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PARAMETER OPTIMIZATION IN 3D PRINTER RECYCLE MACHINE

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ABSTRACT

3D printing technology has evolved rapidly to becoming one of the most postulate method in manufacturing process. Commonly, standard manufacturing process which is subtractive that produces a lot of waste opposite to 3D printing technology is way friendly to the environment. The idea of this application additive manufacturing method in 3D printing leads to less or no wasted materials and consumption of plastic materials has significantly increased due to high demand in market. However, the plastic waste products from the 3D printing still undergo significant increase due to the problem in every human-made creation. In order to minimize the negative impact of plastic waste to the environment, a machine of recycle 3D printing has been made and study on parameter optimization on 3D printer recycle machine have been done. The study used Minitab software to analyze the factor of parameter of 3D printing recycle machine. Taguchi method was used to suggest some experiments to be performed and provides an optimal value for each parameter that needs to be optimized in the operation of extruding. Analysis of extruded filament was conducted for every 30cm with minimum of three repetitions. In comparison of the new extruding filament and original filament show that some minor difference of the mechanical properties by using tensile test method. Percentage of error for diameter of filament indicates that 1.77mm diameter with 1.14% as the lowest error while diameter of 1.82mm with 4.00% as the highest error. This shows that 3D printer recycle machine has been optimized with the percentage of error below than 5% and it could be further improved in order to help in minimizing the negative impact of plastic wastes to the environment.

Keywords: 3D printing, recycle machine, optimization process, filament, sustainable design.

INTRODUCTION

In today's era, technology evolves rapidly from day to day. Rapid prototyping (RP) or mostly known as 3D printing is a good example of growth manufacturing technology which just not increase production rate but also saves time consumption and overall cost including cutting down labor cost (Ramli *et al.,* 2018). There are a lot of advantages in 3D printing especially ability to produce complex physical model in a layer by layer process. Before we can successfully manufacture a batch of zero defect product, there is always some reject of final products due to human error or technical error. Due to this, there will be a bunch of 3D printed material waste (Nazan *et al.,* 2017a).

3D printing plastic filament is available in a variety of types of materials, colours, diameters and lengths. Two types of materials commonly used as filament for 3D printing are Polylactic Acid (PLA) and Acrylonitrile-Butadiene-Styrene (ABS). Both materials are plastic based which are easy to melt once it is exposed to heat. 3D filament is the basic consumable resource that most types of 3D printers use for printing (Nazan *et al.,* 2017b). Most of the filament produced today is from virgin, unused petroleum-based plastic which generates not only increasing amounts of global waste but also contributes to carbon emissions, resulting in significant environmental damage. That is why it is necessary to recycle the rejected products to prevent waste and to achieve cost effective production in 3D printing technology (Mat *et al.,* 2019 & Rosli *et al.,* 2019).

In market, there are many types of 3D printer recycle machine even we can make it by our own. There are some important parameters in 3D printer recycle machine such as material, pressure and temperature. The aim for this project is to optimize parameters of 3D printer recycle machine which could significantly produce a new filament from the recycled material. These can be achieved by recycling error or failed printed of 3D project by shredding and extruding process into a new filament.

LITERATURE REVIEW

3D printing is a common method being used in rapid prototyping technology. It is basically used to manufacture plastic parts that are used for concept visualization or even final parts (Mat *et al.,* 2009). Bak (2003) stated that during future dramatic increase within the application of 3D printing generation. In addition, manufacturers in various industries already implement the use of 3D printing due to its efficiency and faster rate of production. These mean that 3D printing is on rising demand for production line nowadays (Ramli *et al.,* 2019). As the benefits of 3D printing have lured many developers and manufacturers to use it, this situation results the high volume of filament usage for printing. That is why this state has led inventor to develop waste recycle system for low cost 3D printing so that the waste can be put into used without having to spend so much money to buy new set of filaments.

To meet the objective of having an integrated recycle machine of a low cost 3D printing, Ramli *et al.*,

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(2015) came out with a concept system. The concept was about low-cost 3D printers that are integrated with a plastic waste recycle machine which can produce filament with only one cycle of process. In addition, the cost of feedstock for 3D printing were reduced along with the energy used because of the proposed system did not use filament but fed directly from the shredded plastic waste as the source of the recycle machine. In order to optimize manufacturing process, there are several important criteria need to be considered. For 3D printer recycle machine, the important parameter need to optimize are the pressure, temperature and the material used (Udroiu and Nedelcu, 2011).

