Development of Low Cost Recycled HDPE Filament Extruder for 3D Printing Filament

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Abstract: This research aims to make low cost filament extruder machine to form HDPE 3D printing filament. To meet the standard of 3D printing filament quality, it is necessary to examine the effect of process parameters on filament dimension quality. So that in this research examined the influence of heating temperature and screw speed to uniformity of diameter and filament roundness. it was revealed that independently the heating temperature and the screw speed factor had a significant effect on the uniformity of diameter and filament roundness. While the interaction of heating temperature and the screw speed factor only significantly affects the filament roundness, it does not significantly affect the uniformity of diameter. Based on the research data, the regression of the roundness relationship as the function of temperature and screw speed as follows: roundness = - 0.508 + 0.00402 temperature - 0.0030 screw speed. And regression of diameter uniformity relationship as function of temperature and screw speed as follows: uniform diameter = - 0,423 + 0,00202 temperature + 0,0217 screw speed.

Keywords: 3D printing, Filament Extruder, Recycled HDPE, Diameter Uniformity, Ovalityof Filament.

1. Introduction

The 3D printing is defined as a process of pooling material to form objects based on 3D model data, commonly done layer by layer. This work is the opposite of traditional formation done by the method of material reduction or marriage(Garmulewicz *et al.*, 2018). This technology provides an advantage in the ability to produce a very complex form, a form that is almost impossible to do with other manufacturing techniques. In addition, because the nature of the process is the addition of material, not a link, so little material is wasted in the process.

Plastic 3D printing developed rapidly in the last decade was supported by the open source movement (Pîrjan and Petrosanu, 2013). Brief history of open source 3D printing starting from The RepRap 3D printer developed since 2007. The RepRap name is an acronym for replicating rapid-prototyper. The first generation RepRap is a Darwin printer machine and further developed in a second generation machine, Mendel. This open source 3D printing movement was soon followed by many derivatives, such as MakerBot, MakerGear, Ultimaker, RepStrap. This technology continues to grow with the better quality, more convenience features, and the lower cost. The similarities in this process approach is to use a heat extruded, deposition, and fused filament in 3D form.

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Application of 3D printers is found in the fields of medical and dental, consumer products and electronics, aerospace fields (Garmulewicz *et al.*, 2018) with the puIDRose as visualization, prototyping or as the end product. The socioeconomic impact of 3D printing technology is examined by research of Pîrjan & Petroşanu (Pîrjan and Petrosanu, 2013)and Feeley et al (Feeley, Wijnen and Pearce, 2014). Supply chain reductions can be done by eliminating the process of delivering products from producers, to distribution warehouses, to stores, and to consumers.

Barriers to the use of 3D printing technology in industry are the cost and availability of raw materials (Pîrjan and Petrosanu, 2013; Garmulewicz *et al.*, 2018). Especially in Indonesia filament for 3D printing still have to be imported with price around IDR 200.000/kg until IDR 450.000/kg. The availability of 3D printing raw materials is a constraint to the use of 3D printing technology in indonesia.

Research on alternative materials for 3D printing has been done by Hamod (Hamod, 2015), Musil (Zatloukal and Musil, 2012), and Cruz et al (Sanchez *et al.*, 2015)using HDPE and Dubashi & Grau plastics (Dubashi, Grau and McKernan, 2015)using PET plastic. These studies have proven the feasibility of using HDPE and PET plastics technically can be used for 3D printing replacing PLA and ABS plastic materials commonly used in 3D printing. The availability of 3D printing raw materials is a constraint in the use of 3D printing technology. To answer the challenge of providing 3D printing filaments some open source machine have been built to create 3D printing filaments (Albi *et al.*, 2014; Dubashi, Grau and McKernan, 2015; Yang *et al.*, 2016).

On the other hand, quite a lot of plastic waste into environmental burden. Plastic waste that often comes from daily consumption of products such as bottled packaging waste. Plastic waste is one type of waste that causes many problems and requires serious management (Verma *et al.*, 2016). Its non-degradable nature requires different management than other types of degradable, organic waste. One of the proper management is by recycling.

2. Build Of Filament Extruder

The first step in this research is the development of filament extruder, choosing the component specification, designing the filament extruder, making the filment extruder and testing the filament extruder. The filamen extruder that has been built is shown Figure 1. The filament extruder machine consists of two control systems: screw speed control and temperature control.

Fig. 1. Filament ekstruder.

