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Modeling and Simulation of Rapid Heating and Cooling of Injection Mold by FEM-A Review

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Abstract - *Conventional injection mold (CIM) consists of core and cavity and a straight cooling channels machined in a die. According to requirement of high gloss surface appearance, reduced warpage and sink mark a Rapid heating cooling mold (RHCM) is employed in molding. Various methods of heating and cooling the mold are employed in RHCM according to the dynamic temperature control required. In this work, RHCM and Conforming cooling channels are designed for a mold. Drawback of RHCM is that it is difficult to analyze the mould due to critical temperature control. Improper design of the mold results in the defects in the final molded product. Generally the mold is designed based on the mold designers experience in designing. For getting the defect free product trial and error method is applied and the process parameters are adjusted. This leads to loss of production time and increase in the cost. The aim of this study is to incorporate a Rapid heating and cooling method for a 3 Dimensional complex computer peripheral mouse part which is liable to get molding defect like sink mark. Also the transient thermal analysis in ANSYS WORKBENCH is performed to analyze the thermal response of rapid heating and cooling of mold on mold heating and cooling efficiency and cycle time of molding operation. For simulating the injection molding process and to avoid the injection molding defect occurring in molded component Autodesk Mold flow Insight software is useful in the study.*

Key Words: Rapid heating/cooling mold, Injection molding defects, Thermal analysis of mold, Reducing injection molding defects, Rapid heating and cooling methods of mold, Conforming cooling channels in mold.

1. INTRODUCTION

Injection molding is the most important industrial processes in the production of plastic parts. The basic principle of injection molding consists of heating and injecting the polymer melt in impression created by core and cavity. The main phases in an injection molding process are filling, cooling and ejection. The cost-efficiency of the process is dependent on the time spent in the molding cycle. The cooling phase in injection molding is the most significant step amongst the three, it determines the production rate. The longer is the time to produce parts the more are the costs. Reducing the cooling time spent on cooling the part before it is ejected increase the production rate, hence reduce costs. Therefore it is necessary to understand and analyze the heat transfer processes inside a mold efficiently.

1.1 Injection molding process

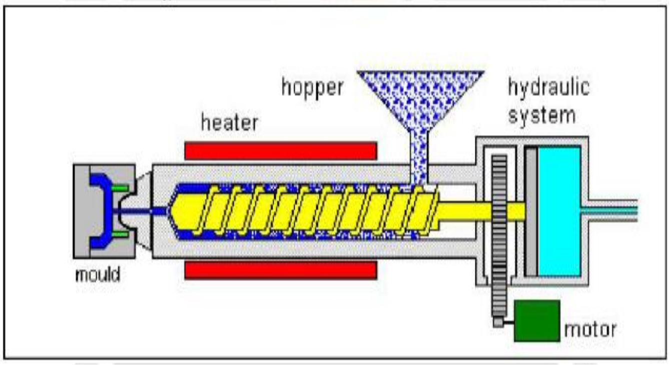

Fig -1: Schematic representation of injection molding machine [16]

Injection molding process begins with the feeding of solid plastic material in the form of granules through the hopper of the heated injection barrel. In the plastication stage, the injection screw rotates at specified RPM and pushes molten material to the screw chamber in front of the screw tip. After sufficient amount of molten material is melted, the plastication stops. During the filling stage, the impression formed by core and cavity halves are filled with the molten polymer. When the cavity is filled, the packing stage in which additional pressure is applied to force molten material into the cavity to compensate for material shrinkage. After this the cooling stage begins which removes the heat from the melt by passing the coolant through the cooling channels. The process ends with the opening of the mould halves and the solidified parts is ejected by means of ejector pins [12].

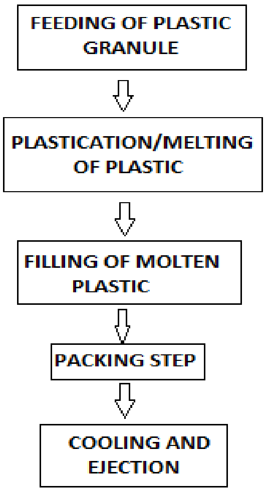

Fig -1: The representation of the complete injection molding cycle [12]

In plastic injection molding the cooling stage is most important because it greatly affects the productivity, cost and the quality of the product. It is a universal fact that more than seventy percent of the cycle time in the injection molding process is spent in cooling the hot polymer melt so that the part is ejected without any warpage. An efficient cooling system design of the cooling channels minimizes undesired defects such as sink marks, thermal residual stress, differential shrinkage, and part warpage [8].

