Review on Performance Enhancement of Plastic Injection Molding using Conformal Cooling Channels

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Abstract— In injection molding the cooling design is very important as it affects the part quality and the cycle time. The cooling can be achieved by conventional drilling method but it is limited to the complexities of the shape. Thus conformal cooling channels are used to reduce the cycle time for cooling and to control the volume shrinkage to attain dimensional stability. Advanced rapid tooling technologies and rapid prototyping technologies have proved to be helpful for making conformal cooling channels. This paper presents a literature review of various types of cooling channels in injection molding so as to get uniform cooling and reduction in cycle time.

Keywords— Plastics, Injection molding, conformal cooling, cooling channels, cycle time, temperature distribution, simulation

INTRODUCTION

Injection molding is a very common plastic processing method to convert raw plastics to an object of practical use. It is a common manufacturing process to make consumer products, engineering parts, medical devices etc. About 80% of cycle time is taken up by cooling phase. The cooling system must be able to remove the heat at the required rate so that the plastic part can be ejected without distortion. At the same time, the cooling of the part should be kept as uniform and balanced as possible so that undesired defects such as shrink marks, differential shrinkage, internal thermal residual stresses and warpage can be reduced.

In cooling design, design variables typically include the size, location and lay out of cooling channels and the thermal properties, temperature and flow rate of the coolant. The analysis of heat transfer within the mold and part plays a crucial role in optimum cooling system design. Among the number of stages involved in injection molding of plastics, cooling stage is a very important as it affects the productivity and mold quality. A careful control of surface temperatures, and heat transfer rates, to increase production are vital. Many manufacturing processes like injection molding, extrusion, blow molding and die casting can be benefitted by implementing the methods of increased and balanced heat transfer within the tooling. In injection molding the heat transfer is generally carried out using straight cooling channels drilled into the mold. It is difficult to position these cooling channels close to the surface of the cavity in such a way it provides optimal cooling. Thus conformal cooling channels are the better alternatives for this. Due to the rapid advancements in Additive Manufacturing it is easy to produce complex conformal cooling channels with the techniques like 3D printing, Direct Metal Laser Sintering (DMLS), Selective Laser Melting (SLM). With the reduction in cycle time, significant cost saving can be achieved.

LITERATURE REVIEW

Eric Dimla [1] investigated the temperature profile along the mold cavity wall to improve cooling system design to determine optimum and efficient design. The Virtual models were made from Solidworks and Moldflow for straight and conformal cooling channels.

Hsu, F, H, et al. [2] considered two different models with normal and conformal cooling design. Results showed that conformal cooling was effective reducing cooling time and product displacement. Using CFD analysis showed the coolant flow behavior showing cooling channel efficiency.

Wang Yu, et al. [3] designed the conformal cooling circuit on the basis of the relationship formulated between conformal cooling and geometry shape of cooling circuit. The cooling design formulation is done with the help of heat transfer model, approximation of cooling depth, spacing of cooling channels and estimation of number of Voronoi sites. The cooling performance is demonstrated on case studies of helmet and cell phone.

Marques Sabrina, et al. [4] proposed parallel circuit and serial circuit conformal cooling. They also have presented a case study on performance of three cooling designs using CAE simulation (Moldflow V10). Conformal cooling channel in series channel proved to be the best choice for the case investigated.

Qiao H. [5] developed an optimization methodology for computer aided cooling design system in injection molding. They have developed a perturbation approach using boundary element method to perform design sensitivity analysis.

Au K. M. and K. M. Yu. [6] proposed a novel scaffold cooling for more uniform cooling channel. The CAE and CFD analysis indicated that this technique offers more uniform thermal distribution with minor in- cavity residual stresses occurrence.

Wu Tong, et al. [7] has proposed a framework for optimization of additive manufacturing of plastic injection molds. They have investigated numerical thermal FEA modeling, thermal mechanical topology optimization in macroscale and material optimization. Conducted advanced numerical simulation of a die with conformal cooling. ANSYS work bench was used for predicting cycle time and other parameters. They have developed a 2D thermo-mechanical topology optimization algorithm.

Wang Yu et al. [8] developed an approach to generate spiral and conformal cooling channels with high curved surfaces. In the comparison it is indicated that spiral cooling channels made using algorithm and BDM analysis based deposition algorithm is easier to fabricate using copper duct bending.

Brooks Hadley and Kevin Brigden [9] introduced a concept of conformal cooling layers filled with self supporting repeatable unit cells that form lattice throughout the cooling channel. They also designed a methodology to create conformal cooling layers. They have conducted a virtual case study to compare three different cooling systems for a rectangular enclosure. The simulations were done using Solidworks Plastic Advanced 2014.

J. C Ferreira and A. Mateus. [10] proposed a new approach to integrate advanced processing technologies such as Rapid Prototyping (RP) and Rapid Tooling (RT).

Au K. M., et al. [11] proposed a new methodology for automatic preliminary cooling using visibility based cooling generation. They have developed an analogy between mould surface and cooling channel based on visibility from each other. A 3D shell model was used and melt flow analysis was done.

Kunnayut Eiamsa et al. [12] A mold is created by conformal bubbler cooling tunnels by metal deposition process.. The mold core is developed in SolidWorks software keeping injection pressure, mold temperature and clamping force the maximum displacement occurred at midpoint between edge of the mold core and web. The CAD MOLD core was converted to an STL file format. The mold core is formed in hybrid machine through deposition process. Number of simulations related to mold cooling have been introduced.

Khurram Altaf et al. [13] fabricated the conformal cooling channels in aluminum filled epoxy mould using rapid prototyping and rapid tooling techniques. They have two moulds with part cavity, one circular and other profiled. Experimental analysis showed reduced cycle time for PCCC moulds.

