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New Design Feature of Mold in Injection Molding For Scrap Reduction
Mehdi Moayyedian, Kazem Abhary, Romeo Marian

Abstract
This paper presents a new cross sectional shape of runner system in the injection molding. The aim of the new geometry is to reduce the scrap and cycle time and also the easier ejection of runner system from mold tools. Short shot defect in the plastic part during the injection molding process is analyzed by SolidWorks Plastic to validate the new proposed geometry. Runner system with elliptical cross section is proposed with different ratio for two circular flat plates with thickness of 1mm. Finite Element Method (FEM) is employed in SolidWorks Plastic for simulation of injected part. Filling time, melt temperature, mold temperature, pressure holding time, and pure cooling time are chosen as input for the injection machine. The contribution of this study is the design of new geometry of cold runner system for reduction in scrap and cycle time and also easier ejection of runner system in injection molding. This study outcomes show no short shot defect with the new geometry. Also, it was shown the significant reduction in scarp and cooling time. 25% and 2.5% reduction in scrap and cooling time were achieved compared to round cross section, respectively. Reduction in contact surface of runner system with mold walls improved the easier ejection of runner system out of the cavity as well.

Keywords: Injection molding process, Mold design, Runner geometry, Short shot defect

1. Introduction

The past century has observed the rapid increase of plastics and their proliferation into all markets. According to world consumption of raw materials by weight, plastic is the highest in comparison with other old materials such as aluminum, steel, rubber, copper, and zinc, resulting from its properties and lower production cost [1, 2]. Injection
molding is one of the most significant processes for manufacturing of plastic products and approximately one-third of all plastics are converted into parts using injection molding processes [3]. The application of injection molding processes is increasing significantly in many industries like packaging, aerospace and aviation, building and construction, automotive parts and household articles [1, 3, 4] . The final quality of injected parts in injection molding depends on the material characteristics, the mold design and the process conditions [4-6]. There are three fundamental operations in injection molding: First, the Plastic granules will be converted into a melt. Then, the molten plastic will be injected into the mold cavity or cavities under pressure via sprue, runner and gate systems and finally, the mold tools will be opened to eject the part from the cavities [1, 7, 8].

One of the parameters which will assess the quality of injected part is Runner system. Runner system is a connection line between sprue and gates. The main purpose of runner system is to transfer the molten plastic from sprue to gates. In cold runner system, the main source of scrap is the scrap from runner and gate system after de-gating. Hence, different rules will be evaluated for runner system design to demonstrate the significance of runner systems in the injection molding such as (a) smaller runner size to minimize the scrap; (b) easy ejection from mold tools and removal from molded parts; (c) filling the cavities quickly with minimum sink marks and weld lines [9-12]. Three factors which will be considered as fundamental parameters for runner system design are cross sectional shape of runner, the diameter and the cavity layout [9]. There are 7 types of cross sectional shapes for runner systems for different applications [9, 10, 13]. Finally, depending on the requirements, different types of runner cross sections can be recommended [14].

The contribution of this paper after the consideration of existing different cross sectional shapes is to define the elliptical geometry for runner system as an effective cross sectional shape. Our fundamental objectives, for designing and using the elliptical cross sectional shape defined in this paper, are basically to have smaller runner size to minimize the scrap, to reduce the total cycle time of injection and to eject the part easily from the mold tools. Further than our anticipation, remarkable phenomena was detected which are related to process parameters and new geometry of runner system that will be discussed in another paper.

For this paper, the design criteria of elliptical or cross sectional shape for runner system will be introduced, and a comparison between round shape and semi-elliptical shape of runner system will be conducted. To the authors best of knowledge, many attempts have been taken in injection molding for process parameters and material characteristics, however for injection system which includes runner, gate, and sprue, there are a few publications, but there is no reference to analyze and simulate the elliptical cross sectional shape of runner system. In this paper, the structure of runner system is simply introduced and advantages of elliptical runner will be evaluated. Then, the injected part with runner and gate system is designed via SolidWorks. For accurate result of simulation, FEM is considered via SolidWorks Plastic.

