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Analysis of the Effectiveness of Mold Runner Geometries on Plastic Flow in Plastic Injection Molding Method

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Abstract

Plastics play an important role as one of the key components of modern industry. The diversity and affordability of plastic materials enable them to find a wide range of uses in industry. The plastics industry has a wide range of products used in various fields such as automotive, packaging, electronics, medical and construction industries. There are many methods used in the production of plastic parts; injection molding, extrusion, blow molding, rotational molding and rotational molding, pressing and thermoforming. The most widely used of these methods is injection molding. Injection molding, one of the plastic injection methods, enables raw materials to be transformed into the desired shape with various production techniques. This method, which enables the production of plastic parts in a single process, accelerates product development processes by providing rapid prototyping for parts with complex geometries. At the same time, the use of recyclable materials that support environmental sustainability in industrial applications contributes to the environmental friendliness of the process. In this study, parts with four different runner geometries (diameter, quadrilateral, rectangular and hexagonal) to be produced by plastic injection molding method were designed with the help of CAD (Computer Aided Design) program. The runner geometry optimization of the designed parts was simulated with the help of CAE (Computer Aided Engineering) program and the changes in the runner pressure, filling time, melt pre-times and injection volume values were analyzed. The results of the analysis were compared with the mathematical results of the runner efficiency calculations in the literature. In both analyses, it was concluded that the optimum process conditions were obtained in the runner with rectangular geometry. This research provides important information on increasing the efficiency of the plastic injection molding process depending on the runner design.

Keywords: *Plastic Injection Molding, Flow Analysis, Runner, Runner Geometry*

1. Introduction

In industry, plastic materials are used in many areas such as automotive, medical devices and consumer products. Due to their lightweight, durable, flexible and economical properties, increasing energy efficiency by reducing production costs makes a great contribution to the global economy. The most common method used in the production of plastic parts is plastic injection molding.

Plastic injection molding method is based on the principle of melting the plastic material in granular form and injecting it into a mold and solidifying the material with the desired temperature and pressure within a certain cooling time and removing it from the mold and forming the desired shape [3].

With the increasing use of plastic materials, the plastic injection molding process is becoming more and more widespread. Accordingly, studies on the chemical structure and mechanical properties of the injection material, applied heat treatments, determination of the type, position and geometry of the runner used, and mold sizing are continuing to increase. Determining the most appropriate process parameters in plastic injection molding is extremely important in terms of production speed, product quality and cost [4, 8].

In order to obtain a quality part in plastic injection molding, proper mold design as well as process parameters are extremely important. However, since the cavity inside the mold expresses the part shape, the solid model of the part is taken into account in mold design. In other words, mold design and part model are intertwined. Therefore, for a conscious mold design, the characteristics of the injection molding machine, mold construction, number of cavities in the mold, gating system, nozzle design, heating or cooling

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condition of the mold, part ejection system, mold material, surface quality and gas outlet system should be known very well [1].

The runner system is a system of channels that distributes the molten resin from the nozzle of the injection molding machine to the cavities in the mold. As it passes through the runner system, the resin encounters a number of hydraulic resistances that cause the pressure to drop. Obstacles such as constrictions in the runner, corners and the quality of the runner surface cause the pressure to drop more. For this reason, the correct design of the runner system is of great importance in mold construction. The most appropriate measure to reduce hydraulic resistances is to keep the runner bushing and runners as short as possible. In addition, in the correct design of gating systems, attention should be paid to issues such as proper distribution of molten resin into the cavities, balanced filling of cavities and openings in multi-cavity systems, minimum scrap, easy removal of the part, minimum energy use and reduction of cycle time [1, 7, 9].

The designs of the parts produced by plastic injection are made using CAD programs. Thanks to CAD programs, the designs of parts with complex geometries can be realized more precisely and quickly. The design of conventional and conformal cooling channels and injection simulations and flow analyses to prove the accuracy of this design are also carried out by CAE programs in computer environment. Flow analysis is of great importance in many aspects such as improving the quality of the product, shortening the cycle time, improving the mold design in the injection molding method [5].

