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EFFECTS OF COOLING CHANNEL DIAMETER, DISTANCE, AND PITCH IN PLASTIC INJECTION MOLDING

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Abstract:

A straight drilled or conventional cooling channel is a linear cooling pathway that circulates around the mold cavity to regulate temperature during the plastic injection molding process. The cooling phase accounts for 70% of the plastic injection molding process, making it crucial to design the cooling channel for reducing cycle time while upholding part quality. This study aims to analyze the effects of cooling channel parameters on the product cavity. The parameters under consideration are the cooling channel's diameter, pitch, and distance. Various designs of cooling channels were examined. This study employed a food container lid made from polypropylene (PP) as a product case study. A 3D model of the food container lid and Straight Drilled Cooling Channel (SDCC) was created using CATIA V5, and these models were subsequently imported into Autodesk Moldflow Insight for simulation analysis. Four results were obtained from the simulation analysis, namely time to reach ejection temperature, average temperature, volumetric shrinkage, and deflection. The results indicate that increasing the diameter and pitch of cooling channels leads to a decrease in the average part temperature and the time required to reach ejection temperature. Conversely, increasing the distance between cooling channels results in an increase in the average part temperature and the time required to reach ejection temperature.

Keywords:

Cooling Performance; Cooling System; Injection Molding.

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Introduction

Plastic injection molding, an innovative manufacturing method, is extensively employed in the production of plastic products. Raw materials, such as plastic pellets, may need to be heated and melted before they are injected into the mold. The process of injection molding is analogous to administering injections with syringes. Injection molding is a method suitable for mass production, even with complex designs. Thanks to this approach, it is now possible to manufacture on a large scale within a relatively short period of time (Finkeldey, Volke, Zarges, Heim and Wiederkehr, 2020). The use of a cooling system reduces cycle time, ensuring that the production process proceeds smoothly and in shorter period (Rusinko, Baron, Panda and Kočiško, 2021).

In the injection molding process, there are four phases: filling, packing, cooling, and ejection (Venkatesh, Ravi Kumar and Raghavendra, 2017). Among these phases, cooling is of paramount importance, as it can significantly influence the quality of the final product. The quality of the product is affected by various process parameters, and multiple defects may arise due to poorly designed molds or incorrectly configured machines (Kovács, and Sikló, 2011). Attributes such as mold temperature, melt temperature, and injection pressure are critical factors in plastic injection molding that impact the product's overall quality (Jaafar et al., 2020). In the context of the injection molding process, the cooling stage can consume as much as 70% to 80% of the total cycle time (Khan, Afaq, Khan, and Ahmad, 2014). Selecting an appropriate cooling channel design can reduce cooling time and enhance the efficiency of the molding process. Furthermore, the manufacturing process parameters continue to influence the quality of plastic products throughout production, with warping being one of the most common quality issues encountered (Ozcelik, and Erzurumlu, 2006).

The quality of the product, as well as the effectiveness of the manufacturing process, are both directly influenced by the temperature of the mold. It is ideal to keep the mold temperature as low as realistically possible to reduce the total time required for the molding cycle, which, in turn, can reduce production costs, as they are based on the duration of the molding cycle (Fan, Guo and Min, 2012). However, reducing the product's cooling time may lead to significant warping and shrinking (Khan et al., 2014). To decrease the cycle time while maintaining product quality, it is necessary to employ an appropriate cooling technique.

According to the study conducted by Behrooz et al., they utilized the sequential simplex approach to minimize both warpage and shrinkage in their research. In the context of their study, "warpage" denotes the distortion or bending of a component that occurs during the injection molding process due to non-uniform contraction at various locations. Conversely, "volumetric shrinkage" refers to the overall reduction in the part's size after it has cooled (Farshi, Gheshmi and Miandoabchi, 2011). Reducing these two defects leads to higher product quality. In practical mold designs, volumetric shrinkage is often considered by incorporating a coefficient of contraction. Excessive shrinkage can result in volumetric changes, leading to dimensions that fall outside the tolerance limits for the final product (Farshi et al., 2011; Dongre, Chaitanya, and Jonnalagadda, 2121). Warpage, cycle time, and part quality represent the most common issues encountered when employing conventional cooling systems (Venkatesh et al., 2017).