2. Cross sectional shape of runner system

The main purpose of runner system is to transfer the molten plastic from sprue to all cavities via gate. There are different cross sectional shapes of runner systems and each of them have different applications [13]. A designer should evaluate different factors for selecting the right shape of runner system for a specific product. The most popular shape of runner system which has the highest efficiency for two plates mold tools is round shape. For Three-plate tools, the trapezoidal and modified trapezoidal are the best options if the runner is to be manufactured only in one half of the mold plates, but still they are not acceptable because the gate cannot be positioned in line with the central flow stream [10]. Ejecting a runner system from the cavity with rectangular, square, and polygon shape is challenging. It has resulted from the existing corners of different cross sections. Pressure drop which leads to incomplete filling of cavities and high level of heat transfer to the mold walls will occur if a designer does not determine the appropriate cross sectional shape of runner system and their dimensions[9, 13, 15]. Hence, different cross-sections of runner system can be considered to regulate the flow rate of molten plastic. Finally, the shape and the length of the channel are significant to have an optimal flow and therefore the best product with less defects [16].

3. Runner system with elliptical cross sectional shape

In injection molding, the most common cross section shape for runner system is round shape. In selecting the round shape for specific part design, three main elements which should be evaluated are (a) smaller runner size to
minimize the scrap; (b) easier ejection from mold tools; (c) filling the cavity quickly with minimum sink marks, weld lines and no short shot. [9-11]. Hence, consideration of new geometry for runner system to minimize the scrap, to be positioned in line with the central flow stream of gate, fill the cavity or cavities properly, and eject the part easily from mold tools is the goal of this paper. Finally, elliptical cross sectional shape is taken into account for runner system. In order to yield an injection-molded part with minimal plastic defects, an accurate comparison between round and elliptical cross sectional shape of runner system is necessary.

To demonstrate the significance of elliptical cross sectional shape of runner and the reason it is selected as a significant issue in mold design, evaluation of other geometries of runner system is necessary. The best geometry of cross section to compare the circle and ellipse is rectangle and square. Rectangle is a kind of square with different width. According to different applications, rectangular runner system with different ratios of width will be chosen. One of the advantages of rectangular shape in comparison with square is in minimizing the scrap of runner system, and easier ejection from mold tools, but pressure drop is one of the disadvantages which will be happen by decreasing the width of the square [13].

The comparison between circle and ellipse has the same structure with square and rectangle. \( D \) is the diameter of circle, \( a \) is major axis length, and \( b \) is minor axis length of ellipse. Major axis length is fixed and the minor axis length has different rates which depend on different industrial applications. Although for reducing the scrap, easier ejection of part out of cavity, and reduction in cycle time it is better to reduce the length of the minor axis, it depends to the part design. Hence, different ratio of \( b \) depends on many factors of part design such as size and thickness. Reduction in scrap, easier ejection of part out of cavity, cycle time reduction, and central flow stream of gate with runner system are the advantages of elliptical cross sectional shape in comparison with round shape.

4. Simulation

After designing two circular parts as two samples for this application, the next step is to simulate the part using SolidWorks Plastic. For simulation part, defining the injection system is necessary. Hence, designing the sprue, runner with \( b=0.7a \) and gate system is considered as shown in Fig. 1a. To make sure that the analysis results are accurate, Finite Element Analysis (FEM) will play a significant role in simulation as shown in Fig. 1b. According to the geometry of samples, the triangle shape of surface meshes for finite element analysis will be chosen. The selected material for this simulation is polypropylene (P.P). Different sizes were evaluated for the surface mesh and finally surface mesh size of 1mm are chosen for injected part but for the injection system which include sprue, runner and gate, smaller sizes were considered, resulting from the sensitivity of injection system as a critical area of this simulation. Hence, surface mesh size of 0.3mm for sprue and runner and 0.2mm for gate are selected for both elliptical and round cross sectional shape of runner in SolidWorks Plastic. The runner and gate length in total is 28mm for two circular parts with diameter of 100mm. Also, the sprue has 60 mm length with draft angle 1.5°.

