

Optimization Injection Molding Parameters of Polypropylene Materials to Minimize Flash Defects Using the Taguchi Method

Nur Kholish Ali Fahmi, Redyarsa Dharma Bintara, Suprayitno

Mechanical Engineering Department, Faculty of Engineering, Universitas Negeri Malang, Indonesia
Jl.Semarang No. 5, Sumbersari, Kec. Lowokwaru, Kota Malang, Jawa Timur 65145, Indonesia. Tel. +62-896-70966.

Corresponding author*

suprayitno@um.ac.id

Abstract: The demands and consumption of plastic in Indonesia, especially in the food and beverage industry, are high. 892 industries produce a rigid packaging, flexible packaging thermoforming, and extrusion with an average production capacity is more than 23.5 ton per year with 70% utility. The utilization of plastic in many fields is owing to the fact that the characteristics of plastic could replace other materials function. The production process of injection molding machine in *bioball* spike product in the industry is not completely perfect. There is a flash product defect that leads to loss in the process and production costs. The Taguchi method is selected to get the optimal parameter in minimizing the flash defect. The flash defect of product could be a big problem for a manufacture company specialized for injection molding. The product defect should be avoided or fixed by counting, analyzing, optimizing the parameters which affect its defect. This study was conducted using experimental method by determining the experiment design through fractional factorial L_9 (3^4) for three cycles of injection trial where the test specimen was using *bioball* spike product with polypropylene material. The parameters used in this study were injection speed, injection pressure, injection time, and melt temperature which all of them was consisted in third level. The study used analysis of means (ANOM) and verified using Taguchi method for getting the average effect in every parameter of its level and getting the plot effect. Analysis of variance (ANOVA) was also used for knowing the average effect of its parameter towards the output, it is aimed to verify the Taguchi method. The result showed that this parameter combination is optimal in minimizing the flash defect and effect of its parameter. The results obtained determine the effect of each parameter, namely the injection speed parameter (I_s) has the most significant effect of 37.91%, the injection pressure parameter (I_p) has an influence of 32.17%, for the injection time (I_t) parameter has an influence of 1.2%, and for the melt temperature (M_T) parameter it is 28.72%. The optimal combination of parameters to cause flash defects with a combination of parameters (I_s) at level 2 (40 cm/s), (I_p) at level 2 (40 kg/cm²), (I_t) at level 3 (5 seconds), and (M_T) at level 1 (180 °C). The results of the comparison of S/N Ratio Smaller the Better before optimization (initial design) and after optimization (robust design) get a gain of 5.609.

Keywords: Injection Molding, Flash Defect, Taguchi Method.

Abbreviations: Injection Speed (I_s), Injection Pressure (I_p), Injection Time (I_t), Melt Temperature (M_T)

Introduction

The need and consumption of plastic in Indonesia are still quite large, especially in the food and beverage industry, 892 plastic packaging industries produce rigid packaging, thermoforming flexible packaging, and extrusion with a production capacity of approximately 23.5 million tons per year with a utility of 70%. the average production

carried out by the packaging industry is 1.65 million tons per year. The use of plastic in various fields of life cannot be separated from the characteristics possessed by plastic materials that can replace the function of other materials such as rubber, wood or metal (De Miranda & Nogueira, 2019). Polypropylene plastic material is lightweight, easy to shape, anti-rust, has cheap economic value and several types of plastic can be

recycled which makes plastic more dominant in demand by the general public from both producers and consumers (Alam & Kumar, 2013). Polypropylene is a common thermoplastic polymer material mostly used in industrial applications. Polypropylene was chosen because it is rigid, translucent, fatigue resistant, heat resistant, tough and chemically durable (Humbe & Kadam, 2014). One of the methods commonly used for the manufacturing process of plastic-based products in the industry is injection molding.

