International Journal of Scientific Engineering and Science
Volume 9, Issue 5, pp. 54-57, 2025. ISSN (Online): 2456-7361

The Influence of Design Parameters on Deformation When Designing Plastic Products for Injection Molding Machines

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Abstract— *This paper is a study on flow analysis in plastic molds and the optimization of gear design, with the specific goal of minimizing shrinkage and warpage of the product. To gain a deeper understanding of this issue, the research utilizes an actual ABS plastic product sample. By applying simulation methods using Moldex3D software, the study focuses on analyzing shrinkage and warpage to propose the most optimal design solutions. The Moldex3D simulation method is employed to enhance product quality performance in mold design. To optimize product quality, it is essential to assess manufacturability and refine the mold system, including powerful tools such as parting surface creation, automatic mold splitting, product quality simulation, and mold system optimization before actual production. Through this paper, the simulation method enables an in-depth analysis of flow behavior, thereby revealing how warpage and shrinkage affect the final product. Understanding these factors allows for the development of the best possible design calculations for mold and gear manufacturing.*

Keywords— *Warpage, simulation, gear, optimal.*

I. Introduction

The design parameters significantly influence deformation in plastic products during injection molding, primarily through the optimization of process variables and mold design. Research indicates that careful manipulation of parameters such as packing pressure, mold temperature, and cooling time can lead to substantial reductions in warpage and shrinkage, enhancing product quality[7]. Mold Design: Optimizing mold design can reduce deformation by addressing uneven material shrinkage, which is a primary cause of warpage in thin-walled parts[1]. Injection Parameters: Parameters like injection time, packing pressure, and cooling time are critical. For instance, a study showed that optimizing these parameters led to a 66% reduction in warpage and a 46% decrease in volume shrinkage[2]. Material Interaction: The interaction between parameters, such as packing time and mold temperature, significantly affects shrinkage deformation, highlighting the need for tailored approaches based on material types[3]. While optimizing design parameters can greatly enhance product quality, it is essential to balance these optimizations with production efficiency and cost considerations, as excessive focus on minimizing deformation may lead to increased manufacturing complexity and expenses[4]. In the manufacturing industry, analyzing flow behavior in plastic molds and applying optimization methods in the design of high-precision stepped gears is a unique and complex field that offers valuable applications in production processes.

The optimization method in stepped gear design not only ensures high precision but also enhances durability, reduces noise, and improves operational efficiency. The use of computers and simulation software allows engineers and designers to evaluate models and test variations before production. This helps save time, resources, and minimize potential errors[5].

With continuous technological advancements, the manufacturing industry increasingly focuses on improving quality and production efficiency. The application of flow analysis and optimization in the design of high-precision stepped gears plays a crucial role in meeting these demands—ranging from creating high-quality products to enhancing production effectiveness and competitiveness in the market[6].

This paper focuses on the simulation analysis of warpage and shrinkage in three types of stepped gears with different geometries. It then optimizes the design for the type with the least shrinkage to achieve the most optimal product design.

II. Experimental Setup

To study warpage and shrinkage in plastic injection-molded products, we conduct simulations on three different types of plastic gears using the same input parameters. This allows us to determine which product exhibits the least shrinkage, helping us optimize its design for the best possible performance. In this study, we utilize Moldex3D software to evaluate the injection molding process of the product.

A. *Input Parameters:*

TABLE 1.1: Input Parameters:

Process parameters of injection molding	
Material	ABS
Melt temperature	235oC(220-250 oC)
Mold temperature	50oC (40-60 oC)
Injection pressure	155MPa

In this section, we primarily evaluate the warpage and volumetric shrinkage of the product during the injection molding process using Moldex3D software.

Warpage: This helps identify the direction in which the product warps after the entire process is completed. Warpage affects both the quality and appearance of the product.

Volumetric shrinkage: Used to assess the distribution of shrinkage across the product. A positive value indicates

Volume 9, Issue 5, pp. 54-57, 2025.
ISSN (Online): 2456-7361

material shrinkage, whereas a negative value signifies volume expansion due to overpacking. Uneven volumetric shrinkage can lead to warpage and deformation of molded parts after ejection with injection pressure 155Mpa.

