Optimizing Injection Molding Parameters to Cycle Time of Bioring Cone Cup Products with Taguchi Method

Farizi Rachman[1], Bayu Wiro Karuniawan [2], Ika Pramestiani[3]. Noorman Rinanto[4]
(Received: 06 September 2023 / Revised: 06 September 2023 /Accepted: 06 September 2023)

***Abstract*— At the Sukodono molding company which produces Bioring cone cups using injection molding machines, a trial and error process to obtain parameter setting values on the machine is still applied in the early stages of production. This problem is detrimental to the company because they have to bear the production burden due to production delays. A solution is needed to optimize injection parameters with cycle time response. Therefore, this study proposes an analysis of the application of the Taguchi method by utilizing the signal for noise ratio to determine the influence of factors and also to optimize parameter such as temperature, pressure, and cooling time for the production process. The trial results show that the ideal blend of factors includes injection pressure parameters at level 1 with a value of 80 bar, injection temperature at level 2 in value of 225°C, and cooling time in level one with a value of 0.1 seconds.**

Keywords— *Cooling Time, Injection Pressure, Injection Temperature*.

I. Introduction

When making products out of plastic, the most crucial production process is injection molding. [2]. Injection molding machines often mold automotive goods, household products, electronic components, and more. This production process begins with determining the optimal parameters to produce perfect product quality [4]. In the production process, melted plastic seeds are injected into a mold with a certain pressure and speed to be formed in a mold [19]. The infusion shaping cycle can be partitioned into seven cycles: closing the mold, melting the material, filling the material, packaging, cooling, opening the mold, and ejection [6].

The materials utilized in the assembling of the item and furthermore the cycle boundaries play a significant part in assembling top notch items [14]. To deliver great items in a brief timeframe, the cycle boundaries should be upgraded [12]. The quality of a good product can be seen from its strength, curvature, durability, surface roughness, aesthetics, etc. In the injection process, there are parameters that need to be considered, namely hoding time, injection pressure, injection temperature, cooling time, and many more [10].

Bioring Cone Cup products are produced by Molding industry in Sukodono with Injection molding machines. However, at the beginning of production in obtaining parameter values still using a trial and error system, so this problem resulted in a fairly long production cycle time. With these problems, this company suffered losses because it had to pay compensation for production delays. So, research is needed that discusses the improvement of injection molding parameters to improve bioring cone cup products' cycle time response. Based on this background, this study raises the topic of optimization of injection molding machine parameters that can be used as reference material in future research on injection molding optimization. The response variable used is cycle time. The material used is High Impact Polystyrene. Injection pressure, injection temperature, and cooling time are the independent variables that need to be evaluated.

Taguchi method is a method that has the aim of improving product quality and reducing production costs so as to produce perfect. This method is often used in industry in optimizing the production process. The taguchi method of experiment design seeks to identify the most suitable response parameters [3]. The aftereffects of the taguchi technique can guarantee great quality from the outset of the interaction. The upside of applying the Taguchi strategy is that it can find impacting factors in a more limited time, in this way diminishing handling costs.

Currently, there are a few examinations that have been led to decide the impact of various boundary minor departure from the consequences of the infusion forming process. Qazi, et al., 2020 investigated the infusion forming process input boundaries of infusion temperature, infusion pressure, infusion speed, and shape temperature utilizing polystyrene and polypropylene materials [17]. The reaction factors examined were surface unpleasantness, shrinkage inflow, and cross-stream bearings. Taguchi technique with L_9 symmetrical cluster and ANOVA were applied to dissect the trial results. This study found that the optimal parameter variations for PS material were infusion temperature at 533,135 K, infusion tension at 60 Bar, infusion speed 80 mm/s, form temperature at

