Injection Molding Cycle Time Reduction for Automobile Headlamp Shell in Moldflow

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Abstract. In the injection molding cycle, the cooling time consumes more than 70% of the molding process, optimizing the molding cycle time can be done through the selection and the design of appropriate cooling system that will be able to achieve equal distribution of the temperature along the part and quickly dissipate the heat. This paper presents an analytic study on the simulation of cool + fill + pack + warp in Autodesk Moldflow 2012 for the automobile headlamp shell, the simulation is made on of four different cooling systems, after comparison of the obtained results, the Spiral Zigzag Conformal Cooling Channel (SZCC) has the lowest time required for the part to reach the ejection temperature, with 61.22 seconds, it also shows an improvement on the volumetric shrinkage with the part’s deflexion that have been reduced from 2.15 mm on the first design to 2.12 mm, making Spiral Zigzag Conformal cooling the best solution for this model.

1. Introduction

Injection molding process is among the largest mass production processing for plastic parts in the world and has an approximaiton of 32wt% of all plastic, making it second place to the extrusion process, which consumes approximately 36%wt[1]. The injection machine takes the granulate polymers, heats them until molten, then force it in the cavities through the nozzle and the sprue. After solidification and cooling, the molten granulate takes the shape of the mold before been ejected from the mold[2,3]. The injection molding process is generally achieved in three stages which are: the filling + packing stage, the cooling stage, and the ejection stage. The cooling stage is the most important among the three since it directly influences the product's quality and the productivity rate [4]. Traditionally, the cooling channels have been designed by drilling straight holes inside the mold, these straight holes also called conventional cooling channels are not uniform to the shape of the part as seen in figure 1a, because of that, the cooling process would take long and obviously the injection molding cycle time will increase while the production rate will decrease. It has been noticed that decreasing the cooling cycle could come out with other undesired defects such as excessive shrinkage and warpage on the product[5]. In order to prevent those defects, a new technic of designing cooling channels has been introduced by plastic molding researchers, it's called conformal cooling channels, and the cooling channel is designed as to conform with the contour of the part. And therefore, makes the cooling uniform in all areas along the part, figure 1b clearly illustrates the design. Conformal cooling channels have contributed in a great way in optimizing the cycle time. Wang et al. developed
the spiral conformal cooling channel[6] and they have come to a conclusion that their design made of spiral curves do not reduce the rate of the coolant flow, which is good but it mostly achieves uniform mold cooling.

Figure 1. (a) straight drilled cooling channel, (b) conformal cooling channel.

Konsulova Bakalova has used thermal simulation software to compare conformal cooling channels with circular and elliptical cross-sections, and concluded that the cooling time has been reduced and the appearance of the part has been improved for the design with conformal cooling[7]. In general, there are four different designs for conformal cooling respectively named the zigzag conformal cooling channels[8], the spiral conformal cooling channels[6,8] the scaffold conformal cooling channels[9] and the Voronoi diagram cooling channels[10]. Each design is chosen according to the need of the mold designer and mainly conditioned by the structure of the part[4].

In this work, we solve a practical problem, by running the cool + fill + pack + warp analysis in Moldflow simulation, we evaluate and compare four different designs of cooling systems of the headlamp shell for which the initial cooling system design was made with baffles cooling channels despite the variation of the thickness in the regions with ribs, the objective is to reduce the molding cycle time and to maintain or increase the quality of the part.

2. Part Design and Cooling System Design
The headlamp shell is meant to be used on the left and right front side of the car to assembly the lightening element such as bulbs, reflector, bezel and lens. The model was designed with Unigraphics NX8 (figure 2) and the parameters are 358 mm in length, 318 mm in width, 452 mm in height, the thickness varies from 2 mm in the flat areas to 3 mm in the areas with strengthening ribs.

Figure 2. 3D model of the headlamp shell.

