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Effect of Extrusion Temperature Variations for Manufacturing 3D Printer Filament Based on Used Bottle Waste on Impact Strength

Herru Santosa Budiono[1], Sigit Joko Purnomo[2]
[1,2]Department of Manufacturing Design Engineering Technology, Universitas Tidar, Indonesia, 56116

herru.santosa@untidar.ac.id

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Abstract

Manufacturing 3d printer filaments based on used plastic bottle waste is a promising solution in reducing environmental impact while utilizing excessive available resources. This research aims to evaluate the effect of variations in manufacturing temperature (210°C, 220°C, and 230°C) on the impact strength of 3D printer filament based on used bottle waste. The experimental method was carried out by printing filament samples at each printing temperature and testing the impact strength using the Charpy method. The research results show that printing temperature affects the impact strength of the filament, with a temperature of 230°C providing optimal results.

Keywords: Filament, 3D Printing, PET, Temperature

Abstrak

Pembuatan filamen printer 3d berbasis limbah botol plastik bekas adalah solusi yang menjanjikan dalam mengurangi dampak lingkungan sambil memanfaatkan sumber daya yang tersedia secara berlebihan. Penelitian ini bertujuan untuk mengevaluasi pengaruh variasi temperatur pembuatan (210°C, 220°C, dan 230°C) terhadap kekuatan impak filamen printer 3D berbasis limbah botol bekas. Metode eksperimental dilakukan dengan mencetak sampel filament pada setiap suhu pencetakan dan melakukan pengujian kekuatan impak menggunakan metode charpy. Hasil penelitian menunjukkan bahwa temperatur pencetakan mempengaruhi kekuatan impak filament, dengan suhu 230°C memberikan hasil optimal.

Kata-kata kunci: *Filamen, 3D Printing, PET, Suhu*

1. Introduction

The use of 3D printers has revolutionized various industries by enabling the creation of prototypes, tools, and even final products quickly and efficiently [1]. However, the serious environmental challenges associated with using plastic materials in the 3D printing process have become a matter of increasing concern [2]. While innovation continues to grow in the selection of environmentally friendly materials, the development of sustainable production processes and the use of sustainable raw materials remains the main focus in efforts to reduce the environmental impact of this technology [3].

PET (Polyethylene Terephthalate) plastic bottle waste offers attractive potential as a raw material source for manufacturing 3D printer filaments [4]. PET is one of the most common plastics in beverage bottles and packaging. Still, much of this plastic waste ultimately ends up in landfills, causing serious environmental problems [5]. Converting PET plastic waste into 3D printer filament can help reduce plastic waste in the environment and create a cheap and sustainable source of raw materials for 3D printing [6]. However, a deep understanding of how production parameters, such as temperature, influence the mechanical properties of the resulting filaments is still limited [7].

This research investigates the effect of temperature variations in manufacturing 3D printer filament based on PET plastic bottle waste on the impact strength of the resulting filament. Impact strength is a critical parameter in engineering and industrial applications, as it can influence the success of a 3D-printed product in resisting stress, resisting deformation, and maintaining structural integrity [8].

This research is expected to provide valuable insights for developing optimal filament production techniques by delving deeper into how temperature variations in the manufacturing process affect filament impact strength. The final aim of this research is to make a significant contribution to the understanding of the influence of temperature on the quality of 3D printer filament based on PET plastic bottle waste and its implications for developing more sustainable 3D printing technology.

2. Method

This research method starts with preparing tools and materials, manufacturing filaments, manufacturing impact test specimens, and analyzing test results.

Waste PET plastic bottles are collected and cleaned to remove contaminants and residue. The PET plastic bottles are then cut into strips lengthwise into small ribbons to facilitate further processing. Materials for manufacturing 3D printing filament is presented in **Figure 1**.

Figure 1. Materials for Manufacturing 3D Printing Filament

Next, the material is fed into a 3D printer filament maker that has been made previously using varying temperatures: 210°C, 220°C, and 230°C. The extrusion process is carried out at a constant speed. The process of manufacturing 3D printing filament is presented in **Figure 2**.

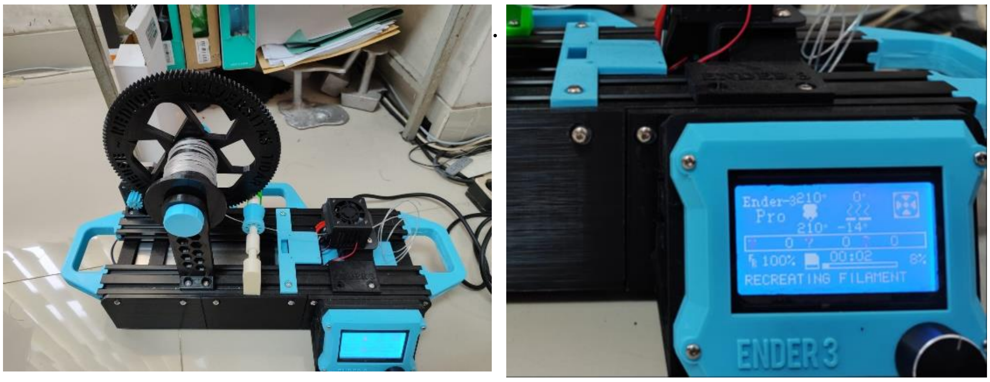

Figure 2. The process of Manufacturing 3D Printing Filament

After finishing the filament, its diameter is measured to obtain average diameter data for each temperature variation. The measurement of PET filament diameter is presented in **Figure 3.**

Figure 3. Measurement of PET filament diameter

Manufacture impact testing specimens begins with creating a specimen design using Solidworks software. The shape and size of the impact test specimen refer to the ASTM D6110-10 standard, which is the Charpy impact test standard **[9]**.

