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COMPARISON OF STRAIGHT, SPIRAL CONFORMAL AND ZIG-ZAG CONFORMAL COOLING CHANNELS IN PLASTIC INJECTION MOLDS

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Abstract – Plastic injection molding is one of the widely used methods of forming plastic materials. The process of cooling the mold in injection molding has an important role in reducing the production costs and increasing the product quality. Thanks to the evolving additive manufacturing technologies, complex geometry cooling channels can be produced. In this study, the effect of the conformal cooling channels was investigated in order to increase the cooling efficiency of plastic injection molds. For the numerical analysis a plastic part with complex geometry was determined. For the cooling of the plastic injection mold, cooling channels with straight, spiral and zigzag form have been designed. In the channel design, the distances of the cooling channels to each other and to the mold cavity are controlled by a design algorithm. Numerical analysis was performed to examine the effect of the designed cooling channels. In the numerical analysis, the change in the cooling time and the temperature distribution on the plastic part were observed. The cooling time is shortened by the use of conformal cooling channels according to the cooling with the straight cooling channel. A more homogenous temperature distribution was obtained as a result of the analysis with the conformal cooling channels. It has been observed that the cooling process with the spiral cooling channel lasts for a shorter period than the cooling done with the zigzag cooling channel.

Keywords – Conformal cooling channels, Plastic injection molding, Plastic part warping, Cooling time, Additive manufacturing

I. INTRODUCTION

In the plastic injection molding process, the molten polymer is injected into the mold and then cooled in a controlled manner. The temperature of the melt polymer is reduced to the ejection temperature from the injection temperature. The cooling process is carried out with a cooling system on the mold. For low cost and high-quality production, the mold should be cooled quickly and homogeneously.

One of the most important parameters that determine the production speed is the cooling time. Shortening the cooling time significantly reduces cycle time. In addition, the temperature distribution on the surface of the mold cavity must be as homogeneous as possible to reduce the formation of warping on the plastic part.

The commonly used method for forming cooling channels is to drill the mold plates with a drill. Although this method is suitable for plastic parts with simple geometry, it is not possible to maintain a uniform cooling of the complex surfaces [1]. In the case of a non-homogeneous temperature distribution, the plastic parts also cause problems such as warpage, sink, residual stresses [2,3].

Using of straight cooling channels, plastic parts geometry is tried to be followed. However, it cannot provide uniform cooling for complex part surfaces [4-8].

The use of conformal cooling channels come into prominence in the mold blocks, which provides a uniform temperature distribution, faster cooling and reduced distortion [9]. Various studies have been carried out on the use of conformal cooling channels for effective cooling in plastic injection molds [1-3,10-14].

Baffle and bubbler methods have been tried to cool the mold cores, but a homogeneous temperature distribution has not been exactly achieved [10]. Thanks to the advanced additive manufacturing technologies, it is possible to produce complex form cooling channels. Various methods have been used to design the conformal cooling channels, which follows the surfaces of the plastic parts [11-15].

Topological optimization studies have been carried out to reduce the costs of mold cores to be produced by the additive production method and to determine the required cooling zones [13-14].

In another study, it was tried to reduce the warpage caused by the inlet and outlet temperature difference of the cooling water. For this purpose, the distance between the cooling channel and the mold cavity is gradually shortened according to the change in the temperature of the cooling water. As a result of the numerical analysis made with the new method developed, it was determined that the cooling time decreased while the amount of the distortion decreased [15].

Voronoi curves and contour curves were used in some of the proposed methods for channel design. However, the distance between channels varies according to the surface slope. In addition, the flow in the channels cannot be fully controlled since parallel flows occur in the channels divided into branches [16].

Thermo-mechanical analyzes were performed in another study in which the conformal cooling channels were examined. An experimental design was made for different wall thicknesses, helical cylindrical and conical cooling channels of different sizes. Numerical analyzes were performed to investigate the cooling time and mechanical loads on the mold for various design parameters [17].

In this study, it is aimed to effectively cool plastic parts with complex geometry. To achieve this, the conformal cooling channels are formed in a spiral and zigzag form according to a design method [18]. Straight channels are also designed to determine the difference between straight channels and conformal channels. The results of the analysis with Ansys Fluent software were compared with the designed channels [19].

II. Materials and Method

For use in numerical analysis, a plastic part with complex geometry is modeled with cad software (Figure 1). Plastic parts have concave and convex surfaces. There are surfaces that are not compatible with the cooling channels on the part. The dimensions of the plastic part are 153x99x43mm and the thickness is 6mm. The draft angle on the side surfaces is 5 °. The part material is ABS (Acrylonitrile butadiene styrene).