The location of the cooling lines is critical to achieving efficient cooling, reducing the defects in the geometry and improving the productivity of the product. The cooling channels should be larger enough to have reasonably low-pressure drop but not so large that excessive flow rate is needed to obtain maximum cooling efficiency via turbulent flow[11]. The first design is the Baffle Cooling Channels (BC) with a diameter of 18 mm, the second is the Baffle Zigzag Conformal Cooling Channels (BZCC), the respective diameters are 18 for baffle and 12mm for the zigzag conformal cooling, the third design is the Baffle Spiral Conformal Cooling Channels (BSCC) with the same dimensions as in the case of (BZCC), the last one is the Spiral Zigzag Conformal Cooling Channels (SZCC) with the diameter of 12 mm on both sides of the mold, Figure 3 shows the design of different cooling systems.
3. Moldflow Analysis

Moldflow has three different types of meshing known as the midplane, the dual domain and the 3D mesh, before starting the analysis, we must understand difference and choose the one that will be suitable for the model we intend to analyse[12]. For this analysis, the 3D mesh type will be used because our model doesn’t only have complex geometry but it also has thickness variance from 2 to 3mm.

3.1. Material selection

The headlamp shell except vibrations, does not sustain to any kind of stress or choc during its use since it is fixed on the car, the thermoplastic material that is going is the polypropylene (pp) because it’s the cheapest among thermoplastic material and can resist to the vibration caused by the engine of the car. The model weights 534g and the thermal and mechanical properties of pp are listed in the Table 1.

| Property                        | Value     |
|---------------------------------|-----------|
| Density (g/cm³)                 | 0.9       |
| Melt temperature (°C)           | 240       |
| Thermal conductivity (10⁻⁴ cal/sec cm°C) | 2.8       |
| Heat capacity (cal/g°C)         | 0.9       |

3.2. Gating system design

The gate is known as the last passageway where the molten material coming out of the barrel of
injection machine should go through to fill the cavities, in order to obtain optimum filling during the process, in this case, the edge gate is the appropriate one due to its capacity of providing wide molding window for robust model, it also insure low shear rates. We choose two injection points located at the edge of the model in the hole where the bulb is supposed to be mounted, it is a cold gate and the geometry is rectangular with 8mm width and 3mm height.

3.3. Runner system design
For the runner system, we have previously compared the half-circular and the trapezoidal cold runner during the design and it has been noticed that the trapezoidal cold runner is best for this analysis since the molten plastic flows quickly, and the turbulent flow that has a tendency to increase stresses and sink marks is avoided. The dimensions of the runner are: top width 12mm, bottom width 8mm, and the height is 8mm.

3.4. Sprue design
We choose hot sprue for this model because, from the position where the runner is located to the surface of the fixed plate, the distance is more than 800 mm making it difficult to use cold sprue because the temperature of the molten material would drop before reaching the runner and the mold will not be completely filled.

4. Results and discussions
The time to reach the ejection temperature representing the overall time needed for the part to be filled cooled and ejected from the mold and the deflection will be discussed here. The results from figure 4 (a) shows that the time to reach the ejection temperature for the Baffle Cooling Channels (BC) is 74.7 seconds. Meanwhile the use of the Baffle Zigzag Conformal Cooling Channels (BZCC) decreases the time to reach the ejection temperature to 71.84 seconds as shown by figure 4 (b). By comparing these two cases, the BZCC provides 3.89% faster Cooling than the BC. The simulation results also show that Baffle Spiral Conformal Cooling Channels (BSCC), figure 4 (c) requires 65.75 seconds to reach the ejection temperature, whereas the Spiral Zigzag Conformal cooling channel (SZCC), figure 4 (d) only needs 61.22 seconds to reach ejection temperature. From these results, it's well known that the BC has to lowest performance in terms of the cooling system and the SZCC has the highest performance among the four cases and is 18.11% faster compared to the BC.

The second parameter of comparison is the deflection, which is conditioned by the volumetric shrinkage and temperature variance during the cooling phase, the cooling lines should be designed as making the temperature of the walls of the mold as uniform as possible in order to reduce the deflection along the axis[13]. Figure 5 presents the simulation results of the deflection for which BC is 2.15 mm, whereas BZCC, BSCC and SZCC respectively show 2.77 mm, 2.65 mm and 2.12 mm. Thus, the SZCC has the minimum deflection among the three cases. The simulation results obtained from Autodesk Moldflow Advisor 2012 are compiled in table 2. From the values obtained in figures 6 and 7 we conclude that SZCC is the most efficient cooling system design for our part. It has the shortest time to reach the ejection temperature, it doesn't have the lowest percentage of volumetric shrinkage compared to the BZCC but has the minimum deflection dimension, which makes it the optimum cooling design for this model.

