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Dimensional Consistency Analysis in High Speed 3D Printing

Doni Fajar Ramadhan[1,4*], Fajar Sodiq[2], Hendri Maja Saputra[3], Mohammad Alexin Putra[1]

[1]Program Studi Teknik Mesin,Institut Teknologi Nasional Bandung, Indonesia
[2]Program Studi Teknik Mesin, Universitas Jenderal Ahmad Yani, Indonesia
[3]Research Center for Smart Mechatronics, Badan Riset dan Inovasi Nasional, Indonesia
Corresponding author: doni.fajar@mhs.itenas.ac.id

Abstract

3D printing technology has been widely applied in various industries, including manufacturing, healthcare, automotive, aerospace, and others. High 3D printing speeds, such as 1200 mm/s, offer the potential to significantly accelerate the production process. However, increasing this speed also presents challenges related to the quality and dimensional consistency of the printed parts. Therefore, understanding how each parameter interacts and affects the printing results is key to optimizing high-speed 3D printing processes. This research focuses on the dimensional accuracy of 3D printed objects. The method used involves printing 5 cube samples measuring 20mm x 20mm x20 mm with a 10 mm through all hole using Acrylonitrile Butadiene Styrene (ABS) Highspeed and Polylactic Acid (PLA) Highspeed materials at a maximum print speed of 1200 mm/s. After the printing process, the dimensions of each sample are carefully measured using a vernier caliper at three different points. PLA material tends to have a larger deviation than ABS, especially in the circle diameter parameter with a deviation percentage of 5.88%, while ABS is 5.02%. Based on the results overall the deviation of length, width, height, and hole diameter dimensions in both materials is not significant for general applications, but the deviation in hole diameter shows a higher value than other dimensions.

Keywords**:** *Highspeed 3D Printing, 3D Printing Material, Dimensional Consystency.*

1. Introduction

3D printing technology has been widely applied in various industries, including manufacturing, healthcare, automotive, aerospace, and others [1-4]. One crucial aspect of the 3D printing process is the dimensional consistency of the printed parts, which is essential. With the increasing need for faster and more efficient production, research on higher printing speeds has become increasingly relevant [5]. High 3D printing speeds, such as 1200 mm/s, offer the potential to significantly accelerate the production process. However, increasing this speed also presents challenges related to the quality and dimensional consistency of the printed parts. Therefore, understanding how each parameter interacts and affects the printing results is key to optimizing high-speed 3D printing processes.

Although high printing speeds can increase production efficiency, there are several issues that need to be addressed to ensure optimal print quality. One major issue is thermal deformation that can occur due to uneven temperatures during the printing process [6-7]. This deformation can lead to dimensional distortion, resulting in prints that do not conform to the desired design. Additionally, high material flow rates can cause instability in the 3D printing material extrusion, which can in turn result in rough surfaces or structural defects in the prints [8]. Dimensional consistency is also influenced by factors such as cooling rate, layer-to-layer interaction, and nozzle wear [9]. Another issue to consider is quality control during the printing process, where sensors and monitoring technologies must be able to detect and correct deviations in real-time to maintain consistent results [10].

This study aims to investigate the dimensional consistency of two commonly used 3D printing highspeed materials, Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS), at high printing speeds. By comparing the performance of these materials, this research seeks to provide insights into how each material maintains dimensional accuracy under high-

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speed conditions, helping to determine which material may be more suitable for applications requiring efficient yet precise production.

This research has several limitations that should be considered. First, this study focuses on the use of specific materials commonly used in 3D printing, such as Polylactic Acid (PLA) and (ABS) Acrylonitrile Butadiene Styrene [11]. Additionally, this study focuses more on testing the dimensional consistency of printed parts without considering other factors such as mechanical strength and surface properties.

2. Material and Methods

This research focuses on the dimensional accuracy of 3D printed objects. The method used involves printing 5 cube samples measuring 20mm x20mm x20 mm with a through all 10 mm hole using ABS Highspeed and PLA Highspeed materials at a maximum print speed of 1200 mm/s. After the printing process, the dimensions of each sample are carefully measured using a vernier caliper at three different points.

To analyze the data, the authors calculated the average deviation and percentage deviation from the design dimensions. The average deviation shows how far the average measurement results deviate from the predetermined design dimensions [12]. The calculation of Average Deviation is shown in Equation 1.

Average Deviation = (Σ |Xi - X̄|) / n ………………………………………(1)

Meanwhile, the percentage deviation provides a clearer picture of the level of inaccuracy in percentage form. Thus, the author can analyze the correlation between the printing process variables and the resulting deviation. The calculation of Average Deviation is shown in Equation 2.