The speed control in the filament extruder serves to regulate the filament production rate. Mechanism consists of hooper, screw conveyor, stepper motor, belt and pulley transmission. The screw speed control component is divided into two: the actuator circuit and the indicator circuit. The actuator circuit serves to adjust the speed of the stepper motor through a potentiometer, arduino microcontroller, and stepper motor driver. Indicator circuit to show motor speed through LCD display. This circuit detects the motor speed from the step pulse that goes into the stepper motor driver. This control system runs with open loop control system.

Heating chamber temperature control consists of barrel extruder, band heater, thermocouple, and temperature controller. Heating in heating chamber is divided into two regions. The preheating region and the final heating region. The preheating region uses two series of heater bands that are arranged in series so as to obtain a circuit heater with an installed power capacity of 125W. The final heating region uses a 250W heater band. Temperature control system runs in closed loop system.

3. Method And Experiment Setup

The experimental setup is set to obtain correlations of uniformity of diameter and roundness as a function of the heating temperature and screw speed. Roundness is expressed by ovality.

$$\text{Ovality} = \frac{\text{D. Maks} - \text{D. Min}}{\text{D. Nominal}} \text{ x } 100\% \quad \text{.............(1)}$$

The uniformity of diameter is expressed by the standard deviation of the filament diameter.

$$S = \sqrt{\frac{n \sum_i^n = 1 \ x_i^2 - (\sum_i^n = 1 \, x_1)^2}{n(n-1)}} \quad \text{.............(2)}$$

Here is a basic model of research conducted:

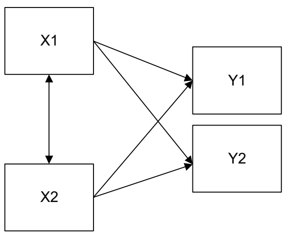

Fig. 2. Experiment model.

where:
X1 = heating temperatur.
180°C, 200°C, 220°C.
X2 = screw speed.
8IDRM, 9IDRM, 10IDRM
Y1 = uniformity of diameter.
Y2 = ovality.

4 Results And Discussion

The results obtained from measurements of the uniformity of diameter shown in Table 1 and the results of the ANOVA calculation in table 2.

Table 1. Diameter uniformity of filament

Varian of DiameterUniformity			
Temperature	Screw Speed (rpm)		
(°C)	8	9	10
180	0,045	0,096	0,406
180	0,027	0,175	0,094
180	0,042	0,067	0,076
200	0,312	0,182	0,207
200	0,256	0,089	0,270
200	0,304	0,120	0,249
220	0,286	0,114	0,236
220	0,190	0,114	0,249
220	0,192	0,114	0,259

Table 2. Variananalysis of diameter uniformity

Analysis of Variance						
Source	DF	Seq SS	Adj SS	Adj Ms	F	P
Temperature (A)	2	0,056085	0,056085	0,028042	5,62	0,013
Speed (B)	2	0,053398	0,053398	0,026699	5,35	0,015
Temp*Speed (A*B)	4	0,053006	0,053006	0,013252	2,66	0,067
Error	18	0,08975	0,08975	0,004986		
Total	26	0,252239				

By hypothesis:
H_o = No significant effect of factors on the uniformity of filament diameter.
H_1 = there is significant effect of factors on the uniformity of filament diameter.

a) Effect of Temperature
From table 2 can be obtained the decision that temperature get P-value equal to 0,013 <Alpha (0,05) then reject H0, which means there is significant effect of temperature to uniformity of filament diameter.

b) Effect of Screw speed
From table 2 can be obtained that the speed screw get P-value equal to 0,015 <Alpha (0,05) then reject H0, which means there is significant effect of screw speed to uniformity of filament diameter.

c) Effect of Temperature and Screw speed interaction.
For the combination effect of temperature and screw speed, can be obtained that P-value is 0,067 ≥ Alpha (0,05) so accept H0, meaning that there is no significant effect of Temperature and Screw speed interaction to uniformity of filament diameter.

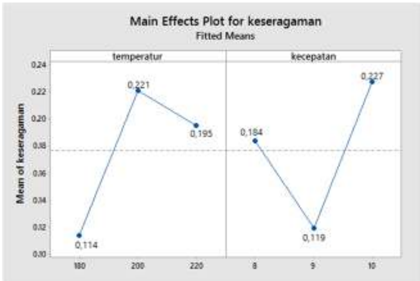

Fig. 3. Main effect respon offilament uniformity.

