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Analysis of Print Speed Variations Effect and Nozzle Temperature on the Tensile Strength of 3D Printed TPU-95A Products

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Abstract

This study aims to analyze the effect of print speed and nozzle temperature variations on the tensile strength of TPU-95A material printed using the fused deposition modeling (FDM) method. The varied parameters include print speeds (70, 80, and 90 mm/s) and nozzle temperatures (230 and 240 ℃). Tensile test specimens were produced using an Ender-3 Pro 3D printer according to the JIS K6251-2017 standard and tested with a Shimadzu AGS-X 10kN tensile testing machine. The results showed that the combination of a 90 mm/s print speed and a 230 ℃ nozzle temperature yielded the highest tensile strength of 318.74 kgf/cm². Conversely, the lowest tensile strength of 212.20 kgf/cm² occurred at a 90 mm/s print speed and a 240 ℃ nozzle temperature due to thermal degradation of the material. This study highlights the importance of selecting optimal printing parameters to enhance the mechanical strength of 3D-printed products made from TPU-95A.

Keywords: additive manufacturing; material testing; printing parameters; mechanical properties.

1. Introduction

The manufacturing industry continues to strive for increased productivity and efficiency in producing products. One rapidly evolving process is additive manufacturing or 3D printing, which plays a major role as a driver in the industry 4.0 revolution [1]. Additive manufacturing technology has attracted widespread attention from both the industry and academia due to its ability to address complex design challenges, shorten production times, and maintain print quality [2], [3]. Currently, fused deposition modeling (FDM) is the most widely used 3D printing method. Its popularity is driven by its simple configuration, relatively affordable equipment costs, and its environmentally friendly impact. The FDM method is extensively used in additive manufacturing (AM) processes to create a variety of components. Products manufactured using this method can compete with products produced by conventional methods such as Injection Molding [4], [5].

FDM operates by melting filaments, such as thermoplastics, inside a nozzle heated to a specific temperature. The melted material is then extruded and arranged layer by layer [6], [7]. One of the materials frequently used in 3D printing is TPU-95A filament, known for its toughness, elasticity, and impact resistance [8]. This TPU-95A filament is often utilized for products that require elasticity, such as medical hoses, car bumper guards, and various other components.

The quality of products produced using 3D printing technology is greatly influenced by Nozzle Temperature and Print Speed. Nozzle Temperature refers to the temperature of the material while it is in the nozzle, whereas Print Speed pertains to the movement speed of the nozzle during material extrusion [9], [10]. Understanding how variations in nozzle temperature and print speed affect the mechanical characteristics of 3D printed TPU-95A filament products, particularly tensile strength, is crucial. Tensile strength measures a material's ability to withstand tensile (pulling) loads before breaking [11] - [13].

This study aims to analyze the effect of Print Speed and Nozzle Temperature on the tensile strength of 3D printed TPU-95A filament products, an area that has not been widely explored. The results of this analysis are expected to provide input to the 3D printing industry in optimizing print parameters to achieve products with desired tensile strength.

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2. Experimental Methods

This research utilizes an experimental method, where the independent variables (nozzle temperature and print speed) are manipulated to observe their effects on the dependent variable (tensile strength). The flowchart for this research is created to facilitate the research process, as shown in Figure 1 below.