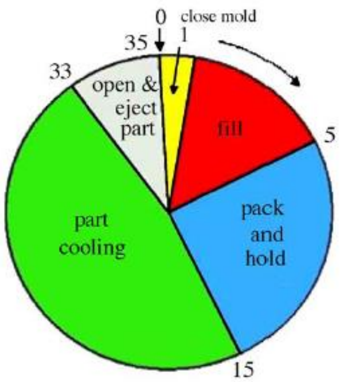

Fig -2: Cycle time in injection molding [8].

2. IMPORTANT BREAKTHROUGH IN INJECTION MOLDING

In RHCM dynamic control is required to rapidly heat and cool the mold. Conventional injection molding (CIM) is useful to mold simple parts that do not necessitate the high appearance. Due to the advancement of technology and increased use of plastic in various applications including aerospace, automotive, electronic the requirement of part appearance has also changed. Part requirement feature has changed to thin plastic part, high gloss appearance and reduced shrinkage and sink marks. To achieve this objective the breakthrough technologies that changed the molding industry are the use of hot runner mold, conforming cooling channels and Rapid heating and cooling mold.

Xiaoxin Wang, Guoqun Zhao, Guilong Wang developed the rapid heat cycle molding process to reduce the sink mark and warpage of the LCD TV front shell. They also suggested the new bench form structure for screw stud, ribs and bosses to reduce sink marks, which appears on the front surface due to local shrinkage because of variation in cross section thicknesses [1]. Gui-long Wang, Guo-qun Zhao, Xiao-xin Wang performed heat transfer simulation based on finite element analysis (FEA) to evaluate the thermal response of the injection mold and thereby improve heating/cooling channels design. Baffles were introduced for heating/cooling channels to improve heating/cooling efficiency and uniformity of the mold [5]. Guilong Wang, Guoqun Zhao, Xiaoxin Wang developed a new rapid mold heating and cooling in which cartridge heaters are assembled in the holes of the mold. Between the heaters and the corresponding mounting holes, there are annular gaps which are full of water. During mold heating, the heat generated by the heaters passes through the water gaps firstly and then transfers into mold base to raise cavity surface temperature. For rapid mold cooling, pressured cooling water is passed though the annular gaps [6]. Cheng-Long Xiao, Han-Xiong Huang developed a rapid thermal cycling molding (RTCM) technology with electric heating and water impingement cooling. To illustrate the feasibility of this technology in injection molding, a RTCM mold for cover plate is constructed. Experimental measurements and numerical simulations are conducted to evaluate the mold thermal response. The results show that the desired characteristics of high mold heating and cooling efficiencies are achieved [10].

3. RAPID HEATING AND COOLING MOLD TECHNOLOGY

3.1 What is rapid heating and cooling mold (RHCM)

Rapid heat cycle molding (RHCM) is a new injection molding technology, which improves surface quality of the plastic parts without increasing the cycle time of process. In the RHCM, the mold cavity surface is heated by various types of heating methods to a high mold temperature before melt injection, generally higher than the glass transition temperature (Tg) of the polymer, then kept at the high temperature during filling and packing stages, and finally the mold is cooled down rapidly to solidify the polymer melt in cavity for ejecting the part [3].

In RHCM only the outer surface of the plastic part is required to have a high gloss appearance therefore only one side of the mold i.e cavity side is heated and cooled rapidly while the core side is just cooled with the normal coolant like water or oil [1].

3.2 Advantages of RHCM

Due to the high mold temperature during filling, the molten plastic has good flow ability and can be easily transformed into the geometry of the cavity. The surface of injected plastic parts has extra-high gloss if the surface of mold cavity is glossy. The inherent injection molding problems which occur in CIM are solved by RHCM technology [2]. The mold surface temperature is very crucial in the plastic injection molding. If the mold surface temperature is high then surface quality of the part will be better, but the cooling time will increase and thus the cycle time will increase. If the mold surface temperature is reduced the cooling time will also reduce, but in exchange the surface quality of part have to be compromised [3].

