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Analysis of the Effect of Print Speed and Layer Height on the Hardness of TPU-95A Filament 3D-Printed Products

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Abstract

The effect of print speed and layer height settings can influence the mechanical properties of 3D-printed products; however, the impact of print speed and layer height on the hardness of products printed with TPU-95A filament has not been extensively studied. This research employs an experimental method by creating specimens according to ASTM D2240 standards, using various print speed settings (70, 80, and 90 mm/s) and layer heights (0.15 and 0.20 mm). The results show that a combination of lower print speeds and thinner layer heights yields higher hardness test results. A print speed of 90 mm/s and a layer height of 0.15 mm produced the highest hardness, while the combination of 90 mm/s print speed and 0.2 mm layer height resulted in the lowest hardness. This study contributes to the optimization of 3D printing parameters for flexible material applications, such as TPU-95A, in relation to product hardness outcomes.

Keywords: 3D printing; hardness; layer height; printing speed; TPU-95A.

1. Introduction

In the era of Industry 4.0, the development of three-dimensional printing () has opened new opportunities in the manufacturing sector, especially in the production of prototypes and components with intricate/complex shapes [1]. 3D printing is one of the most efficient and innovative machines using Additive Manufacturing (AM) technology, capable of creating 3D objects with various unique structures and shapes [2]. Fused Deposition Modeling (FDM), the most used technique in AM modeling, allows production results to compete with conventional manufacturing industries such as Injection Molding [3], [4].

The working principle of 3D printing is based on the layer-by-layer method, where the filament is heated to a specific temperature and printed layer by layer until a detailed 3D object is formed [5]. Filament is the main material used in 3D printing as the filling material for the mold. Common types of filaments include polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), and polycarbonate (PC) [6]. Fused Deposition Modeling (FDM) technology continues to evolve, especially in the use of flexible materials as the primary forming material [7], [8]. One popular flexible material is TPU-95A (Thermoplastic Polyurethane), known for its elastic, flexible properties and good hardness [9].

Several parameter settings in 3D printing, such as print speed, layer height, infill density, and printing temperature, can produce good mechanical properties in terms of optimal hardness for TPU 95A filament products [10]. Previous studies have discussed the effect of 3D printing process parameters on the elasticity of TPU (Thermoplastic Polyurethane) products. The results of these studies show that changes in nozzle temperature and layer thickness significantly affect the flexibility of the final product made from TPU material [11]. Another study by Ahmad Zamheri and his team in 2021 concluded that a print speed of 25 mm/s, a layer height of 0.25 mm, and a printing temperature of 220°C are the optimal parameter combination to achieve maximum hardness and contributing 41.929 % to the final result [12], [13].

Although print speed and layer height have been studied previously, their impact on TPU 95A material has not been researched. Therefore, this study focuses solely on two variations, namely print speed and layer height, which may influence the hardness values of TPU 95A material. It is hoped that this research will make a broad contribution to the development of 3D printing technology using flexible materials such as TPU-95A filament.

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2. Experimental Methods

This study uses an experimental method aimed at understanding the cause-and-effect relationship between the independent variable (which is manipulated) and the dependent variable (which is measured). In the 3D printing process, precise parameter settings are essential, involving various process parameters such as fixed and variable parameters. The stages of the research process are outlined in a flowchart, as shown in Figure 1.

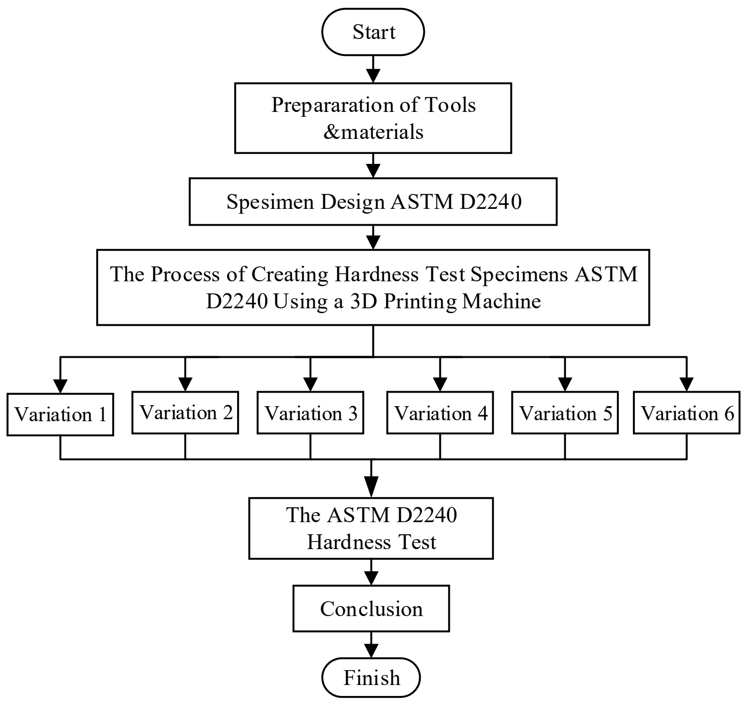

Figure 1. Flowchart

2.1 Material

The material used is TPU 95A filament with a diameter of 1.75 mm and a clear white color, produced by Shenzen Esun Industrial Co. Ltd., China (eSun Filament). The specifications of the TPU 95A material used in this study are shown in Table 1.