Percentage Deviation = [(Actual Value - Reference Value) / Reference Value] x 100%………(2)

The reference values used in this study are the length, width, height dimensions of the sample cube design of 20 mm and the hole diameter of 10 mm. The sample cube design in this study is shown in Figure 1.

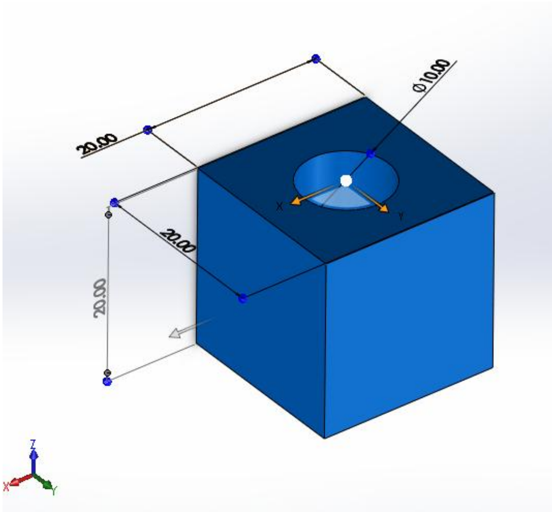

Figure 1. Sample Cube Size 20x20x20mm and 10 mm diameter hole

2.1. 3D Printing Setting and Material

In this study, experiments were conducted by adjusting the 3D printer machine according to the characteristics of each material. For ABS, the nozzle temperature was set in the 230-260°C range with a bed temperature of 100-110°C, while for PLA the nozzle temperature was set at 190-220°C and the bed temperature at 60-70°C. Both materials use print fans and enclosures to ensure optimal print quality. The machine settings are shown in Table 1.

Table 1. 3D Printer Setting

Setting	ABS	PLA
Nozzle Temperature	230-260°C	190-220°C
Bed Temperature	100-110°C	60-70°C
Print Fan	On	On
Enclosure	Yes	Yes
Brim/Raft	Yes	Yes
Support	No	No
Maximum Printing Speed	1200 mm/s	1200 mm/s

3. Result and Discussion

3.1 Dimension measurement result

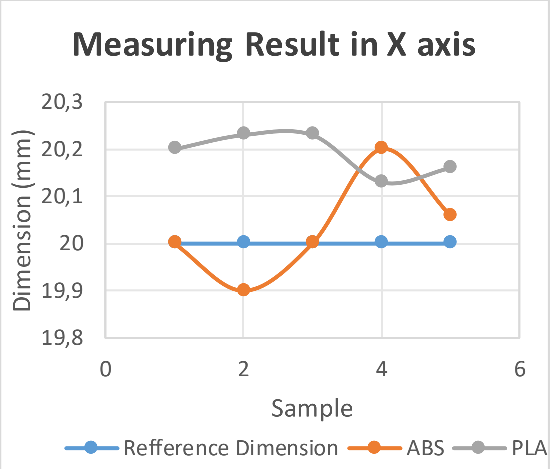

Figure 3. Measuring Result in X axis

Based on the results of measuring the dimensions of 3D printed objects in the X-axis using PLA and ABS materials shown in Figure 3, there is a significant deviation compared to the reference dimensions. In PLA material, the resulting dimensions are always larger than the reference dimensions. The dimension range on the PLA samples ranged from 20.05 mm to 20.2 mm, with the largest deviation seen on the 4th sample reaching around 20.22 mm, while the smallest deviation was found on the 1st sample.

On the other hand, the ABS material showed greater fluctuations. In most samples, the ABS dimensions were below the reference dimensions, with the lowest deviation recorded in the 2nd sample which had dimensions of about 19.95 mm. However, in the 4th and 5th samples, the ABS dimension actually exceeded the reference value, reaching more than 20.1 mm.

Based on the graph of the dimensional measurement results of 3D printed objects on the Y-axis shown in Figure 4, there is a deviation or error between the printed results with PLA and ABS materials compared to the reference dimensions. For the PLA material, the resulting dimensions are consistently larger than the reference dimensions. At first, the deviation was relatively small, around 20.2 mm, but increased significantly by the 4th sample, reaching over 20.45 mm, before decreasing slightly by the 5th sample. This indicates that the PLA material tends to produce larger dimensions and is less stable against the reference. Meanwhile, the ABS material showed a different deviation pattern. In the initial sample, the ABS dimension was larger than the reference dimension, hovering around 20.3 mm, but started to decrease drastically in the 4th sample, reaching a value below 20 mm, before finally rising back to near the reference value in the 5th sample. The largest deviation occurred in the 4th sample, where the ABS dimension dropped below the stable reference value.

