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Characterization of FDM 3D Printed Parts Using TPU+PETG Filaments For Shin Guard Products

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Abstract

3D printing machines are used to print products that support sports activities, such as shin guards. During sports, shin guards are protective equipment to prevent injury to the lower legs. Filaments that are suitable for making shin guards are Thermoplastic Polyurethane (TPU) and Polyethylene Terephthalate (PETG) because they have impact resistance properties needed to protect the feet during sports. The variation is the level parameter layer height, nozzle temperature, printing speed, and bed temperature. Next, an impact test will be carried out to determine the optimal parameter variation on the 3D printing machine, which is expected to be a reference for printing quality products. This study uses a 3D printer, Ender V3, to print specimens and shin guard products. The material used is TPU+PETG filament. The Taguchi method with the orthogonal matrix $L9(3)^4$ was repeated thrice for each experiment. After that, an analysis of variance was carried out. Parameter variations used in the study were layer height (0.1 mm, 0.2 mm, and 0.3 mm), nozzle temperature (220°C, 225°C, and 230°C), printing speed (45mm/s, 45mm/s, and 50mm/s) and bed temperature. (70°C, 75°C, and 80°C). In this study, Charpy impact testing will be carried out. The combination of factors that can produce an optimal impact test is layer height level 2 (0.2 mm), nozzle temperature level 1 (220°C), printing speed level 3 (50 mm/s) and bed temperature level 2 (75°C) with an impact strength value the highest was 27.20 and the lowest was 11.07. The combination of factors that have the most significant effect on the impact test strength values is layer height 63.97%, nozzle temperature 6.19%, printing speed 2.07% and bed temperature 4.74%.

Keywords:

3D printing, additive manufacturing, Charpy impact, FDM, PETG, TPU.

1 Introduction

Additive Manufacturing (AM), also commonly referred to as three-dimensional (3D) printing, has attracted significant research interest [1]. In recent decades, the rapid development of intelligent technology required multifunctional and flexible polymeric materials [2] with great potential and low investment risk. According to [3], various sectors, including the manufacturing, health, industrial and sports sectors, have implemented 3D printing according to their needs. Over time, the types and types of 3D printing have also continued to develop.

The FDM process is a cheap and environmentally friendly 3D printing process that utilizes thermoplastic polymers as raw materials in filaments [4]. FDM technology works by melting a thermoplastic filament through a hot nozzle at a specific melting temperature and overlapping it with layers to produce an ideal object [5]. Even though FDM technology has drawbacks, namely visible lines on the product's surface due to the formation process per layer, this technology is still applied in various fields.

3D printing machines are beneficial for printing products or prototypes in manufacturing. User skills, experience, and developments in printers and printing materials shape trends in 3D printing. Indeed, photopolymerization covers a wide range of fields: industry and engineering, smart composites, soft robotics, flexible electronics, superhydrophobic 3D objects, medical and biomedical, prosthetics and orthotics, sports equipment, jewelry, etc. [6]. In sports, 3D printing machines are used to print products that support sports activities, such as leg protectors and shin guards [7].

Shin guards are one of the recommendedprevention methods. Its primary function is to protect the soft tissues and bones of the lower extremities from external impacts. The shin guards provide shock absorption and facilitate energy dissipation, reducing the risk of serious injury [8]. Currently, shin guards are generally produced by the injection molding method. However, many wearers of shin guards want a particular shape or adjustment to the size of their feet. One of the right solutions besides using the injection molding process is 3D printing. The advantages of the 3D printing process, as well as the variety of options available, have created a demand for custom shin guards with 3D printing is increasing. Thermoplastic Polyurethane (TPU) and Polyethylene Terephthalate (PETG) filaments are suitable choices for making shin guards.

In previous research by [9], a comprehensive structural evaluation of composite materials in 3D-printed shin guards for soccer was conducted. This study designed a lightweight shin guard by utilizing PETG/CF composites. The results showed that shin guards made of PETG, Carbon Fiber (CF), or a combination of PETG/CF exhibited superior mechanical properties.

