

# Optimization Injection Molding Parameters of Polypropylene Materials to Minimize Product Not Complete Defects Using the Taguchi Method

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**Abstract:** The plastic manufacturing industry is currently developing in the manufacturing industry field. The plastics manufacturing industry is particularly suitable for mass-producing products of complex sizes. More than 30% of all plastic parts are produced by an injection molding process. The products produced by injection molding machines are not completely perfect. There are some product defects caused by several environmental and machine factors. This product defect is a problem for companies in the manufacturing sector, especially injection molding, as it disrupts production and reduces company profits. Overcoming the product defect results, the researcher chose the Taguchi method since this method was used to analyze and optimize through experimental design, which was completed by conducting a series of methods and experiments to obtain the optimal solution. Therefore, the researcher wants to make and find the parameter settings to minimize a product-not-complete which is detrimental to the company. This research was conducted experimentally by determining the design of the experiment (DoE) using fractional factorial L<sub>9</sub> (3<sup>4</sup>) for 3 initial injection cycles, where the test specimen was a bio ball spike product with polypropylene material. The parameters used are injection pressure, injection speed, injection time, and melt temperature with each parameter consisting of 3 levels. The results of the data that have been processed were then calculated by analysis of means (ANOM) to determine the average effect of each parameter at each level and obtain plot effects. Analysis of variance (ANOVA) was also calculated to determine the effect of each parameter on the output which aims to verify the Taguchi method used. Using the results obtained, the researcher knew the effect of each parameter and the optimal combination of parameters to minimize product-not-complete defects. The results of the experimental study indicate that injection pressure and injection time are the dominant factors determining the quality because reducing the pressure that presses the molten plastic material to enter the mold will have an effect on product-not-complete filling.

**Keywords:** Design of Experiments (DoE), Injection Molding, Optimization, Product Not Complete, Taguchi Method.

**Abbreviations:** Injection Speed (IS), Injection Pressure (IP), Injection Time (IT), Melt Temperature (MT).

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## Introduction

Competition in today's manufacturing industry is getting tougher. All companies are competing in portion able to survive and compete in the global market, to remain competitive, each company is required to be more aggressive in the world of the manufacturing industry. To overcome this, every company must be able to implement good strategies, to be able to achieve the success of a product. In the exIn thence of intense competition,

companies continuously improve product quality through good production processes in very large quantities, meanwhile the tools or machines used must be in good condition to avoid product defects that can reduce company profits (Sari et al., 2011). and cause a decrease in the quality of manufacturing industry competition. The plastic manufacturing industry is very suitable for mass-producing products with complex size shapes, more than 30% of all plastic parts are produced by

injection molding (Abohasima HS et al., 2015). A wide variety of products can be manufactured using injection molds of varying sizes and complexities.

Plastic products produced by injection molding machines use a variety of materials or materials. One of the materials used is Polypropylene due to the advantages of low cost, high heat distortion temperature, good mechanical properties, and easy recycling (Hou et al., 2021) with a melting point of 190 – 200°C, while the crystallization point is between 130 – 135°C. Polypropylene has high chemical resistance, but low impact strength. This polypropylene (PP) material is heated and injected into the molinith a slow-motion which can produce a product according to the mold design (Kemal Karasu et al., 2014). Products produced by injection molding machines are not all perfect, some have product defects caused by several environmental factors and machine factors. Product defects that are often experienced during the production process include; burns, flash, product not complete, flow marks, warpage, sinks, voids, weld line, jetting, and silver streaks. The result of this product defect is a problem for companies in the manufacturing sector, especially injection molding. The results of product defects must be avoided or overcome by taking into account, analyzing, and optimizing the parameters that affect the occurrence of defects (product defects). Overcoming the product defect, the researcher chose the Taguchi method because this method was used to analyze and optimize through experimental design, which was completed by conducting a series of methods and experiments to obtain the optimal solution (Sreedharan & Jeevanantham, 2018).

This problem makes the injection molding production process disrupted or hampers and reduces company profits. Therefore, the researcher wants to create and find parameter settings to minimize preproduction complete which is detrimental to the company by using the Taguchi method.

## Materials and Methods

### Study area

The specimen test product in the form of a bio ball spike made of polypropylene (Figure 1) is one of the polymer-type materials with high market demand (Kosior & Mitchell, 2020). Plastic is a type of synthetic or hydrocarbon polymer, generally made by linking many hydrocarbon monomers into long-chain molecules (Guo & Li, 2020). The bio ball spike product is manufactured using an injection molding machine type KT-150G from a manufacturing industry company in UD. Bina Jaya. The ball spike is very much needed for fish farming consumers where it functions as a filtration media tool to filter out impurities in the pond or aquarium.



