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APPLICATION OF TAGUCHI METHOD IN OPTIMIZING INJECTION MOLDING PARAMETERS TO NETTO OF BIORING CONE CUP PRODUCTS

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ABSTRAK

Produk Bioring Cone Cup diproduksi oleh industri molding Sukodono dengan mesin *injection molding.* Namun pada awal produksi dalam mendapatkan nilai parameter masih menggunakan sistem *trial* and *error*, sehingga permasalahan ini mengakibatkan adanya cacat yang menyebabkan berat produk tidak sesuai kesepakatan sehingga produk ini harus didaur ulang kembali dengan menghabiskan waktu yang cukup lama. Dengan permasalahan tersebut, perusahaan ini mengalami kerugian dikarenakan harus membayar kompensasi keterlambatan produksi. Sehingga dibutuhkan penelitian yang membahas optimalisasi parameter *injection molding* terhadap respon *netto* produk bioring cone cup. Penelitian ini menggunakan parameter *injection pressure, injection temperature*, dan *cooling time*. Metode yang digunakan adalah taguchi dengan kriteria rasio signal to noise yaitu smaller is better untuk mengetahui pengaruh factor dan juga parameter yang optimal untuk proses produksi. Dari hasil eksperimen, didapatkan hasil kombinasi variabel yang optimal yaitu parameter *injection pressure* pada level 1 dengan nilai 80 bar, *injection temperature* pada level 3 dengan nilai 230°C, dan *cooling time* pada level 3 dengan nilai 0,5 detik.

Kata kunci: co*oling time, injection pressure*, *injection temperature*, *netto*, taguchi

ABSTRACT

Bioring Cone Cup products are produced by Sukodono molding industry with injection molding machine. However, at the beginning of production in getting the parameter value still uses a trial and error system, so this problem results in defects that cause the weight of the product is not in accordance with the agreement so that this product must be recycled again by spending a long time. With this problem, the company suffered losses because it had to pay compensation for production delays. So that research is needed that discusses the optimization of injection molding parameters on the net response of bioring cone cup products. This research uses the parameters of injection pressure, injection temperature, and cooling time. The method used is taguchi with signal to noise ratio criteria, namely smaller is better to determine the effect of factors and also the optimal parameters for the production process. From the experimental results, the optimal combination of variables is obtained, namely the injection pressure parameter at level 1 with a value of 80 bar, injection temperature at level 3 with a value of 230°C*, and cooling time at level 3 with a value of 0.5 seconds.*

Keywords: *cooling time, injection pressure, injection temperature, netto, taguchi*

INTRODUCTION

Currently, the existence of the manufacturing industry is experiencing intense competition and one of the current product competitions is plastic or polymer products. The use of plastic products is increasing because plastic is more efficient and more durable than iron products that are easily porous (Admadi & Arnata, 2015). One of the commonly used technologies that can support the production of plastic is the Injection Molding machine (Purnomo, et al., 2017).

Injection molding is a machine that is widely used by the manufacturing industry in the production process made of plastic. The reason for choosing this machine is widely used in the industry because this machine can adjust the shape to the most complex with a fast process time (Mufid, et al., 2017). A common problem that occurs in injection molding machines is that in the process, this machine is never separated by product defects (Fathoni, et al., 2015). In general, defects produced by injection molding are due to non-optimal parameter settings (Purnomo, et al., 2017).

Bioring Cone Cup product is one of the products produced by Sukodono molding industry using Injection molding machine. Since the start of production, the parameter value still uses a trial and error system, this results in a net not according to specifications and requires it to be processed again until the product weight is appropriate. With this problem, the company suffered losses because it had to pay compensation for production delays because it took a long time. All of these things happen because of the settings on the injection molding machine process parameters such as injection pressure, injection temperature, cooling time, and material properties. So that research is needed that discusses the optimization of injection molding parameters on the net response of bioring cone cup products.