Previous research [10] showed that TPU and PETG filaments can be used to produce shin guards. PETG filament has the most significant impact strength value at a 0.3 mm layer of 1.20 kJ/m^2. Meanwhile, research by [11] shows that TPU filaments have a stress of around 10 MPa when stretched to 200 mm, regardless of thickness. The properties of PETG, which are resistant to impact, and weather conditions, and its ability to adhere well, make it a good choice for scoring shin guards. On the other hand, TPU, with high flexibility, elasticity and shock resistance, as well as good abrasion and tear resistance, also has the potential to be used in molding shin guards.

Therefore, this study aimed to evaluate the effect of the parameters layer height, nozzle temperature, printing speed, and bed temperature on the level of impact strength of shin guard products printed using TPU+PETG filaments through FDM technology. In addition, this study also aims to identify the combination of printing parameters that produce optimal impact strength values. Therefore, this research will provide a deeper understanding of the effect of printing parameters on the impact of 3D printing strength of shin guard products with TPU+PETG filaments, as well as provide recommendations regarding the optimal combination of printing parameters to achieve the desired results.

2 Research Methods

This study uses experimental research and analysis to determine the parameters of the influence of variations in the 3D printing process on the impact properties of specimens with TPU+PETG filaments. The research was conducted at the

IsDBMechanical Design Laboratory Building, Faculty of Engineering, Department of Mechanical Engineering, University of Jember, Jember Regency, East Java.

According to [9], in addition to impact tests, aspects such as tensile strength, compressive strength, flexural strength, weight analysis and ergonomics, energy absorption capability, dimensional stability, ventilation, lightness, and adaptability to different body shapes are considered. However, the main function of the shin guard is to protect the shins of soccer players and the biggest risk to these limbs is impact. Therefore, the impact test was chosen as the shin guard quality test.

2.1 Materials and Tools

The materials used in this study were Thermoplastic Polyurethane (TPU) and Polyethylene Terephthalate Glycol (PETG), with yellow colors for TPU and red for PETG, which is shown in Fig. 1. The specifications for TPU and PETG filament are presented in Table 1.

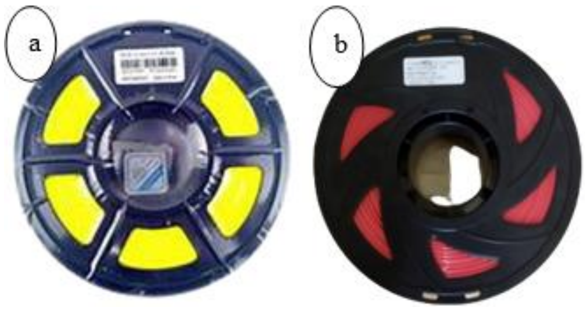

Fig. 1. Filaments.(a) TPU and (b) PETG.

Table 1. Properties TPU and PETG

Specification	Value
3D printing filament	TPU
Filament diameter	1.75
Recommended extruder temperature	210°C-230°C
Recommended bed temperature	40°C-60°C
Density	1.21
Abrasion resistance	High
Chemical resistance	Medium to high
Shrinkage	0.8%-1.8%
3D printing filament	PETG
Density (g/cm^3)	1.27
Melt flow index (g/10min)	20(250°C/2.16kg)
Durability	8/10
Printability	9/10
Extruder temperature (°C)	220°C–250°C
Bed temperature (°C)	75°C –90°C
Printing speed	40–100mm/s

The 3D printing machine with the Ender V3 brand was used to make the impact test specimens, as shown in Fig. 2.

Fig. 2. 3D printing Ender V3 machine.

2.2 Procedures for Work

TPU+PETG filaments are used as materials in the manufacture of specimens. The impact test specimens were printed according to ISO 179-1 standard, with the size of the impact test specimens having a length of 80 mm, a width of 10 mm and a thickness of 4 mm of 27 specimens with a printing process using the 3D printing machine Ender V3 than a Charpy impact strength test was carried out using a testing machine the Zwick/Roell impact. ISO 179-1 standard specimens as shown in Fig. 3.