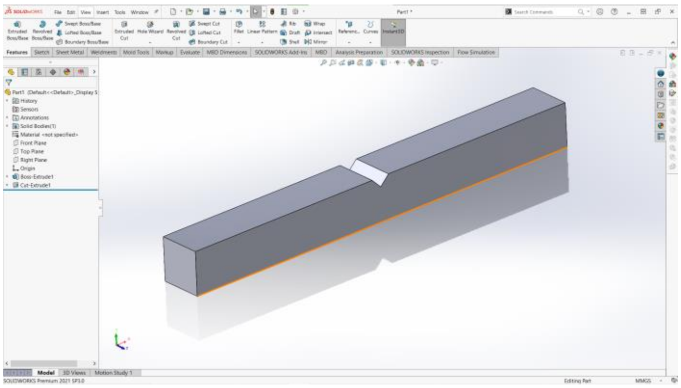

Figure 4. Creating of Specimen Design

Next, the specimen design results are subjected to a printing setup process using Cura software. Specimen printing parameter settings are presented in **Figure 5**.

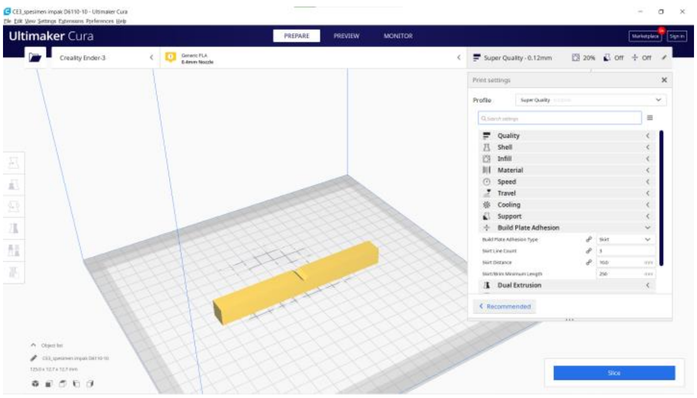

Figure 5. Specimen Printing Parameter Settings

The next step is to print the test specimen using a 3D printer. Five specimens were made for each temperature variation. Printing of impact test specimens is presented in **Figure 6.**

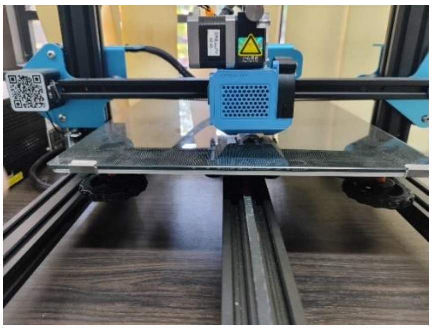

Figure 6. Printing of Impact Test Specimens

The filaments produced at each extrusion temperature (210°C, 220°C, and 230°C) were then tested to evaluate their impact strength. The Charpy impact test is presented in **Figure 7.**

Figure 7. Charpy Impact Test

Impact strength testing was done using a Charpy impact testing machine with uniform testing conditions for all samples. Impact testing was carried out using a Charpy impact tester according to ASTM D6110-10 standards. The results of the impact test in the form of the final angle are entered into equation (1) as follows:

$$EI = Ep1 - Ep2$$
$$= m1 \times g1 \times h1 - m2 \times g2 \times h2$$
$$= m \times g \times (h1 - h2) \quad \ldots\ldots (1)$$

where:

EI : Impact Energy (Joule)

m1 = m2 : Pendulum mass (Kg)

g1 = g2 : Gravitational acceleration (m/S2)

h1 : Height of the pendulum before impact (m)

h2 : The height of the pendulum after the collision (m)

Each temperature variation consists of five specimens. Impact strength test results were recorded and analyzed statistically to determine the effect of temperature variations on the filament's mechanical strength.

3. Results and Discussion

After testing the impact strength of 3D printer filament extruded at three temperature variations (210°C, 220°C, and 230°C), the results are as **Table 1** shows.