There are many studies related to optimizing the plastic injection molding process. Plastic flow simulation, design of experiments methods, artificial intelligence applications are frequently used tools. By using these tools alone, it is highly unlikely that many factors affecting the process can be improved at the same time and the desired optimum result can be achieved. On the other hand, a certain systematization is needed to utilize all these tools correctly. The use of these tools in accordance with a designed design methodology will enable process optimization to be much more successful [6].

2. Purpose

In this study, it is aimed to investigate the changes in filling time, injection volume, runner pressure, melt pre-timing parameters due to different runner geometries and to determine the most suitable runner design by using analysis programs for products made of PA66 GF30 material. This study provides an important contribution on how runner geometries can be optimized to achieve the best performance.

3. Scope

This study was supported experimentally by Demircioglu Group, R&D Center. CAD and CAE programs were used for the experiments.

4. Materials and Methods

4.1. Material

PA66 GF30 material was used in the plastic injection method performed within the scope of the analysis study. The properties of the material used are given in Table 1.

Table 1: PA66 GF30 material properties

Material Specifications	Value
Bending Stress (MPa)	157,5
Flexural Elongation (%)	4,1
Density (g/cm3)	1,368
Tensile Stress (MPa)	130,1
Yield Stress (MPa)	116,9
Elongation at Yield Point (%)	1,7
Elongation at Break (%)	2,4
Modulus of Elasticity (MPa)	8782
Melting Temperature (°C)	255

4.2. Process Parameters

After the meshing process was performed on the designed part, finite element analysis was performed at the optimum process parameters given in Table 2. The analysis data are analyzed and shared in the findings section.

Table 2: Optimum Process Parameters

Process Name	Value
Cycle Time (sec)	69,69
Filling Time (sec)	0,69
Ironing Time (sec)	4
Cooling Time (sec)	60
Mold Opening Time (sec)	5
Maximum Injection Pressure (MPa)	143
Melt Temperature (°C)	280-300
Mold Temperature (°C)	60-100
Injection Temperature (°C)	160
Air Temperature (°C)	25

4.3. Runner Design

In the study, the runner position and runner geometries were determined and placed on the designed product with the help of CAD program. Table 3 shows the geometries of diameter, rectangular, rectangular, rectangular, hexagonal runner geometries designed.

5. Findings

Products with four different runner geometries were simulated with the help of CAE program. The results are compared with the results obtained from the runner efficiency calculations depending on the runner geometry given in Table 4.

Table 3: Runner Geometries (Çelikkol, 2008)

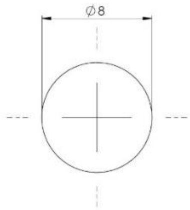
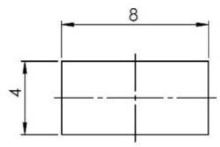
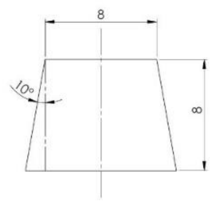
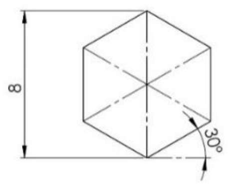
Type of Runner	Runner Geometry
Diameter Runner	
Rectangle Runner	
Quadrilateral Runner	
Hexagonal Runner	

Table 4. Runner Efficiency Calculation According to Runner Geometry [2]

Runner Geometry	Runner Efficiency Calculator
Diameter Runner	$\frac{alan}{çevre} = \frac{{}^{1}/_{4}\pi D^2}{\pi D}$ = 0.25D
Rectangle Runner	$\frac{alan}{çevre} = \frac{D^2(1+tan10°)}{2D(1+cos10°)^{-1}+tan10°}$ =0.268 D
Quadrilateral Runner	$\frac{alan}{çevre} = \frac{D}{8\ tan30°}$ =0.216 D
Hexagonal Runner	$\frac{alan}{çevre} = \frac{D^2}{6D}$ =0.167 D

As a result of the calculations, the diameter runner efficiency value was obtained as 2, the quadrilateral runner efficiency value as 2.14, the hexagonal runner efficiency value as 1.73, and the rectangular runner efficiency value as 1.33. The runner efficiency ensures that the molten plastic is effectively and efficiently transferred to the mold cavity and thus the part quality is increased. For this reason, it is preferred that the runner efficiency value is high. In the calculations, the highest runner efficiency value was obtained in the quadrilateral runner geometry. This result is consistent with the findings obtained in a similar study conducted by Çelikol [2].