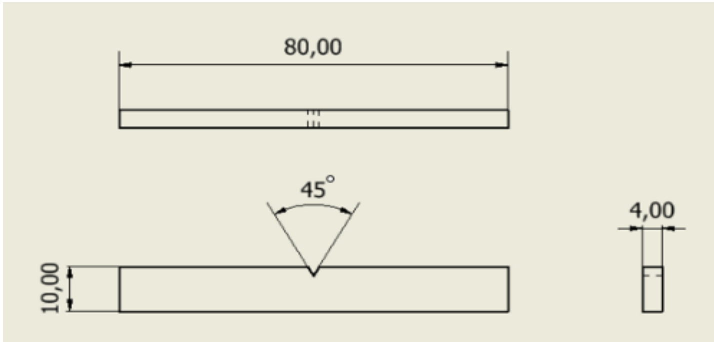

Fig. 3. ISO 179-1 specimen.

2.3 Printing Parameters

The factorial design used the Taguchi orthogonal arrays L9 (4)^3 method with various parameters used in the study, namely layer height (0.1 mm, 0.2 mm, and 0.3 mm), nozzle temperature (220°C, 225°C, and 230°C), printing speed (45 mm/s, 45mm/s, and 50mm/s) and bed temperature (70°C, 75°C, and 80°C) with three levels for each parameter. After making the specimen design and selecting the parameters according to the factorial design, 27 specimens were printed. Then the impact test strength data was processed with ANOVA, SN Ratio, and Minitab.

3 Results and Discussion

Then do the recording and data collection. The Charpy impact test specimen results as shown in Fig. 4.

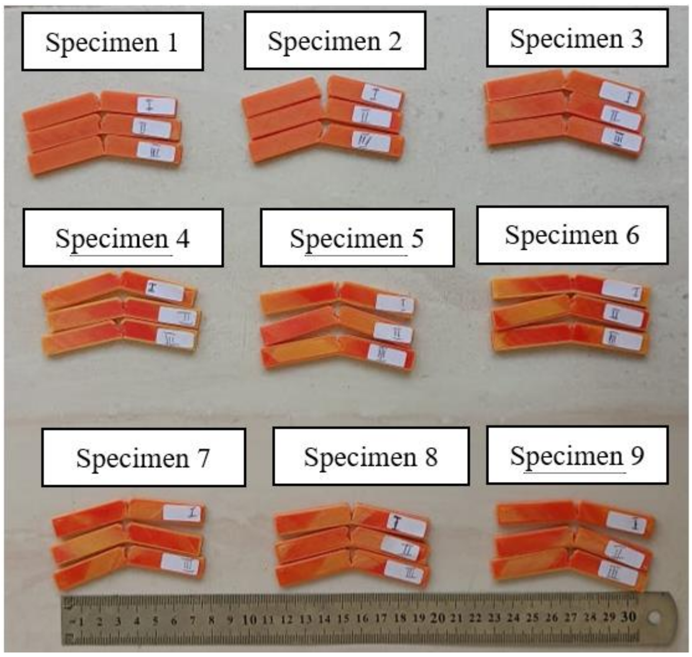

Fig. 4. Specimen results of the Charpy impact test.

The Charpy impact test results are calculated to determine the parameters that have a significant effect and the optimal variation of parameters. The following are the parameters, namely Layer Height (LH), Nozzle Temperature (NT), Printing Speed (PS) and Bed Temperature (BT). Data from the test results as shown in Table 2.

Table 2. Impact test results data

Control factor				Impact test results (kJ/m²)replikasi				
LH	NT	PS	BT	1	2	3	Ave-rage	S/N *Ratio*
0.1	220	40	70	11.64	14.64	10.53	12.27	21.53
0.1	225	45	75	10.42	10.22	15.87	12.17	21.20
0.1	230	50	80	12.08	11.6	9.53	11.07	20.74
0.2	220	45	80	25.52	28.7	27.39	27.20	28.66
0.2	225	50	70	18.83	26.53	29.64	25.00	27.46
0.2	230	40	75	15.41	35.87	27.89	26.39	26.79
0.3	220	50	75	22.09	23.81	25.17	23.69	27.45
0.3	225	40	80	10.03	14.58	15.98	13.53	22.08
0.3	230	45	70	16.28	14.37	14.19	14.95	23.44
							18.47	

The SN calculation is obtained after the impact strength value is carried out. The ratio of each parameter is used to obtain the influential parameters. The SN ratio value as shown in Table 3.