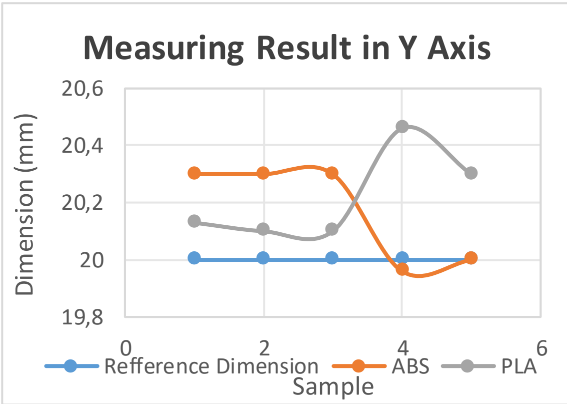

Figure 4. Measuring Result in X axis

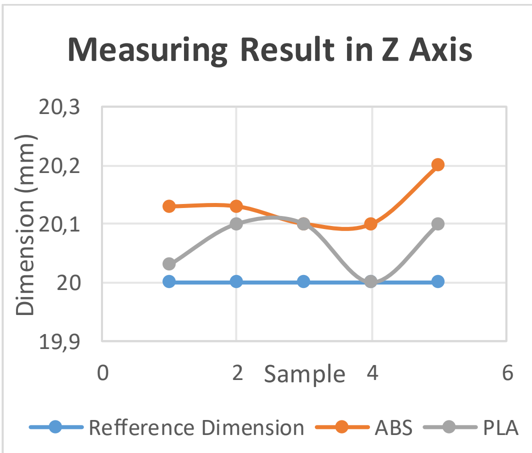

Figure 5. Measuring Result in X axis

Based on the graph of the dimensional measurement results of 3D printed objects on the Z-axis shown in

Figure 5, it can be seen that there is a deviation or error between the printed results using PLA and ABS materials compared to the reference dimensions. In PLA material, the dimensions produced tend to vary but are relatively more stable than ABS. The measurement results on PLA show dimensions that range from around 20.05 mm to 20.15 mm. Although there are fluctuations, the largest deviation occurs in the 5th sample with dimensions reaching almost 20.15 mm, which is still slightly above the reference dimensions. Meanwhile, the ABS material showed a more significant deviation pattern. In the initial samples, the ABS dimensions were larger than the reference, hovering around 20.15 mm to 20.18 mm. However, by the 5th sample, the ABS dimensions increased significantly, reaching more than 20.2 mm. The largest deviation in ABS occurred in the 5th sample, showing a much higher increase compared to the reference dimension.

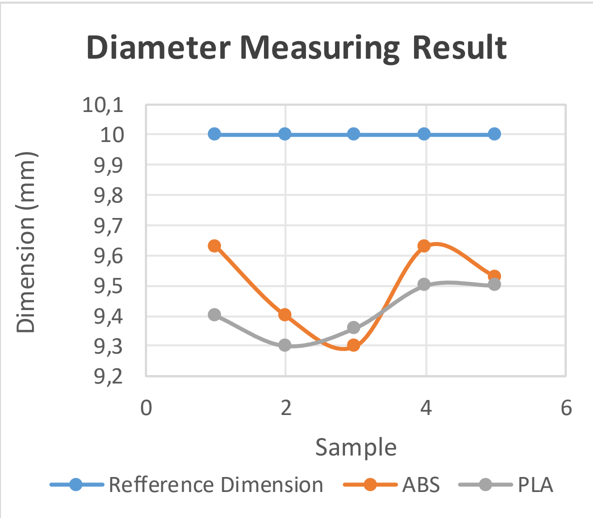

Figure 6. Hole Diameter measuring result

The graphs based on Figure 6 shown that the dimensional measurement results of the 3D printed PLA and ABS objects show a significant deviation compared to the reference dimensions. It can be seen that the ABS material tends to produce objects with dimensions that are slightly larger than expected, especially in the 3rd and 4th samples. In contrast, the PLA material shows the opposite tendency, where the dimensions of the objects produced are generally smaller than the reference dimensions, especially in the 2nd sample.

