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Optimization Of Wall Bracket Process Parameters Using Taguchi Method For Sink Mark Defect

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ABSTRACT: *Injection Molding is a widely used process for producing plastic products. In the design of injection-molded products, determining the ideal process parameters is a crucial task, as it affects product quality, production rate, production cost, and energy consumption. Achieving optimal process conditions and mold design is the key challenge to enhancing product quality. Sink marks are one of several significant defects in injection-molded parts. This paper combines numerical simulation with the Taguchi design-of-experiment (DOE) technique to assess the impact of process conditions and cavity geometry on sink marks in injection-molded parts and to optimize process conditions and cavity design. The simulation process parameters considered in this study, in addition to melting temperature and injection pressure, are detailed. During the research, polypropylene was injected into a wall bracket product under various processing conditions. Moldflow software simulated the injection process to examine the effect of process parameters on sink mark deflection in the wall bracket. The Taguchi orthogonal arrays and signal-to-noise ratio were utilized to identify the optimal parameter settings and to highlight the influence of the process parameters on sink marks. The most significant parameter identified was the melt temperature for the design.*

Keywords: Wall Bracket, Taguchi Method, Brick, Injection Molding Process

1. INTRODUCTION

Plastic processing refers to the various methods used to convert raw plastic materials into finished products. These methods involve shaping, molding, or forming plastic into specific shapes and sizes. Each plastic processing method has its advantages and is chosen based on factors like the complexity of the part, production volume, material type, and cost considerations. The plastic production process consists of injection molding, extrusion, blow molding, thermoforming, and rotational molding. These methods allow for the creation of a wide variety of plastic products used in everyday life, from packaging to automotive parts and electronics.

The wall bracket is one of the products produced by Guppy Plastics Industries (Penang) Sdn Bhd that has been ordered by Eco Elite Sdn Bhd through the injection molding process. The main issue with this product is the defect of sink marks. The injection molding process necessitates the use of raw plastic material, a mold, and an injection molding machine. The plastic is melted in the injection molding machine and then injected into the mold, where it cools and hardens into the final part. The injection molding process itself is a complex combination of temperature, time, and pressure variables, with numerous potential defects that may arise without the correct balance of processing parameters and design elements.

Plastic injection molding is the most widely used method for the mass production of plastic components with various geometries and shapes (Viana J.C et al., 2011). The production of items through this method involves heating plastic pellets inside a barrel, melting them, and then injecting the molten plastic into a mold cavity, where it cools and solidifies into the shape of the cavity (Mathivanan et al., 2010). Factors contributing to sink marks and voids include low injection and packing pressure, short holding or cooling times, high melt or mold temperatures, and localized geometric features. Once the material on the surface has cooled and solidified, the core material begins to shrink. This shrinkage pulls the surface of the outer wall inward, resulting in a sink mark. If the outer skin is sufficiently rigid, as in engineering plastics, deformation of the skin may be replaced by the formation of a void in the core.

Moreover, low injection pressure often leads to incomplete filling, causing sink marks, weld lines, mold lines, and air traps. Additionally, increasing injection pressure can reduce shrinkage and increase product density. However, if the injection pressure is too high, the workpiece may warp, potentially reducing the sink mark (P.K. Bharti, 2010). Therefore, determining the optimal injection pressure and packing time can ensure enough melt volume to improve product quality by reducing shrinkage and warpage. Furthermore, high mold temperatures help reduce cracking in the product. Additionally, increasing the melt temperature results in lower viscosity, which reduces shear stress and cavity pressure.

Design of Experiments (DOE) has been extensively used by researchers to optimize the injection molding process, control defects, and enhance quality. In their study, various processing variables, such as mold temperature, melt temperature, packing pressure, rib cross-section, and rib orientation, were considered to reduce warpage and sink index using Taguchi methods (Twust, et al., 2009).

Moreover, reducing sink marks and warpage in the molded part during rapid heat cycle molding, which addresses the issue of sink marks, involved conducting experiments using Taguchi methods to systematically investigate the effects of processing parameters like melt temperature, injection time, packing pressure, packing time, and cooling time on warpage. Injection molding simulations using Moldflow were performed to measure the sink marks of plastic parts produced under varying processing conditions (Muhammad et al., 2013). The melt temperature has also been recognized as the most crucial control parameter for tensile strength, with the control parameters optimized using the Taguchi orthogonal array design and the ANOVA method (R. Pareek et al., 2013).

2. MATERIALS AND METHODOLOGY

2.1 Taguchi's Orthogonal Method

The impact of various process parameters based on Taguchi's orthogonal design can be effectively determined through matrix experiments. This method allows for the collection of experimental data that can reflect the situation with a reduced number of simulation tests. Additionally, this approach focuses on enhancing the design of the manufacturing process or product. The tool used in the Taguchi method is the orthogonal array (OA), which enables the effects of multiple parameters to be assessed and guides the parameter design process. The optimal level of a factor is the highest level that provides the best signal-to-noise (S/N) ratio (Kitayama S. et al., 2018). These S/N ratios are intended to serve as indicators of how noise factors influence performance characteristics. S/N ratios consider both the degree of variability in the response data and the closeness of the average response to the target value. In this study, the injection parameters considered are melt temperature and injection pressure. Based on Figures 1.0 and 2.0, these are the steps for using the Taguchi method. It can be seen that the analysis was conducted using the Mini Tab software to obtain the appropriate parameters.