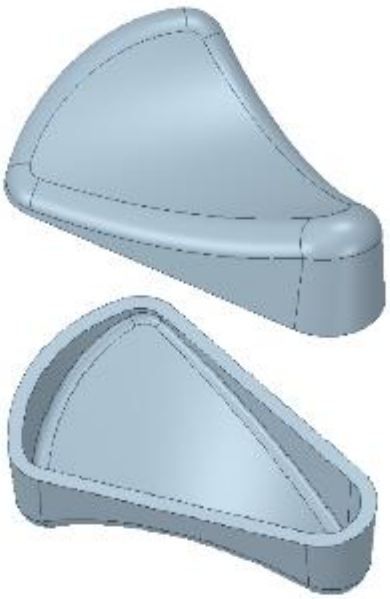

Fig. 1 Plastic part's top and bottom sides

The dimensions of the cooling channels were determined according to the wall thickness of the plastic part. For 6mm wall thickness, the channel diameter is 8mm, the distance between the two channels is 20mm and the distance between the channel and the cavity surface is 12mm (Figure 2).

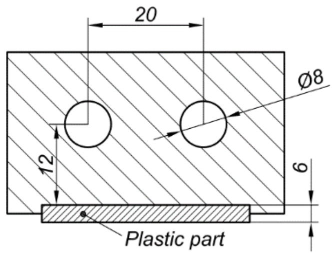

Fig. 2 Section and dimensions of cooling channels

A design algorithm was used in which the distance between the channels and the channel -cavity surface was kept constant while designing the conformal cooling channels [18]. First, the surface of the workpiece is offset. The offset distance determines the distance of the cooling channels from the mold surface. A sweep surface is formed following the boundary curve of the offset surface. The cross section of the sweeping surface is a circle. Circle radius determines the distance between channels. In the next step, the intersection curves of the offset surface and the sweep surfaces were obtained. Processes in the previous step were repeated and new sweep surfaces and new cross-sectional curves were obtained by using the formed curves.

The obtained curves were trimmed and smoothened. Then them used as the center curve of the cooling channels.

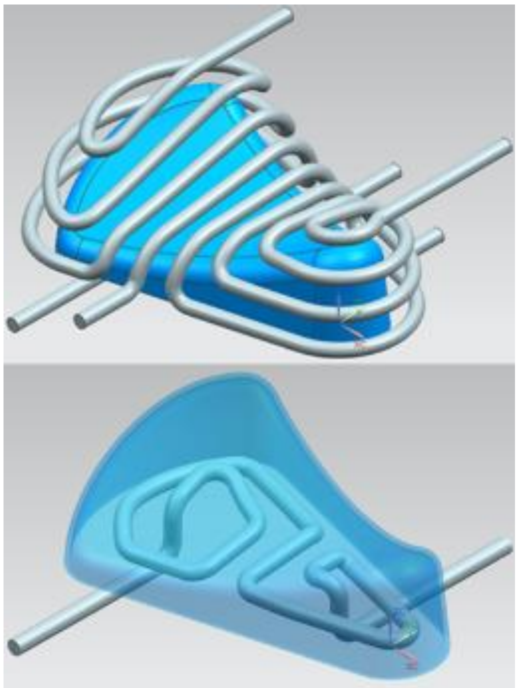

Fig. 3 Plastic part's top and bottom sides

Using the design method, the cooling channels are designed in a spiral (Figure 4a) and in a zigzag form (Figure 4b). Cooling channels are formed for both halves of the mold. In addition, the straight cooling channels used in the conventional cooling method were formed (Figure 4c).

Numerical analysis was performed to determine the efficiency of the cooling channels. Cooling analysis was performed using Ansys Fluent software. Transient analysis was conducted to determine the variation in temperature distribution over plastic parts and molds over time.