There are two types of filament that are commonly being used in 3D printing which are Polylatic Acid (PLA) and Acrylonitrile butadiene styrene (ABS). Two recent open-source equipment innovative improvements, 3D printers and RecycleBots, offer another way to deal with polymer reusing enveloping the potential for disseminated handling to high-value included items (Kudus *et al.*, 2019). Kreiger *et al.*, (2014) stated that this can reverses the historical trend towards centralized recycling facilities. Commercial 3D printers, which allow for accurate fabrication of merchandise or scale fashions, are a beneficial production and design tool.

Kreiger *et al.,* (2014) stated that the processes involve in transforming plastic wastes of 3D printing into usable filament are shredding and extruding. Company such as MakerBot and Filamaker had as of now start the mission to reuse the plastic squanders. From that point, different open source designers took after their means in improving the reuse innovation and agree to the objective to lessen the effects to the earth.

Tensile testing, also known as tension testing is a fundamental materials science and engineering test in which a sample is subjected to a controlled tension until failure. Properties that are specifically measured by means of a ductile test are extreme elasticity, breaking quality, most extreme extension and lessening in zone. From these estimations the accompanying properties can likewise be resolved: Young's modulus, Poisson's proportion, yield quality, and strain-solidifying attributes (Tanikella *et al.*, 2017).

Uniaxial elastic testing is the most regularly utilized for acquiring the mechanical qualities of isotropic materials. A few materials utilize biaxial tractable testing. The examples of filament are tried for elasticity strength during tensile test. The outcomes are displayed and conclusions are drawn about the mechanical properties of different melded filament manufacture materials. The examination exhibits that the elasticity strength of a 3D printed specimen depends to a great extent on the mass of the specimen, for all materials (Mohan *et al.,* 2017).

METHODOLOGY

Taguchi Method

The recycled material of ABS was chopped in small form to be placed in a recycle machine Filastruder for easier melting process. Filastruder machine is set with parameters of power, speed and temperature from Taguchi optimal extruding parameters suggestion. Taguchi method will be used to design a suitable orthogonal array experiment for a new filament. L9 orthogonal array design is used to conduct this experiment. The information needed to get from this experiment is an average diameter of every nine experiment results. Measurement for each filament‘s diameter is done by using vernier caliper for every 50mm. After that, this data will be entered into the Taguchi method to obtain the result of the optimal process parameter values. Results that can be obtained from Taguchi method are analysis of the signal-to-noise and analysis of variance. This analysis is to investigate which of the process parameters significantly affect the performance characteristics. The lower-the-better performance characteristic for diameter of filament should be taken for obtaining optimal machining performance. Taguchi method also can give the predicted regression equation to determine the optimal diameter for extruding filament.

Table-1 shows experimental layout for the three extruding parameters using the L9 orthogonal array. On this observe, L9 orthogonal array are used. This array has twenty six ranges of freedom and it may cope with three-level parameters.

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Table-1. Experimental layout using an L9 orthogonal array.

Experiment number	Extruding parameter level			
	C1	C2	C3	C4
	Power (W)	Speed (m/s)	Temperature (C)	Diameter (mm)
1	1	1	1	
2	1	2	2	
3	1	3	3	
4	2	1	2	
5	2	2	3	
6	2	3	1	
7	3	1	3	
8	3	2	1	
9	3	3	2	

Extruding Process

Acrylonitrile butadiene styrene (ABS) such as error/failed printed product is used to be a raw material. The material was chopped in small form to be put in Filastruder for easier melting process. Then, the switch for temperature controller is put on in order to let the heater band to heat the connector and the end part of barrel evenly.

Initial temperature was set at 225°C. The 12V and DC-geared motor rotate the drill bit smoothly without causing friction with the inner side of the barrel. That is possible with the help of the coupler. Small amount of the waste granules is poured into the hopper in order to observe and determine the performance of the extrusion system. The motor is turned off for a while in order to let the waste polymer to melt properly before being extruded. Figure-1 shows the extruded filament.

