DIMENSIONAL ACCURACY OF ULTRASONIC ASSISTED FUSED DEPOSITION MODELING SYSTEM PRINTED SPECIMEN

S. Maidin[1], N.I. Iryani[1], K.H. Ting[1] and E. Pei[2]

[1]Faculty of Manufacturing Engineering,
Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

[2]College of Engineering, Design and Physical Science,
Brunel University, Kingston Lane, Uxbridge,
Middlesex, UB8 3PH, United Kingdom.

Corresponding Author's Email: [1]shajahan@utem.edu.my

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ABSTRACT: Studies on the effects of ultrasonic vibration on the dimensional accuracy and surface roughness of machined specimen have been conducted extensively. However, the effects of ultrasonic vibration on the dimensional accuracy of FDM specimen has never been recorded. This study investigates the effect of various frequencies of ultrasonic vibration on the dimensional accuracy of 3D printed specimens. An open-source FDM printer integrated with an ultrasonic piezoelectric transducer was used to print the test specimens. The frequency was set at 0 kHz, 7 kHz, 15 kHz, and 20 kHz to print ABS and PLA filament material. The printed specimens' dimensional accuracy was tested using a coordinate measuring machine. Parameters such as the length, width, height, thickness, corner radius, angularity, and perpendicularity were checked. Frequency set to 20 kHz results in drastic improvement of dimensional accuracy for PLA specimen. In contrast, for the ABS specimens, the ultrasound frequency (7 kHz and 15 kHz) affect and improved only the thickness accuracy. However, all other geometries failed to meet the expected dimensional accuracy. The application of ultrasound does not result in any significant changes in the dimensional accuracy of the 3D printed specimens in ABS material.

KEYWORDS: *Fused Deposition Modeling; Ultrasound Vibration; Dimensional Accuracy; Coordinate Measuring Machine*

1.0 INTRODUCTION

FDM is an AM process where a small diameter of the filament is fed into a heated nozzle where it melts and extrudes from the print heat. Nonetheless, stair-stepping is one of the problems of FDM, the seam lines show between layers and excess material become a residue on the surface which will cause the poor surface and bad quality of finishing [1]. The dimensional accuracy of the part, the degree of agreement between the produced dimension and its specification, is the main element for assuring that the produced components are repeatable with the correct dimension [2]. In contrast, ultrasonic-assisted machining (UAM) has been implemented in various type of production areas since its development. The ultrasonic piezoelectric transducer is used to convert electrical energy to mechanical energy [3]. UAM technology has been used in many industrial areas to enhance the process of machining and to enhance the finishing and quality of the produced parts [4-6].

Nsengimana et al. [2] suggested that the immersion of ABS test pieces into an acetone bath produced excellent dimensional accuracy. Tiwari and Kumar [7] studied the factors which affect the dimensional accuracy of the parts produced by FDM printed with PLA and found the effect of orientation and the effect of support features with regards to dimensional accuracy. Smith et al. [8] have defined and evaluated the dimensional errors resulting from Electron Beam additive manufacturing (EBM). The study focuses on the importance of heat management in features with negative surfaces to yield accurate dimensional of parts.

Studies on the effects of ultrasonic vibration on the surface roughness of the FDM specimen have been previously published by the authors in other publication. However, no data about the dimensional accuracy on the effects of ultrasonic vibration of FDM specimen has ever been recorded. Dimensional accuracy is the measurement that examines how close the product sizes are to the desired product dimension. Dimensional accuracy is vital in various engineering application. This study aims to determine the impact of ultrasonic vibration on the dimensional accuracy of the 3D printed specimens. The objective of this research was firstly to create a CAD drawing of the specimen, convert it to STL format and print it with a different frequency of vibration by using an open-source FDM 3D printer. Secondly, Coordinate Measuring Machine (CMM) was used to determine the result of the dimensional accuracy of the specimen that 3D printed with the assisting of ultrasonic vibration. Finally, the result of the dimensional accuracy of the specimen was compared with the standard specimen. In addition, comparison between ABS and PLA material was also made as these materials were used often in the FDM process as well as to identify the material that reacts significantly to the ultrasonic frequencies.

2.0 METHODOLOGY

2.1 Experimental Setup

An open-source FDM 3D printer was used to print the test specimen. The piezoelectric transducer that was connected to a function generator was fixed to the printing platform of the 3D printer to apply ultrasonic frequency that produces ultrasonic vibration across the printing platform during the printing process. The specimens were printed using ABS and PLA materials with a frequency of 0 kHz, 7 kHz, 15 kHz, and 20 kHz. A total of eight specimens were printed to measure various dimensional accuracy. The experimental setup is shown in Figure 1.