Gear A

- Simulation Results

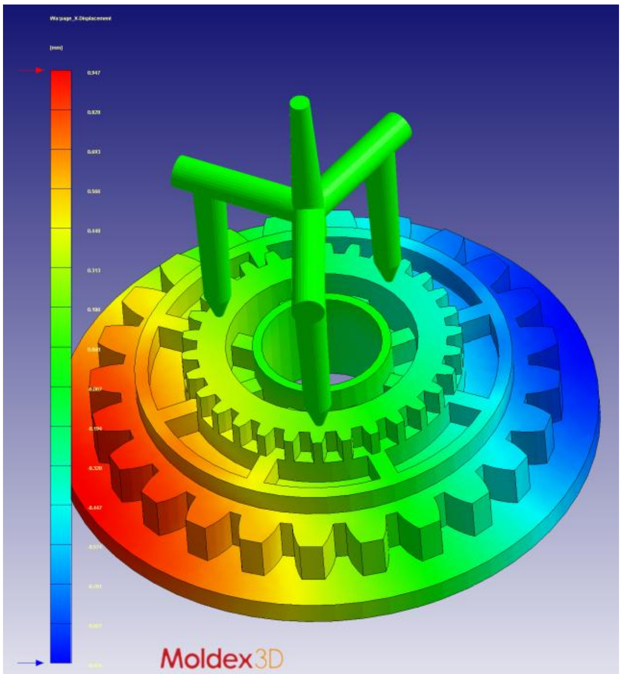

Figure 1.1: Warpage of the Gear A

Based on the analysis results shown in figure 1.1, we can see that the front part of the gear tends to expand from -0.947 mm to 0.954mm. The maximum warpage of the product is 0.947mm, while the maximum expansion is 0.954mm. The warpage amount is calculated as □$= 0,947 + 0,954 = 1,901(mm)$

Gear B

Simulation Results

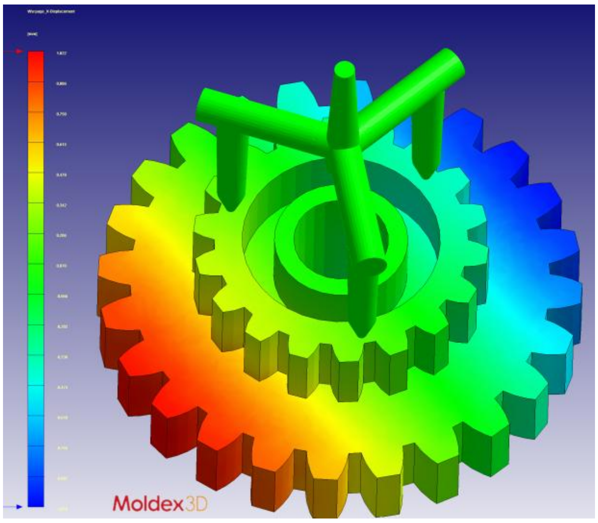

Figure 1.2: Warpage of the Gear B

Based on the analysis results shown in figure 1.2, we can see that the front part of the gear tends to expand from -1.018 mm to 1.022mm. The maximum warpage of the product is 1.018mm, while the maximum expansion is 1.022mm. The warpage amount is calculated as

□$= 1.022 + 1.018 = 2,040(mm)$

Gear C

Simulation Results

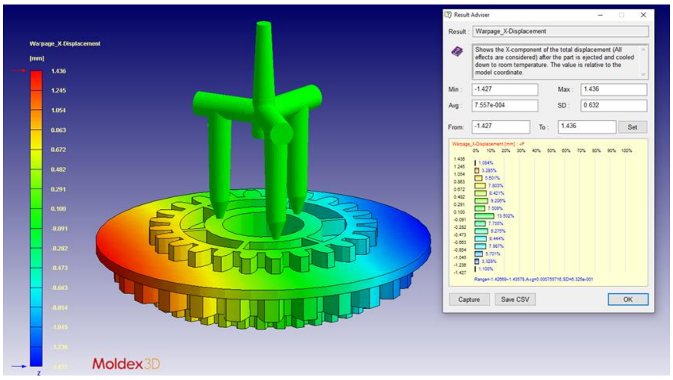

Figure 1.3: Warpage of the Gear C

Based on the analysis results shown in figure 1.3, we can see that the left side of the gear expands by 1.3mm, while the right side contracts by 1.4mm. The warpage amount is calculated as □$= 1.436 - (-1.427) = 2.863(mm)$

After the simulation, the results were obtained as follows:

TABLE 1.2: Simulation results of three types of gears

Gear type	Warpage (mm)
A	1.901
B	2.040
C	2.863

From the analysis results of the three gears above, using the same input parameters and identical gate positions, it is evident that Gear C has the Maximum warpage. Therefore, in the next calculations, we select Gear C for further optimization in the injection molding product design process.

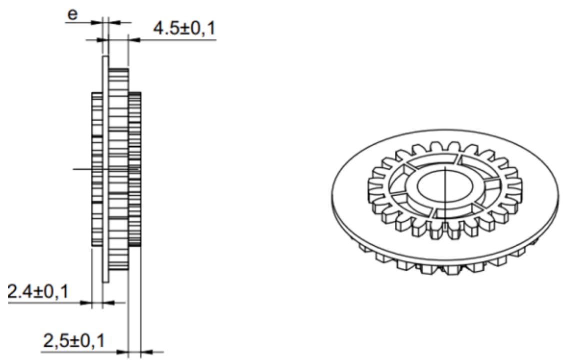

Figure 1.4 shows the structure of gear C

Optimization Method for Gear C:

The analysis shows that Gear C still exhibits a relatively high shrinkage and warpage coefficient, which affects product quality. Therefore, adjustments to the design or cooling system can be made to reduce shrinkage and warpage to acceptable levels.