The design of the cooling channel plays a crucial role in achieving both a uniform temperature distribution and a rapid cooling rate within a short period. It is imperative to have a cooling

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system capable of efficiently dissipating heat at the required rate to prevent degradation of the plastic part and ensure its deformation-free ejection (Hassan, Regnier, Le Bot, and Defaye, 2020). Moldflow Insight is simulation software designed to analyze the impact of injection molding designs and part models. By visualizing product quality issues, Moldflow Insight can conduct simulations to identify shrinkage and warping problems in the plastic injection molding process. Additionally, it allows for the detection of the causes of warping and the implementation of shrinkage compensation measures during the analysis stage (Jaafar et al., 2020). Throughout the simulation, these elements can be examined and refined to enhance efficiency (Kovács et al., 2011).

A conventional cooling channel, often referred to as a straight-drilled cooling channel (SDCC), is constructed externally to the mold in a linear fashion. These channels feature a significant coolant pathway within the mold itself (Venkatesh et al., 2017). The production of conventional cooling channels involves drilling multiple straight holes, creating cooling channels within the mold's core and cavity (Khan et al., 2014). However, the conformal cooling channel design emerged as the most favourable option in terms of ejection time, average part temperature, volumetric shrinkage, and deformation (Hisham and Saman, 2022). When determining and selecting key design parameters for these cooling channels, such as size, shape, and placement, it is crucial to consider factors like cooling performance, mechanical strength, and coolant pressure drop. This meticulous attention to detail is vital for maintaining uniform temperature distribution and achieving rapid cooling, which ultimately leads to a reduction in cycle time (Mohamed, Masood, and Saifullah, 2013). One critical indicator of the suitability of a chosen cooling channel for product production lies in its ability to attain the ejection temperature, ensure uniform temperature distribution, and minimize warping in a shorter cycle time (Feng, Kamat, and Pei, 2021). Ensuring a uniform cooling effect results in consistent shrinkage and minimal warpage (Shayfull, Sharif, Zain, Saad, and Fairuz, 2013).

This study is being conducted to analyse the effects of cooling channel parameters on the product cavity, aiming to achieve the most effective cooling and minimize defects. This will be achieved by evaluating various cooling channel parameters based on criteria such as the time required to reach injection temperature, volumetric shrinkage, the average part temperature, and the deformation observed in the simulation results obtained from Moldflow Insight.

Methodology

To achieve the study's objectives, the part model and cooling channel were designed and analyzed. The part model was developed with consideration for the requirements of the plastic injection molding process. A straight-drill cooling channel will be employed in the analysis. The parameters to be assessed for the cooling channel include diameter, pitch between the cooling channels, and the distance between the cooling channels and the part cavity. CATIA and Moldflow Plastic Insight Simulation software were utilized to create the 3D model and perform computational analysis simulations.

The research commences with the design of a lid for a food container, serving as the case study for the entire investigation. A total of 15 different combinations of cooling channel parameters will be evaluated using simulation software, each with a distinct set of parameters. The study's outcomes will consider four criteria: average part temperature, time required to reach ejection temperature, volumetric shrinkage, and deflection.

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Case Study and Modelling

Figure 1 displays a 3D model of the lid of a food container, which serves as a case study throughout this research. In total, this part possesses a volume capacity of 20,018 mm³, with the following dimensions: a length of 113 mm, a width of 74 mm, a height of 6.5 mm, and a thickness of 2 mm. Additionally, the product features a rounded corner shape with a 20 mm radius.

The lid of the food container was crafted from thermoplastic polypropylene (PP), a material well-recognized in the plastic food container industry for its unique combination of properties, including its ability to withstand high temperatures, flexibility, strength, lightweight nature, stability, resistance to moisture, and resistance to chemicals (Jaafar et al., 2020). Table 1 provides an overview of the thermal and mechanical properties of polypropylene.

Figure 1: 3D Model of Food Container Lid

Table 1: Properties of the material

Number	Property	Value
1	Density (g/cm3)	0.9
2	Melt temperature (°C)	210-290
3	Thermal conductivity (10-4 cal/sec cm °C)	2.8
4	Heat capacity (cal/g °C)	0.9

Design of Cooling Channel

According to the study by Chil-Chyuan Kuo and Trong-Duc Nguyen, the design of a cooling channel is based on the product's wall thickness, as illustrated in Figure 2 (Kuo, Nguyen, Zhu, & Lin, 2021). Since the food container's lid is 2 mm thick, the diameter of the cooling channel should range between 4 and 8 mm. The distance between the centers of the channels should be approximately 1.5 to 2 times the diameter of the cooling channel. Regardless of whether it is positioned below or above the product, the center distance of the cooling channel with respect to the product should be 2 to 3 times the diameter of the cooling channel.