Table 3. SN ratio value

Level	Layer height (LH)	Nozzle temperature (NT)	Printing Speed (PS)	Bed Temperature(BT)
1	21.16	25.88	23.47	24.15
2	27.64	23.58	24.43	25.15
3	24.33	23.66	25.22	23.83
Delta	6.48	2.30	1.75	1.32
Rank	1	2	3	4

The main effects plot graph as shown in Fig. 5.

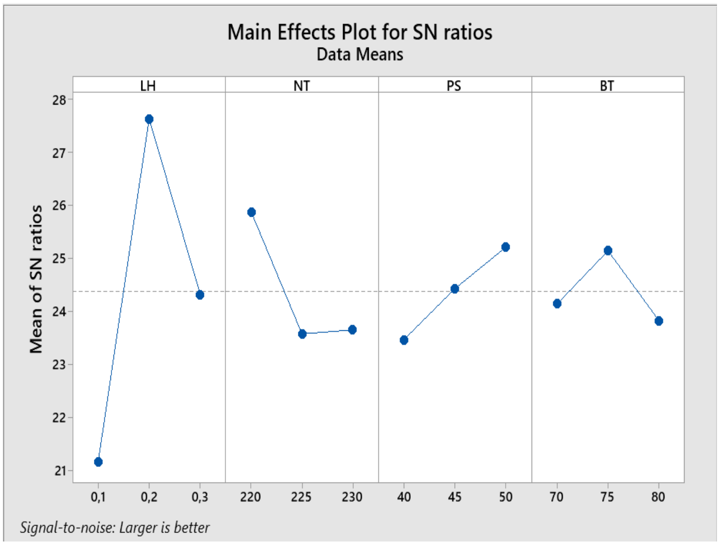

Fig. 5. Main effects plot.

Based on the SN Ratio, the level of parameters influences the impact strength. It is apparent that the layer height (0.2 mm), nozzle temperature (220°C), printing speed (50 mm/s) and bed temperature 75°C. The F-Ratio is then calculated using Analysis of Variance (ANOVA). Data from ANOVA results as shown in Table 4.

Table 4. Data ANOVA

Source	DF	Seq- SS	Contribution	Adj MS	F-Value	P
LH	2	944.00	63.97%	472.00	25.00	Significant
NT	2	91.32	6.19%	45.66	2.42	Not significant
PS	2	30.48	2.07%	15.24	0.81	Not significant
BT	2	69.99	4.74%	35.00	1.85	Not significant
Error	18	339.80	23.03%	18.88		
Total	26	1475.58	100.00%			

In this study, the value of the F test or alpha error was 0.05, with a possible error of 5%. Table 4 shows that layer height has a significant effect compared to the others because the F test value of 25.00 is greater than the F value of Table 2.82. Once the significant parameters are known, the percent contribution of each parameter is calculated. The percentage contribution as shown in Table 4. Based on the results obtained from Table 4, a discussion of the effect of the parameters can be produced.

3.1 Effect of Layer Height on Impact Strength

Layer height is the factor that most influences the impact strength properties of 3D printing printed materials in this study. Layer height affects the bond strength of the printout. Higher layer thickness, e.g. at a layer height of 0.3 mm, will result in a more robust structure due to better adhesion between layers. However, the coating thickness is considered too large, which can compromise print quality and increase the risk of defects.

This study found that a layer thickness of 0.2 mm achieves good strength with an optimal balance between mold detail and surface quality. Layers with a thickness of 0.2 mm produced the highest strength value of 27.20 kJ/m², influencing the impact strength with the percentage of significant parameters and the highest contribution, 63.97% of the total calculated percentage of parameter contributions. As a comparison, another study [11] found that PETG filaments had the most outstanding impact strength value at the 0.3 mm layer, namely 1.20 kJ/m². So, the results of this study indicate that using a layer thickness of 0.2 mm produces a much higher impact strength than using a layer of 0.3 mm on PETG filament.