Farizi Rachman is with Departement of Marine Engineering, Politeknik Perkapalan Negeri Surabaya, Surabaya, 60111, Indonesia,
E-mail: *farizirachman@ppns.ac.id*
Bayu Wiro Karuniawan is with Departement of Marine Engineering, Politeknik Perkapalan Negeri Surabaya, Surabaya, 60111, Indonesia,
E-mail: *bayuwiro@ppns.ac.id*
Ika Pramestiani is with Departement of Marine Engineering, Politeknik Perkapalan Negeri Surabaya, Surabaya, 60111, Indonesia
E-mail: ikapramestiani02@gmail.com
Noorman Rinanto is with Departement of Electrical Engineering, National Taiwan University of Science and Technology, Taiwan,
E-mail: d10807818@mail.ntust.edu.tw

313,15 K. With respect to PP material, the ideal boundary results are infusion temperature at 513,15 K, infusion tension at 60 Bar, infusion speed 70 mm/s, mold temperature at 313,15°K.

Other research was also conducted by Saad, et al., 2019 examined injection molding parameters, namely form temperature, soften temperature, pressing strain, pressing time, cooling time, infusion speed, and infusion pressure [18]. The response variables studied were warpage and volumentric shrinkage. The hereditary calculation technique was applied to limit the two imperfections. Assuming that the initial data of defects is very important for optimization, the results can be shown that there is a close match with the results of the optimization, which differ by about 7% from the initial data.

Li, et al., 2019, examined the most effective optimization method in adding fiber parameters for the infusion shaping interaction. The response variables studied were warpage, volumetric shrinkage, and stress residual. Taguchi, RSM, and NSGA-II methods were combined with the aim of optimizing the fiber-reinforced composite injection molding procedure. The consequences of this study show that utilizing RSM and NSGA-II strategy is a viable technique to tackle the advancement issue for fiber-built up composite infusion shaping improvement.

Furthermore, there is research by Wang, et al., 2019 which examines the parameters for the injection molding procedure's input, namely melt temperature, injection speed, and mold temperature using polypropylene material. The response variable studied was the value of shrinkage defects. Taguchi method and ANOVA were applied to dissect the exploratory outcomes. The optimal parameter variation can be concluded to be 240°C melt temperature, 30 mm/s injection speed, and 90°C mold temperature [21].

Taguchi method is a method that has the aim of improving product quality and reducing production costs so as to produce perfect. This method is often used in industry in optimizing the production process. The purpose of designing experiments in the taguchi strategy is to decide the ideal boundaries for the reaction (Chen, et al., 2013) The consequences of the taguchi technique can guarantee great quality from the very start of the cycle. The upside of applying the Taguchi strategy is that it can find impacting factors in a more limited time, in this way decreasing handling costs.

In enhancement research, various mixes of cycle boundaries can be utilized. This is applied using the design of experiments and then statistically analyzing the experimental results according to the method chosen to produce the optimal machining process [9]. This exploration centers around deciding the ideal boundaries for the infusion shaping interaction on HIPS material to deliver an ideal process duration. The exploratory plan utilizes Taguchi technique, and the reactions are handled and broke down utilizing Sign to clamor proportion and ANOVA to assess the impact of every boundary on machining execution. It is hoped that this final project can be used as a reference, if there are the same problems in product analysis with different methods so that it will produce more accurate results.

II. Method

A. Taguchi Method

The Taguchi method is one way to make a process work better. This method aims to determine the combination of factors of the research to be carried out to raise the standard of the goods and services produced. Taguchi methods was picked on the grounds that contrasted with other advancement strategies, this enhancement procedure doesn't take into consideration reaction crashes [7].