3.2 Average Deviation and Deviation Percentage

Analysis of the deviation data in 3D printing with ABS and PLA materials based on Table 2 and Table 3. shown that there is a mismatch between the printed dimensions and the design dimensions. In general, both ABS and PLA materials experienced deviation from the expected dimensions. In ABS, the largest deviation occurred in the diameter axis, reaching 5.02%. This indicates that the printing process tends to produce smaller object diameters compared to the initial design. Meanwhile, in the PLA material, the largest deviation also occurred in the diameter axis, which amounted to 5.88%. This result shows a similar trend to the ABS material, where the object diameter tends to be smaller than planned.

Table 2. ABS 3D printing deviation

Sample	Deviation			
	X Axis (mm)	Y Axis (mm)	Z Axis (mm)	Diameter (mm)
1	0.00	0.30	0.13	-0.37
2	-0.10	0.30	0.13	-0.60
3	0.00	0.30	0.10	-0.70
4	0.20	-0.04	0.10	-0.37
5	0.06	0.00	0.20	-0.47
Average Deviation	0.07	0.19	0.13	0.50
Deviation Percentage	0.36 %	0.94 %	0.66 %	5.02%

Dimensional deviations observed in high-speed 3D printing using PLA and ABS materials are closely linked to the intrinsic thermomechanical properties of each polymer and their interaction with the process dynamics [13]. PLA, while popular for its ease of printing and biodegradability, has inherent limitations that affect its dimensional stability under rapid manufacturing conditions. One critical factor is its relatively high coefficient of friction, which increases surface abrasion as the material moves through the extrusion system. This elevated friction generates additional mechanical stress on the printed layers, causing distortion—especially in high-speed conditions where the material is deposited more rapidly and with less cooling time between layers [14]. Furthermore, PLA has a lower glass transition temperature and poorer heat resistance, making it more prone to softening and deformation under sustained thermal and mechanical loads. These characteristics compromise PLA's ability to retain its intended shape during rapid deposition, particularly in the lateral (X and Y) dimensions where nozzle-induced drag and acceleration changes are more pronounced.

Table 3. PLA 3D printing deviation

Sample	Deviation			
	X Axis (mm)	Y Axis (mm)	Z Axis (mm)	Diameter (mm)
1	0.20	0.13	0.03	-0.60
2	0.23	0.10	0.10	-0.70
3	0.23	0.10	0.10	-0.64
4	0.13	0.46	0.00	-0.50
5	0.16	0.30	0.10	-0.50
Average Deviation	0.19	0.22	0.07	0.59
Deviation Percentage	0.95%	1.09%	0.33%	5.88%

In addition to friction and heat sensitivity, PLA's longer cooling time also contributes to dimensional inaccuracy. In high-speed printing, the nozzle moves quickly from one region to another, often depositing new layers before the previous ones have sufficiently cooled and solidified. This can result in poor interlayer adhesion and geometric warping, especially near sharp corners or unsupported sections [15]. As a result, prints made from PLA under these conditions may exhibit swelling or shrinkage depending on local thermal gradients, further distorting the final geometry. Conversely, ABS demonstrates better structural resilience during high-speed printing due to several favorable material attributes. Although ABS is known to be more difficult to print due to its tendency to warp under normal conditions, its higher thermal resistance and more stable wear behavior provide an advantage in high-speed scenarios. The increased porosity of ABS filaments enhances thermal dissipation and allows more even shrinkage, which helps maintain structural uniformity. Moreover, ABS undergoes more predictable thermal contraction during cooling, which, when properly managed, leads to consistent dimensional results.

In this study, ABS showed relatively lower deviation in lateral dimensions, as well as better control over diameter changes, despite a slightly higher vertical deviation. The vertical deviation in ABS may be attributed to its faster cooling rate, which can cause micro-gaps or layer separation along the build direction if the process is not adequately optimized. However, overall, ABS's mechanical robustness and thermally balanced behavior enable it to perform more reliably in high-speed 3D printing applications, where dimensional fidelity is critical. Therefore, for applications that demand high-precision and consistency across multiple axes in rapid prototyping or mass customization workflows, ABS is generally a more suitable material than PLA, provided that warping issues can be mitigated through enclosure control, bed adhesion techniques, or post-processing calibration [16].

4. Conclusion

Based on the results of the research on dimensional consistency in the high-speed 3D printing process, it was found that there were deviations in the printouts of both ABS and PLA materials. Overall, the deviation of length, width, height, and hole diameter dimensions in both materials is not significant for general applications, but the deviation in hole diameter shows a higher value than other dimensions. PLA material tends to have a larger deviation than ABS, especially in the circle diameter parameter with a deviation percentage of 5.88%, while ABS is 5.02%. This shows that although high-speed 3D printing can improve production efficiency, the quality of dimensional consistency is still affected by print speed and material selection.

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