Table 1. Impact Test Results Data

Specimen	Temperature (^{0}C)	impact value $(Joule/mm^2)$	Average $(Joule/mm^2)$
1	210	0,1120	0,1120
2		0,1119	
3		0,1121	
4		0,1120	
5		0,1119	
1	220	0,1158	0,1157
2		0,1155	
3		0,1159	
4		0,1155	
5		0,1156	
1	230	0,1188	0,1188
2		0,1188	
3		0,1189	
4		0,1187	
5		0,1188	

The graphic of impact test results is **Figure 8.**

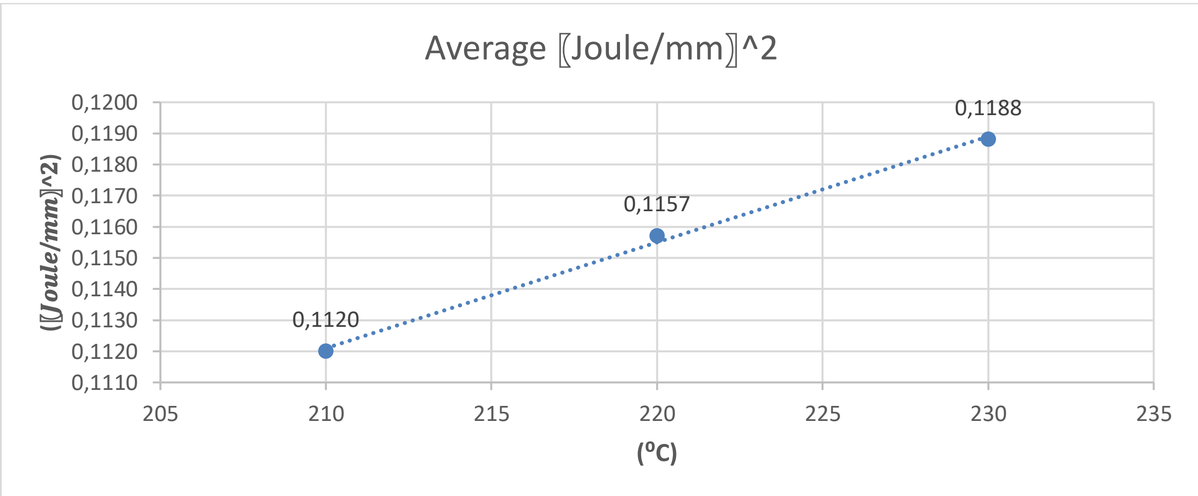

Figure 8. Graphic of Impact Test Results

Measuring the diameter of the filament involves measuring several parts of the filament and then calculating the average. Data from filament diameter measurement results is presented in **Table 2**.

Table 2. Data From Filament Diameter Measurement Results

Temperature (⁰C)	Position	Diameter (mm)	Average (mm)
210	1	1,51	1,47
	2	1,47	
	3	1,46	
	4	1,48	
	5	1,47	
220	1	1,56	1,55
	2	1,55	
	3	1,57	
	4	1,56	
	5	1,55	
230	1	1,71	1,71
	2	1,70	
	3	1,70	
	4	1,71	
	5	1,71	

The impact test results show an increase in the impact strength of 3D printer filament based on PET plastic bottle waste which is extruded at different temperature variations. Of the three temperature variations used, the temperature variation of 230 ⁰C has the highest average impact value, namely 0.1188 $Joule/mm^2$, then followed by the temperature 220 ⁰C, namely 0.1157 $Joule/mm^2$, and the last 210 ⁰C which is 0.1120 $Joule/mm^2$. In the filament diameter measurement test, the closest size to the factory filament was the temperature variation of 230 ⁰C, namely 1.70 mm, then the temperature variation of 220 ⁰C, namely 1.55 mm and finally the 210 ⁰C variation, namely 1.47 mm.

From the data it can be found that the extrusion temperature affects the impact strength of the filament. In general, increasing the extrusion temperature tends to increase the impact strength of the filament. This can be caused by changes in the molecular structure of the material at higher temperatures, which can produce filaments with better mechanical strength.

The higher extrusion temperature at 230 ⁰C allows the PET (Polyethylene Terephthalate) plastic material from used bottles to melt more thoroughly and evenly. This can produce filaments with a more homogeneous molecular structure, which in turn increases the mechanical strength of the filaments. At higher temperatures, the physical properties of PET plastic materials can change, including viscosity and tensile strength. At an extrusion temperature of 230 ^{0}C, there may be an increase in viscosity allowing for smoother extrusion and the formation of filaments with more consistent diameters. The extrusion process at higher temperatures can also affect the crystallinity structure of PET plastic materials, which directly affects the mechanical properties of the filament. With optimal extrusion temperature, the filament can have higher impact strength due to a denser and more homogeneous structure.

Apart from the above, the size of the filament produced also influences the impact strength. A larger filament diameter tends to increase impact strength because a larger volume of material can withstand the force applied to the object. The larger the filament diameter, the higher the possibility of greater impact forces due to the presence of more material to absorb the energy and withstand the pressure. However, the relationship between filament diameter and impact strength is not always linear and can be influenced by other factors such as material structure, mold orientation and other printing parameters

4. Conclusion

Based on the test results, it can be concluded that the extrusion temperature affects both the impact strength and the diameter of the filament produced. Where the extrusion temperature of 230°C emerged as the best choice in terms of increasing the impact strength and approaching the factory filament diameter. However, the choice of extrusion temperature must also consider other factors such as mold stability, mold surface quality and overall production efficiency.

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