4. Types of mold heating methods

The rapid mold heating methods include resistance heating, high-frequency proximity heating, gas-assisted heating, induction heating, infrared heating, and convection heating using hot fluids such as oil, water and steam [10]. The existing mold heating techniques is divided into two categories.

4.1 Exterior Heating

For exterior heating, the heat source or heating device installed outside mold base. The exterior mold heating methods include infrared heating, flame heating, and induction heating, surface resistance heating. For exterior mold heating the heat generated by heating element is concentrated only on the exterior surface of the mold and hence the rapid mold heating with high heating rate is possible. But exterior mold heating methods has poor design flexibility of the external heating source or device resulting in uneven temperature distribution of the cavity surface, low coating layer strength for multi-layer mold and also safety issues for flame heating method. Other than these methods, another special external mold heating method which uses a thin layer of material with low thermal conductivity is coated or sticked on the mold surface. The cavity surface is heated by the injected hot polymer during filling and thus it does not need external heating source. Drawback of this method is difficulty in achieving high cavity surface temperature as required in RHCM [6].

4.2 Internal Heating

In inner mold heating, the heat source is located inside the mold base. Inner mold heating method uses the convective heating by using heating sources like hot medium like air, steam, oil and electric heating. These method have low heating efficiency because the whole mold base is heated to raise the cavity surface temperature thus consumes high energy. The inner mold heating methods include especially steam heating method and electric heating method; have been widely used in industrial production of RHCM.

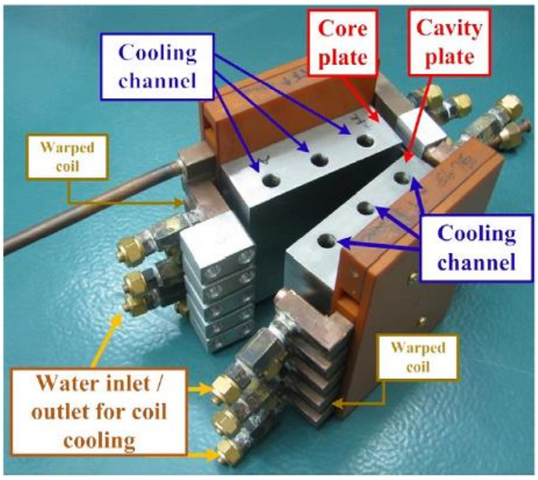

Fig -3: RHCM with induction heating [4]

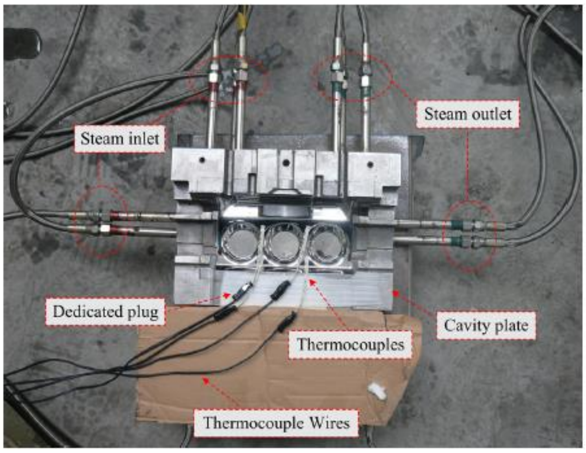

Fig -4: RHCM with steam heating [5]

5. COOLING METHOD IN RHCM

In rapid mold cooling methods, the conventional method by circulating water in mold cooling channels is employed. To increase the cooling efficiency, the optimized layout of cooling lines and the coolants with low temperatures and large flow rates are used. The conformal cooling is proved to be essential in rapidly cooling the mold. To shorten molding cycle, mold temperature need to be kept much lower than the frozen temperature of the polymer melt. As a result, hot polymer will freeze much early as soon as it contacts the mold wall, which results in a premature solidification which brings a many problems such as flow mark, jetting mark, weld mark, short shot and floating fibers. The most effective method to eliminate these problems is to raise the mold temperature during filling. However, this will in turn increase the molding cycle time and hence decrease productivity. For rapid mold cooling, the conventional method of mold cooling is employed. However, the coolant temperature is much lower than in CIM. For rapid mold heating there are various mold heating techniques. Following section lists some of the heating methods which are used in mold heating [6].