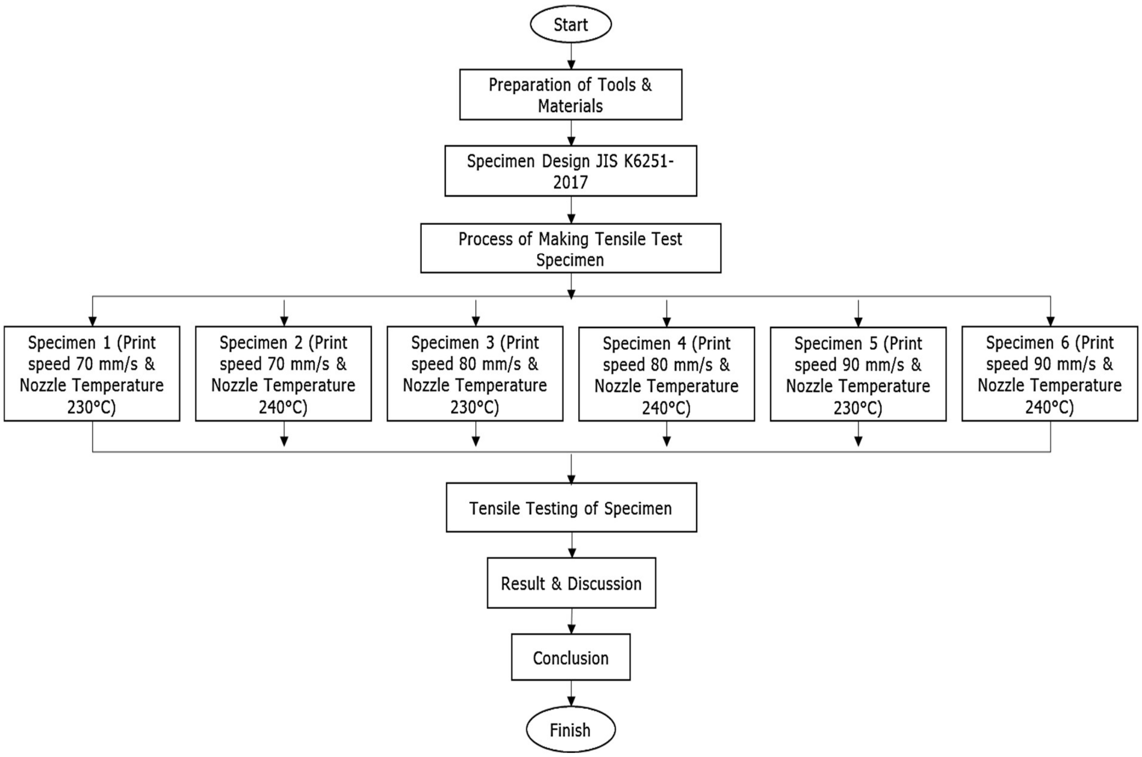

Figure 1. Flowchart

2.1. Materials

In this study, the material used is TPU95A filament with a diameter of 1.75 mm and clear white color, produced by Shenzen Esun Industrial CO, Ltd. China (eSun Filament) to create tensile test specimens. The specifications of this filament can be seen in Table 1.

Table 1. Specifications of TPU 95A filament

Specification	Description
Diameter	1.75 mm
Printing Temperature	220 – 250 °C
Printing Speed	20 – 100 mm/s
Bed Temperature	45 - 60 °C

2.2. Specimen Manufacturing Process

In this study, 12 tensile test specimens were printed with 6 variations of parameters, meaning that 2 identical specimens were made for each parameter variation. This was done to obtain accurate and valid tensile strength values. The specimens were made using the Ender-3 Pro 3D printer according to the JIS K6251-2017 design standard. This standard is used for testing the properties of elastomer materials such as rubber.

The manufacturing process includes designing the 3D specimen using Autodesk Inventor 2024 software, followed by setting the print parameters using Ultimaker Cura software (layer height, print speed, infill density,

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nozzle temperature, bed temperature, and infill pattern). After that, the design is converted to a G-code format, transferred to an SD card, and the machine is preheated for preparation. The filament is then loaded into the extruder, the print file is selected, the automatic printing process begins, and finally, the printed specimen is named.

This study includes two types of parameters: fixed parameters and varying parameters. The fixed parameters used are as follow: layer height of 0.15 mm, concentric infill pattern, 100 % infill density, and bed temperature of 60 °C. These parameters remain unchanged throughout the printing process. The varying parameters can be seen in Table 2.

Table 2. Varying parameters

Specimen Name	Print speed (mm/s)	Nozzle temperature(°C)
Variation 1	70	230
Variation 2	70	240
Variation 3	80	230
Variation 4	80	240
Variation 5	90	230
Variation 6	90	240

The design of the tensile test specimen follows the shape standardized by JIS K6251-2017, which has a length of 100 mm, a width of 25 mm, and a thickness of 2 mm, as shown in Figure 2. Meanwhile, Figure 3 shows the result of the printed specimen.