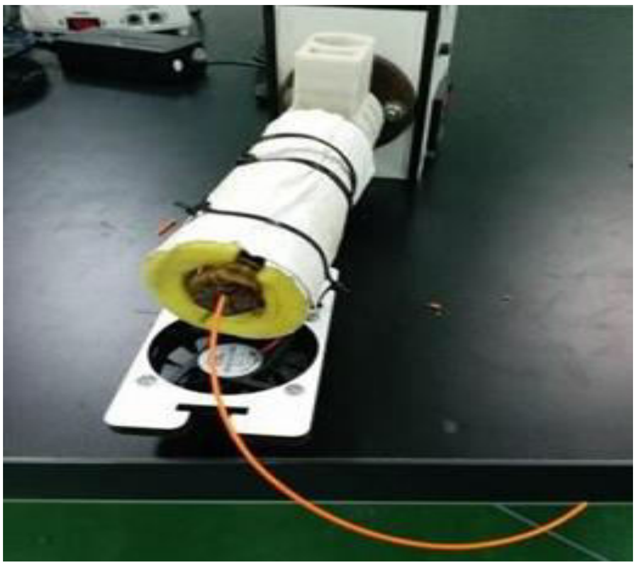

Figure-1. Filament extruded out from nozzle.

New filament produced from Filastruder need to be extruded to 300mm. After that, the measurement of average diameter of new filament every 300mm is done using vernier calliper. From this data, the percentage of error will be obtained as to determine the dimensional accuracy of new extruded filament compare to dimensional of original filament. The formula is shown in equation below.

$$\text{Percentage of error (\%)} = \frac{\text{Dia. Experimental - Dia. theoretical}}{\text{Dia. theoretical}} \quad \text{(Eqn. 1)}$$

Printing Process

Fused Deposition Modelling (FDM) is used to print the specimen test using these two materials (ABS) filament and recycled filament. Products with same polar print, infill density, layer thickness, dimension and printing setting are printed. Kossel is an open source of Fused Deposition Modelling machine made is used to print the product. The product to be printed is a dog bone or specimen test for tensile test in order to obtain a mechanical properties such as stress, strain and young Modulus.

The product to print is a dog bone or specimen test for tensile test to obtain a mechanical properties such as stress, strain and young modulus. An open source machine (Kossel) is used to print the specimen test as shown in Figure-2 and a specimen test in STL format that was designed using Repetier software is shown in Figure-3.

Figure-2. Fused Deposition Modelling (FDM) used to print the product.

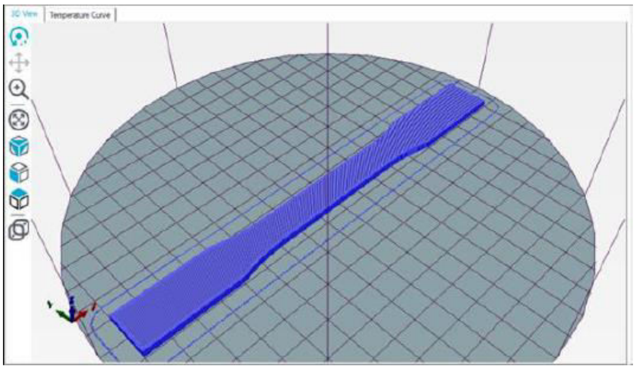

Figure-3. Tensile test specimen in STL format.

In order to compare the mechanical properties of two different material of filaments, the specimen test must be printed in same print characteristic. Table-2 shows the print characteristics of (ABS) filament and new extruded filament.

Table-2. Characteristic print of filament.

Dimension	Standardized
Polar print	Rectilinear
Layer height	0.2 mm
Infill density	20 %
Angle	45 °
Temperature nozzle	220 °C
Temperature bed	90 °C

Tensile Test

Another analysis is obtained from tensile test for new filament and original filament by using Instron Material Testing machine. Figure-4 shows the shape of ductile specimen at various stage of testing. The aim of this analysis is to produce theoretical data and based on this, only the parameter optimization can be performed. Analysis data also required as to compare the data of new recycled filament and data of original filament. In order to get a new recycled filament with occupied a specification of good filament, thermoplastic material and other waste polymer materials are used.