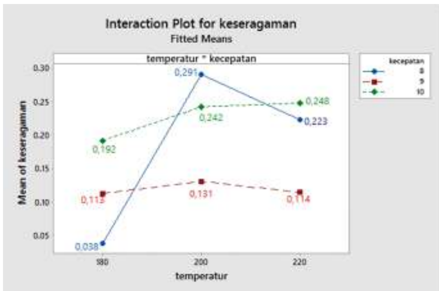

Fig. 4. Interaction plot respon of uniformity.

From calculation with minitab software obtained regression result as follows: uniform filament diameter = - 0,423 + 0,00202 temperature factor + 0,0217 speed factor.

The results obtained from measurements of ovality shown in Table 3 and the results of the ANOVA calculation in table 4.

Table 3. OvalityDiameter of filament.

OvalityDiameter of Filament Result			
Temperature	Screw Speed (rpm)		
(°C)	8	9	10
180	0,064516	0,154	0,476
180	0,033898	0,277	0,164
180	0,060606	0,095	0,098
200	0,476	0,211	0,256
200	0,491	0,118	0,400
200	0,476	0,207	0,333
220	0,571	0,171	0,303
220	0,353	0,182	0,375
220	0,333	0,182	0,400

Table 4. Variananalysis of ovality.

Analysis of Variance						
Source	DF	Seq SS	Adj SS	Adj Ms	F	P
Temperature (A)	2	0,166249	0,166249	0,083125	9,63	0,001
Speed (B)	2	0,113472	0,113472	0,056736	6,57	0,007
Temp*Speed (A*B)	4	0,175558	0,175558	0,043889	5,09	0,006
Error	18	0,15535	0,15535	0,008631		

Total	26	0,610629

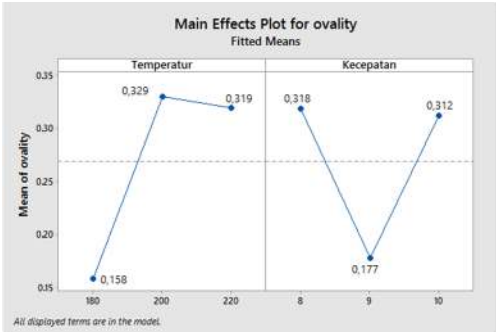

Fig. 5. Main effect responof filament ovality.

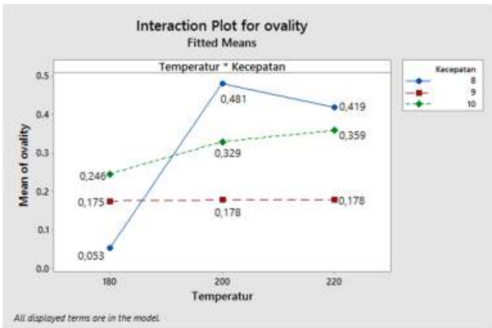

Fig. 6. interaction plot responof ovality

By hypothesis:
H_0 = No significant effect of factors on the ovality of filament diameter.
H_1 = There is significant effect of factors on the ovality of filament diameter.

a) Effect of Temperature
From table 4 can be obtained the decision that temperature get P-value equal to 0,001 <Alpha (0,05) then reject H0, which means there is significant effect of temperature to ovality of filament diameter.

b) Effect of Screw speed
From table 4 can be obtained that the speed screw get P-value equal to 0,007 <Alpha (0,05) then reject H0, which means there is significant effect of screw speed to ovality of filament diameter.

c) Effect of Temperature and Screw speed interaction.
For the combination effect of temperature and screw speed, can be obtained that P-value is 0,006 <Alpha (0,05) then reject H0, which means there is significant effect of Temperature and Screw speed interaction to ovality of filament diameter.

4. Conclusions

The experimental showed that the temperature had significant effect to uniformity of filament diameter, which can be seen from the calculation of anova with P-value (0,013) <Alpha (0,05). As for the effect to ovality, factor of temperature have significant effect which can be seen from calculation of anova P-value (0,001) <Alpha (0,05). The experimental showed that the screw speed had significant effect on the uniformity of diameter, which can be seen from the calculation of anova with P-value (0,015) <Alpha (0,05). As for the response to ovality, factor of screw speed have significant effect which can be seen from calculation of anova with result of P-value (0,007) <Alpha (0,05). Based on research data obtained regression results as follows:ovality = - 0.508 + 0.00402 temperature - 0.0030 screw speed. Uniformity = - 0,423 + 0,00202 temperature + 0,0217 screw speed.

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