In this study, we choose to modify the design by increasing the thickness of the reinforcing disc to minimize the warpage of the component

- Let e be the thickness of the stiffening disc.
- The allowable working clearance of gear C is 15 mm.
- Currently, the part has a thickness of 11 mm. We adjust the value of e in the range from 1.5 mm to 5.5 mm, and then perform a simulation using Moldex3D software to determine the case with the least warpage.

TABLE 1.3: Thickness parameter e of gear C

Case	e_1	e_2	e_3	e_4	e_5
Thickness (mm)	1.5	2.5	3.5	4.5	5.5

We conducted warpage simulations for each case using Moldex3D software to identify the optimal design parameter that results in the least warpage.

III. Results And Discussions

We conducted warpage simulations for each case using Moldex3D software to identify the optimal design parameter that results in the least warpage.

Process parameters of injection molding	
Material	ABS
Melt temperature	235oC(220-250 oC)
Mold temperature	50oC (40-60 oC)
Injection pressure	155Mpa

A summary of the simulation results is presented in the table below:

TABLE 1.4: Simulation Results Summary

e	e_1	e_2	e_3	e_4	e_5
Thickness (mm)	1.5	2.5	3.5	4.5	5.5
Warpage (mm)	2.863	0.821	0.920	1.175	0.907

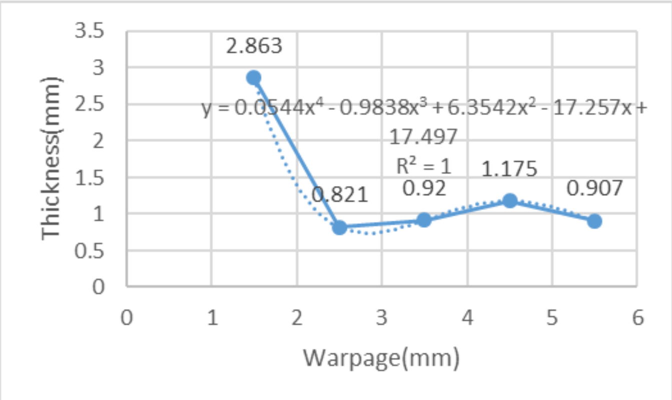

Figure 1.5: Scatter plot between disc thickness and warpage

From Figure 1.5, we obtained the equation using Excel

$$y = 0.0544x^4 - 0.9838x^3 + 6.3542x^2 - 17.257x + 17.497$$

Therefore, the minimum value of f(x) on the interval [1.5-5.5] occurs at x = 2.5, and the maximum value of f(x) on the interval [1.5-5.5] occurs at x = 1.5. Thus, we conclude that with e = x = 3, the warpage of the product is minimized. Therefore, we use e = 2.5 as the optimal design parameter for gear C.

Based on the simulation results from Figure 1.5 for the cases we established, we observe that the case with a thickness of 2.5 mm exhibits the least warpage. Therefore, we select the case with a thickness of e = 2.5 mm as the optimal design parameter

IV. Conclusion

Based on the Moldex3D software, we used the input parameters to simulate the product as follows. We used ABS material with a melt temperature of 235°C and a mold temperature of 50°C, as obtained from the data, with a packing pressure of 155 MPa. After establishing these input parameters, we began simulating the cases. We observed that the structure of gear C exhibited the lowest warpage. Therefore, we selected gear C as the basis for optimizing the design in order to reduce warpage after molding.

We optimized the design by varying the thickness of the stiffening disc from 1.5 mm to 5.5 mm, followed by simulations using Moldex3D software. After analyzing the results, we determined that the optimal design parameter was the case where the stiffening disc thickness was 2.5 mm, as this case exhibited the least warpage among the remaining four cases.

In the next phase of research, further investigation can focus on the combined effect of multiple design and process parameters on the warpage and mechanical performance of gear C. Specifically, the following areas can be explored:

- Multi-parameter optimization: Instead of only varying the stiffening disc thickness, future studies can analyze the combined influence of parameters such as gate location, cooling time, injection speed, and holding pressure using design of experiments (DOE) or response surface methodology (RSM).

- Material comparison: Evaluate alternative thermoplastic materials (e.g., PC, PA6, or POM) to determine if lower warpage or better mechanical performance can be achieved compared to ABS under similar conditions.

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International Journal of Scientific Engineering and Science
Volume 9, Issue 5, pp. 54-57, 2025. *ISSN (Online): 2456-7361*

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