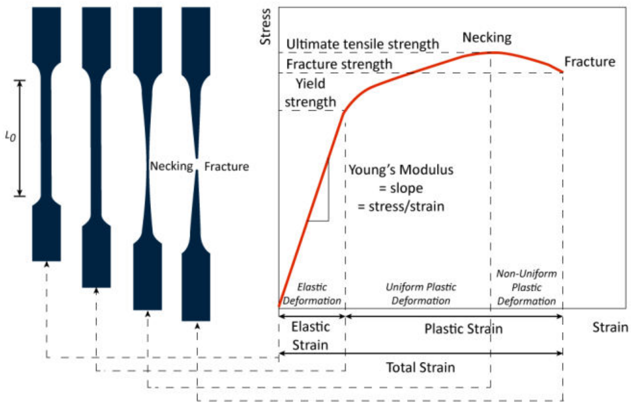

Figure-4. Tensile test specimen at various stage of testing (https://www.admet.com).

RESULTS AND DISCUSSIONS

Taguchi Results

Printed product wastes (recycled filament) were chopped in small form and put in recycle machine Filastruder for easier melting process. Optimization of the extruding parameters primarily based at the parameter design of the Taguchi method that is adopted in this paper to improve dimensional in an extrude operation. Based on background study, the melting temperature point for ABS material is between 190-260°C. The initial extruding parameters were as follows: a power of 67.5 watt, a speed of 0.003 m/s, and a temperature of 225°C. The feasible range for the extruding parameters was recommended by a background study, power in the range 54.0-81.0 watt, and speed in the range 0.001-0.005 m/s, and temperature in the range 215-235°C. Therefore, three levels of the cutting parameters were selected as shown in Table-3. The diameter of new filament must be nearest to the original diameter of 1.75 mm.

Table-3. Extruding parameters and their levels.

Symbol	Extruding parameter	Level 1	Level 2	Level 3
C1	Power (Watt)	54.0	67.5	81.0
C2	Speed (m/s)	0.001	0.003	0.005
C3	Temperature (°C)	215	225	235

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Table-4. Experimental results for surface roughness and S/N ratio.

↓	C1	C2	C3	C4	C5	C6
	Power (w)	Speed (m/s)	Temperature (c)	diameter (mm)	SNRA1	MEAN1
1	54.0	0.001	215	2.187	-6.79698	2.187
2	54.0	0.003	225	2.007	-6.05095	2.007
3	54.0	0.005	235	1.800	-5.10545	1.800
4	67.5	0.001	225	2.067	-6.30681	2.067
5	67.5	0.003	235	1.927	-5.69763	1.927
6	67.5	0.005	215	2.087	-6.39045	2.087
7	81.0	0.001	235	2.247	-7.03206	2.247
8	81.0	0.003	215	2.153	-6.66088	2.153
9	81.0	0.005	225	2.027	-6.13707	2.027

Table-4 shows the experimental results and S/N ratio of diameter of filament. The implication of S/N ratio for the power at degrees 1, 2 and 3 can be calculated by averaging the S/N ratios for the experiments 1-3, 4-6, and 7-9, respectively. The mean S/N ratio for each level of the opposite reducing parameters may be computed within the comparable way. The imply S/N ratio for each level of the parameters is summarized and known as the suggest S/N response table for diameter of filament as in Table-4. Similarly, the entire imply S/N ratio for the 9 experiments is likewise calculated and indexed in Table-5. Figure-5 shows the mean S/N ratio graph for diameter of filament. The S/N ratio corresponds to the smaller variance of the output characteristics around the desired value.

Table-5. Response table mean S/N ratio for diameter factor and significant interaction.

Symbol	Extruding parameter	Mean S/N ratio		
		Level 1	Level 2	Level 3
C1	Power	-5.984	-6.132	-6.610
C2	Speed	-6.712	-6.136	-5.878
C3	Temperature	-6.616	-6.165	-5.945
Total mean S/N ratio = -6.242				

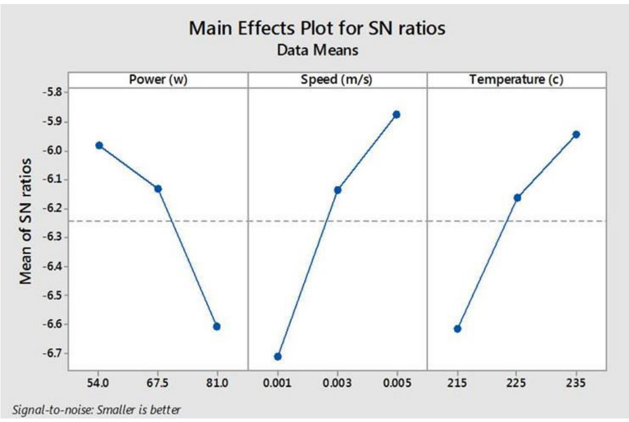

Figure-5. The mean single-to-noise graph for diameter of filament.