This study encompasses 15 conventional cooling channel designs, resulting in a total of 15 cases for simultaneous assessments, as shown in Table 1. The assessment focuses on three

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basic variables: diameter ranging from 4 to 8 mm, pitch variables with values of 10 and 18 mm, and distance variables between 12 to 24 mm.

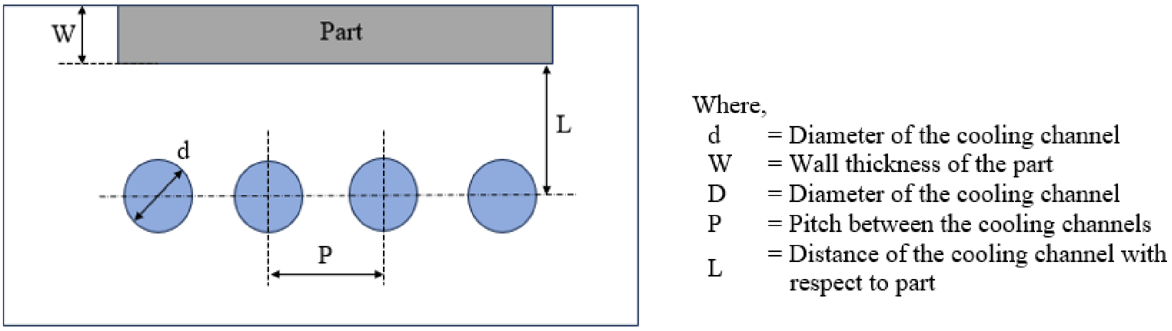

Figure 2: Cooling Channel Of Injection Moulding Layout

Table 1: Properties Of The Material

Case Number	d (mm)	P (mm)	L (mm)
1	4	12	18
2	5	12	18
3	6	12	18
4	7	12	18
5	8	12	18
6	6	10	18
7	6	12	18
8	6	14	18
9	6	16	18
10	6	18	18
11	6	12	12
12	6	12	15
13	6	12	18
14	6	12	21
15	6	12	24

The cooling channel was designed using the computer-aided design (CAD) tool CATIA, in accordance with the parameter values specified in Figure 2. This study employed a conventional cooling channel in the shape of a straight hollow cylinder, constructed from P20 steel. The cooling channel was appropriately configured with 8 inlets and 8 outlets to facilitate the flow of the coolant fluid.

In order for the mold generation to be considered complete, the cooling channels and the feed system must be represented by underlying curves in either scenario. The length of the cooling channel was adjusted to be 30 mm longer than the product's length, which measures 143 mm. The dimensions of the mold were chosen so that the only components protruding from it were the inlet and outflow of the cooling channel. Figure 3 displays the mold generated through the

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mold block wizard. The mold and cooling channel were meshed prior to conducting the analysis.

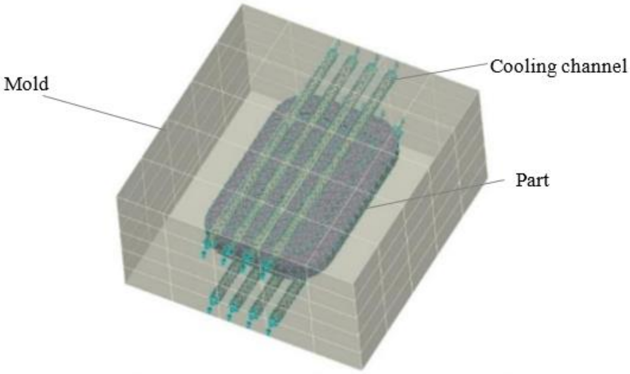

Figure 3: Cooling Channel Of Injection Moulding Layout

Results and Discussion

The simulation of the injection moulding process with cooling channels was conducted using 15 different cooling channel parameters. In this analysis, four variants of simulation results were assessed, including average part temperature, time required to reach ejection temperature, volumetric shrinkage, and deflection.