Figure 1, Figure 2, Figure 3 and Figure 4 shows the filling- runner pressure graph obtained as a result of the analysis of four different runner geometries. The diameter has a filling time of 0.723 seconds and a maximum pressure of 126.2 MPa. The runner with quadrilateral geometry has a filling time of 0.653 seconds and a maximum pressure of 77.518 MPa. The six-way geometry has a filling time of 0.78 seconds and a maximum pressure of 135.107 MPa. The runner with rectangular geometry has a filling time of 0.721 seconds and a maximum pressure of 52.334 MPa. It is seen that the runner with rectangular geometry has the lowest pressure value and the shortest filling time compared to other geometries

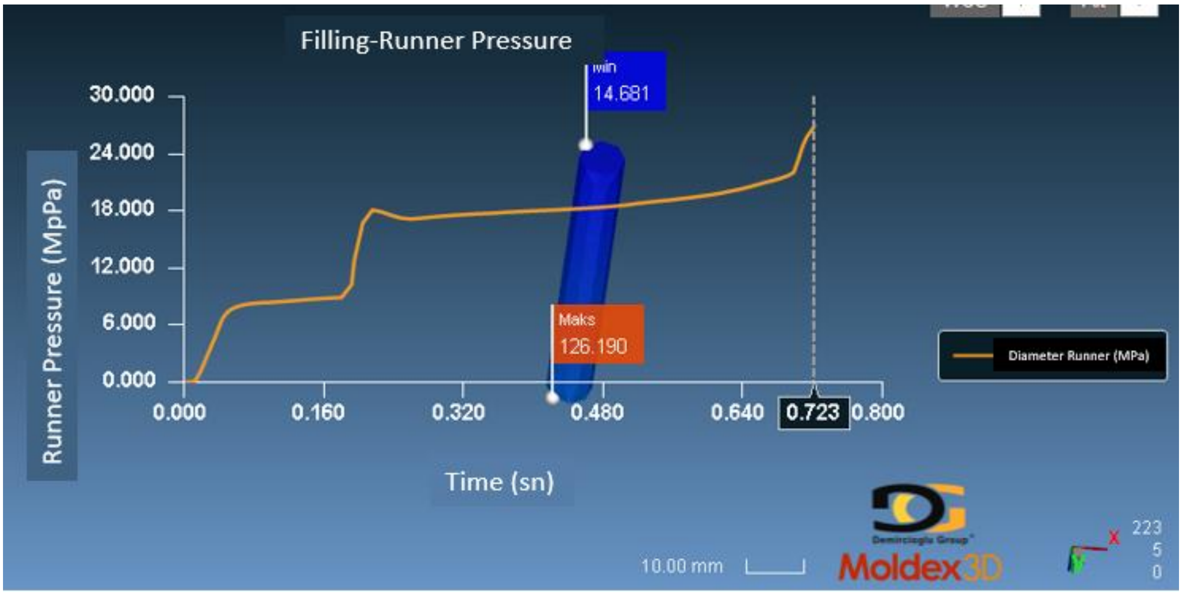


Figure 1. Filling-diameter runner pressure graph

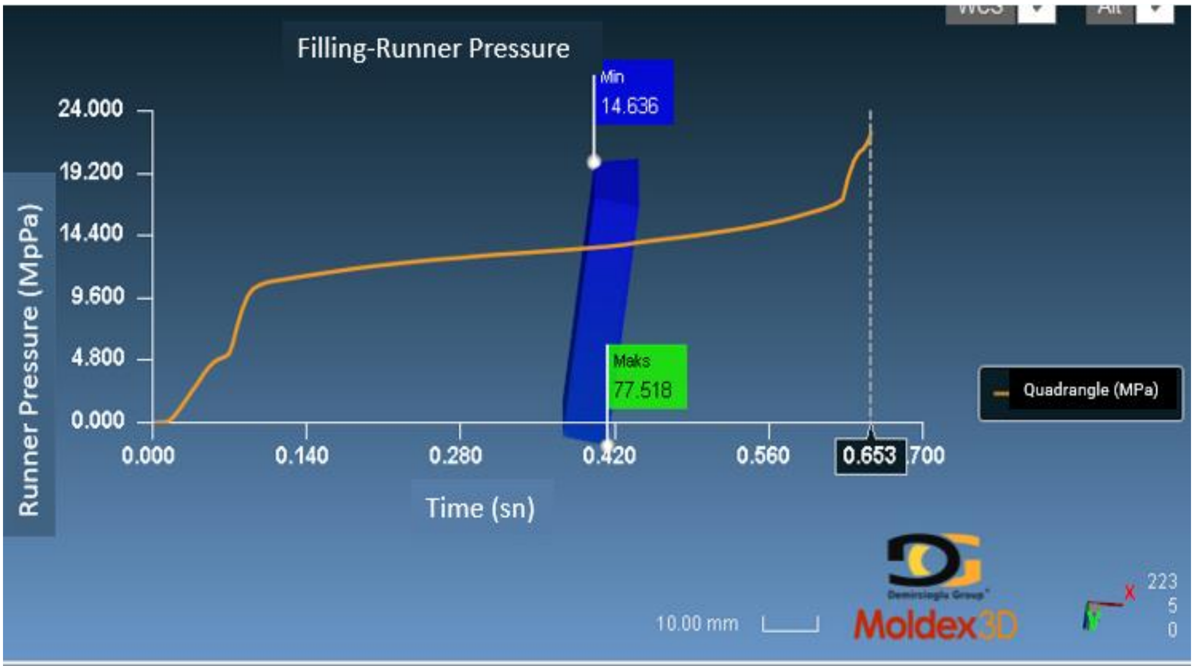