In the Taguchi technique, there is an estimation of the S/N proportion that is utilized to upgrade the cycle boundaries [5]. The selection of the S/N ratio value is the highest among the others because it is the appropriate combination of process parameters [11]. S/N ratio has 3 criteria, but only one is chosen in this research, namely smaller is better because the response chosen in this research if the value is smaller, the value is better to apply. The more modest is better quality attribute of the S/N proportion is determined utilizing this condition [17].

$$S/N\ ratio = -10 \log \left[\sum_{i=1}^{n} \frac{y_{i=1}^2}{n} \right] \quad (1)$$

After obtaining S/N ratio value, the next step is to analyze data using ANOVA. Analysis of variance (ANOVA) is an analysis that aims to find out the most optimal parameters that affect predetermined variables [15]. These results are collected from data that has been interpreted using statistical methods. ANOVA is an experimental data analysis technique whose calculations use degrees of freedom (df), number of squares, mean of square, and Fvalue as in the following table.

The next step is to analyze the data using ANOVA. The stage after Anova is the calculation of optimal parameters which aims to determine the most ideal parameter level for the response under study. Then calculating the predictive value and confidence interval which aims to decide the degree of boundaries that affect the reaction. The form of the equation used is as follows.

$$\mu_{prediksi} = \gamma_m + \sum_{i=1}^{q} \gamma_i - \gamma_m \quad (2)$$

Equation for prediction confidence interval,

$$Cl_p = \sqrt{\frac{F_{\alpha; d_{f1}; d_{f2}} MS_E}{n_{eff}}} \quad (3)$$

Equation for confirmation confidence interval,

$$Cl_k = \sqrt{F_{\alpha; d_{f1}; d_{f2}} MS_E \left[\frac{1}{n_{eff}} + \frac{1}{r} \right]} \quad (4)$$

B. Experimental Work

Cycle time measurement is carried out when injecting material until the product is finished. Measurement of cycle time in the process of making this product starts when taking high impact polystyrene (HIPS) polymer material from the hopper, then injecting plastic into the mold until the product is removed from the mold with the help of an ejector pin. This cycle time measurement uses the help of a stopwatch because the injection molding machine with the Ningbo Sanyuan SYM-1000 brand still uses a manual system unlike other injection machines that already use computers. Figure 1 is the injection process carried out on the infusion forming machine.

Figure 1 Injection molding machine

C. Design and Experiment

Experimental design is an attempt to improve the design of a process by controlling several factors (parameters) that affect the response. At the experimental design stage, these are very complex steps because they must be prepared long before the experiment to get an analysis of the results and conclusions on the problems discussed [15]. In this research, there are 3 parameters that will be combined. These parameters are injection pressure, injection temperature, and cooling time. Each parameter has 3 different levels. The determination of the value of each parameter is adjusted to the abilities and particulars of the machine. High Impact Polystirene is the substance that was used in this study. Table 1 shows the boundaries interaction and their levels.

TABEL 1.
LEVEL OF PARAMETERS

Symbol	Parameter	Level 1	Level 2	Level 3
A	Injection Pressure (Bar)	80	85	90
B	Injection Temperature (℃)	220	225	230
C	Cooling Time (s)	0,1	0,3	0,5

The number of degrees of freedom with the number of levels of the chosen factor is used to select an appropriate orthogonal array matrix (Li, et al., 2023). 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 past machine use and furthermore the capacity of the infusion shaping machine. The equation of factor and degrees of freedom are as follows:

Vn = (Number of Level – 1)

In this examination there are three variables, so the levels of opportunity of elements and levels are gotten as displayed in table 2 below:

TABEL 2.
DEGREES OF FREEDOM OF FACTORS AND LEVELS

Symbol	Degrees Of Freedom	Amount
A	3-1	2
B	3-1	2
C	3-1	2
Total degrees of freedom for factor and level		6

In the calculation of the degrees of freedom of factors and levels, the value of 6 is obtained. The orthogonal array that corresponds to these calculations is $L_9(3^4)$. Table 3 is the calculation of the orthogonal array matrix using Minitab 19 software.

TABEL 3.
ORTHOGONAL ARRAY MATRIX

Combination	**Independent Variabel**		
	***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 symmetrical exhibit has three boundaries with three levels. There were a sum of nine mixes with three replication, and randomization was performed utilizing Minitab programming to balance the impact of wild figures on each investigation.

