Recycled Polypropylene Filament for 3D Printer: Extrusion Process Parameter Optimization

Herianto¹, S I Atsani², and H Mastrisiswadi³
¹,² Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada, Indonesia
³ Department of Industrial Engineering, UPN “Veteran” Yogyakarta, Indonesia
E-mail: herianto@ugm.ac.id

Abstract. The presence of recycled plastic materials for the 3D printing process expects that the production process will be more environmentally friendly and solve the problem of plastic waste globally. However, recycled plastic as a filament material in the 3D printing process is still limited. One of the ways to make recycled plastic filaments is by extrusion. This research aims to optimize the extrusion process parameters in the manufacture of recycled plastic filaments (Polypropylene) that have never been conducted before. The extrusion process was analysed using the Taguchi and ANOVA methods. The results of this study indicate that the spooler speed of 4 rpm, extrusion speed of 40 rpm, and extrusion temperature of 200°C in the parameter setting produce an average filament diameter of 1.6 mm. However, filaments made from Recycled Plastic (Polypropylene) have a rough and easily curved surface, so further research is needed.

1. Introduction

Plastics are used in various fields of life such as packaging, transportation, building materials, electronic components, and consumer products [1,2]. The high demand for plastic causes an increase in plastic production in the world [3]. However, most plastics are only used in a short time and then discarded. This plastic waste then contaminates almost all parts of the world and becomes a global problem [1,4–6].

To be able to deal with the increasing amount of plastic waste, various efforts have been made to be able to recycle. The use of recycled plastic is expected to reduce the amount of plastic waste in the world. One of the developing technologies and applications of plastic as its main material is Fused deposition modelling (FDM). In FDM, material in the form of plastic filament is heated to near the melting point and then extruded according to the existing design [7,8]. The use of filament made from recycled plastic has been done before [9,10], but it is still very limited. With the use of recycled plastic material on FDM technology, it is expected that an FDM process that is more environmentally friendly and can solve the problem of plastic waste globally is expected.

The process of making material in the form of plastic filament for FDM can be done using an extrusion process [11]. The extrusion process is carried out by an extruder machine which functions to push or force the material through the gap to get the product as an extrudate [11]. In this extrusion process, many factors can affect the quality of the product.

Research on optimal parameters in the extrusion process has been carried out by many researchers. [12] used the extrusion temperature and winding machine parameters for PLA material
from corn. The results of this study stated that there was a match between extrusion temperature and extrusion speed and the diameter of the resulting filament. Besides, the winding machine influences the regularity of the filament. [13] conducted a study using the die temperature, roller puller speed, spindle speed, and inlet temperature as parameters for PCL-PLA composite materials. In his research, the results showed that the roller puller speed and spindle speed have a strong interaction as a factor in making filaments. Meanwhile, [14] conducted research using barrel and platform temperature parameters on PP material. In the study, the best temperature parameters were obtained to process PP between 210°C-250°C.

Until now, there have been no studies to find out about how to optimise the extrusion process on recycled plastic as FDM material. Although [14] uses PP material, the material used is not recycled material. Besides that, the parameters used are only limited to the temperature. In this study, other parameters will be added, namely spooler speed and extrusion speed. Therefore, this study aims to determine the optimal parameters in recycled plastic extrusion as FDM material so that it can be utilized in the production process.

2. Methods

2.1. Material

The material used in this study is Polypropylene (PP). PP has been widely used in human life, such as electric devices, automotive parts, and household appliances. Research on recycled PP material as FDM material has been carried out by [10]. From the research, it can be concluded that recycled PP can be used as an FDM material, except that it hasn't optimized the extrusion process.

2.2. Response variable

The response variable in this study is the filament diameter. Ideally, the filament must have a constant diameter along with the spool. The diameter of the commonly used filament in FDM is 1.75, with a tolerance standard of 0.05 mm. If the filament diameter is not constant, a severe problem will arise. If there is a decrease in diameter, the extrusion process will decrease the amount of material needed so that the filament fails to enter the hot end. If there is an increase in diameter, the extrusion process will experience an excess amount of material so that the extruder is not strong enough to attract the filament to enter the hot end.

2.3. Experimental design
The process of data retrieval is conducted by doing an extrusion process under the parameters to be optimised. The parameters in the extrusion process are spooler speed, extrusion speed and extrusion temperature. Spooler speed has two levels, 2 and 4 rpm. Extrusion speed also has two levels, 40 and 50 rpm while extrusion temperature has three levels, that are 180°C, 190°C, and 200°C.

2.4. Based on the parameters that have been determined, the experiment was compiled using L36 orthogonal array. The experimental design used in this study can be seen in Table 1. The extrusion process is carried out according to the design of the experiment that has been made. Filament results of extrusion for each element were then measured in diameter and analysed using the Taguchi and ANOVA methods. The use of the Taguchi method is used to determine the optimal level for each parameter, while the ANOVA is used to determine the relationship of parameters with the response variable. The results of processing these data are then tested for validity.