3.2 Effect of Nozzle Temperature on Impact Strength

The nozzle temperature in the 3D printing process also affects the impact test strength of mixed filament prints. The nozzle temperature influences the material properties of the printed material in mixed filament 3D printing results. The printed result may be rough, uneven, and brittle if the nozzle temperature is too low. On the other hand, if the nozzle temperature is too high, the printout will break and crack easily. In addition, the nozzle temperature also affects the bond strength between the layers of printed material on the mixed filament. Therefore, the nozzle temperature must be appropriately adjusted to achieve optimal bond strength. Therefore, the nozzle temperature must be adjusted in such a way as to produce a smooth and even surface to achieve optimal impact test strength.

Although the effect of the parameters is not significant at α 0.05 and accounts for 6.19% of the total calculation of the percent contribution of the parameters, the nozzle temperature in this study uses 220°C, 225°C and 230°C. The nozzle temperature of 220°C is the optimum temperature with the highest value of 27.20 kJ/m². It follows [12], who conducted research on testing the impact strength of ST-PLA filaments and concluded that with a nozzle temperature of 220°C, the highest impact test strength value was 6.53 kJ/mm².

3.3 Effect of Printing Speed on Impact Strength

Printing speed in the 3D printing process can also affect the impact test strength of mixed filament prints due to several factors that affect the effect of printing speed on the strength of the impact test on mixed filament 3D printing results. A higher printing speed of 50 mm/s can increase the structural strength of printed objects when facing impact tests. As the printing speed increases, the material deposited between the layers has a shorter time to cool and solidify, resulting in a stronger bond between the layers. A stronger bond between layers can increase the structural strength of the entire printed object, making it more resistant to impact forces. It can help reduce the risk of deformation or distortion of the printed object in impact testing. When the material is printed at a slower speed, there is an increased risk of the material being exposed to heat and shrinkage of the material.

By increasing the printing speed to 50 mm/s, the risk of deformation can be reduced because it shortens the contact time with heat. It can produce molded objects that are more geometrically accurate and maintain better dimensions when tested under impact loads. Lower printing speeds, such as 40 mm/s and 45 mm/s, may require more printing layers to achieve the same result, affecting printing time and increasing the risk of print defects. Although the influence of the parameter is not significant at α 0.05 but contributes 2.07% of the total calculation of the percent contribution of the parameter, the printing speed in this study uses 40 mm/s, 45 mm/s and 50 mm/s. The printing speed of 50 mm/s influences the highest impact strength value of 27.20 kJ/m^2. It follows [13], which researched testing the impact strength of filaments. ST-PLA concluded that with a nozzle temperature of 220℃, the highest impact test strength value was 6.53 kJ/mm^2.

3.4 Effect of Bed Temperature on Impact Strength

Bed temperature in the 3D printing process can also affect the impact test strength of the printout, especially on mixed filaments consisting of two or more types of printing materials. Several factors influence the effect of bed temperature on the impact test strength of mixed filament 3D printing results, among others. A bed temperature that is too low can cause warping of the mold. When a material cools too quickly after molding, parts closer to bed temperature may shrink faster than others. It can distort the print and make it uneven. However, if the bed temperature is too high, the material may be too soft and may cause deformation or difficulty removing the object after printing is complete. A bed temperature of 75℃ is the optimal temperature to help ensure that the print adheres firmly during printing and avoids unwanted deformation.

Although the effect of the parameter is not significant at α 0.05 because it accounts for 4.74% of the total calculation of the percent contribution of the parameter, the bed temperature in this study uses a bed temperature with a range of 70℃, 75℃ and 80℃ with a temperature of 75℃ is the optimal parameter. It is in line with research [14] with a bed temperature range of 40℃, 45℃, and 50℃ bed temperature with a temperature of 45℃ as the optimal parameter.

3.5 TPU+PETG Shin Guard Protection Product

The following is the result of shin guard products using optimal parameters. The shin guard manufacturing process begins with a design using Computer-Aided Design (CAD) software to create a 3D model according to customer specifications. After the design is finalized, suitable materials, such as TPU and PETG, are selected based on the customer's requirements to print the shin guards.