III. Results and Discussion

A. *Data Collection*

This experiment uses an injection molding machine with the brand Ningbo Sanyuan SYM-1000 in the Sukodono molding industry workshop. Cycle time measurement is carried out when injecting material until the product is finished. Measurement of cycle time in the process of making this product starts when taking high impact polystyrene (HIPS) plastic seed material from the hopper, then injecting plastic into the mold until the product is removed from the mold with the help of an ejector pin. This cycle time measurement uses the help of a stopwatch because this injection molding machine still uses a manual system unlike other injection machines that already use computers.

B. *Data Analysis*

Optimization is the solution to find out the optimal process in working on a product or to improve performance and find the product parameters based on the responses involved [1]. Cycle time optimization is useful for evaluating production time if there is a delay in product manufacturing, so that factor treatment will always be observed in the experimental process. The flow of processing cycle time data starts with the calculation of the S/N ratio, then continues using ANOVA calculations and finally calculates the optimal parameters to determine the parameter variables that are in accordance with the response.

Cycle time uses the characteristics of smaller is better which means the smaller the value, the better because the cycle time in the product manufacturing process is faster. In table 4 which is the result of the calculation of the S/N ratio cycle time. Based on table 4, it can be seen that the maximum S/N Ratio value is -22.234 in combination 8, while the minimum S/N Ratio is -31.427 in combination 5.

TABEL 4.
VALUE OF S/N RATIO CYCLE TIME

Combination	**R1**	**R2**	**R3**	**S/N Ratio**
1	13,96	13,33	13,70	-22,713
2	21,93	21,68	21,56	-26,739
3	35,57	35,66	35,88	-31,054
4	23,71	23,49	23,75	-27,477
5	37,18	37,56	37,06	-31,427
6	13,95	13,49	14,08	-22,824
7	36,06	36,18	36,54	-31,189
8	12,93	12,82	13,05	-22,234
9	23,61	23,11	23,76	-27,420

Next is the Analysis of variance stage, which is a quantitative calculation by estimating contribution of each element to all reaction estimations. The next stage is the Analysis of variance stage, which is a quantitative calculation by estimating contribution of each element to all reaction estimations [8]. ANOVA calculation requires the help of Minitab19 software to analyze the data. Table 5 shows the ANOVA results calculated using Minitab.

TABEL 5.
ANALYSIS OF VARIANCE OF S/N RATIO CYCLE TIME

Source	**DF**	**SS**	**MS**	$\mathbf{F_{hitung}}$
Injection Pressure	2	0,265	0,133	1,865
Injection Temperature	2	0,196	0,098	1,382
Cooling Time	2	111,972	55,998	786,66
Error	2	0,142	0,071	
Total	8	112,576		

Based on table 5, the F-value cycle time value for factor A (Injection Pressure) is 1.865, the value of factor B (Injection Temperature) is 1.382, and the value of factor C (Cooling Time) is 786.66. The Fvalue results will be utilized for speculation testing by looking at the Fvalue for each element with the F-table. In this experiment using F-table with a confidence level of 95% and $\alpha = 0.05$. The decision made is if Fvalue is bigger than F-table so H_0 is dismissed, however if Fvalue is more modest than F-table so H_0 is acknowledged. The hypothesis testing results are shown in table 6.

TABEL 6.
HYPOTHESIS TESTING

Parameter	F-value	F-table	Decision
Injection Pressure	1,865	19,00	H0 accepted
Injection Temperature	1,382	19,00	H0 accepted
Cooling Time	786,66	19,00	H0 rejected

The optimal level and effect on the response can be known by using the optimal parameter calculation. The largest S/N ratio can be used to determine the results of the optimal parameter combination. or determining the maximum value for each factor level [20]. The results of the optimal parameter calculation for cycle time are shown in Table 7.