An example of previous injection molding research is research conducted by Purnomo, M. H., Sidi, P. & Arumsari, N. (2017) regarding the level effect of injection molding parameters on net fox glue stamp products. The independent variables used are melting temperature (250°C, 260°C, 270°C), injection speed (45 mm/s, 50 mm/s, 55 mm/s), holding time (2s, 2.5s, 3s), and cooling process time (5s, 7s, 9s). In this study, the optimal combination of parameters was obtained, namely melt temperature 260°C, injection speed 55 mm/s, holding time 2 seconds, and cooling time 5 seconds (Purnomo, et al., 2017). The second research was conducted by N.H. Kamarudin, M.H.I. Ibrahim, R. Asmawi, R.L. Muhamud, and M.H. Ibrahim, (2020) regarding the effect of injection molding parameters on hardness and ultimate tensile strength. The independent variables used are molding temperature (170°C, 180°C, 190°C), molding pressure (30%, 35%, 40%), molding speed (30%, 35%, 40%), and cooling time (5s, 6s 7s) (Kamarudin, et al., 2021). Another research was conducted by Karunia, Yoga, Purwanti, E. P. & Karuniawan, B. W. (2020) on researching the effects of injection molding machine parameters on head travel kit products on cycle time and product weight. The independent variables used are injection speed (15 mm/s, 20 mm/s, 25 mm/s), injection pressure (1500 bar/KN, 1600 bar/KN, 1700 bar/KN), and holding pressure (800 bar/KN, 900 bar/KN, 1000 bar/KN). The ideal parameter settings in this study are 25 mm/s for injection speed, 1586.8687 bar/kN for injection pressure, and 1000 bar/KN for holding pressure (Karunia, et al., 2020).

Therefore, this research raises the topic of optimization of injection molding machine parameters which aims to reference reading material in injection molding optimization studies. The response variable used is the net Bioing Cone Cup product. The material used is High Impact Polystyrene. The independent variables to be tested are injection pressure, injection temperature, and cooling time. Taguchi method is the method chosen to be applied in this study to determine the combination of factors of the research to be carried out to improve the quality of the production process of an item (Pujari & Naik, 2016).

Taguchi method is an optimization method that aims to optimize a process. This method is used to determine the combination of factors of the research to be carried out to improve the quality of the production process of goods and services (Soejanto, 2009). The Taguchi method was chosen because, compared to other optimization techniques. This optimization method does not allow for response collisions (Gupta, et al., 2020). The selection of an appropriate orthogonal array matrix is based on the number of degrees of freedom with the number of factor levels selected. In this experiment, the level used in each independent variable is three levels. The selection and determination of the level value in this independent variable is based on the specifications of the previous machine usage and also the capability of the injection molding machine.

The results of this research will be in the form of machine parameters that are better than before by using careful calculations and experiments. So that these optimal parameters can be useful for changing the injection results of the Bioring Cone Cup to be of higher quality and can produce a product weight that is agreed upon and uniform.

Changes in parameter settings for injection pressure, injection temperature, and cooling time are expected to have a major effect on production results. The success of this experiment certainly contributes greatly to the company in achieving profits because it can avoid weight errors that make production time longer than it should be.

RESEARCH METHODS

This research includes testing using an injection molding machine and analyzing the product results obtained. Experiments were carried out in the Sukodono molding service workshop for 5 months using the parameters that had been planned. As we know, injection molding research can differ based on the type of material used and the problems in the products made.

An example of problems in the research of Karunia, Yoga, Purwanti, E. P. & Karuniawan, B. W. (2020) using 25 mm/s for injection speed, 1586.8687 bar/kN for injection pressure, and 1000 bar/KN for holding pressure [5]. This research uses the same response variables as the author but is carried out with different calculation methods. While the problem in Purnomo, M. H., Sidi, P. &

Arumsari, N. (2017) used a melt temperature of 260°C, injection speed of 55 mm/s, holding time of 2 seconds, and cooling time of 5 seconds [10]. This research uses the same method as the author, but with different response variables.