Injection molding is a manufacturing technique that has a series of cyclical processes and is used to print thermoplastic materials (Humbe & Kadam, 2014). The injection molding process is often used for mass production. The injection molding process begins by inserting plastic pellets into the hopper, then the plastic will melt when heated in the barrel and pushed by a screw to the nozzle, the melted material will be pushed through the sprue and enter cavity and be given pressure (holding pressure) to avoid warpage when the cooling process until the plastic material is printed by the desired shape (Rajalingam & Vasant, 2016). The use of plastic materials that are increasingly advanced and developing, requires efforts to minimize production time and costs with maximum results (Hussin et al., 2013). In injection molding products, product defects often occur, such as product not complete, warpage, flash, welding, cracks, shrinkage, imperfect shape defects, spilling of plastic material, product dimensions outside the specified tolerance (excess dimensions), and others. -other caused by several factors (Bhargavkumar, 2020).

Flash is a defect in injection molding products where there are thin cavities between the molds, resulting in the insertion of crevices where the plastic will flow and form a thin layer, this is due to wear on the molds or improper handling (Kazmer, 2016). Flash defects can occur if there is a very small separation of the bottom of the mold during the molding cycle (Chen et al., 2020).

This problem makes the injection molding production process disrupted or hampers and reduces the company's profits, especially at UD. Bina Jaya. Therefore, the researcher wants to create and find parameter settings to minimize products

not complete which is detrimental to the company by using the Taguchi method.

Materials and Methods

Study Area

Plastic products produced in UD. Bina Jaya with an injection molding machine type KT-150G, one of which is a bioball spike product that is very much needed for fish cultivation consumers both in aquariums and in fish ponds, the function of the bioball spike is as a filtration media tool to filter out impurities in the pond or aquarium. The material used in the bioball spike is polypropylene. Polypropylene is widely used because of the advantages of low cost, high heat distortion temperature, good mechanical properties and easy recycling (Hou et al., 2021). Polypropylene material has density properties from 0.90-0.91 g/cm³, and has a melt flow index of 10.78 g/10 min (Zou et al., 2021). The bioball spike product is produced in one injection process (1 cycle) which can produce 12 pcs, where there are some products that have flash defects as shown in (Figure 1). Flash defects often occur at the end of a series of cycles in the bioball spike production process, where these defects often occur between the final 21-30 cycles and occur repeatedly (Goodship, 1997). This condition is the center of attention to avoid or minimize product defects that are flash which have an impact on the company's losses in terms of materials and in terms of production operations.

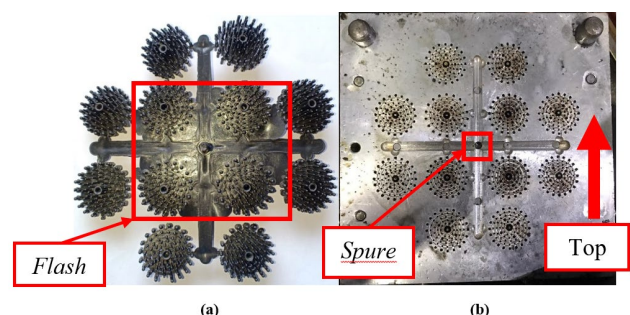


Figure 1. (a) Flash Defective Product, (b) Mold

Procedures

Design of Experiment (DoE)

Is an engineering tool that manages an experiment efficiently using scientific analytical methods to

analyze experimental data in order to get a more optimal plan (Montgomery, 2012). For this study, the experiment was designed using the Taguchi method using orthogonal arrays L_9 (3^4). Table 1 shows the parameters used with three-level variations. With the current condition (initial design), the parameters used are at leBio ball Bioball Spike Mass Measurement

The mass measurement process is carried out after the injection process with specimen vabyance with orthogonal arrays L_9 (3^4) for 3 injection cycles. Quantification is to determine the percentage of flash defects in equation 1. The calculation results can be seen if the lower the percentage value of each 1 pcs bioballbio ballproduct then it is said to be a perfect product (0%), otherwise if the percentage value is greater then it is said to be flash (1%-100%).