Figure 1. Material polypropylene

The product is baballpike produced in one injection process (1 cycle) which can produce 12 pcs, where several products have a product, not complete defects as shown in Figure 2. Product not complete defects occur at the beginning of the ball spike production process, where these defects can be seen between the first 1-3 cycles occurs repeatedly. This condition is the ththe centref attention to avoid or minimize product defects that are not complete which have an impact on the company's losses in terms of materials and terms of production operations.

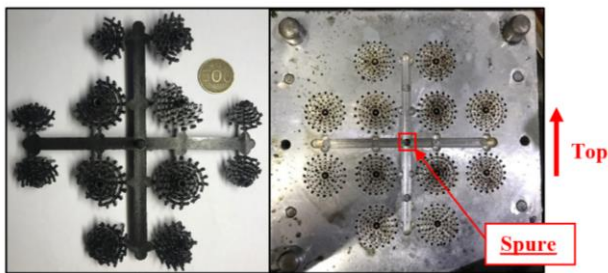


Figure 2. (a) Product bioball spike (b) Mould

## Procedures

### Design of experiment (DoE)

It is an engineering tool that manages an experiment efficiently by using scientific analysis methods to analyze experimental data in tot a more optimal plan. Adopting research conducted by (Zhao et al., 2020) which explains the functions and parts of injection molding machines and sees research from (Kerkstra & Brammer, 2018) about troubleshooting defect product not complete. So for this study, the experiment was designed using orthogonal arrays  $L_9(3^4)$  the Taguchi method. Table 1 shows the parameters used with three levels of variation. With the current condition (initial design), the parameters used are at level 2.

### Bio ball spike mass measurement

The process is carried out after the injection process with specimen variations according to orthogonal arrays  $L_9(3^4)$  for 3 injection cycles, Quantification to determine the percentage of defects is product not complete in equation 1. The results of the calculation can be seen if the lower the percentage value of each 1 pcbio ball spike then it is said to be product complete (0%), otherwise if the percentage value is greater then it is said to be the product not complete (1%-100%).

### The 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 product defects not complete. 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 factors or errors where these factors cannot be controlled (Yang et al., 2012). Taguchi method sets the signal-to-noise ratio, commonly known as the S/N ratio as a gauge to measure the performance of robust desdesigninst noise or disturbing factors (Taguchi & Phadke, 1986). The value of the S/N ratio is calculated using the “smaller the better” formula as shown in equation 2 and the value for minimizing product, not complete defects is shown in Table 2.

## Data analysis

For parameter selection and level variations that affect the product, not complete defects were obtained from interviewing researchers with operators and seeing the condition of the machines used. As seen in Table 1.

Table 1. Parameter Injection Molding.

Parameter	Level 1	Level 2	Level 3
Injection Speed	35 cm/s	40 cm/s	45 cm/s
Injection Pressure	35 kg/cm <sup>2</sup>	40 kg/cm <sup>2</sup>	45 kg/cm <sup>2</sup>
Injection Time	3 s	4 s	5 s
Melt Temperature	180 °C	195 °C	210 °C

Percentage calculation with data information of the mass (grams) which has been processed into a percentage value using Equation 1.

$$\% \text{ Not Comp} = \frac{\text{MassProduct Complete} - \text{Mass Product}}{\text{MassProduct Complete}} \times 100\% \quad (1)$$

This study uses a “smaller the better” S/N ratio because the researcher wants to minimize non-complete product defects that often occur and interfere with the production process. Equation 2 is the calculation used in this study (Semioshkina & Voigt, 2006).

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

## Results and Discussion

The results obtained after calculating the mean, standard deviation, and S/N ratio are shown in

Table 2, that the highest S/N ratio value is in the 3rd experiment of everything in the orthogonal

arrays  $L_9 (3^4)$ , thus the 3rd experiment is called the best  $L_9$

Table 2. Data Product Not Complete.