Although the research uses the same machine parameters, the results of the research are certainly different. It can be concluded that the type of polymer and product also greatly affects the optimal parameters.

The research steps are carried out according to the flow chart below, this can help the research to be more focused on the objectives.

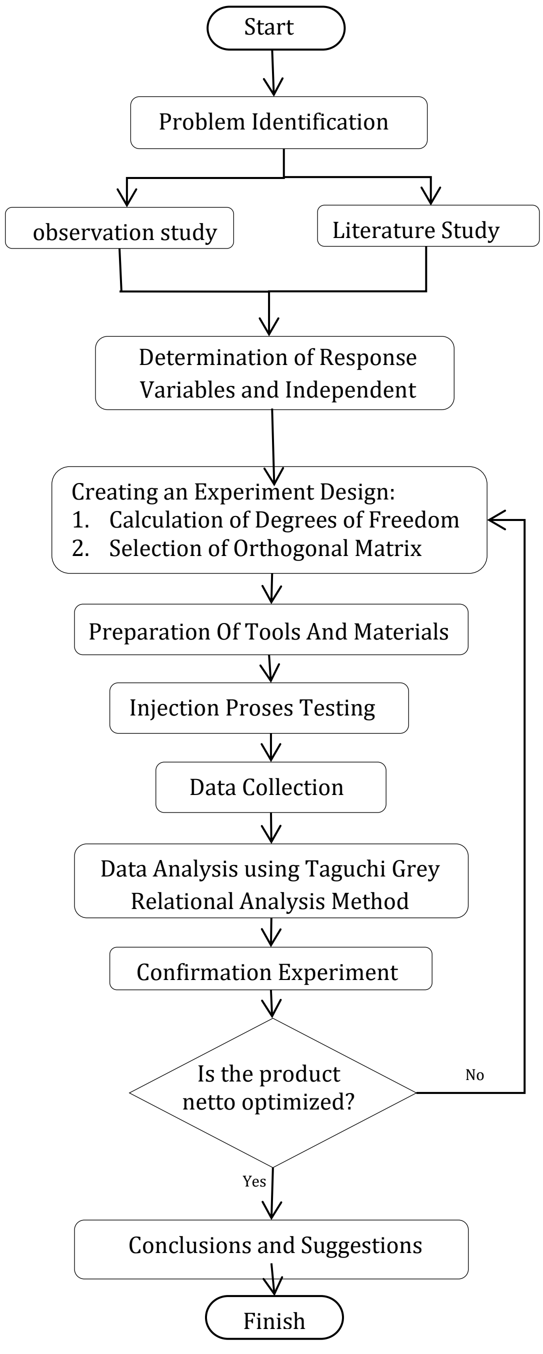

Figure 1. Research Methods

Selection of Response Variables and Independent Variables

The variables used in this experiment are as follows:

a. The response variable under study is net product. The characteristic chosen for netto is Smaller is Better, which means that the smaller the net difference value from the agreed value, the better the quality. Netto was determined to be the research response on the grounds that most of the product weight did not match the value specified by the customer.
b. The independent variables consist of the following parameters:
   1. Injection Pressure
      This parameter is used to determine the optimum condition because if the pressure value is too low, the nozzle cannot remove the plastic material from the inside (Soejanto, 2009).
   2. Injection Temperature
      Injection temperature is the temperature to melt a plastic material before it is injected through the nozzle.
   3. Cooling Time
      Cooling time is the time required to cool a product in the cavity.

Experiment Concept

In the research to be conducted, the level of each parameter is determined based on the conditions available on the machine. Table 1 shows the levels used in the independent variables.

Tabel 1. Independen Variabel

Variabel Independen	Level 1	Level 2	Level 3
IP (Bar)	80	85	90
IT(°*C*)	*220*	*225*	*230*
CT (s)	0.1	0.3	0.5

In this experiment, L9 (3^4) was used. This is adjusted to the results of the calculation of degrees of freedom.