The results concerning the average part temperature indicate the mean temperature across the thickness of the part, determined at the end of the cooling phase. It is crucial to maintain minimal temperature fluctuations within the part. Higher average temperatures in certain regions may be attributed to either thicker sections of the part or areas with insufficient cooling. The outcome of the time required to reach ejection temperature reveals how long it takes to attain the ejection temperature from the initial filling. Ideally, the part should solidify uniformly, but prolonged freezing times in certain regions may suggest thicker sections or areas where heat generation occurs due to shear during the filling or packing process.

Volumetric shrinkage upon ejection represents the reduction in local volume from the end of the cooling phase until the part has cooled to the ambient reference temperature (25°C). Elevated shrinkage values might indicate the presence of sink marks or voids within the part. It is important that shrinkage values are consistent throughout the part to ensure the structural and visual integrity of the component.

The degree of deflection at each node of the part is reflected in the deflection results. Both shrinkage and the cooling system influence the part's deflection. A part with the lowest deflection value indicates better quality compared to others.

Figure 4 shows an example of the average temperature distribution for Case 11. These results were determined at t=30s after the injection of the material at 200°C. The left and right sides of the part exhibit higher average temperatures, possibly due to their greater distance from the cooling channels, resulting in reduced cooling effects from the cooling system. The temperature distribution trends are consistent across all 15 cases. To assess the impact of parameter variations, we considered the maximum values provided by the software.

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Figure 5 presents a comparison of the average temperature distribution with varying diameters, pitches, and distances of the cooling channels. As the diameter and pitch of the cooling channels increase, the part temperatures decrease. However, increasing the distance between the cooling channel and the part cavity results in higher temperatures. Among these cases, Case 11 is the most favorable for achieving a minimum average part temperature, with a diameter (d) of 12mm, pitch (P) of 12mm, and distance (L) of 12mm.

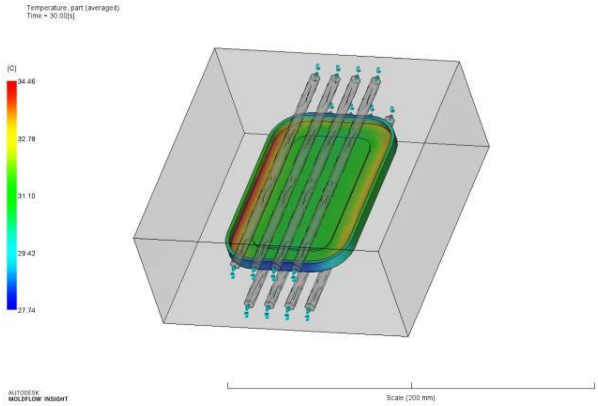

Figure 4: Temperature Part Average

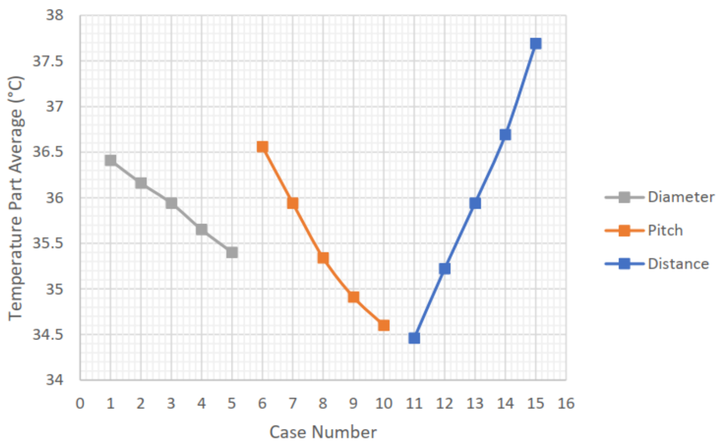

Figure 5: Comparison Of The Average Temperature Distribution With Varying Parameters Of The Cooling Channels

Figure 6 displays the results for the time it takes to reach the ejection temperature for case 11. The red color appearing in the middle of the product represents the longest duration required to reach the ejection temperature. This position essentially corresponds to the junction of the sprue and part, where the material flows into the cavity. The time needed to reach the injection temperature is approximately equivalent to the time required for the entire operational cycle, which begins with product filling and concludes with ejection. In terms of 3D flow, the results demonstrate the longest duration across the local thickness, with the color mapping progressing from the inside to the outside of the product. Overall, all parts of the region indicate a similar blue color, except for the central area, which signifies the average time required for solidification, sufficient cooling, and stabilization before ejection.