6. TWO MAIN DEFECTS IN RAPID HEATING AND COOLING OF MOLD

Common defects which occurs in conventional injection molding (CIM), such as silver mark , flow mark, short shot , weld mark , jetting mark, exposed fibers, etc. does not occur in RHCM. Warpage and sink mark are two main defects occurring in injection molding due to high temperature employed and complex geometrical design of part.

6.1 Warpage defect

Warpage is a distortion when the shape of the molded part deviates from the required shape of the design. It is caused by the residual stresses in the molded plastic part after cooling and ejection. The residual stresses occur due to the non-uniform shrinkage of the plastic material in different parts of the part. Non-uniform shrinkage is unavoidable due to non-uniform cooling, product structure, non-uniform pressure distribution, mold design, processing conditions. Due to so many influencing factors, minimization of warpage is a very complicated task [1].

6.2 Sink mark defect

Sink mark is a depression or dimple on the part surface which is caused by the relatively larger localized shrinkage of the plastic material within the vicinity of variation of thickness in cross section. During the cooling stage, the thicker sections shrink more than the adjacent thinner sections, resulting in depressions on the front surface of the plastic part. These depressions, usually resembling grooves or dimples, are called sink marks [1].

The larger localized shrinkage occurs because of local thick-wall structure, such as ribs, bosses, etc. Both the defects warpage and sink mark are the result of non-uniform shrinkage of the plastic materials. The higher cavity surface temperature in RHCM is required for improving the temperature and pressure uniformity, alleviating molecules and additives orientations, and also reducing the part shrinkage by enhancing the effect of packing pressure, which should help reducing the warpage and sink mark [1].

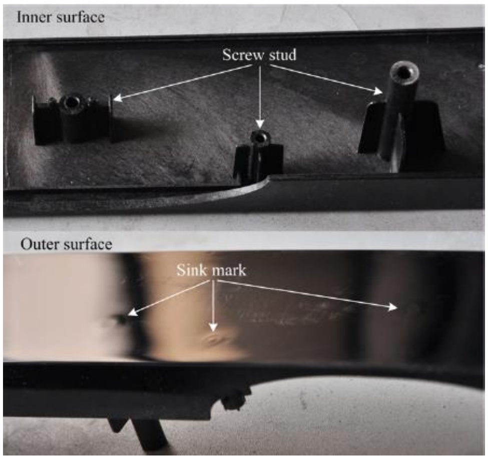

Fig -5: Sink mark on the front surface of LCD TV shell [1]

Fig -6: Warpage on the front surface of LCD TV shell [1]

7. STEPS IN DESIGN OF INJECTION MOLD

After defining the mechanical properties required and selecting the material for specific applications CAD modeling of the part commences.

7.1 Computer Aided Part Modelling

A 3D CAD model is created in CAD modeling software. There are various commercial software packages available like Catia, Creo, Unigraphics. Each software has its own advantages and shortcomings. The surface modeling capability of Catia is very unique and it is cost economical. Also it has a separate core and cavity workbench in which the core and cavity half is extracted from the created CAD model. The extracted core and cavity is used as an basic element to model the whole injection molding tool.