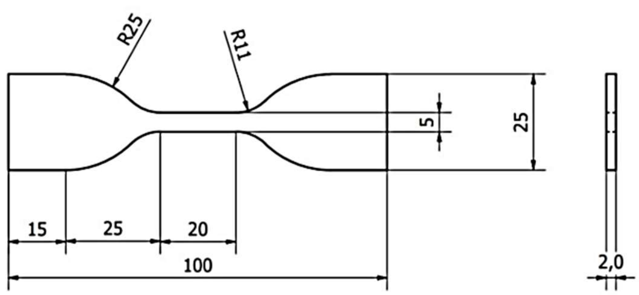

Figure 2. Dimensions and design of the tensile test specimen [14]

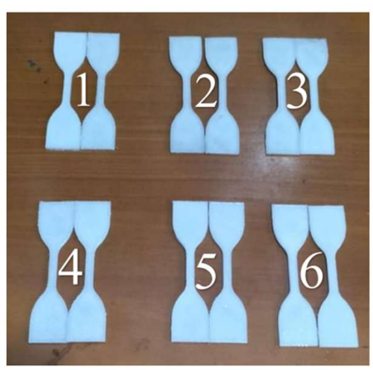

Figure 3. 3D printed specimen result

2.3. Tensile Testing Process

Tensile testing is conducted according to the JIS K6251 standard, aimed at measuring tensile strength, elongation, and the mechanical properties of elastomeric or rubber materials. This process is performed using a Shimadzu AGS-X 10kN tensile testing machine, which pulls the specimen until it breaks to determine its

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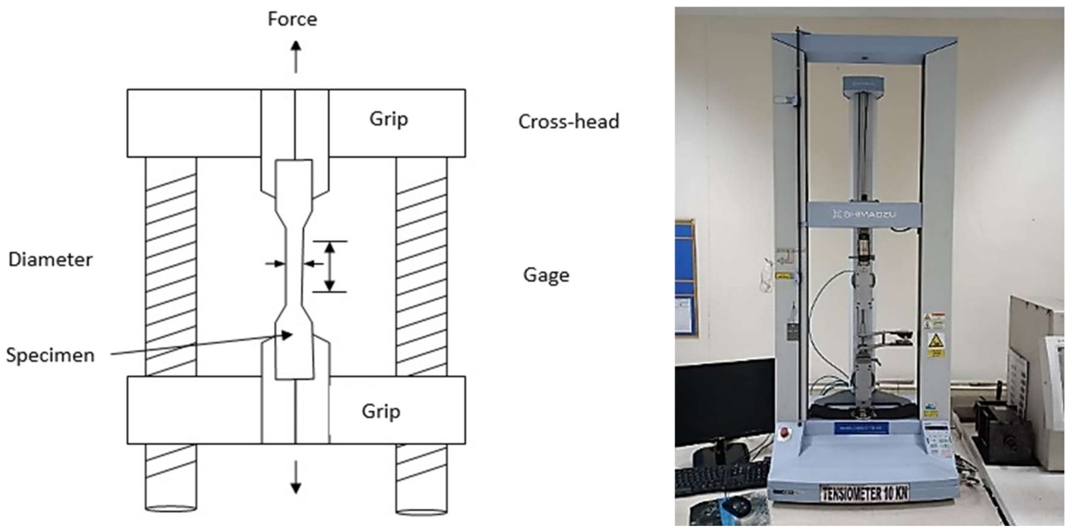
mechanical characteristics. The specimen is then mounted on the machine's grips. The gripping must be done evenly to ensure the specimen does not shift or slip during the tensile process.



(a) (b)

Figure 4. Testing Process (a) Illustration of the test and (b) Tensile testing machine

In this study, the testing machine is set to operate at the specified test speed of 100 mm/min. This speed is determined according to the requirements of the JIS K6251 standard to ensure that the test results can be accurately compared. When the test begins, the machine pulls the specimen at a constant speed while recording the tensile force applied to the specimen and the elongation (change in length) that occurs. The test continues until the specimen breaks.