Table 1. Specifications of TPU 95A Filament

Specification	TPU 95A
Diameter	1.75 mm
Printing temperature	220 – 250 °C
Printing speed	20 – 100 mm/s
Bed temperature	45 - 60 °C
Net weight	1 kg

2.2. Specimen Preparation Process

In this study, the hardness test specimens were made using an Ender-3 Pro printer. The design of the hardness test specimens was created using Autodesk Inventor 2023 software. The dimensions of the hardness test specimens follow the ASTM D2240 testing standard for polymers and polymer blends and were saved in the Standard Tessellation Language (STL) file format. The STL file was then imported into Ultimaker Cura Software,

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where both fixed and variable parameter settings were applied. The file was then converted directly into G-code format and saved or transferred to an SD card. The next step was the printing process using the 3D printer, with the settings in the Ultimaker Cura software adjusted to match the 3D printer settings. There are two parameters used in the specimen printing process: fixed parameters and variable parameters. The fixed parameters used are as follows: Infill density 100 %, bed temperature 60 °C, printing temperature 220 °C, and infill pattern type concentric. The variable parameters are shown in Table 2.

Table 2. Variable Parameters

Print speed (mm/s)	Layer height (mm)	Specimen Name
70	0.15	Variation 1
70	0.2	Variation 2
80	0.15	Variation 3
80	0.2	Variation 4
90	0.15	Variation 5
90	0.2	Variation 6

A total of 6 hardness test specimens were made using a 3D printer with settings that included several variable print parameters and fixed parameters. The hardness test specimens are square shaped with dimensions of 2 x 2 x 6 mm, following the ASTM D2240 standard, as shown in Figure 2.

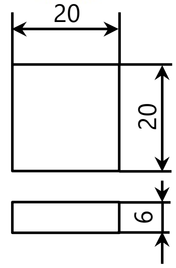

Figure 2. Hardness test specimen dimension design

Figure 3 shows the process of creating the printed specimen using a 3D printer, featuring the hardness test specimen design following the ASTM D2240 standard, created with Autodesk Inventor 2023 software.

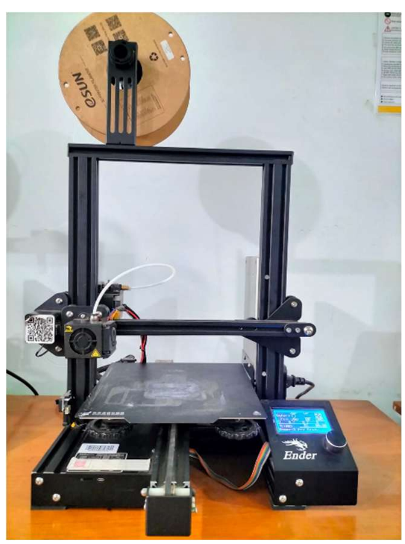

Figure 3. Specimen fabrication process using a 3D printer

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Based on the results of the hardness test specimen creation process, the printed specimens show good quality in terms of shape and size, with the 3D printer settings using various fixed and variable parameters. The results of the 6 hardness test specimens are shown in Figure 4.

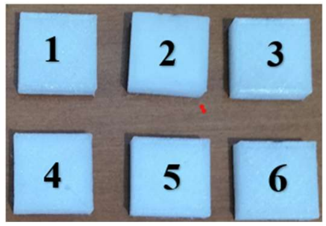

Figure 4. Printed hardness test specimens

2.3 Hardness Test Specimen Procedure

The hardness testing procedure was carried out using a Digital Durometer (Shore A) with a precision level of 0.01, as shown in Figure 5. This hardness testing procedure follows the ASTM D2240 standard [14]. The testing steps include ensuring that the specimen is free from contamination and placed on a flat surface, preparing and calibrating the durometer, pressing the durometer perpendicularly until the indenter fully penetrates the specimen's surface, and performing tests at five different points with a minimum distance of 6 mm between each point, as shown in Figure 6.

(a) (b)

Figure 5. (a) Digital shore a durometer (b) Specimen testing process

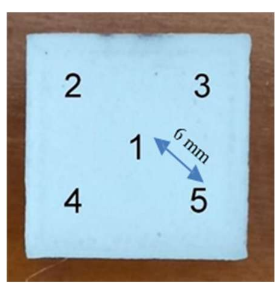

Figure 6. Illustration of test points on the specimen

Based on the specimen procedure that was carried out, the test results from each point were recorded, and the hardness values were noted for further analysis to determine the overall hardness of the specimen. This procedure ensures that the testing is performed accurately and precisely [15].

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3. Results and Discussion

3.1. Hardness Test Results

In the hardness testing conducted on TPU 95A filament specimens produced with varying parameters, print speeds, and layer heights, data was obtained in the form of hardness test results.