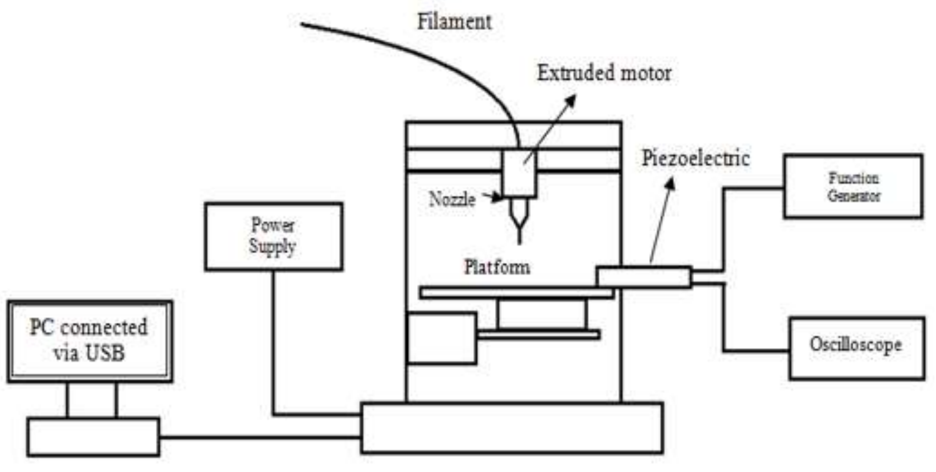

Figure 1: Experimental setup of ultrasonic-assisted FDM system

2.2 Up Plus 2 FDM Printer

The UP Plus 2 is an open-source FDM printer that has 0.4 mm of nozzle diameter and body dimension of 140 mm x 140 mm x 135 mm. It was used to print the specimen (Figure 2). ABS and PLA were used in this study. The filaments were heated until the form of semi-molten with a temperature of 270°C. Meantime, PLA filament was extruded at 190°C as it is the recommended setting by Cura software for PLA. UP software was used to convert the CAD drawing of the specimen into the STL format due to the Up Plus printer can only function with the file in STL format.

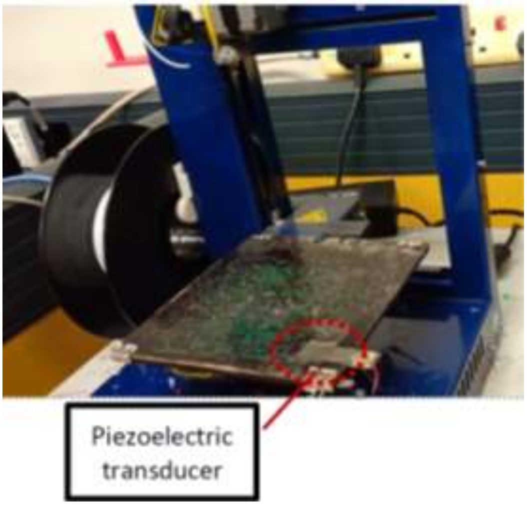

Figure 2: Open source 3D printer (UP Plus 2)

2.3 Ultrasonic Piezoelectric Transducer

In this study, a piezoelectric transducer (Figure 3) was attached to the printer platform. The function of the piezoelectric transducer is to convert the electrical signal to mechanical vibration or vice versa.

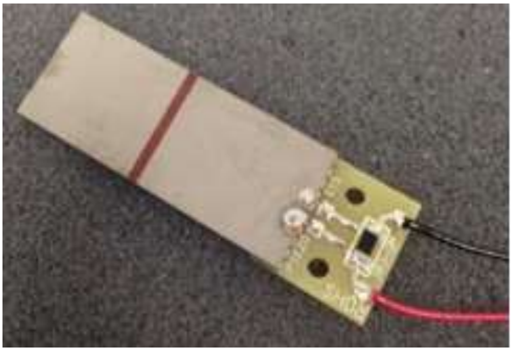

Figure 3: Ultrasonic piezoelectric transducer

2.4 Function Generator

The function generator can generate various types of repeating waveforms over a range of frequencies. The function generator has a typical frequency of up to 20MHz. The frequency was set at 0 kHz, 7 kHz, 15 kHz, and 20 kHz. In order to produce the ultrasonic frequency, the function generator was linked straight to the piezoelectric transducer. For each frequency, the amplitude was set to 9 Vp-p. The amplitude remained constant and acted as one of the fixed variables.