Parameter				Exp.	Mean (gram)	Std. Deviation	S/N Ratio
Is	Ip	Ir	M <sub>r</sub>				
35	35	3	180	1	0,773	0,134	2,107
35	40	4	195	2	0,344	0,269	7,199
35	45	5	210	3*	0,067	0,040	22,131
40	35	4	210	4	0,521	0,219	4,954
40	40	5	180	5	0,255	0,272	8,578
40	45	3	195	6	0,215	0,226	10,123
45	35	5	195	7	0,362	0,300	6,550
45	40	3	210	8	0,318	0,251	7,852
45	45	4	180	9	0,119	0,139	14,758

\* The best design of orthogonal array  $L_9$

**Analysis of Mean**

After obtaining the S/N ratio highest value then ANOM (analysis of mean) is which aims to determine the average size average the effect of each parameter at each level and get the effect plot (Pallmann & Hothorn, 2016).

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 mean 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 3.

Table 3. Main Effect S/N Ratio ANOM.

Level	Is	Ip	Ir	M <sub>r</sub>
1	1,118	-4,824	-2,667	-0,880
2	-1,476	-1,485	-0,391	-1,404
3	0,359	6,309	3,058	2,284

Mean system 9,361

Based on Table 3 shows the ANOM data obtained to determine the effect of each parameter, which can later determine the optimal combination of parameters to minimize the occurrence of product, not complete defects, as shown in Figure 3. Using the results of the plot effect of the S/N ratio already represents a combination of the overall parameters, because the S/N ratio already

takes into account the standard deviation and not just the average.

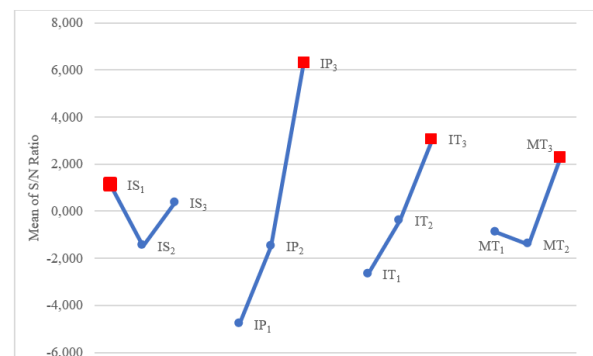


Figure 3. Main Effect Plot S/N Ratio.

In Figure 3, it can be seen that the highest level value of each parameter is obtained, so that the optimal parameter combination predictions are obtained, namely the injection speed level 1, injection pressure level 3, injection time level 3, and melt temperature level 3.

by looking at the main effect plot S/N ratio (Figure 3) using the ANOM calculation and obtaining the same combination of parameters with the best results from using the fractional factorial  $L_9 (3^4)$  see Table 2, the next data processing process is not carried out result verification. Due to the optimization design using orthogonal arrays  $L_9 (3^4)$ , we have obtained the same combination of

optimum parameters from the total number of experiments (full factorial) of 81 samples.

**Analysis of Variance**

Calculation of ANOVA (analysis of variance) to determine the effect of each parameter on the output where the output used in this study is the product not complete. The use of the ANOVA method also aims to verify the Taguchi method used (Hussin et al., 2013).

In Table 4 for the ANOVA S/N ratio, It can be seen that the largest influence is on the  $I_P$  parameter with a contribution of 69.88% and a cross-check is carried out in (Figure 3) for the  $I_P$  parameter. It can be seen that the fluctuation between level 1 and level 3 is very large. The most influential factor lies in setting the injection pressure parameter which makes product defects frequent in cycles 1 to cycle 3. The second influential parameter is  $T_I$  with a contribution effect of 17.79%. The third parameter is  $M_T$  with a contribution of 8.52%, for this  $M_T$  parameter it can be said that the parameter with little effect on the occurrence of incomplete product defects. The last parameter that has very little effect is the  $I_T$  parameter where its contribution is only 3.81%, in

other words, compared to the 4 parameters that have the least effect on the  $I_T$  parameter which has the least effect on the occurrence of product, not complete defects.

**Table 4.** Main Effect S/N Ratio ANOVA.

Factor	SS	DoF	MS	C
$I_S$	10,67	2	5,34	3,81%
$I_P$	195,85	2	97,93	69,88%
$I_T$	49,86	2	24,93	17,79%
$M_T$	23,89	2	11,94	8,52%
Error	-	-	-	-
<b>Total</b>	<b>280,27</b>	<b>8</b>		<b>100,00%</b>