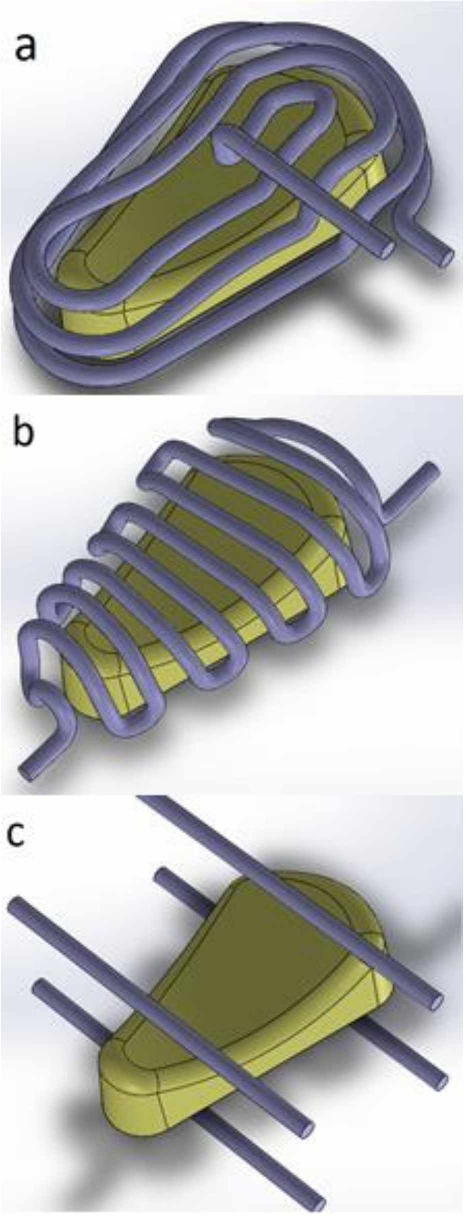

Fig. 4 Spiral, Zig-zag and straight cooling channels

The material properties used in the analysis are shown in Table 1.

Table 1. Materials in numerical analysis

Material	Density Kg/m^3	Specific Heat J/Kg-K	Conductivity W/m-K
Steal (mold material)	7800	440	14
ABS (plastic part material)	1020	1386	0,172
Water (coolant material)	998	4182	0,6

The plastic material was cooled down from the injection temperature to the ejection temperature. The boundary conditions used in the cooling analysis are shown in Table 2.

Table 2. Materials in numerical analysis

Injection temperature	230°C
Ejection temperature	90°C
Mold temperature	50°C
Coolant temperature	50°C
Mass flow rate of coolant	10lt/min

III. Results

Time-dependent cooling analysis were performed. Ansys Fluent software was used for analysis. The analysis was carried out until the average temperature of the part was reduced to 90°C. According to the results, the cooling times lasted approximately 48 seconds. Figure 5 shows the temperature distributions in 48th seconds of cooling. The measured temperature value at the black point is about 4 degrees lower than the conventional method in cooling with the conformal channel.

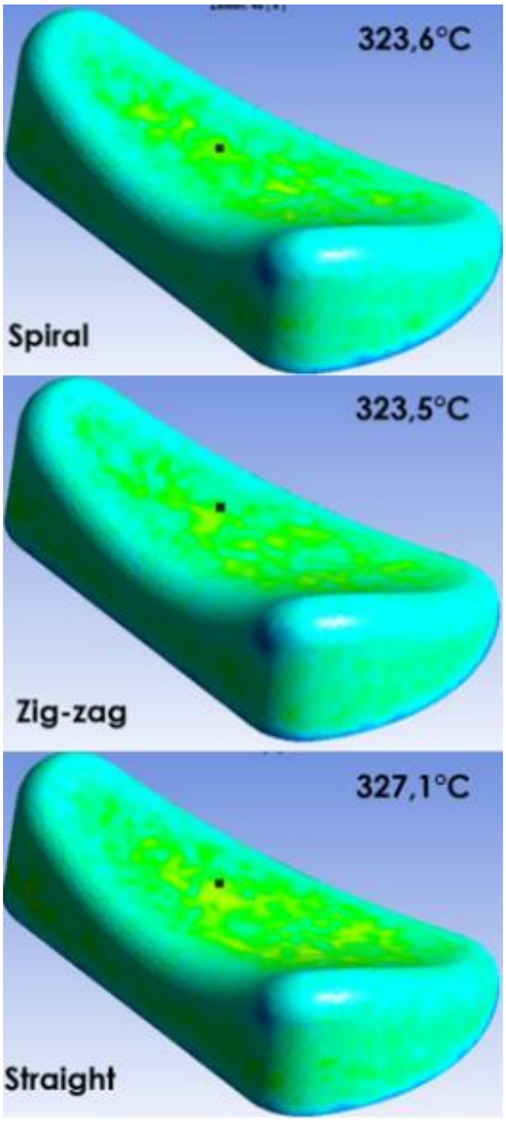

Fig. 5 Temperature distribution on part surface at 48^{th} second of cooling process

The temperature distribution in the interior of the plastic part is shown in section in Figure 6. Molds with a shape adaptation cooling channel have a lower distribution around the mold cavity.