2.5 Coordinate Measuring Machine (CMM)

The 3D-printed specimens were checked for dimensional precision by the CMM. It was used for measuring length, parallelism, flatness, length, width, a radius of the corner and height of the specimen.

2.6 Dimension Measured and Drawing

CATIA was the CAD system used to draw the test specimen model. Figure 4 displays the geometry of the test specimen. The geometry was decided as it not too complex and consist of the important dimensions that were used for the accurate measurement. Figure 5 shows the printed 3D specimen that was later measured using the CMM. There were seven measurements taken to study the accuracy of the geometries. The lists of the geometries are as Table 1.

Table 1: The lists of geometries

Description	Measurements
Thickness	15 mm
Corner Radius	10 mm
Angle (Chamfer)	45°
Perpendicularity	90°
Hole Diameter	10 mm
Flatness	Pass or Fail
Width	22 mm

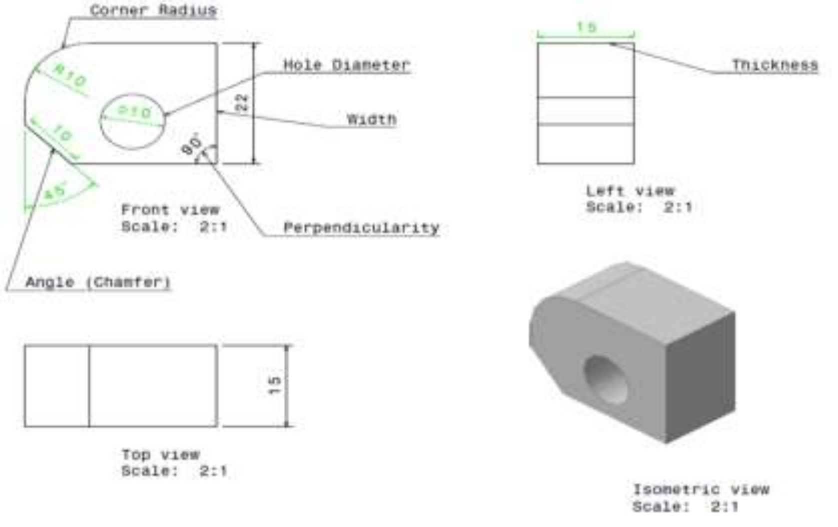

Figure 4: Geometry of the test specimen

Figure 5: Printed 3D specimen

3.0 RESULTS AND DISCUSSION

3.1 Comparison between ABS and PLA Result

The desired geometry measurements for both PLA and ABS are the same and were measured perpendicular in the direction. The thickness of the specimens should be 15 mm. The diameter of the holes is 10 mm. The angle of the chamfer should be 45°. The perpendicularity of the specimen is expected to be 90°. The corner radius is 10 mm. The specimens must pass the flatness test, and the width should be 22 mm. Table 2 shows the results obtained when the specimens were tested using the CMM. The underlined values are those nearest to the actual value. Based on the results below, it is proven that the application of ultrasound affects PLA more than ABS. When the frequency is set to 20 kHz, the dimensional accuracy for the PLA specimen improved that shows the measurements were near to the desired values.

This finding supports the studies of ultrasound-assisted machining, which also showed that ultrasound could improve dimensional accuracy [9]. The measurements obtained for 20 kHz PLA are the nearest to the desired value. Despite that the addition of ultrasound frequency improves the dimensional accuracy of the ABS specimens; the measurements were not as accurate as 20 kHz PLA specimens. The results of the measurements for both materials were plotted in the same graph to show the differences clearly for comparison and to reduce the number of graphs in this section.