TABEL 7.
THE RESULTS OF THE OPTIMAL PARAMETER FOR CYCLE TIME

Level	*Injection Pressure*	*Injection Temperature*	*Cooling Time*
1	-26,835	-27,126	-22,590
2	-27,242	-26,799	-27,212
3	-26,948	-27,093	-31,223
Delta	0,41	0,33	8,63
Rank	2	3	1

Based on table 6, the optimal parameters on the cycle time response are the injection pressure factor at level 1 with a value of 80 bar, the injection temperature factor is at level 2 with a value of 225℃, the cooling time factor is at level 1 with a value of 0.1 s. Figure 2 is the result of the graph of the optimal parameter factor level against the cycle time response in minitab software.

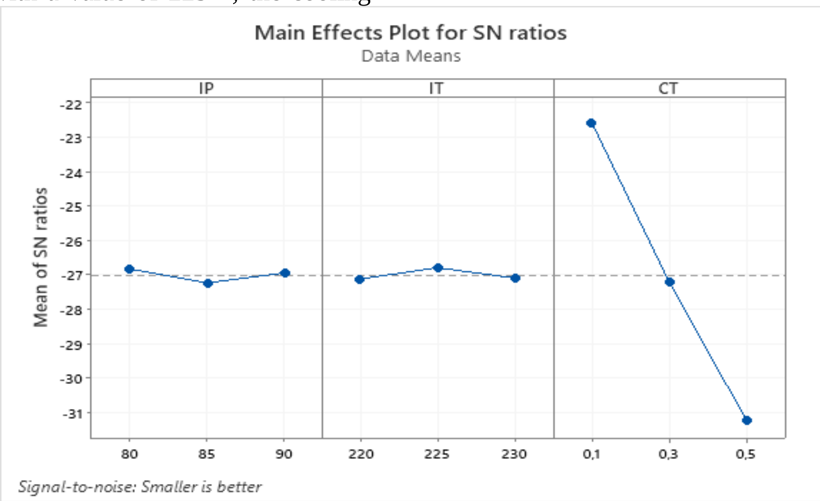

Figure 2 Graph of the optimal parameter factor for cycle time

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

$$\mu_{prediksi} = \gamma_m + \sum_{i=1}^{q} \gamma_i - \gamma_m$$

= -27,008 + (- 26,835 - 27,008)+(- 26,800- 27,008) + (- 22,590 - 27,008)

= - 22,209

The next step is to interpretation 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} = banyaknya pengamatan efektif

$$= \frac{9x3}{1+2+2+2}$$

= 3,857

$$Cl_p = \sqrt{\frac{F_{\alpha;df_1;df_2} MS_E}{n_{eff}}}$$

$$= \sqrt{\frac{18{,}513x0{,}071}{3{,}857}}$$

= ± 0,584

$$\mu_{prediksi} - Cl_p \leq \mu_{prediksi} \leq \mu_{prediksi} + Cl_p$$

-22,209 – 0,584 $\leq \mu_{prediksi} \leq$ -22,209 + 0,584

-22,793 $\leq \mu_{prediksi} \leq$ -21,624

C. 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.

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

$$= \sqrt{18{,}513x0{,}071 \left[\frac{1}{3{,}857} + \frac{1}{3}\right]}$$

$$= \pm 0{,}884$$

$$\mu_{konfirmasi} - CI_k \leq \mu_{konfirmasi} \leq \mu_{konfirmasi} + CI_k$$

-22,347 – 0,884 $\leq \mu_{konfirmasi} \leq$ -22,347 + 0,884

-23,231 $\leq \mu_{konfirmasi} \leq$ -21,464

The minimum and largest confidence levels are -23.231 and -21.464, respectively, which are 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.