![Fig.1 (a) Finalized part with sprue, runner and gate system; (b) Finite element analysis of finalized part](image)

The next step is to define the process parameters. Based on the selected materials and injection machine, filling time is 0.59 sec, melt temperature is 230°C, mold temperature is 50°C, pressure holding time is 2.04 sec, and pure cooling time is 3.9 sec. The geometry and size of the injection system are evaluated as significant criteria whose effect the operation cycle time, cooling time, different defects such as sink mark and short shot. The main factors to check if the new runner system is acceptable in terms of new geometry and size, are ease of fill, filling time analysis, sink mark analysis, and injection pressure at the end of injection. As shown in Fig. 2a, ease of fill for elliptical cross section is at green area which is in the most acceptable level. Another common defect which is related to gate and runner dimension and geometry is sink marks. A sink mark is the depression on the surface of
injection molded plastic which occur during the cooling process [17]. As shown in Fig. 2b, there is no sink marks for the injected part except for the sprue which is not in a critical region and also the surface quality of sprue and runner are not significant because they consider as scrap at the end of the injection. Therefore the surface quality of injected part for both round and elliptical cross section is the same.

![Fig. 2 (a) Easy filling of injected part with elliptical cross; (b) Sinks marks simulation for elliptical cross sectional shape of runner system](image)

One of the common defects in injection molding is short shot. Short shot will occur far from the gate if there are long flow distances or on thin walls [17]. According to the simulation result, this part can be successfully filled and even the filling time for elliptical cross sectional shape of runner is lower than that of for the round cross sectional shape as shown in Fig. 3.

![Fig. 3 Filling time for (a) Elliptical cross section and (b) Round cross section](image)

Another parameter to make sure that there is no short shot for the injected part is to evaluate the flow front central temperature which represents the flow front temperature at every region of injected part. SolidWorks Plastic recently added this module which is suitable for short shot analysis. As shown in Fig. 4, based on SolidWorks Plastic simulation, the flow front central temperature in every region of the injected part is 230.15°C for both elliptical cross sectional shape of runner and round cross sectional shape. It means that the possibility of short shot in the cavities is low for both geometries.

![Fig. 4 Flow front central temperature for (a) Elliptical cross section and (b) Round cross section](image)

One of the most significant parameter which is necessary to evaluate for determination of the right size of runner and gate system is the maximum inlet pressure. This part can be successfully filled with injection pressure 42.1 MPa. The injection pressure is less than 66% of the maximum injection pressure limit which is satisfactory as shown in Fig. 5. The injection pressure for round cross section is 39.655 MPa which is close to elliptical cross
section.

Fig. 5 Injection pressure for both round and elliptical cross section shape of runner system

5. Conclusion

The main reason of scrap in cold runner system of injection molding is the feeding system which consists of sprue, runner and gate system. Runner has different cross sections for different applications. In this study, new geometry of runner system with elliptical cross section in comparison with round cross section was successfully developed for injecting two circular plates with thickness 1mm. filling time, melt temperature; mold temperature; pressure holding time and pure cooling time are evaluated as process parameters.

Elliptical cross section in comparison with round cross section which has the highest efficiency among current geometries of cross section has 25% reduction in scrap and 2.5% in cooling time for injected parts. The result from simulation demonstrates that the elliptical cross sectional shape of runner is an effective geometry to reduce the scrap and total cycle time and also the easy ejection of molded part out of the cavity. It demonstrates the robustness of new geometry of runner system. Further than our anticipation, remarkable phenomena was detected which is related to process parameters and new geometry of runner system that will be discussed in another paper. The experimental set up will be conducted to justify the simulation result.

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