Figure 7 provides a comparison of the time it takes to reach the ejection temperature with varying diameters, pitches, and distances of the cooling channels. For easier understanding, we considered the maximum time for each case. As the diameter and pitch of the cooling channels

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Volume 6 Issue 17 (June 2024) PP. 44-55
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increase, the time required to reach the ejection temperature decreases. However, increasing the distance between the cooling channel and the part cavity results in longer durations. Once again, Case 11 emerges as the best option for achieving a shorter time to reach the ejection temperature.

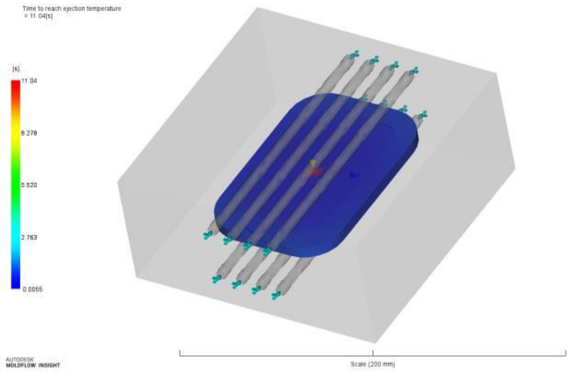

Figure 6: Time to Reach Ejection Temperature

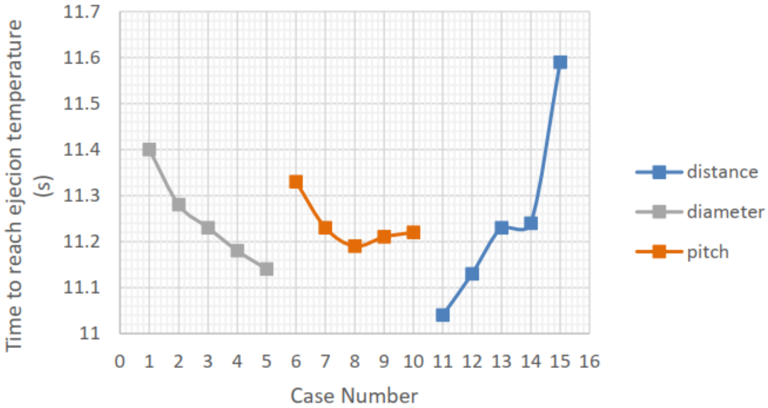

Figure 7: Comparison Of Time To Reach Ejection Temperature With Varying Parameters Of The Cooling Channels

Figure 8 depicts the results of volumetric shrinkage. The highest volumetric shrinkage is observed at the injection point. It is crucial for shrinkage values to remain uniform throughout the entire part. This uniformity is essential for effectively packing the material and ensuring the structural and visual integrity of the part. In general, the majority of the part area exhibits a consistent blue color, except for the central area, which indicates uniform shrinkage along the material thickness.

Figure 9 offers a comparison of volumetric shrinkage with varying diameters, pitches, and distances of the cooling channels. To enhance understanding, we considered the maximum shrinkage percentage value for each case. The results demonstrate that the volumetric shrinkage for all parameter combinations remains consistently around 9.42%. However, Figure 8 shows less than 1% volumetric shrinkage in the majority of the part area.

Figure 10 displays the results of part deflection during the process cycle. Both shrinkage and the cooling system have an impact on the part's deflection. Figure 10 shows that the deflection of the part ranges from 0.3 to 0.8mm, with the highest value indicated by the red color in the round corner of the part, while the lowest deflection is indicated by the blue color on the flat surface at the center of the part.

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Figure 11 displays a comparison of deflection values for different combinations of cooling channel diameters, pitches, and distances. The maximum deflection value for each case, as provided by the software, is compared. The results indicate that deflection remains consistently around 0.84 mm for all parameter combinations, irrespective of the variations in cooling channel parameters.