Analysis of Variance

Table-6 indicates the effects of ANOVA for surface roughness of the filament. It may be found that the speed is the significant extruding parameter that affected the diameter of filament. The alternate of the power and temperature inside the range (Table-1) has mere impact on diameter of filament.

Table-6. Results of the analysis of variance for surface roughness.

Source of variation	Degree of freedom	Sum of square	Mean square	F ratio	Contribution %
Power (w)	1	0.03125	0.031248	5.86	20.90
Speed (m/s)	1	0.05743	0.057428	10.76	38.40
Temperature (°C)	1	0.03420	0.034202	6.41	22.87
error	5	0.02667	0.005335		17.83
total	8	0.14955			100

From analysis of ANOVA, the regression equation to determine the optimal diameter for extruding filament is given below:

Diameter = 3.540 + 0.00535 power (Watt) - 48.9 speed (m/s) - 0.00755 temperature (°C)

The experiments have been carried out to verify the most beneficial extruding parameters. The percentage contributions of power, speed and temperature are 20.90, 38.40 and 22.87 respectively. In extruding, use of low power (54.0 watt), high speed (0.005 m/s) and high temperature (235 °C) are recommended to obtain better dimensional for the specific test range.

Extruding Data

Percentage of error is used to calculate the percent value of difference between the experimental and theoretical dimension of the extruded filament with the original filament. Table-7 shows the results of percentage error for each set of temperature. From the result of the percentage error, it indicates that all of the diameter values are below 5% of error. The lowest error is 1.77mm diameter with 1.14% while the highest error is 1.82mm diameter that equal to 4%.

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Table-7. Results of percentage error for diameter of filament.

Sample #	Diameter of filament (mm)	Percentage of error (%)
1	1.78	1.71
2	1.79	2.29
3	1.81	3.43
4	1.82	4.00
5	1.80	2.86
6	1.80	2.86
7	1.78	1.71
8	1.77	1.14
9	1.78	1.71
10	1.77	1.14

Tensile Test and Analysis Data

Figure-6 shows the plot graph of original filament. The necking point of original filament specimen appears after 3% of extension and slightly decrease before rapture. Figure-7 shows the plot graph of new extruded filament. The necking point of new filament specimen is nearly to 3% and extremely decrease to rapture

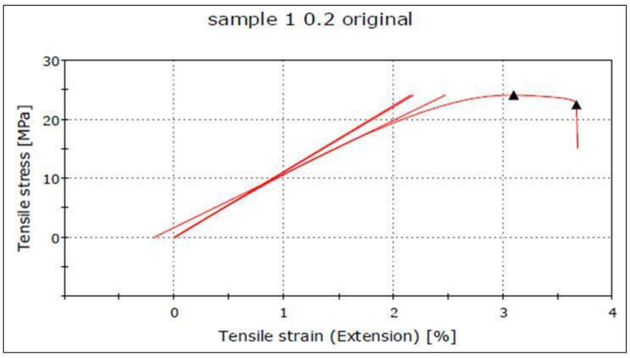

Figure-6. Results of original filament in tensile stress versus tensile strain.

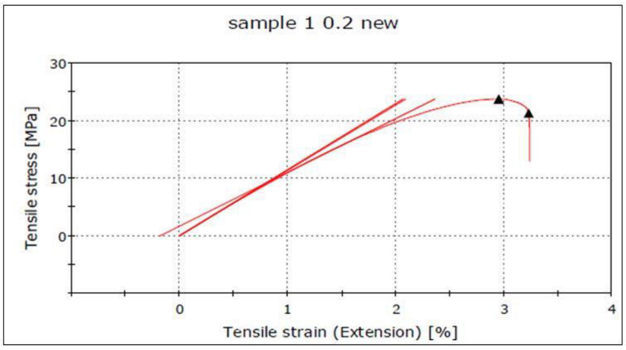

Figure-7. Results of new extruded filament in tensile stress versus tensile strain.