Table 2. Summary of the results obtained from the analysis.

| Cooling channel | Time to reach ejection Temperature seconds | Volumetric Shrinkage % | Deflection mm |
|-----------------|-------------------------------------------|------------------------|---------------|
| BC              | 74.75                                     | 17.73                  | 2.15          |
| BZCC            | 71.84                                     | 17.71                  | 2.77          |
| BSCC            | 65.75                                     | 18.57                  | 2.67          |
Figure 4. Time to reach ejection temperature with (a) Baffle Cooling Channels (BC); (b) Baffle Zigzag Conformal Cooling Channels (BZCC); (c) Baffle Spiral Conformal Cooling Channels (BSCC); (d) Spiral Zigzag Conformal Cooling Channels (SZCC).

Figure 5. Deflection with (a) Baffle Cooling Channels (BC); (b) Baffle Zigzag Conformal Cooling Channels (BZCC); (c) Baffle Spiral Conformal Cooling Channels (BSCC); (d) Spiral Zigzag Conformal Cooling Channels (SZCC).
5. Conclusion
This study introduces the simulation analysis in Autodesk Moldflow of four different cooling channels respectively named, Baffle Cooling Channels (BC), Baffle Zigzag Conformal Cooling Channels (BZCC), Baffle Spiral Conformal cooling channel (BSCC) and the Spiral Zigzag Conformal Cooling Channels (SZCC), all designed for the cooling of the automobile headlamp shell. The cool + fill + pack + warp analysis was performed in Moldflow 2012. The time to reach ejection temperature that was previously 74.7s for BC has been gradually improved to 61.2s for the SZCC, the volumetric shrinkage and the part deflection have not been improved as much as expected but still the values are in the range of acceptance because the automobile headlamp shell does not require high dimension accuracy and high aesthetic due to its use condition. our main goal was then to reduce the molding cycle time and if possible, decrease the volumetric shrinkage and improve the dimension accuracy of the model, but nevertheless, the simulation shows that with the Spiral and Zigzag conformal cooling channels the production rate has been improved by 18.12%. The SZCC design, it’s then the appropriate solution for this study. However, manufacturing the conformal cooling channels could be expensive and challenging since it requires some special tooling and technic of non-conventional machining. But nevertheless, conformal cooling designs can help make great profit and time saving during mass production cycle.

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References
[1] Rosato D V and Rosato M 2000 Injection Molding Handbook. SPB Publishing the Springer p 246
[2] Kazmer, David O 2016 Injection mold design engineering. Carl Hanser Verlag GmbH Co KG
[3] Isayev, Avraam. 1991 Modeling of polymer processing: recent developments 312
[4] Park, Hong-Seok, and Xuan-Phuong Dang 2017 Development of a smart plastic injection mold with conformal cooling channels J. Procedia Manufacturing chapter 10 48-59
[5] Shoemaker J 2006 Moldflow Design Guide: A Resource for plastics Engineers, Hanser Publishers vol 10
[6] Wang Y, Yu K M, Wang C C L 2015 Spiral and conformal cooling in plastic injection molding J Computer-Aided Design chapter 63 1-11
[7] Dimla E 2015 Design Considerations of Conformal Cooling Channels in Injection Molding Tools Design J. Thermal Engineering chapter 1 627-635
[8] Park H S, Pham N H 2009 Design of conformal cooling channels for an automotive part J Automotive Technology chapter 10 87-93
[9] Au K M and Yu K M 2007 A scaffolding architecture for conformal cooling design in rapid plastic injection molding *J. Advanced Manufacturing Technology* chap 34 496-515

[10] Wang Y, Yu K M, Wang C C L, Zhang Y 2011 Automatic design of conformal cooling circuits for rapid tooling *J. Computer Aided Design* chapter 43 1001-1010

[11] Khan, Muhammad, Kamran Afaq S, Nizar Ullah Khan, and Saboor Ahmad 2014 Cycle time reduction in injection molding process by selection of robust cooling channel design *J. ISRN Mechanical Engineering* vol 2014 1-8

[12] Oliveira, André Antunes 2016 Structural Analysis of Components Obtained by the Injection Molding Process

[13] Wang Y, Yan Z and Shan X 2018 Optimization of Process Parameters for Vertical-Faced Polypropylene Bottle Injection Molding *J. Advances in Materials Science and Engineering* vol 2018 1-9