Figure 2. Filling-quadrilateral runner pressure graph

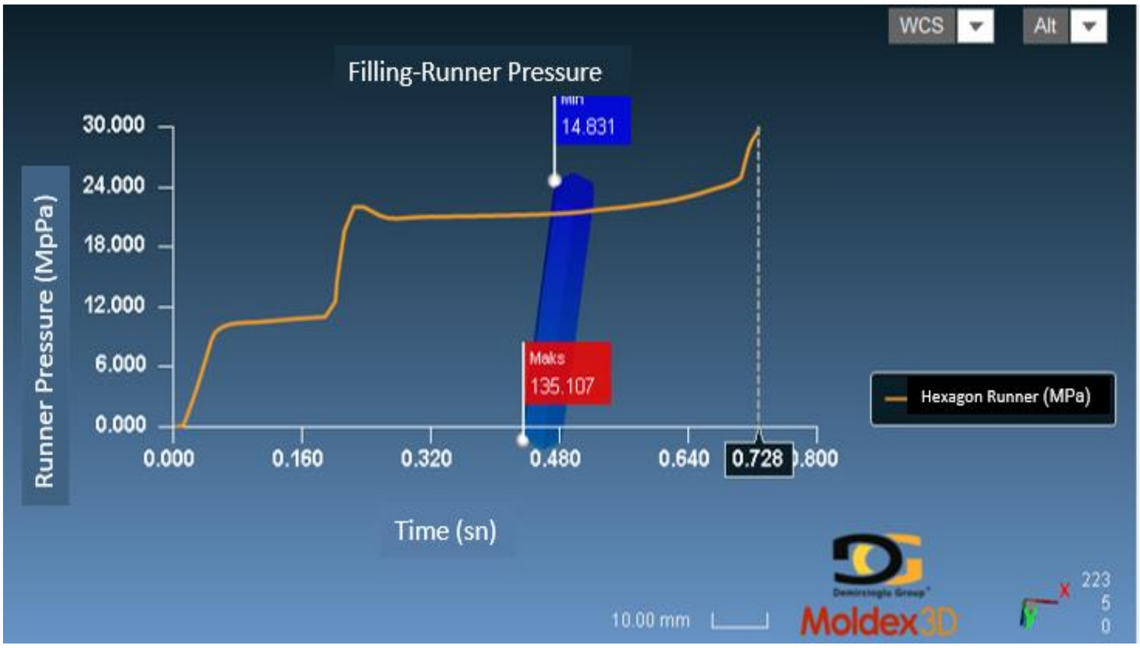


Figure 3: Filling - hexagon runner pressure graph

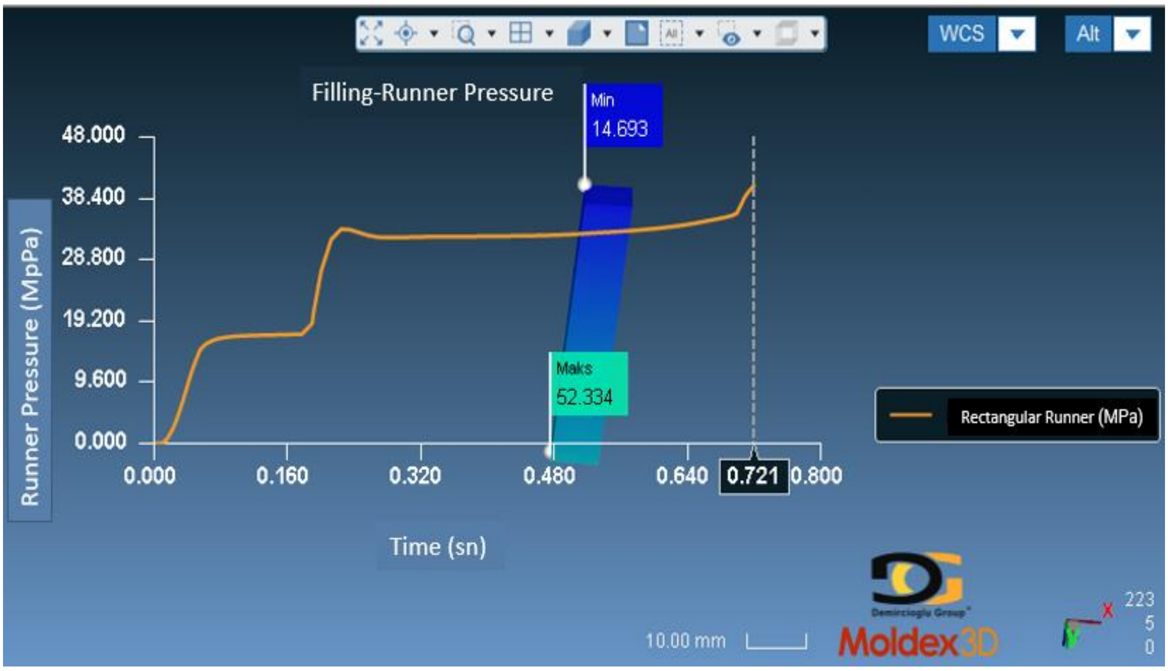


Figure 4: Filling rectangular runner pressure graph

Figure 5 shows the filling time change graph according to the runner geometry and Figure 6 shows the pressure change graph according to the runner geometry. When the filling analysis was examined, it was determined that the runner with rectangular geometry performed the filling process in the shortest time with 0.62206 seconds, while the runner with diameter geometry performed the filling process in the longest time with 0.69425 seconds.

When the pressure values are analyzed, the lowest pressure was realized in the rectangular runner geometry with a value of 22,45 MPa and the highest pressure was realized in the hexagonal runner geometry with a value of 40,65 MPa. When the runner pressure is increased, the speed at which the molten plastic fills the mold cavity also increases, thus shortening the filling time. This results in a faster production process, but at the same time there is a risk that the high pressure can cause mold wear and potential internal stresses. When the runner pressure is reduced, the speed at which the molten plastic fills the mold cavity decreases and the filling time increases. This can lead to less internal stress and a smoother surface finish. However, longer filling times can reduce production efficiency and may result in some complex parts not being filled completely. The results obtained in this context are consistent with the results of the study conducted by Pınar (2010).