The mechanical properties between two filaments can be compared, based on Tables 8 and 9 show the value of maximum load (N), tensile stress (MPa), tensile strain (mm/mm), and Modulus Young's.

Table-8. Mechanical properties data of original filament specimen.

	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]
1	724.104	24.137	0.0309
	Load at Yield (Zero slope) [N]	Tensile stress at Yield (Zero slope) [MPa]	Tensile strain (Extension) at Yield (Zero slope) [mm/mm]
1	724.10	24.137	0.0309
	Load at Break (Standard) [N]	Tensile stress at Break (Standard) [MPa]	Tensile strain (Extension) at Break (Standard) [mm/mm]
1	676.350	22.545	0.0367
	Extension at Break (Standard) [mm]	Modulus (Automatic Young's) [MPa]	Modulus (Automatic) [MPa]
1	2.5645	1118.917	1105.626

Table-9. Mechanical properties data of new extruded filament specimen.

	Maximum Load [N]	Tensile stress at Maximum Load [MPa]	Tensile strain (Extension) at Maximum Load [mm/mm]
1	713.517	23.784	0.0295
	Load at Yield (Zero slope) [N]	Tensile stress at Yield (Zero slope) [MPa]	Tensile strain (Extension) at Yield (Zero slope) [mm/mm]
1	713.52	23.784	0.0295
	Load at Break (Standard) [N]	Tensile stress at Break (Standard) [MPa]	Tensile strain (Extension) at Break (Standard) [mm/mm]
1	640.133	21.338	0.0323
	Extension at Break (Standard) [mm]	Modulus (Automatic Young's) [MPa]	Modulus (Automatic) [MPa]
1	2.2575	1150.559	1135.525

Table-10 shows the comparison values of mechanical properties of these two filaments. From the data of mechanical properties of original filament, the maximum load that specimen is 724.104 N. For tensile stress at maximum load is 24.137 MPa and tensile strain at maximum load is 0.0309 mm/mm. For data of mechanical properties of new extruded filament, the maximum load that specimen is 713.517 N. For tensile stress at maximum load is 23.784 MPa and value tensile strain at maximum load is 0.0295 mm/mm. The Modulus Young's for original filament is 1118.917 MPa and for new extruded filament is 1150.599 MPa.

It shows that maximum load and tensile stress that these two filaments can absorb is nearly the same with only 1.47% and 1.46% of difference percentage value. For changes in the length of the specimen at the maximum load given shows that original filament is more elasticity than new extruded filament with 4.53% difference percentage value. Modulus Young's obtained from value tensile stress over tensile strain shows that the original filament is lower than new extruded filament with percentage of difference only 2.83%. Overall, the results validated that there are only minor differences of mechanical properties of these two filaments.

Table-10. Comparison value of mechanical properties.

	Original filament	New extruded filament	Percentage (%)
Maximum load (N)	724.14	713.517	1.47
Tensile stress (MPa)	24.137	23.784	1.46
Tensile strain (mm/mm)	0.0309	0.0295	4.53
Modulus Young's (MPa)	1118.917	1150.599	2.83

CONCLUSIONS

In can be concluded that the experimental results proved that the speed is the main parameter among the three controllable factors (power, speed and temperature) that influenced the diameter of filament in extruding process. Taguchi method analysis used to determine the optimal diameter for extruding filament. It showed that the extruding parameters, use of low power (54.0 watt), high speed (0.005 m/s) and high temperature (235°C) are recommended to obtain better dimensional for the specific test range.

The filament was finally extruded even it does not follow the standard size. The filament that produced was of 1.79 ± 0.03 mm with 1.77mm as the thinnest while 1.82mm as the thickest. From that maximum thickness, it means that the error percentage is still below 5% from original dimensional filament. It is also showed that only minor difference percentage of these two filaments with overall percentage below 5%. Last but not least, this project indicated that the optimization can be further improved for recycle 3D printing machine in order to help in minimizing the negative impact of plastic waste to the environment.

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