Table 3. Hardness test results of specimens

Specimen	Print speed (mm/s)	Layer height (mm)	Hardness value (Shore A)					Average hardness test (HA)
			Test 1	Test 2	Test 3	Test 4	Test 5	
Variation 1	70	0.15	72	74	78.5	70	74	73.7
Variation 2	70	0.2	70.5	73.5	75.5	73	74	73.3
Variation 3	80	0.15	71.5	72.5	77.5	72.5	71.5	73.1
Variation 4	80	0.2	71.5	70.5	70.5	71	72.5	71.2
Variation 5	90	0.15	74	70.5	76.5	75	77	74.6
Variation 6	90	0.2	60.5	62	59.5	63.5	59	60.9

Based on the data obtained from Table 3, it is evident that variations in printing process parameters result in different hardness values for each specimen. This study shows that variations in print speed and layer height have a significant impact on the hardness values of 3D-printed specimens [16]. In this study, there are six parameter variations, with each variation being a combination of two-layer height values (0.15 and 0.2 mm) and three print speed values (70, 80, and 90 mm/s). Table 3 presents the hardness test results for each parameter variation with five hardness test points.

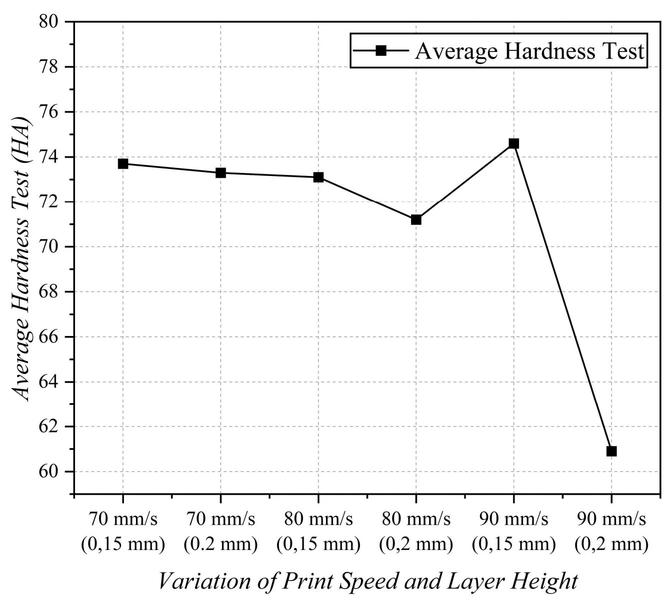

Figure 7. Average hardness test results

Figure 7 shows the average hardness test results, indicating an average hardness range from a minimum of 60.9 HA to a maximum of 74.6 HA. Based on this data, Variation 5, which uses a combination of 90 mm/s print speed and 0.15 mm layer height, produces the highest hardness value of 74.6 HA. Meanwhile, Variation 6, using a combination of 90 mm/s print speed and 0.2 mm layer height, yields the lowest hardness value of 60.9 HA. This indicates that lower print speeds and smaller layer heights tend to produce specimens with higher hardness.

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3.2. Discussion

Based on the results of the study, using a slower print speed, specifically 70 mm/s, allows the material more time to harden and form stronger bonds between layers during the printing process, resulting in specimens with higher hardness values [17]. This is proven in the hardness test results for Variation 1, which uses a combination of 70 mm/s print speed and a 0.15 mm layer height, with a hardness value of 73.7 HA.

One of the main factors affecting the hardness value of specimens is layer height. Using a lower layer height can lead to better hardness results in specimens [18]. Thinner layers, such as 0.15 mm, tend to result in higher hardness compared to thicker layers, such as 0.2 mm. This is because a lower layer height produces thinner layers, which increases density and reduces porosity in the specimen. Thinner layers enable better inter-layer adhesion, resulting in a denser structure [19].

The results of this study demonstrate that optimizing 3D printing parameters is essential for achieving desired mechanical properties [20]. In this case, a print speed of 90 mm/s and a layer height of 0.15 mm were found to be the most optimal parameter combination for producing specimens with high hardness. This study has significant implications for the development of 3D printing technology, particularly in optimizing process parameters to achieve desired mechanical properties. In the additive manufacturing industry, selecting the right print parameters is crucial to ensure the quality of the final product.

4. Conclusion

The results of this study indicate that there is an optimal value among the combinations of print parameters. This study demonstrates that print speed and layer height parameters significantly affect the hardness test results of 3D-printed products using TPU-95A filament. Slower print speeds (70 and 90 mm/s) tend to result in better and more optimal hardness, as the material has more time to harden and form stronger bonds between layers. A lower layer height (0.15 mm) produces specimens with higher hardness compared to a higher layer height (0.2 mm). The combination of a 90 mm/s print speed and a 0.15 mm layer height provides the highest hardness value of 74.6 Shore A, while the combination of a 90 mm/s print speed and a 0.2 mm layer height results in the lowest hardness at 60.9 Shore A.

5. Acknowledgments

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