Tabel 2. Konsep Eksperimen

Kombinasi	Variabel Independen		
	Injection Pressure (bar)	*Injection Temperature* (°*C*)	*Cooling Time* (s)
1	80	220	0,1
2	80	225	0,3
3	80	230	0,5
4	85	220	0,3
5	85	225	0,5
6	85	230	0,1
7	90	220	0,5
8	90	225	0,1
9	90	230	0,3

The tools and materials used in this experiment are as follows:

a. Ningbo Sanyuan injection molding machine model SYM-1000 for molding Bioring Cone Cup products.
b. An analytical balance is used to measure the net of the product.
c. The laptop is equipped with Minitab software.
d. Plastic seed material (High Impact Polystyrene). High Impact Polyestyrene was chosen because this material has a lower heat level, so this material has the advantage of providing an easy process in melting the material and saving costs (PT Cuan, 2020).

The experiment was conducted by molding High Impact Polystyrene plastic seed material using an injection molding machine in accordance with the experimental design regarding the combination of parameters and orthogonal matrices that have been determined previously. This test was carried out for nine times with the results of three replications. The results obtained will be measured by weight using an analytical balance.

Data Processing

This research applies the Taguchi method which aims to analyze the results obtained from the experiment. The following are the stages used in data processing (Rachman, et al., 2019):

a. Calculation of S/N Ratio
   The characteristic used for the net response is smaller is better, the form of the equation used is as follows:
   $$S/N\ ratio = -10log\left[\sum_{i=1}^{n}\frac{y_{i=1}^{2}}{n}\right] \quad (1)$$
b. Analysis of Variance (ANOVA) calculation
   ANOVA is used as one of the stages of analysis which aims to find out whether the parameter affects the response or not (Yanto, et al., 2018).
c. Optimum Value Calculation
   This stage aims to determine the most ideal parameter level for the response under study.
d. Prediction Value Calculation
   This calculation aims to determine the level of parameters that have an impact on the response. The form of the equation used is as follows:
   $$\mu_{prediksi} = \gamma_m + \sum_{i=1}^{q}\gamma_i - \gamma_m \quad (2)$$
e. Prediction Confidence Interval
   This calculation uses the form of the equation below:
   $$Cl_p = \sqrt{\frac{F_{a;\,d_{f1};d_{f2}}MS_E}{n_{eff}}} \quad (3)$$
f. Confirmation Confidence Interval
   This calculation uses the form of the equation below:
   $$Cl_k = \sqrt{F_{a;\,d_{f1};d_{f2}}MS_E\left[\frac{1}{n_{eff}}+\frac{1}{r}\right]} \quad (4)$$

RESULT AND DISCUSSION

After making the product on the injection molding machine, the next step is to process the data with the steps below:

Data Collection

Bioring Cone Cup products that have been molded in an injection molding machine will be measured using an analytical balance. Table 3 is the result of measuring the weight of the product on an analytical balance.

Tabel 3. Overall Experiment Data

Combination	R1	R2	R3
1	4,626	4,662	4,642
2	4,793	4,785	4,807
3	4,525	4,51	4,662
4	4,987	4,995	4,964
5	4,812	4,846	4,834
6	4,863	4,887	4,957
7	5,045	5,031	4,914
8	5,052	5,167	5,146
9	5,073	5,074	5,167

Netto has a specification value of 4.5 grams, the value will be reduced by 4.5 to find the smallest difference value so that the response can be optimized. The difference results are shown in table 4 below.