**Optimal Parameter Analysis and Comparison**

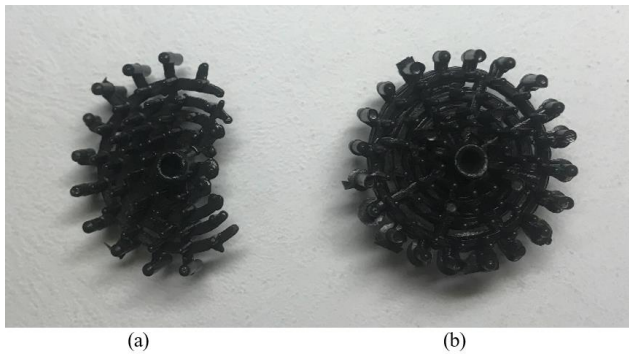
The results of the plot effect can be seen in the parameters and their influential levels and can see the optimal combination of parameters. After the calculation, the comparison shown in Table 5 has been compared with the value of the S/N ratio and the optimal combination of parameters from robust design. The calculation step is to see the value of the S/N ratio from the initial design, namely by conducting experiments using a combination of initial design parameters for 3 injection cycles with 3 repetitions each.

**Table 5.** Robust Design with the initial design.

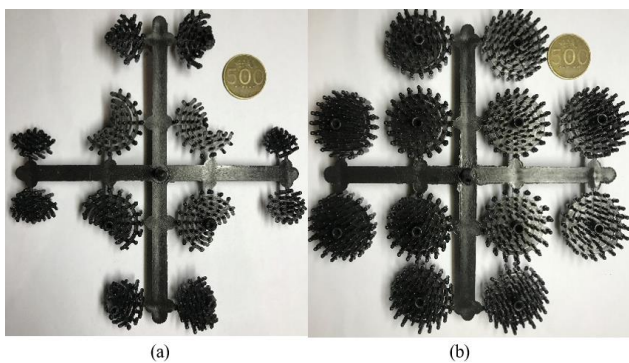
	Parameter				Mean	Stdev	S/N	Gain
	$I_S$ (cm/s)	$I_P$ (kg/cm <sup>2</sup> )	$I_T$ (s)	$M_T$ (°C)				
<b>Initial design</b>	40	40	4	195	0,520	0,276	4,599	17,532
<b>Robust design</b>	35	45	5	210	0,067	0,040	22,131	

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. It can be seen in Table 5 that the comparison of the value of the S/N ratio for the robust design is 22.131 while the value of the S/N ratio for the initial design is 4.599. So it can be said that there is an increase in the S/N ratio of 17.532. Figure 4 and Figure 5 are the resultsof one of the visuals of the bio ball spike product before optimization and after optimization using a

combination of initial design parameters in cycle 3 for image (a), while in figure (b) using a combination of robust design parameters in cycle 3. Researchers display images with the same cycle, it is hoped that the data compared is fair. by looking at the last cycle, because the results of interviews with operators of product, not complete defects occurred at the beginning of the injection cycle.



**Figure 4.** (a) Initial parameter injection molding result (b) Optimum parameter injection molding results.



**Figure 5.** (a) 12 pcs before optimization (b) 12 pcs after optimization

## Discussion

The effect of each parameter injection molding on a product, not complete defects, which has the greatest influence on the parameter ( $I_p$ ) with the effect of 69.88%, as shown in Figure 3 a large fluctuation occurs between injection pressure with level 1 on injection pressure with level 3, where this happens because it is getting smaller or reducing the pressure that presses the liquid plastic material to enter into the mold will affect the filling that is not complete (product not a complete defect). So, for setting the parameter injection pressure it is not recommended that it be too large or too small, as research conducted by (HS et al., 2015) wherein his research injection pressure greatly affects product quality for incomplete filling or product defects. which causes time and material loss. Product, not complete defects can be seen visually and occur due to too fast ( $I_t$ ) injection time and too low ( $I_p$ ) injection pressure. Therefore, to avoid incomplete product defects, it is recommended to increase the ( $I_p$ ) and ( $I_t$ ) because if you look at the results of the contribution from the ANOVA calculation and the plot effect it looks

very influential on the quality of the bio ball spike product.

## Conclusions

The optimal combination of parameters to minimize product, not complete defects, or reduce the occurrence of incomplete filling product defects is obtained by using a combination of parameters ( $I_s$ ) at level 1 (35 cm/s), ( $I_p$ ) at level 3 (45 kg/cm<sup>2</sup>), ( $I_t$ ) at level 3 (5 s), and ( $M_T$ ) at level 3 (210 °C). The results of the comparison to minimize product defects are not complete before optimization (initial design) with the Taguchi method is 4.559 and for the value after optimization with the Taguchi method is 22.131, where the gain or increase occurs is 17.532.

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**Conflict of Interest:** The author declares that there is no conflict of interest regarding the publication of this article.

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