The 3D printing process is then carried out using the selected TPU or PETG material. The shin guards are printed in 3D using 3D printing technology. After printing, the shin guard product is cut and cleaned to produce the finished product. Furthermore, shin guard products are tested to test impact resistance. Impact testing is carried out to assess the quality of the product and ensure that it can provide adequate protection. The results of this test will assist in determining whether improvements or enhancements are needed to the design or materials used. In this research, shin guards are compared with other market products. The two materials to be compared are impact-strength polypropylene 7.00 kJ/m^2, used in market products, and TPU+PETG, with an impact strength of 27.20 kJ/m^2.

The analysis results show that the TPU+PETG material has a much higher impact strength than the polypropylene used in market products. It indicates that shin guards made using TPU+PETG can more effectively absorb and withstand impact energy, thus providing better protection for the shins during sports. Thermoplastic Polyurethane (TPU) and Polyethylene Terephthalate Glycol (PETG) are thermoplastic materials often used in shin guards because of their properties that suit the needs of protection and comfort during sports. The process of making shin guard products as shown in Fig. 6.

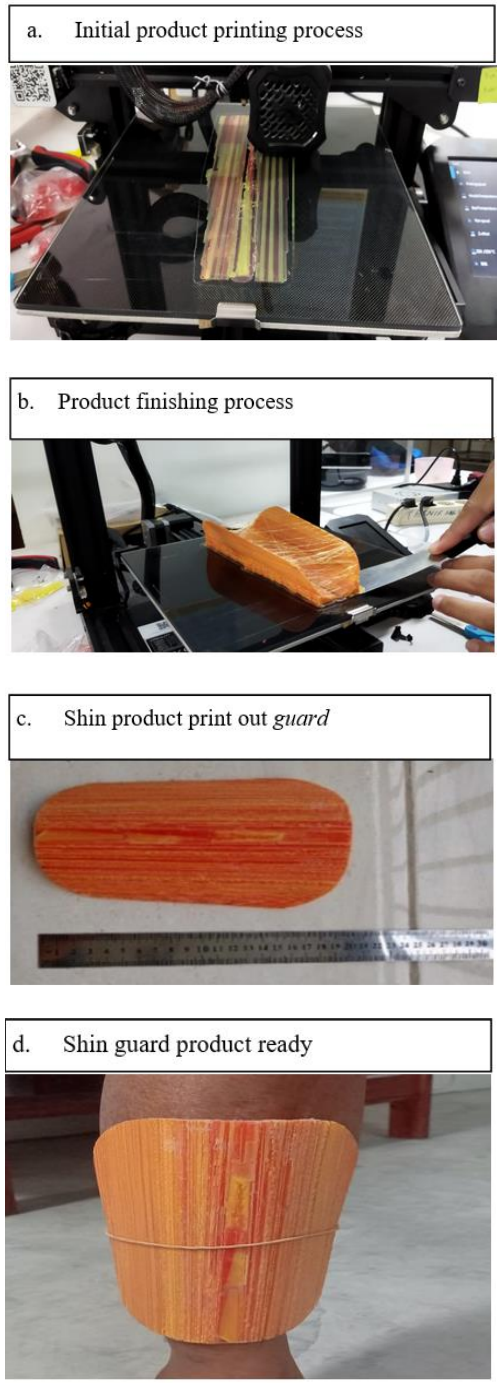

Fig. 6. Results of shin guard products.

4 Conclusion

The conclusions obtained from the research on optimizing the impact strength of 3D printing results from TPU + PETG with various parameters are:

1. Parameters that affect the impact strength of 3D printing results made from TPU+PETG are layer height of 63.97%, nozzle temperature of 6.19%, printing speed of 2.07%, dan bed temperature of 4.74%.
2. The combination of parameters that can produce the most optimal impact strength value based on calculations using the Taguchi method is a layer height of 0.2 mm, nozzle temperature of 220℃, printing speed of 50 mm/s, and bed temperature of 75℃. With these optimal parameters, a reference is made for the parameters for making shin guard products.

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