Taguchi Method

After the data is obtained and processed, the Taguchi method is applied to the design of the experiment to determine the effect of each process parameter on flash defects. In addition, the main goal of the Taguchi method is to make a product/design robust against noise, so it is often

referred to as a robust design. Robust means strong, while noise means error, so what is meant by robust against noise means that a design must be designed to be strong and resistant to the influence of noise or error factors which these factors cannot be controlled. The Taguchi method determines the signal-to-noise ratio or commonly known as the S/N ratio as a measure to measure the performance of a robust design (Taguchi & Phadke, 1986). The value of the S/N ratio is calculated manually using the “smaller the better” formula as shown in equation 3 and the value for minimizing product not complete defects is shown in (Table 5).

Data Analysis

Design of Experiments (DoE) is an engineering tool that manages an experiment efficiently by using scientific analytical methods to analyze experimental data to get a more optimal plan. For this study, the experiment was designed using the Taguchi method using orthogonal arrays L_9 (3^4). The parameters used with three-level variations as in (Table 1). With the current condition (initial design), the parameters used are at level 2.

Table 1. Injection Molding Control Parameters

Parameters	Level 1	Level 2	Level 3
Injection Speed (I_s), cm/sec	35	40	45
Injection Pressure (I_p), kg/cm ²	35	40	45
Injection Time (I_t), seconds	3	4	5
Melt Temperature (M_t), °C	180	195	210

$$\% \text{ Flash (absolut)} = \frac{MASS_{Product} - MASS_{Perfect}}{MASS_{Product Complete}} \times 100 \% \quad (1)$$

The results of the percentage calculation with data in the form of mass (grams) that havn

processed into percentage values in Equation 1. The overall percentage value obtained from 3 cycles can be seen in (Table 2)

Table 2. Data Processing Results Percentage of Flash Defects

Parameter Combination				Exp.	Flash Percentage		
I _s	I _p	I _r	M _r		1	2	3
1	1	1	1	1	31.9	35.7	31
1	2	2	2	2	14	17.4	17.1
1	3	3	3	3	8.6	12.1	6
2	1	2	3	4	27.6	26.9	28.6
2	2	3	1	5	2.6	2.4	4.8
2	3	1	2	6	0.2	5	7.4
3	1	3	2	7	21.9	20	23.3
3	2	1	3	8	16.9	18.3	15.7
3	3	2	1	9	8.6	9	6.9

Results and Discussion

Flash Defects

The Taguchi method is applied to the design of experiment to determine the effect of each process parameter on product not complete defects. In addition, the main goal of the Taguchi method is to make a product/design robust against noise, so it is often referred to as a robust design. Robust means strong, while noise means error, so what is meant by robust against noise means that a design must be designed to be strong and resistant to the influence of noise or error factors which these factors cannot be controlled. The Taguchi method determines the signal signal-to-noise or

commonly known as the S/N Ratio as a measure to measure the performance of a robust design (Taguchi & Phadke, 1986). The S/N Ratio value is calculated manually using the “smaller the better” formula and the value for minimizing flash defects is shown in (Table 5).

$$\text{Flash Min. (absolut)} = \frac{\text{Mass}_{\text{product}} - \text{Mass}_{\text{perfect}}}{\text{Cycle to}} \quad (2)$$

So the mathematical equation S/N ratio used in this study can be seen in Equation 3.

$$S/N_{STB} = -10 \cdot \log_{10} \left(\frac{1}{n} \sum_{i=1}^n y_i^2 \right) \approx -10 \cdot \log_{10} (y^2 + s^2) \quad (3)$$

Table 5. L₉ Experiment Design Flash Data Processing Results

Parameter Combination				Exp.	Test			Mean	St. Dev	S/N Ratio (STB)
I _s	I _p	I _r	M _r		1	2	3			
1	1	1	1	1	0.479	0.517	0.433	0.476	0.042	6.407
1	2	2	2	2	0.219	0.252	0.248	0.240	0.018	12.389
1	3	3	3	3	0.450	0.567	0.250	0.422	0.160	6.905
2	1	2	3	4	0.414	0.390	0.400	0.401	0.012	7.926
2	2	3	1	5*	0.039	0.034	0.067	0.047	0.017	26.033
2	3	1	2	6	0.004	0.081	0.115	0.067	0.057	21.164
3	1	3	2	7	0.329	0.290	0.327	0.315	0.022	10.014
3	2	1	3	8	0.296	0.308	0.245	0.286	0.028	10.833
3	3	2	1	9	0.133	0.136	0.100	0.123	0.020	18.088

* The best design of the L₉ orthogonal array

Based on (Table 5), it can be seen that the highest S/N Ratio value is in the 5th experiment of all those in the orthogonal arrays L₉ (3⁴), thus the 3rd experiment is called the best L₉.