The data obtained during the test, which includes the maximum tensile force and the elongation (change in length) of the specimen, are used to calculate several mechanical properties of the material. Tensile strength is calculated using equations 1, as follows [15].

$$\sigma = \frac{F}{A} \quad (1)$$

where σ is tensile stress (MPa), F is Maximum tensile force (N), and A is Initial cross-sectional area of the specimen (mm²).

3. Results and Discussion

After conducting a tensile test on the TPU-95A filament 3D printing specimen, the tensile strength of the specimen was obtained. The data from this test was then analyzed to investigate the effect of nozzle temperature and print speed parameters on the tensile strength of the 3D printer printed results.

3.1. Analysis of Tensile Test Results

Tensile testing is conducted to determine the mechanical properties of the material, such as tensile strength, strain, and elastic modulus of the TPU-95A specimen. The purpose of this test is to understand how strong the material is in withstanding tensile forces before undergoing permanent deformation or failure. The data from this test can be seen in Table 3, where the tensile strength values for each specimen are presented, including the test repetitions (replicates) and the average tensile strength values.

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Table 3. Tensile strength test results

Specimen name	Replicate 1	Replicate 2	Average (kgf/cm²)
Variation 1	226.63	225.08	225.85
Variation 2	220.16	230.27	225.22
Variation 3	269.17	235.47	252.32
Variation 4	301.88	250.49	276.19
Variation 5	322.48	315.00	318.74
Variation 6	209.56	214.84	212.20

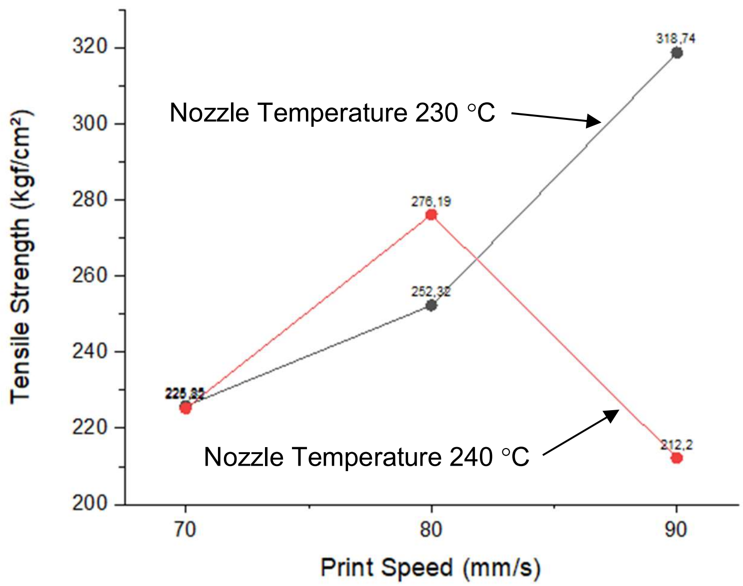

Figure 5. Graph of print speed influence and nozzle temperature on tensile strength

In the graph above, we can see that the combination of nozzle temperature and print speed influences the mechanical properties of a product printed using an FDM 3D printer. The graph shows a red line representing a nozzle temperature of 240 °C, while the black line represents a nozzle temperature of 230 °C. The graph illustrates changes in the mechanical properties of TPU-95A material at print speeds of 70, 80, and 90 mm/s on the X-axis, with a combination of nozzle temperatures of 230 and 240 °C.

3.1.1 The Influence of Nozzle Temperature

After analyzing the test results of the specimens, it is found that at a nozzle temperature of 230 °C, TPU-95 A melts well, allowing for a uniform material distribution and forming strong interlayer bonds. This is reflected in the tensile strength results, which are higher compared to 240 °C. The best combination at a temperature of 230 °C with a print speed of 90 mm/s (Variation 5) results in the highest tensile strength of 318.74 kgf/cm².

Meanwhile, at a nozzle temperature of 240 °C, the TPU material experiences thermal degradation, leading to a decrease in mechanical properties. The material becomes too fluid, resulting in uneven layer distribution and weak interlayer bonds. At this temperature, the worst combination is observed at a print speed of 90 mm/s (Variation 6), yielding the lowest tensile strength of 212.20 kgf/cm²

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3.1.2 The Influence of Print Speed

At a print speed of 70 mm/s, the time for each deposited layer becomes longer, allowing for greater cooling of the material before the next layer is applied. This can lead to weaker cohesion between layers. Based on the tensile strength generated at temperatures of 230 and 240 °C, it is relatively lower compared to higher printing speeds.