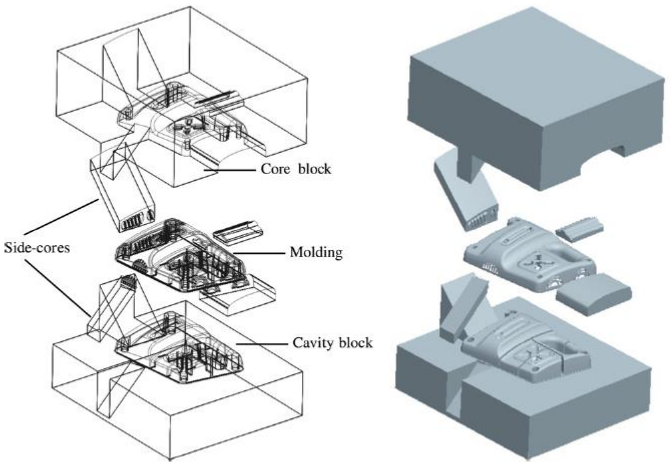

Fig -7: Extracted core and cavity half of the mold [15]

7.2 Computer Aided injection molding simulation

There are various specifically designed injection molding simulation software available. These are MOLDEX 3D, Solid Work Plastic Autodesk Moldflow insight etc. In these softwares, the created 3D model is imported and is checked for various defects so that they are prevented from coming in the manufactured product. The simulation includes ease of filling simulation, filling time simulation, simulation to check for warpage and sink marks etc. If the part design consist of rib and bosses then they are more liable to get warp and sink marks. Hence based on the simulation results the part design is modified. Once the part is final after iterations then the actual modeling of the injection mold structure design begins.

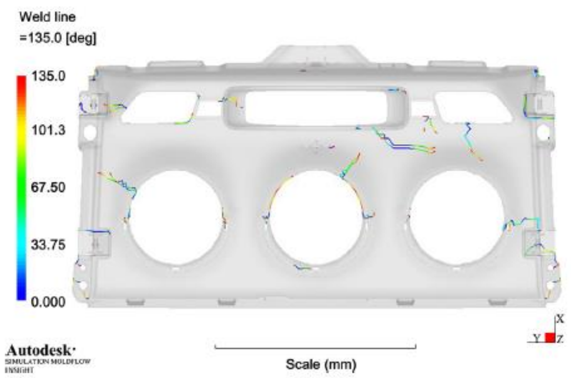

Fig -6: Simulation result for the predicted weld mark position

7.3 Modeling of injection molding tool

All parts of the mold are designed from a basic core and cavity insert that is created by extracting core and cavity. Top plate, Bottom plate, Core and cavity plate, runner and gate size and shape is incorporated in this stage in a mold. Fastening screws are selected and the material of this component is selected. The plates and other components are designed according to the manufacturer's catalogue so that they are readily available and lead time is reduced. According to the selected plastic material, molding temperature requires and strength criterion of the mold the mold base material is selected.

7.4 Transient thermal analysis of mold

Analysis of mold is performed by FEA software. Ansys APDL, Hypermesh, LSDIANA, Nastran, Abacus etc. The results obtained by Ansys APDL in cited in literature on mold analysis shows that it gives close result with the experimental one. Also Ansys APDL software is economical to the customers.

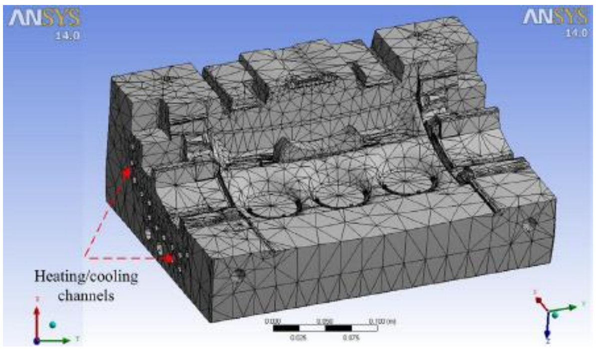

Fig -7: FEA mesh model of the cavity plate[5]

3. CONCLUSIONS

This paper presents a review on research work conducted on mould design improvement. This paper also outlines the breakthroughs in the injection molding process including rapid heating and cooling methods, conforming cooling channels, hot runner mold. There are various methods of mold heating and each method has its own advantages and disadvantages. Due to the complicated temperature control required in injection molding the pre analysis of mold is necessary to avoid the defect occurring in the final injection molded product. FEA software Ansys Workbench has a capability of performing transient thermal response of the mold in Rapid heating and cooling of mold. Also simulating the injection molding process before actual production to check for ease of fill, sink marks and warpage defect is necessary. Commercial Autodesk Moldflow Insight software is useful in simulating injection molding process.

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