A. B. M. Saifullah and S. H. Masood [14] have studied the optimum design for conformal cooling channels using finite element analysis and thermal heat transfer analysis. They have optimized cooling time by ANSYS thermal analysis software.

Omar A Mohamed et al. [15] have done a simulation study of different types cooling channels. The channel was designed using Pro/ Engineer Wildfire 5. The IGES CAD model was imported to Autodesk Moldflow Insight (AMI) simulation software for analysis using dual domain meshing. Molding Window has been used for the analysis.

Hong-Seok Park and Xuan-Phuong Dang [16] proposed the use of cooling channel with array of baffles, the performance of heat exchanger in the injection mold can be improved. They have also presented a new algorithm for calculating various parameters that are significant in cooling.

Ping Hu et al. [17] investigated several models of cooling channel designs considering the evaluation indicators as maximum temperature, temperature uniformity, pressure drop between and outlet and maximum velocity in channels. They have defined a figure of merit (FoM). The physical model comprised solid region and liquid region. They have created a CAD model using CATIA. The multi-indicator comprehension evaluation method, it was concluded that serpentine conformal cooling channel has best cooling performance.

D. E. Dimla [18] generated a virtual model of cooling system using Model Master in I-DEAS and used mold flow software to find the best position for the runner. They have conducted a finite element analysis using MPA as a tool material. Simulation results helped in optimization and prediction of best location for channels.

Neculai Ivascu and Cătălin Fetecau [19] proposed a new cooling system that uses a metallic mold with thin walls, to increase heat absorption. They have calculated total amount of heat carried into the mold. Through their work they have found that reduction in wall thickness, reduction in cycling time and reduction in clamp tonnage reduces the cost.

Q Niu .et al. [20] developed an intelligent cooling channels design system including automatic layout of cooling system, interface checking, automatic assembly of accessories by interactive interfaces. System was developed using Unigraphics NX CAD/CAM platform. Results were analyzed this using genetic algorithm.

A. B. M. Saifullah et al. [21] presented a comparison between square section conformal cooling channel (SSCCC) and convectional straight cooling channels (CSCC) and simulated using Moldflow Plastic Insight (MPI) software. SSCCC was proven to be better with less cooling time and better temperature distribution.

Emanuel Sachs et al. [22] have compared the mold surface temperature during injection cycle of a 3D printed mold with conformal cooling channels and mold machined with conventional straight channels. They have demonstrated that inserts with conformal cooling channels exhibit more uniform surface temperature than straight channels.

Velia García Loera et al. [23] have done a significant work in setting the process variables in thermoplastic injection molding operation. They were first to do a practical case study based on the application of Data Envelopment Analysis (DEA).

Z. Nooraizedfiza et al. [24] evaluated the performance of cooling channels compared to straight drilled cooling channels in order to minimize warpage on thin shallow parts. The results of simulation were analyzed by using Taguchi method and Analysis of Variance.

C. I. Li et al. [25] developed a framework for layout design for the cooling system. They also have devised a search tree to represent the design process. By conducting the experimental analysis they have verified their layout design.

A. B. M. Saifullah and S. H. Masood [26] designed the CAD model of core and cavities for conformal cooling using Pro/Mold design and Pro-Engineer software. The part chosen was plastic canister made by polypropylene thermoplastic. The thermal analysis was done using ANSYS. The results have indicated that 35 % reduction in total cycle time can be obtained.

B. Duleva and F. Greskovic [27] have described the capabilities and performance of conformal cooling and its manufacturing by Direct Metal Laser Sintering (DMLS).

K. Poornima and M. N. M. Ansari [28] have compared the straight drilling cooling channel (SDCC) with conformal cooling channels. This was done by analyzing multi-cavity rectangular plate for inappropriate draft angles and nominal wall thickness. Designing of rectangular plate was done using Pro-E Wildfire 5 and imported to Autodesk Moldflow for analysis. Spiral cooling channel needed the least cooling time.

Alban Agazzi et al. [29] presented a new approach for determination of cooling system of a 3D industrial part. They have done this formulating the control problem for optimal fluid temperature distribution along cooling surface and then by doing thermal analysis for the location of isotherms in quasi-stationary thermal zones.

Shayfull Zamree Abd Rahim et al. [30] presented a new design of milled grooved square shape conformal cooling channels. They have examined the warpage and cooling time for the molded parts. When simulated using Autodesk Moldflow Insight 2013 and compared with conventional straight drilled cooling channels, the conformal cooling channels were better.

Z. Shayfull et al. [31] presented milled grooved square shape conformal cooling channels gives better cooling than circular or other types of cooling channels. They investigated the case study on front panel housing by simulating on Autodesk Mold Flow Insight.

Melissa Hall and Mark Krystofik [32] discussed about the driving forces of conformal cooling channels. They have also discussed the design limitations for these channels. They have identified four factors that define the feasibility region for length and diameter of cooling channels, coolant pressure and temperature variations, ability to remove support material and actual part geometry.

Juan M. Jauregui-Becker et al. [33] developed a software engineering tool for automating the design of cooling system for injection molding. A comparison of results obtained from the proposed software tool and by applying best practice tool engineering design approach was done. These methods were applied to the mould design of two thin-walled products, namely a rectangular flat box and a cylindrical container with a flat base. The CAD model was developed using SolidWorks API and the algorithm for cooling generation was developed using C#.

CONCLUSION

The above study showed that conformal cooling channels are the most suitable cooling system for plastic injection molding as compared to conventional cooling channels. Better cooling properties are obtained due to low volume shrinkage and lower time to reach ejection temperature which led to reduction in cycle time, less energy consumption. Virtual 3D CAD models for determining optimum and efficient design and effectiveness can be analyzed using simulation software's. With optimum cooling pattern a reduction in cost is achieved.

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