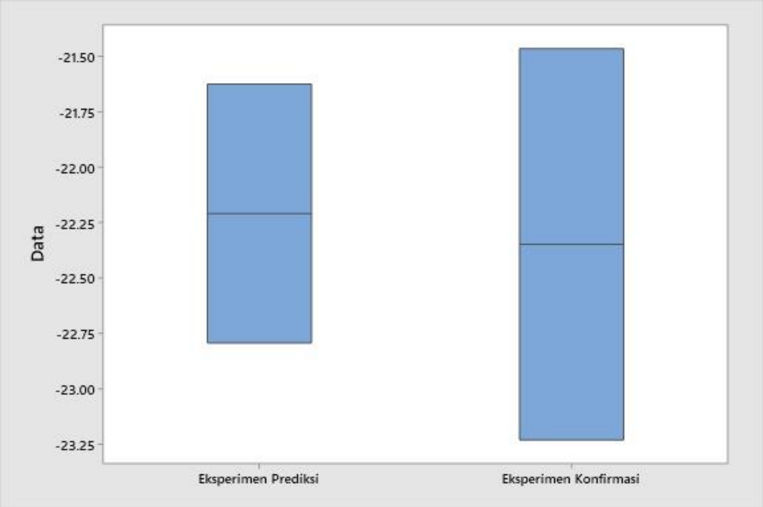

Figure 3 Comparison of Prediction and Confirmation Intervals

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.

IV CONCLUSION

In this study, the experimental design was created using the Taguchi method with orthogonal matrix $L_9(3^4)$ as much as three replication to obtain optimal parameter variation. In light of the consequences of information examination, the optimum combination of parameters for cycle time is injection temperature with a value of 80 bar, injection temperature with a value of 225°C, and cooling time with a value of 0.1s. The confidence level used is 95% (α = 0.05). The cooling time parameter has a significant influence with a contribution percentage value of 99.463%, while the injection pressure and injection temperature parameters do not have a significant effect on cycle time response, with contribution percentage values of 0.236% and 0.175%. For future research can be carried out experiments with the same response or product, but using different parameters.

ACKNOWLEDGEMENTS

The author would like to thank Politeknik Perkapalan Negeri Surbaya and machine operators in Sukodono molding industry services who have helped the author in collecting experimental data, providing support, and also motivation in completing this research.

REFERENCES

[1] Abel, A Barnabas; A, Oyentunji; S, O Seidu; Adeolu , A Adediran; Emmanuel, Igbafen (2019). Optimization of Parameters of Antimony Modified Carbidic Austempered Ductile Iron (CADI) using Taguchi Method. *Cogent Engineering, 6:1*.

[2] Alicia, B. R.-Y., Yaileen , M. M.-V., & Mauricio, C.-R. (2014). Simulation-based process windows simultaneously considering two and three conflicting criteria in injection molding. *Production & Manufacturing Research Vol. 2, No. 1* (pp. 603–623). Taylor and Francise.

[3] Chen, D. C., Jhang, J. J., & Guo, M. W. (2013). Application of Taguchi design method to optimize the electrical discharge machining. *Journal of Achievements in Materials and Manufacturing*, 76-82.

[4] Chen, W. C., Nguyen, M. H., Chiu, W. H., Chen, T. N., & Tai, P. H. (2016). Optimization of the plastic injection molding process using the Taguchi method, RSM, hybrid GA-PSO. *International Journal of Advanced Manufacturing Technology, 83*, (pp. 1873-1886).

[5] Feng, Q., & Zhou, X. (2019). Automated and robust multi-objective optimal design of thin-walled product injection process based on hybrid RBF-MOGA. *The International Journal of Advanced Manufacturing Technology, 101*, 2217-2231.

[6] Guan, Y. L., Wei, J. S., Feng, J. C., Chen, H. C., Ren, H. T., Sheng, J. W., et al. (2023). Optimize Injection Molding Process Parameters and Build an Adaptive Process Control Systems Based on Nozzle Pressure Profile and Clamping Force. *Journal Polymers Vol.15*.

[7] Gupta, M. K., Mia, M., Pruncu, C. I., Khan, A. M., Rahman, M. A., Jamil, M., et al. (2020). Modeling and performance evaluation of Al2O3 MoS2 and graphite nanoparticle-assisted MQL inturning titanium alloy: An intelligent approach. *Journal of the Brazilian Society of Mechanical Sciences and Engineering, 42(4)*, 1-21.

