Sun et al. (2002) [14] proposed a U-shaped conformal cooling channel that is created by using CNC machine. So a U-shaped channel was created having inserts by milling process. To predict the effectiveness of mouse cover, milled grooves were made of 6 mm, with a depth of 30 mm and center-lines distance between the channels is 20 mm. COSMOS a FEM method of simulations was used for analysis and it was found that cooling efficiency was increased by 18%.

Sun et al. (2004) [15] proposed a milled groove insert method for cooling of the mold for a household iron part and generated milled groove in core and mold. They ABAQUS analysis software was used for cooling analysis and thermal residual stress analysis. A comparative analysis was done for circular and rectangular channels and the results showed that the cooling time for conventional straight drilled channels and milled grooved channels were 31sec and 21sec respectively. They also found that cooling time of the milled groove channel can be reduced up to 13.3sec by considering the layout of the cooling channels in the mold and core. They stated that conventional

method of creating cooling channels by CNC/EDM machine were causing lower cost than creating channels by rapid prototyping method.

Tang et al. (1997) [16] optimized a cooling channel design for multi-cavity of an injection molding. The parameters considered for the optimal cooling were location of cooling channels, size of the channels, coolant flow rate. To get the optimal cooling layout Jacobi conjugate gradient algorithm was used. The jacobi numerical analysis indicated the proper size of channel and temperature distribution. Finite element analysis was conducted for optimized transient thermal analysis. They have taken steel and polymer as mold and plastic materials respectively. They optimized the cooling channels spacing, size of the channels, and cooling time by varying size of the channels and temperature distribution in part using FEA analysis. It was found that Jacobi FEM is robust, efficient for practical applications.

Venkatesh G and Ravi Kumar Y (2017) [17] did research on conformal cooling channel of injection mold for thermal analysis using DOE method and ANSYS software. They have taken a gear as component and using Creo 2, part has been modeled. Part having dimensions of 120mm×120mm×70mm and cooling channel diameter has taken as 10mm. L27 (3³) orthogonal array is used for optimizing effects of Von-mises stress, heat flux, cooling time and surface temperature. Taking 10mm channel diameter, coolant temperature 25°C, mold temperature 75°C and ABS plastic with melt temperature 250°C, analysis have been performed and they found circular channel with spiral path with 19mm centerline were efficient for injection molding of gear part. Conformal cooling has taken 90.36°C as compared to conventional cooling 100.33°C and hence reduced cycle time of the injection mold.

3. CONCLUSION AND FUTURE SCOPE

Conformal cooling channel method helps in improving the heat dissipation in injection molds as the temperature can be accurately controlled to give a homogenous cooling, less residual stresses, less warpage and shortened cycle times. With the modifications in conventional cooling channels like square, circular, rectangular cross sections, the optimum cooling can be achieved. Changing the method of manufacturing in conventional cooling like straight drilled or milled grooved type, the cooling process can be optimized. The other way to optimize the cooling channel is to use conformal cooled channels which not only conforms to the shape of part but also gives optimum heat dissipation and less cycle time along with enhanced properties of the part. Also changing the mold material gives optimum result. Making conformal cooling channels using traditional manufacturing techniques is a difficult task and time consuming process. Conventional cooling channels are the preferred ones when the dimensional accuracy is not preferred. But when working with the high precision and lower dimension tolerance parts, conventional cooling induce defects and lead to longer cooling time. Hence, to overcome this and to get enhanced part quality, Rapid prototyping or 3D printing techniques are used like Selective Laser Sintering techniques or Direct Metal Laser Sintering

techniques or metal deposition techniques. These rapid prototyping techniques have helped in the enhancement of the properties but these processes are cost effective.

Thus there lies a scope for further research in design and analysis of channels for optimizing plastic injection molding parameters. This would help in improving the plant efficiency by reducing part rejections and cycle time.

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