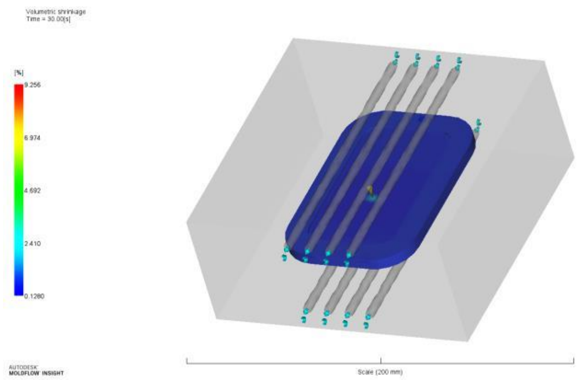

Figure 8: Volumetric Shrinkage

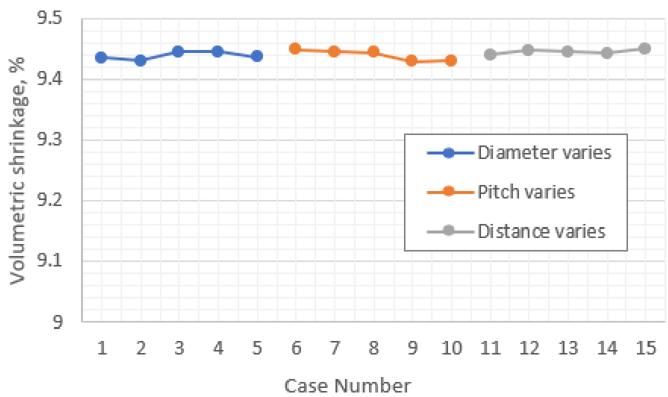

Figure 9: Comparison Of Volumetric Shrinkage With Varying Parameters Of The Cooling Channels

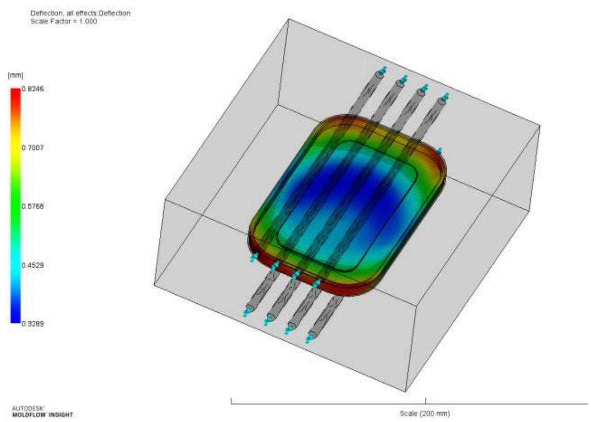

Figure 10: Part Deflection

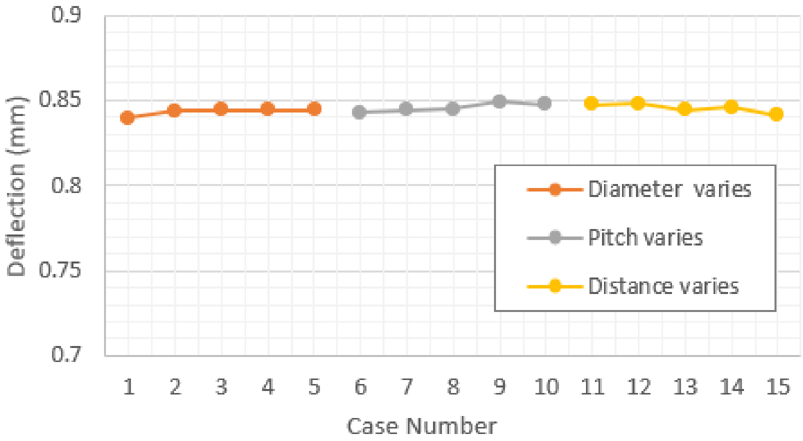

Figure 11: Comparison Of Part Deflection With Varying Parameters Of The Cooling Channels

Conclusion

In summary, this study has effectively achieved its primary objective, which involved the examination of how cooling channel parameters impact the product cavity. The investigation specifically focuses on four key simulation analysis outcomes: the time required to reach ejection temperature, the average temperature, volumetric shrinkage, and deflection. The study involved a comparison of various cooling channel parameters, including their diameter, pitch, and distance.

The findings suggest that increasing the diameter and pitch of cooling channels leads to a reduction in both the average part temperature and the time needed to reach ejection temperature. Conversely, enlarging the distance between cooling channels results in an elevation of both the average part temperature and the time required to reach ejection temperature. It is crucial to maintain a minimal variation in the average temperature throughout the part and ensure uniform freezing to prevent poorly cooled areas, which would extend the ejection time and consequently prolong the overall product cycle.

In conclusion, this research significantly contributes to our comprehension of how cooling channel parameters affect cooling efficiency and the occurrence of defects in injection molding. Ultimately, it enhances the practices in injection molding cooling processes, benefiting manufacturers, customers, and the environment.

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