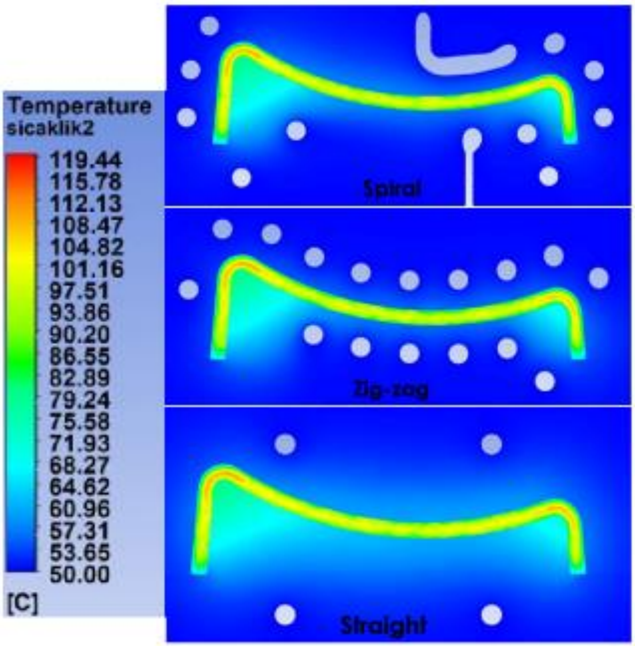

Fig. 6 Temperature distribution on section at 48th second of cooling process

It is seen that the cooling times with the zigzag and spiral cooling channels are very close to each other (Figure 7). The cooling time with the flat cooling channel is approximately 2% longer than the cooling time with the conformal cooling channels.

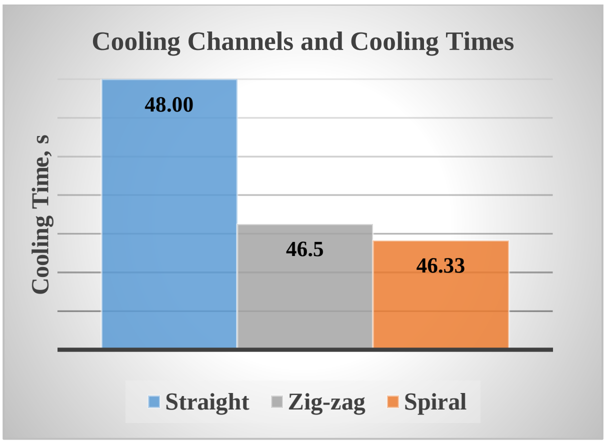

Fig. 7 Cooling times

In the analysis, the standard deviation values of the temperature distributions on the plastic part surface were investigated during the cooling periods. The lowest standard deviation was obtained by using zigzag cooling channels (Figure 8).

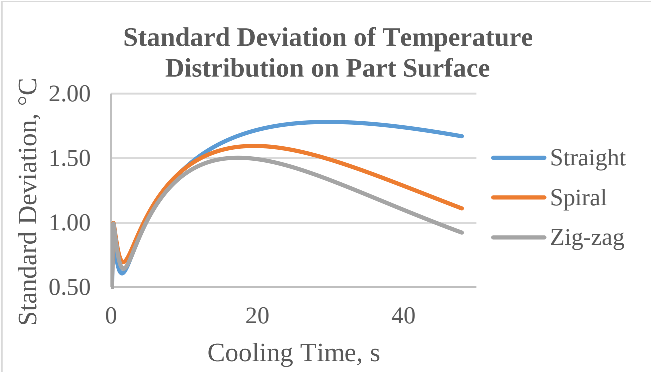

Fig. 8 Standard deviations of temperature distribution on plastic part surface

IV. DISCUSSION

When the results are examined, the cooling time difference between the conformal cooling channels and the use of the straight cooling channel is 2%. Although this difference may be low compared to the total time, it will provide significant advantages considering the high-volume production. The findings obtained are close to the findings of the literature [20].

According to the results of the analysis, the standard deviation of the temperature distribution on the part surface is lower with the use of the conformal cooling channels. Accordingly, a more homogenous cooling process has been carried out by the use of conformal cooling channels. With the new methods proposed, the amount of warping on the plastic parts will be reduced.

V. CONCLUSION

The conformal cooling channels for a plastic part with complex geometry are designed according to a design algorithm [18]. Spiral, zigzag and flat form cooling channels are designed. Cooling analysis were performed by using the created channels. The cooling time was shortened with the use of conformal cooling channels and a more homogeneous temperature distribution was obtained.

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