Figure 7 shows the pre-melt time graph according to the runner geometry. Pre-melt time is the time it takes for the raw material granules to melt into a homogeneous melt. When the graph values are analyzed, the quadrilateral runner was found to be the runner geometry with the fastest pre-melt time with a value of 0.65 seconds.

Figure 8 shows the injection volume plot according to the runner geometry. Injection volume refers to the amount of molten plastic injected to fill the mold cavity. The injection volume depends on the size and shape of the part to be produced. When the graphical values are analyzed, the rectangular runner was obtained as the runner geometry with the highest injection volume with a value of 289.38 cc. The fact that the pre-melt time is low and the injection volume is high in the use of the runner in quadrilateral geometry shows that larger volumes of plastic can be melted in a shorter time and process efficiency can be achieved.

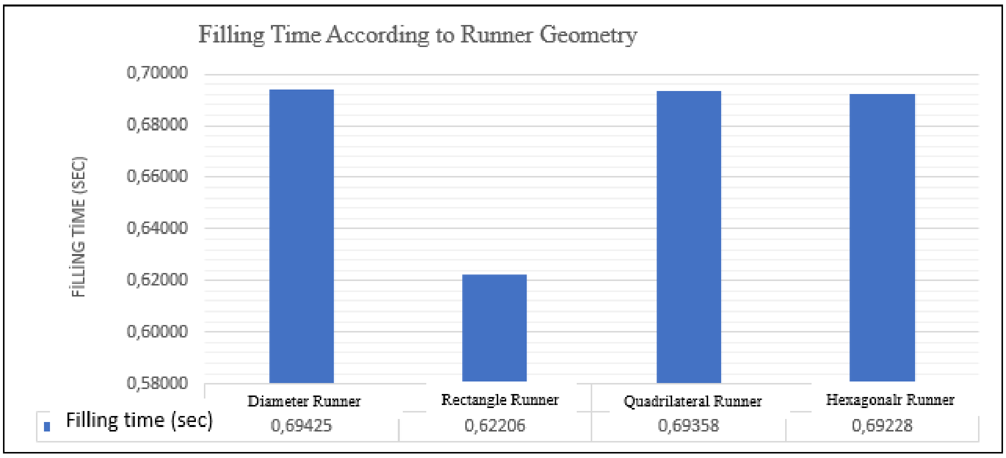


Figure 5: Filling time graph according to runner geometry

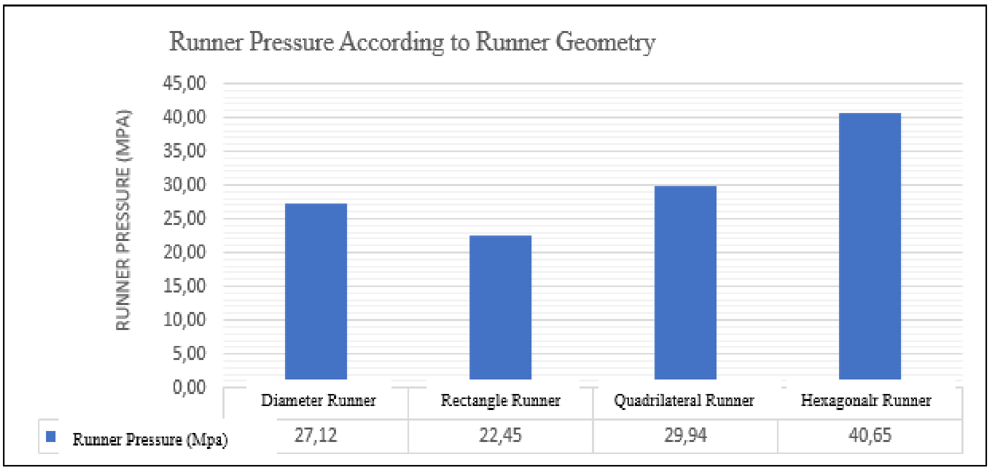


Figure 6: Pressure graph according to runner geometry

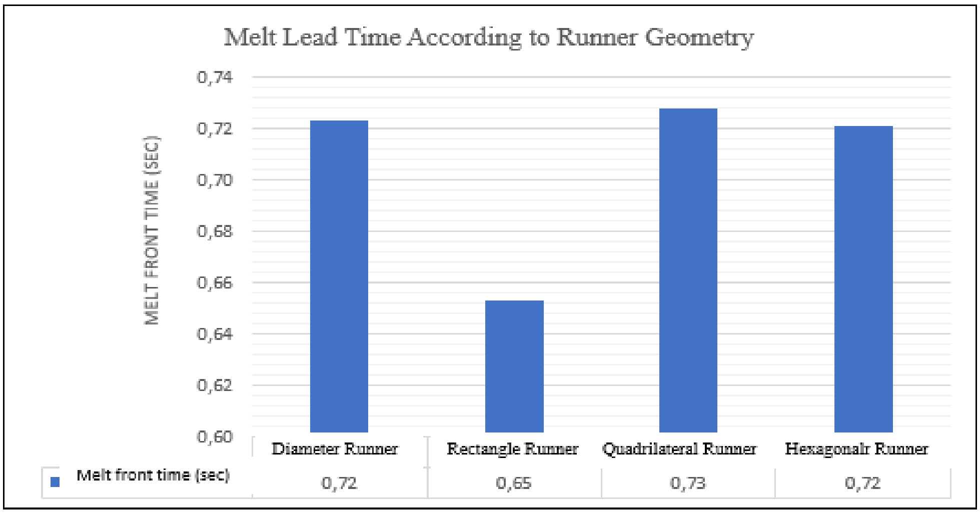


Figure 7. Pre-melt time plot according to runner geometry

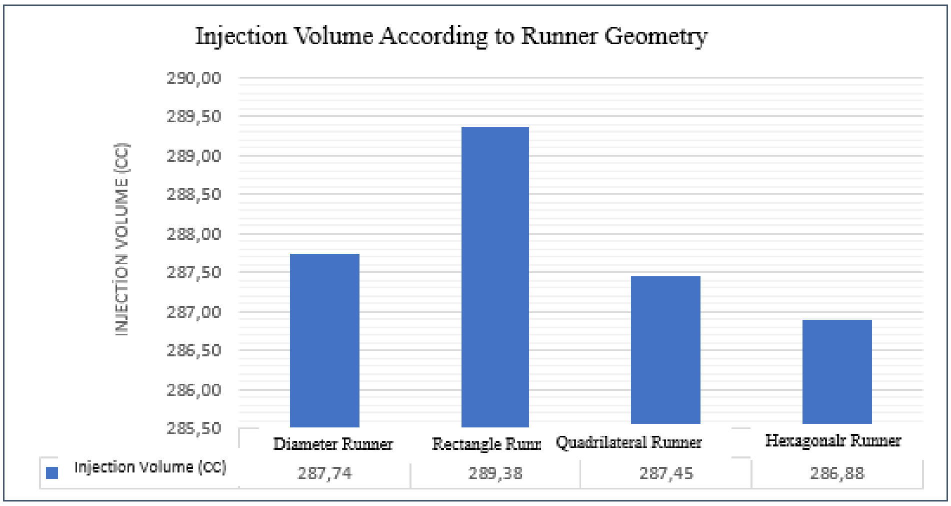


Figure 8. Injection volume plot according to runner geometry

6. Conclusion

In this study, the optimum conditions for the products to be produced by plastic injection method were analyzed with the help of CAE program. As a result of the analysis;

- Due to the high cost of trial and error method in process optimization, the use of engineering tools has become inevitable. In this context, simulation and numerical methods have provided more economical and effective solutions.

- It is possible to optimize only the process parameters without making any changes in the mold and product design to eliminate quality problems. This approach has avoided extra price differences in mold cost and hence part cost. This reduced the need to allocate additional resources for quality improvements and increased efficiency in the production process.

- For the runner geometry selection, the output values obtained from the analysis were compared with the values obtained from mathematical calculations and according to these results, it was seen that the quadrilateral runner geometry was suitable for the optimization of the process.

- It was seen that the relationship between the melt pre-time and injection volume of the runner with rectangular geometry can be positive in terms of productivity and production rate.

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