| Experiment | Spooler speed (Rpm) | Extrusion speed (Rpm) | Extrusion temperature (°C) |
|------------|---------------------|-----------------------|---------------------------|
| 1          | 2                   | 40                    | 180                       |
| 2          | 2                   | 40                    | 190                       |
| 3          | 2                   | 40                    | 200                       |
| 4          | 2                   | 40                    | 180                       |
| 5          | 2                   | 40                    | 190                       |
| 6          | 2                   | 40                    | 200                       |
| 7          | 2                   | 40                    | 180                       |
| 8          | 2                   | 40                    | 190                       |
| 9          | 2                   | 40                    | 200                       |
| 10         | 2                   | 50                    | 180                       |
| 11         | 2                   | 50                    | 190                       |
| 12         | 2                   | 50                    | 200                       |
| 13         | 2                   | 50                    | 180                       |
| 14         | 2                   | 50                    | 190                       |
| 15         | 2                   | 50                    | 200                       |
| 16         | 2                   | 50                    | 180                       |
| 17         | 2                   | 50                    | 190                       |
| 18         | 2                   | 50                    | 200                       |

3. Result and Analysis

3.1. Taguchi analysis

Before carrying out the Taguchi analysis, measurements were made on the diameter of the filament produced by each experiment. Filament measurements are carried out at three different points every 9 cm. Measurements are made using a digital Vernier calliper. The results of these measurements are then calculated as averages and standard deviations (Table 2).

| Experiment | Location 1 | Location 2 | Location 3 | Average | Standard deviation | S/N Ratio |
|------------|------------|------------|------------|---------|--------------------|-----------|
| 1          | 1.88       | 1.92       | 1.82       | 1.87    | 0.05               | 18.09     |
In this study, the variable response is the filament diameter. The ideal filament diameter is a diameter close to 1.75 mm. Therefore the "normal is best" condition in Taguchi is chosen. After measuring the diameter, the next step is to calculate the S/N ratio. The S/N ratio calculation in Taguchi is done by entering the response value and factors in the Minitab Software. The results of the calculation of S/N ratio can be seen in Table 2. After calculating the S/N ratio, the next step is to calculate the average signal to noise ratio for each parameter and level (Table 3). In Table 3, the largest delta value is in the C (Extrusion temperature) parameter and followed by the spooler speed and extrusion speed.

**Table 3. Average signal to noise ratio for each parameter and level**

| Parameter | Level | A     | B     | C     |
|-----------|-------|-------|-------|-------|
|           | 1     | 22.07 | 23.3  | 21.32 |
|           | 2     | 23.3  | 22.07 | 22    |
|           | 3     | -     | -     | 24.73 |
| Delta     | 1.24  | 1.23  | 3.4   |
| Rank      | 2     | 3     | 1     |
The average signal to noise ratio data is then created in the form of scatter plots that can be seen on Figure 1. Based on Figure 1, the best diameter response from factor parameters is extrusion temperature 200°C (C3), spooler speed 4 rpm (A2), and extrusion speed 40 rpm (B1).

![Figure 1. Scatter plot of average signal to noise ratio](image)

3.2. ANOVA

ANOVA is used to determine the relationship between each parameter to the filament diameter. ANOVA can only be done if the data used is normally distributed. Before conducting ANOVA, a normality test was carried out on the average data (Figure 2) and the S/N ratio (Figure 3).

![Figure 2. Normality test for average data](image)
Figure 3. Normality test for S/N ratio data

ANOVA is done using the help of the Minitab software. The results of ANOVA can be seen in Table 4. In Table 4, it can be seen that the parameters A (spooler speed) and C (extrusion temperature) have a P-value of less than 0.05. It means that both settings are parameters that have a significant effect on filament diameter.

Table 4. ANOVA results

| Source | DF | Adj SS | Adj MS | F-value | P-value |
|--------|----|--------|--------|---------|---------|
| A      | 1  | 1.538  | 1.538  | 64.4    | 0       |
| B      | 1  | 0.076  | 0.076  | 3.22    | 0.08    |
| C      | 2  | 2.084  | 1.042  | 43.65   | 0       |

3.3. Validity test

Validity test is conducted by extruding the filament using optimal parameters. The results of the extrusion process using optimal parameters are then measured at three different points. The results of this measurement are then used to calculate the actual S/N ratio and mean. The actual results are compared with prediction results and then the rate of deviation is calculated. The calculation of the validity test can be seen in Table 5. In Table 5, it can be seen that the deviation of the S/N ratio is 5.7%. It shows that the accuracy rate is 94.3%. However, the results of the extrusion process with this parameter have a rough and easily curved surface, so further research is needed.

Table 5. The calculation of the validity test

| Point | Diameter | Actual  | Prediction | Error Level |
|-------|----------|---------|------------|-------------|
|       |          | S/N ratio | Mean | S/N ratio | Mean | S/N ratio | Mean |
| 1     | 1.72     | 27.44   | 1.65  | 25.96     | 1.39  | 5.7%       | 18.7%|
| 2     | 1.65     |          |       |           |       |           |       |
| 3     | 1.58     |          |       |           |       |           |       |

4. Conclusion

The extrusion process to produce filament as material on FDM can be done using recycled PP. Based on the Taguchi analysis, the optimal parameter for producing recycled PP is extrusion temperature 200°C (C3), spooler speed 4 rpm (A2), and extrusion speed 40 rpm (B1). Meanwhile, based on
ANOVA parameters that have a significant effect on filament diameter are spooler speed and extrusion temperature. The results of this study were tested for validation and obtained an S/N ratio deviation rate of 5.7%. Further research is still needed to be able to produce recycled PP filaments with better properties.

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