However, at a speed of 80 mm/s, there is a slight balance between cooling time and cohesion between layers. Nevertheless, the results are still lower compared to the printing speed of 90 mm/s. This can be seen in the test results of the specimens at parameter variations 3 and 4.

Based on the tables and graphs from the research results, a printing speed of 90 mm/s with a nozzle temperature of 230 °C has a significant impact on the tensile strength of TPU 95A specimens, with a tensile strength reaching 318.74 kgf/cm². At this printing speed, cooling time between layers is reduced, allowing the layers to remain warm enough to form strong bonds. The combination of a print speed of 90 mm/s and a nozzle temperature of 230 °C provides the best tensile strength.

3.2. Discussion

This study analyzes how variations in nozzle temperature and print speed affect the tensile strength of 3D printed TPU-95A specimens through a series of tests. The results indicate that the optimal parameter combination is a nozzle temperature of 230 °C and a print speed of 90 mm/s (Variation 5), which yields the highest average tensile strength of 318.74 kgf/cm². Conversely, the lowest tensile strength, with an average of 212.20 kgf/cm², occurs at a nozzle temperature of 240°C with the same print speed (Variation 6).

These findings highlight that both nozzle temperature and print speed do not always have a significant impact on tensile strength, as seen in the test results of specimens 1 and 2, which show nearly similar tensile strength values. This occurs because both specimens use the same print speed of 70 mm/s. At lower speeds, the filament has more time to form stable interlayer bonds, even though the nozzle temperatures differ. However, the test results for specimens 3 (Variation 3), 4 (Variation 4), and 5 (Variation 5) show a significant influence on tensile strength. For instance, at a nozzle temperature of 230 °C and a print speed of 90 mm/s, the TPU 95A filament melts efficiently, resulting in uniform material distribution and strong interlayer bonds. Higher print speeds minimize cooling time between layers, preventing premature solidification and maintaining structural integrity.

However, at a temperature of 240 °C with the same print speed, the tensile strength decreases, likely due to thermal degradation caused by excessive heat. This degradation reduces the mechanical properties of the material and causes the filament to become overly fluid, resulting in uneven layer distribution and weak interlayer bonds. Additionally, inadequate cooling or imperfect layer bonding further compromises the structural integrity of the specimens, leading to a decrease in tensile strength.

The selection of these print parameters is based on several considerations. For instance, the nozzle temperatures used are 230 and 240 °C. These variations were chosen based on the recommendations from the TPU 95-A filament manufacturer, which suggests a temperature range of 220-250 °C. To minimize the risk of print failures, the mid-range temperatures of 230 and 240 °C were selected. Meanwhile, the chosen print speed levels are those commonly used in 3D printing [16]. Panjaitan et al. [10] states that all printed products have rough surface characteristics. However, the higher the printing speed and nozzle temperature, and the lower the infill percentage, the better the product quality, with lower or smoother surface roughness. Additionally, the geometric accuracy of the product ranges from 0.91 % for length dimensions to 7.73 % for width dimensions.

The distinction in this research lies in the material used and the research focus. The previous study used PLA material and focused on the surface roughness of the printed product, and it also stated that higher nozzle temperatures result in better product quality. Meanwhile, in this study, excessively high nozzle temperatures tend to produce low-quality products [10].

4. Conclusion

Based on the results of this study, it is shown that variations in nozzle temperature and print speed significantly affect the tensile strength of 3D printing specimens using TPU-95A filament. The combination of nozzle temperature 230 °C and print speed 90 mm/s provides optimal tensile strength with an average value of 318.74 kgf/cm². It indicates that this condition results in strong and uniform material distribution between the printed layers. On the other hand, the combination of nozzle temperature 240 °C and print speed 90 mm/s produces the lowest tensile strength, 212.20 kgf/cm², which is believed to be caused by material degradation due to excessive temperature.

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