Analysis of Mean

After obtaining the highest value of S/N Ratio, then the ANOM (analysis of mean) is carried out which aims to determine the average effect of each parameter at each level and obtain plot effects.

The data used for the calculation is the S/N Ratio by calculating the average value of the S/N Ratio of each parameter at each level, then calculating the difference between the results of these values and the system average (system meter to obtain a large effect (main effect) of each parameter at each level on the S/N Ratio. The data from the calculation of the ANOM S/N Ratio can be seen in (Table 6).

Table 6. Main Effect S/N Ratio ANOM

Level	Is	Ip	It	Mt
1	-4.470	-5.191	-0.505	3.536
2	5.068	3.112	-0.506	1.216
3	-0.328	2.079	1.011	-4.752
Main System	9.361			

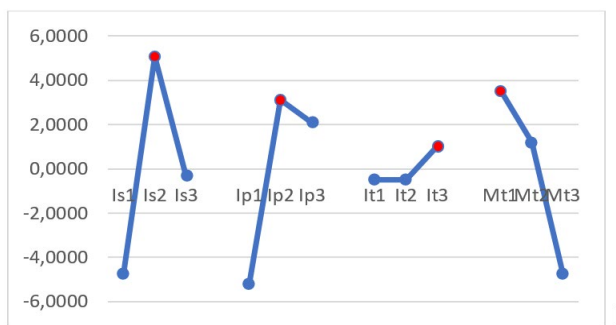


Figure 2. Main Effect Plot S/N Ratio

In (Figure 2) it can be seen that the level value of each parameter is the highest, so the prediction of the optimal combination of parameters is obtained, namely the injection speed level 2 (40 cm/s), injection pressure level 2 (kg/cm²), injection time level 3 (5 seconds), and melt temperature level 1 (180 °C).

So by knowing the optimal combination of parameters, by looking at the main effect plot S/N Ratio (Figure 3) using ANOM calculations and

getting the same combination of parameters with the best results from using fractional factorial L₉ (3⁴) see (Table 5), the data processing process then no verification process is carried out. Due to the optimization design using orthogonal arrays L₉ (3⁴), it has been found that the optimum combination of parameters has been obtained from the total number of experiments (full factorial) of 81 samples.

Analysis of Variance (ANOVA)

Calculation of ANOVA (analysis of variance) to determine the effect of each parameter on the output where the output used in this study is flash. The use of the ANOVA method also aims to verify the Taguchi method used. The results of manual ANOVA calculations can be seen in (Table 7) for ANOVA S/N Ratio.

Table 7. Main Effect S/N Ratio Flash

Faktor	SS	DoF	MS	C
Is	144.768	2	72.384	37.91%
Ip	122.854	2	61.427	32.17%
It	4.598	2	2.299	1.20%
Mt	109.681	2	54.841	28.72%
Error	-	-	-	-
Total	381.9004	8		100.00%

Optimal Parameter Analysis and Comparison

The results of the plot effect can be seen with the parameters and their influential level, and can see the optimal combination of parameters. After the calculation, the comparison shown in (Table 8) has been compared with the value of the S/N Ratio and the optimal combination of parameters from the best L₉ (3⁴), where the IS parameter is the injection speed, the IP parameter is the injection pressure, the IT parameter is the injection time, and MT is the melt temperature can be seen as (Table 8) below.