Taguchi Design

Design Summary

Taguchi Array	L9(3^3)
Factors:	3
Runs:	9

Columns of L9(3^4) array: 1 2 3

Figure 1.0 Taguchi Method Design

Taguchi Analysis: DEFECT versus A, B, C

Response Table for Signal to Noise Ratios

Smaller is better

Level	A	B	C
1	-53.02	-52.41	-54.08
2	-52.41	-53.83	-52.00
3	-55.08	-54.27	-54.43
Delta	2.68	1.87	2.42
Rank	1	3	2

Figure 2.0 Analysis of the Taguchi Method

2.2 Data Parameter Setting for the Machine for PP-062 Material

Table 1.0 shows the typical parameter settings recommended by the factory for the production of the wall bracket. These parameter settings often experience issues with the barrel overheating. Due to the excessive barrel heating, these parameter settings are closely monitored every time a product is produced. Overheating of the barrel can cause the material to burn, resulting in defects in the finished product.

Table 1.0 Parameter Setting Injection Molding Machine

PARAMETER INJECTION MOLDING USING BY INDUSTRY	
H1	240
H2	255
H3	260
H4	230
H5	220
V1	25
V2	48
V3	45
V4	30
V5	19
P1	75
P2	-
P3	-
P4	-
P5	-
HOPPER TEMPERATURE	70˚C
BACK PRESSURE	5
CLAMPING FORCE	180

3. RESULTS AND DISCUSSION

Figure 3.0 shows the results after analyzing using Mini Tab software for the Taguchi method. Some numbers placed are within the range specified according to the material specifications. This Taguchi analysis was conducted to find the optimum melt temperature value for the PP-062 material used to produce the wall bracket. To understand further, (H1, H2, H3) represent the stage zones within the barrel where the raw material is melted. Figures 4.0 and 5.0 show the Taguchi method graphs obtained after analyzing the data using Mini Tab. The signal-to-noise (S/N) ratios are used to measure the sensitivity of the quality characteristics being investigated in a controlled manner. In the Taguchi method, the term ‘signal’ represents the desired outcome, while ‘noise’ refers to the undesired effects (signal disturbances, S.D) on the output characteristic, which are influenced by external factors, i.e., noise factors.

↓	C1	C2	C3	C4
	A	B	C	defect
2	1	2	2	600
3	1	3	3	500
4	2	1	2	400
5	2	2	3	450
6	2	3	1	560
7	3	1	3	620
8	3	2	1	660
9	3	3	2	480

Figure 3.0 Analysis of the Taguchi Method

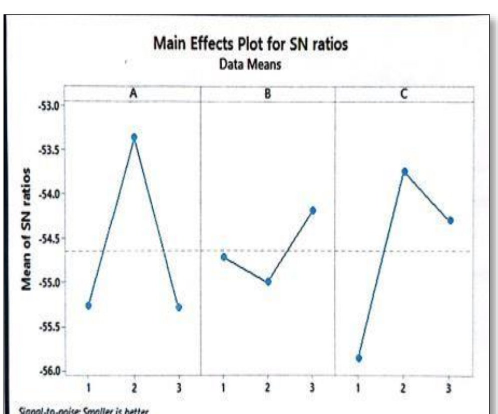

Figure 4.0 Analysis of the Taguchi Method

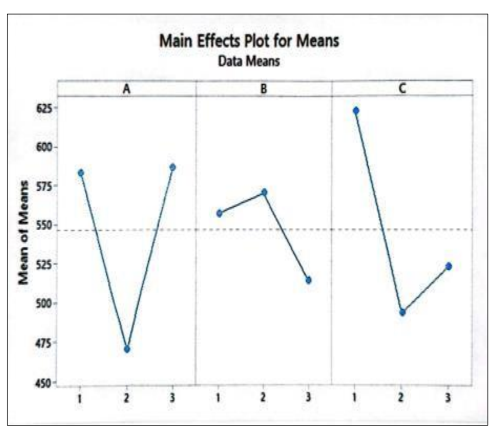

Figure 5.0 Analysis of the Taguchi Method

Table 2.0 is a set of proposed parameters using the Taguchi method based on the specifications of the material type used in the production of the wall bracket. The temperature in zone H1 until H5 has been reduced for improvement to address the sink mark issue. As a result of this improvement, the number of sink mark defects has been reduced by 60%. This shows a positive outcome in reducing sink mark defects.

Table 2.0 Parameter Setting Injection Molding Machine by Taguchi Method

PARAMETER INJECTION MOLDING BY TAGUCHI METHOD	
H1	220
H2	240
H3	240
H4	230
H5	220
V1	25
V2	48
V3	45
V4	30
V5	19
P1	75
P2	-
P3	-
P4	-
P5	-
HOPPER TEMPERATURE	70˚C
BACK PRESSURE	7
CLAMPING FORCE	180

4. CONCLUSION

This research was carried out to determine the optimal parameters for an existing plastic injection machine at Guppy Plastics Industries (Penang) Sdn Bhd. The goal is to establish a parameter setting for producing the Wall Bracket. The material chosen for this investigation is polypropylene. Currently, the production process follows the parameters recommended by the industry without conducting a thorough analysis. In this research, simulations for optimizing the plastic injection molding parameters, focusing on minimizing sink marks, were performed using Moldflow software and the Taguchi Method. The Moldflow simulation determines the order of molding process parameters that impact sink marks, ranked by melting temperature and injection pressure. The Taguchi method was utilized to assess the influence of melt temperature and injection pressure. Melting temperature is the most significant parameter.

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