$\Delta W = W1 - W2$

Description:
W1 = Weight of experimental product
W2 = Weight of the initial product specification

Tabel 4. Netto Difference Result

Combination	R1	R2	R3
1	0,126	0,162	0,142
2	0,293	0,285	0,307
3	0,025	0,01	0,162
4	0,487	0,495	0,464
5	0,312	0,346	0,334
6	0,363	0,387	0,457
7	0,545	0,531	0,414
8	0,552	0,667	0,646
9	0,573	0,574	0,667

Data Processing and Analysis

The experimental results are then processed into the S/N ratio with the aim of finding parameters that have an impact on the response. The characteristic used is smaller is better using the form of equation 1. The S/N ratio value is shown in table 5 below. The calculation results of the first two experiments are as follows:

a. Experiment 1
   $$S/N_1 = -10log\left[\frac{0{,}126^2 + 0{,}162^2 + 0{,}142^2}{3}\right]$$
   $$= 16{,}827$$

b. Experiment 2

$$S/N_2 = -10log\left[\frac{0{,}293^2 + 0{,}285^2 + 0{,}307^2}{3}\right]$$
$$= 10{,}599$$

Tabel 5. S/N ratio calculation of Netto results

Combination	R1	R2	R3	S/N Rasio
1	0,126	0,162	0,142	16,827
2	0,293	0,285	0,307	10,599
3	0,025	0,01	0,162	20,463
4	0,487	0,495	0,464	6,336
5	0,312	0,346	0,334	9,604
6	0,363	0,387	0,457	7,866
7	0,545	0,531	0,414	6,018
8	0,552	0,667	0,646	4,101
9	0,573	0,574	0,667	4,347

After obtaining the S/N ratio value, the analysis of variance stage is continued, which is a quantitative calculation by estimating the contribution of each factor to all response measurements. In this stage, it is necessary to calculate the degrees of freedom (df), Sum of squares (SS), Mean of square (MS), and also F_{value}. Table 6 is the result of the calculation of the analysis of variance of the netto S/N ratio.

Tabel 6. Analysis of variance Netto

Source	DF	SS	Cont.	MS	F_{hitung}
IP	2	198,265	77,58%	99,132	22,08
IT	2	11,784	4,61%	5,892	1,313
CT	2	36,526	14,29%	18,263	4,069
Error	2	8,978	3,51%	4,489	
Total	8	255,552	100,00%		

The hypothesis test for this experiment uses Ftabel with a 95% confidence interval. Df1 is the number of degrees of freedom for the factor while Df2 is the number of degrees of freedom for the *error.* If $F_{value} < F_{tabel}$, then it is decided that H0 can be accepted, which indicates that the response is not significantly affected. Meanwhile, if $F_{value} > F_{tabel}$, then H0 is rejected, indicating that there is a large influence on the response.

Tabel 7. Hypothesis Test

Source	F_{hitung}	Hypothesis
IP	22,08	H_0 ditolak
IT	1,313	H_0 diterima
CT	4,069	H_0 diterima

Next is the stage of finding the most optimal parameter level value. This optimal parameter level will be used as a reference for process improvement in the *net* response*. The* data used in the optimal calculation is the S/N ratio value.

Tabel 8. Most optimized parameters for netto

Level	IP	IT	CT
1	15,963	9,727	9,598
2	7,935	8,102	7,094
3	4,822	10,892	12,028
Delta	11,141	2,790	4,934
Rank	1	3	2

Based on table 8, the optimal parameters for the netto response are the injection pressure factor at level 1 of 80 bar, the injection temperature factor at level 3 of 230℃, and the cooling time factor at level 3 of 0.5 s. Figure 2 is the result of the graph of the optimal parameter factor level against the net response in Minitab software.

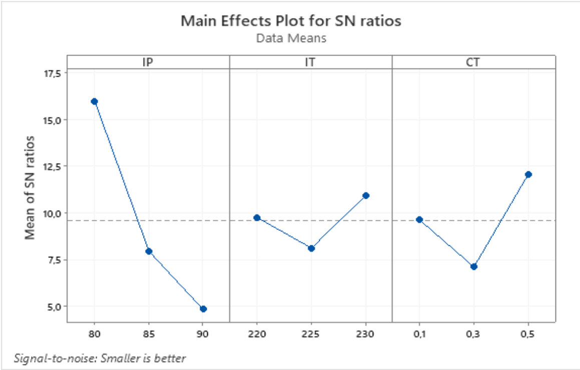

Figure 2. Graph of influential parameter values

The following is the calculation of the predicted value using equation 2.