Table 8. Best L₉ (3⁴) with Initial Design

Exp.	Parameters				Flash		
	Is (cm/s)	Ip (kg/cm ²)	It (second)	Mt (°C)	Mean	St. Dev	S/N Ratio
Initial Design	40	40	4	195	0.072	0.062	20.425
Best L ₉ /Robust Design	40	40	5	180	0.047	0.017	26.033
Gain							5.609

The combination of optimal parameters that have been obtained is compared with the combination of parameters used (initial design) or before the optimization process is carried out, which later can be seen in the increase that occurs between before optimization and after optimization. In (Figure 3) and (Figure 4) are comparisons of flash defects with perfect products.

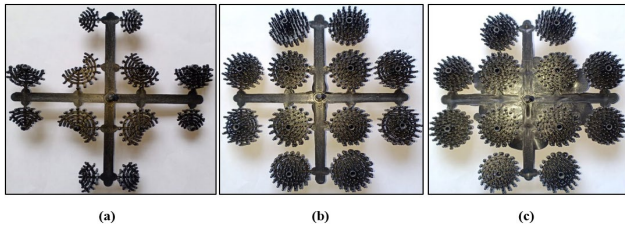


Figure 3. Initial Design Product, (a) First Cycle Product to 10th Cycle, (b) 11th Cycle Product to 20th Cycle, (c) 21st Cycle Product to 30th Cycle.

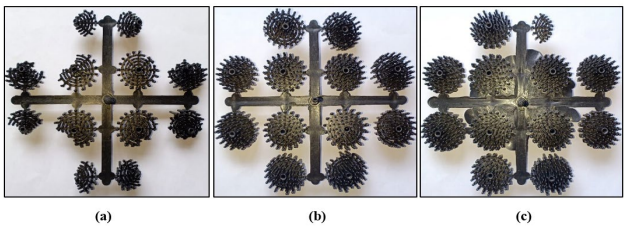


Figure 4. Robust Design Products, (a) First Cycle Products to 5th cycle, (b) 6th Cycle Products to 27th cycles, (c) 28th Cycle Products to 30th cycles.

Discussion

The effect of each injection molding parameter on flash defects which has the greatest influence is on the injection speed (I_s) parameter with an effect of 37.91%, as shown in (Figure 2) a large fluctuation occurs between injection speed and level 1 on injection. The speed with level 3, where this happens because the speed and pressure that presses the molten plastic material to enter the mold will affect the volume of the material at the time of filling. So, for setting the injection speed parameter it is not recommended that it is too large or too small, such as research conducted by (H.S et al., 2015) where in his research the injection speed greatly affects product quality for incomplete filling or flash defects that cause losses wasted time and material (Sreedharan & Jeevanantham, 2018). Research by (Chen et al., 2020) shows that if the injection pressure (I_p) is too low, it will cause flash

defects at the right injection pressure (I_p) setting is needed. A long injection time (I_t) will reduce product defects from spilling because the product is getting stronger or there is a tendency for the product to be denser so that it can fill all gaps and can minimize flash defects. The higher the melt temperature (M_T) value, the greater the flash defects that occur in plastic material products, this is in by research by (Zou et al., 2021) namely the high value of the melt temperature (M_T) number will be one of the factors causing the melt temperature (M_T) to occur flash product defects.

Conclusions

The influence of each injection molding parameter on the flash defect value is as follows. Parameter injection speed (I_s) has an effect of 37.91%, injection pressure (I_p) has an effect of 32.17%, injection time (I_t) has an effect of 1.2%, and melt temperature (M_T) of 28.72 %. The optimal combination of parameters was obtained to minimize flash defects or reduce the occurrence of product defects, namely by using a combination of parameters injection speed (I_s) at level 2 (40 cm/s), injection pressure (I_p) at level 2 (40 kg/cm²), injection time (I_t) at level 3 (5 seconds), and melt temperature (M_T) at level 1 (180 °C). The results of the comparison to minimize flash defects before optimization (initial design) with the Taguchi method are 20.425 and the value after optimization with the Taguchi method is 26.0332, with a gain or increase of 5.609.

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Conflict of Interest: The authors declare that there are no conflicts of interest concerning the publication of this article.

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