[8] Gurmet, S., Vivek, J., & Dheeraj, G. (2017). Multi-objective Performance Investigation of Orthopedic Bone Drilling using Taguchi Membership function. *Journal of Engineering in Medicine Vol. 231, issue 12*.

[9] Karuniawan, B. W., Rachman, F., & Setiawan, A. A. (2019). Optimasi Parameter Mesin Fused Deposition Modelling (FDM) terhdap Kekasaran Permukaan Prouk Menggunakan Metode Taguchi. *Jurnal Techno Bahari*, Volume 6, Nomor 2.

[10] Kashyap, S., & Datta, D. (2015). Process parameter optimization of plastic injection molding. *International Journal of Plastics Technology, 19(1)*, (pp. 1-18).

[11] Khamis, S. Z., Othman, M. H., Hasan, S., Main, N. M., Masrol, S. R., Shaari, M. F., et al. (2019). Multiple Responses Optimisation in Injection Moulding Parameter for Polypropylene-Nanoclay-Gigantochloa Scortechinii via Taguchi Method. *Journal of Physics: Conference Series*.

[12] Kitayama, S., Ishizuki, R., Takano, M., Kubo, Y., & Aiba, S. (2019). Optimization of Mold Temperature Profile and Process Parameters for Weldline Reduction and Short Cycle Timein Rapid Heat Cycle Molding. *The International Journal of Advanced Manufacturing Technology, 103*, 1735-1744.

[13] Li , K., Yan, S., Zhong, Y., Pan, W., & Zhao, G. (2019). Multi Objective Optimization of the Fiber-Reinforced Composite Injection Molding Process Using Taguchi Method, RSM, and NSGA-IIhod, R. *Simulation Modelling Practice and Theory Vol.91*, 69-82.

[14] Li, J., Zhao, C., Jia, F., Li, S., Ma, S., & Liang, J. (2023). Optimization of Injection Parameters Process Parameters for the Lining of IV Hydrogen Storage Cylinder.

[15] Lopez, A., Aisa, J., Martinez, A., & Mercado, D. (2016). Injection Molding parameters influence on weight quality of complex parts by mens of DOE application. *Measurement, Volume 90*, 349-356.

[16] Maden, H., & Cetinkaya, K. (2022). Production of The Design Developed to Assembly Filter Parts, Optimization of Welding and Field Test. *Strojniski Vestnik-Journal of Mechanical Engineering*, 657-668.

[17] Qazi, M. J., Tufail, H., Sahar, N., Muhammad , A., Shakir, A., & Qazi, M. Y. (2020). Multi Response Optimization of injection molding process parameters of polystirene and polypropylene to minimize surface roughness and shrinkage's using integrated approach of S/N Ratio and Composite Desirability Function. *Cogent Engineering*.

[18] Saad, M. M., Hanafy, M. O., & Fahad, A. A.-M. (2019). Experimental-Based Multi-objective Optimization of Injection Molding Process Parameters. *Arabian Journal for Science and Engineering*, 7653-7665.

[19] Singh, G., & Verma, A. (2017). A Brief Review on Injection molding manufacturing process. Materials Toda. *Materials Today: Proceedings 4(2)* (pp. 1423-1433). https://doi.org/10.1016/j.matpr.2017.01.164.

[20] Singh, G., Pradhan, M. K., & Verma, A. (2018). Multi Response Optimzation of Injection Molding Process Parameters to Reduce Cycle Time and Warpage. *Materials Today: Proceedings, 5(2)*, 8398-8405.

[21] Wang, M. W., Arifin, F., & Huang, J. Y. (2019). OPTIMIZATION OF THE MICRO MOLDING OF A BICONCAVE STRUCTURE. *International Journal of Technology 10(2)*, 269-279.