$$\mu_{prediksi} = \gamma_m + \textstyle\sum_{i=1}^{q} \gamma_i - \gamma_m$$
$$= 9{,}573 + ((15{,}963 — 9{,}573)) + (10{,}892 — 9{,}573)) + (12{,}028 — 9{,}573))$$
$$= 19{,}736$$

The next stage is to interpret the experimental data which attempts to calculate the prediction interval value that will be contrasted with the confirmation experimental interval value. The chosen confidence interval value is 95% with $F_{(0,05;1;2)}$ = 18.513. This calculation uses equation 3.

n_{eff} = number of effective observations

$$= \frac{9x3}{1+2+2+2}$$
$$= 3{,}857$$

$$Cl_p = \sqrt{\frac{F_{a;\,df1;df2} MS_E}{n_{eff}}}$$
$$= \sqrt{\frac{18{,}513x4{,}489}{3{,}857}}$$
$$= \pm 4{,}642$$

$$\mu_{prediction} - Cl_p \leq \mu_{prediction} \leq \mu_{prediction} + Cl_p$$
$$19{,}736 - 4{,}642 \leq \mu_{prediction} \leq 19{,}736 + 4{,}642$$
$$15{,}095 \leq \mu_{prediction} \leq 24{,}378$$

Confirmation Experiment

This stage of the confirmation experiment is used to confirm the predicted value whether it is in accordance with field conditions or not. This calculation uses equation 4 for the calculation of the confirmation confidence interval.

$$Cl_k = \sqrt{F_{a;\,d_{f1};d_{f2}} MS_E \left[\frac{1}{n_{eff}} + \frac{1}{r}\right]}$$

$$= \sqrt{18{,}513x4{,}489 \left[\frac{1}{3{,}857} + \frac{1}{3}\right]}$$

$$= \pm 7{,}018$$

$$\mu_{confirmation} - Cl_k \leq \mu_{confirmation} \leq \mu_{confirmation} + Cl_k$$

$$15{,}519 - 7{,}018 \leq \mu_{confirmation} \leq 15{,}519 + 7{,}018$$

$$9{,}502 \leq \mu_{confirmation} \leq 23{,}537$$

The minimum and maximal confidence levels are 9.502 and 23.537, This was obtained from the confidence interval calculation results. In addition, as shown in figure 3 below, the graph is used to compare the confidence interval values of the prediction experiment and the confirmation experiment.

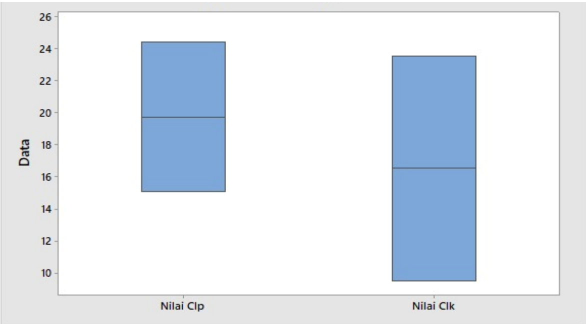

Figure 3. Comparison graph of predicted and confirmed experimental values

Based on the confidence interval graph in Figure 3, it can be seen that both confidence intervals have intersecting values. Then the prediction results are declared successful with the evidence of the implementation of the confirmation experiment.

CONCLUSION

Based on experience on *injection* molding machines and the theory of *injection molding* machines, it is known that the parameters that affect the net response are injection *pressure, injection temperature,* and *cooling time*. However, in this test, it is found that the influential parameter is *injection pressure* by 77.58%, while the parameters of *injection temperature* and *cooling time* do not have a significant effect on the *net* response, namely with a percentage contribution value of 4.61% and 14.29%.

The levels of the ideal process parameters obtained by applying the Taguchi method are *injection pressure of* 80 bar, *injection temperature of* 230°C, and cooling time of 0.5 s.

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