Table 2: Results for ABS and PLA CMM measurement

Geometry measured	ABS 0 kHz	ABS 7 kHz	ABS 15 kHz	ABS 20 kHz	PLA 0 kHz	PLA 7 kHz	PLA 15 kHz	PLA 20 kHz
Thickness (mm)	15.178	15.058	15.027	15.153	15.268	15.245	15.149	15.062
Hole diameter (mm)	9.587	9.668	9.695	9.667	9.625	9.558	9.440	9.845
Angle/ Chamfer (°)	44.932	45.583	45.366	45.279	45.467	44.680	45.018	45.005
Perpendi-cularity (°)	89.718	89.577	89.606	89.565	89.747	89.664	89.754	89.816
Corner Radius (mm)	9.414	9.061	10.470	9.935	10.421	9.702	9.568	9.891
Width (mm)	21.973	22.067	22.096	22.081	22.059	22.054	22.072	22.114
Flatness (pass/fail)	pass	pass	pass	pass	pass	pass	pass	pass

3.2 Result of Thickness Measurement

Figure 6 shows the graph for the thickness vs frequency of ABS and PLA material. The specimen which has the closest value to the desired value of thickness, 15 mm, was ABS 15 kHz, which is at 15.027 mm. The dimensional accuracy for the thickness of ABS improved by 0.99% when printed using ultrasound frequency. As for PLA, the specimen printed with 20 kHz frequency resulted in the best accuracy for the thickness, which is at 15.062 mm with a slight deviation of only 0.062 mm. The dimensional accuracy had improved by 1.35% from the 0 kHz specimen.

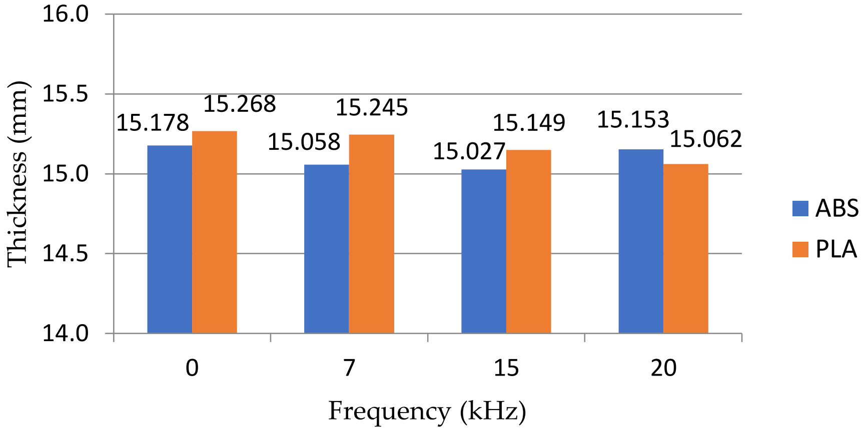

Figure 6: Graph for thickness vs frequency of ABS and PLA

3.3 Result of Hole Diameter Measurement

The graph of the hole diameter vs frequency of ABS and PLA specimens is shown in Figure 7. For ABS specimen, the hole diameter for the specimen printed with 15 kHz shows the reading nearest to the desired value of 10 mm. The accuracy improved by 1.13% compared to the standard ABS specimen. The results obtained indicate that the specimen with the best hole diameter is specimen PLA 20 kHz with an increment of 2.29% from the 0 kHz specimen. The measurement obtained was 9.845 mm, which was the nearest to 10 mm.

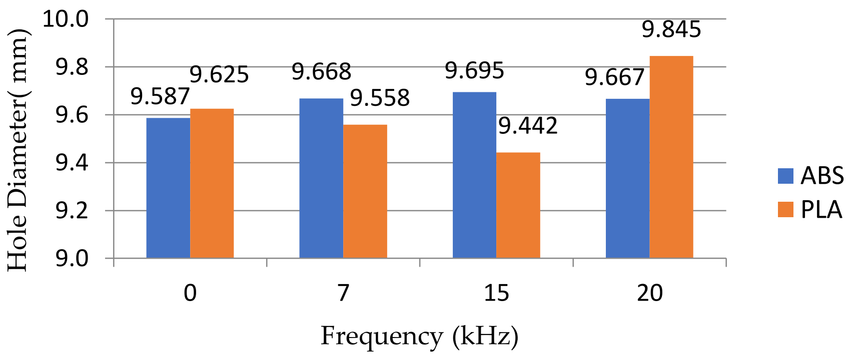

Figure 7: Graph for hole diameter vs frequency of ABS and PLA

3.4 Result of Chamfer Measurement

Figure 8 indicates the graph for the chamfer vs frequency of ABS and PLA specimens. The measurement of angle (chamfer) for every specimen was different, and all value approaches 45°. However, for the ABS specimens, the optimum measurement was obtained by the specimen printed without any aid of ultrasound frequency. As for PLA, the nearest is 45.005°; which is the reading obtained by PLA 20 kHz. The accuracy for the 20 kHz PLA specimen escalated up to 1.02% from 0 kHz PLA specimen.

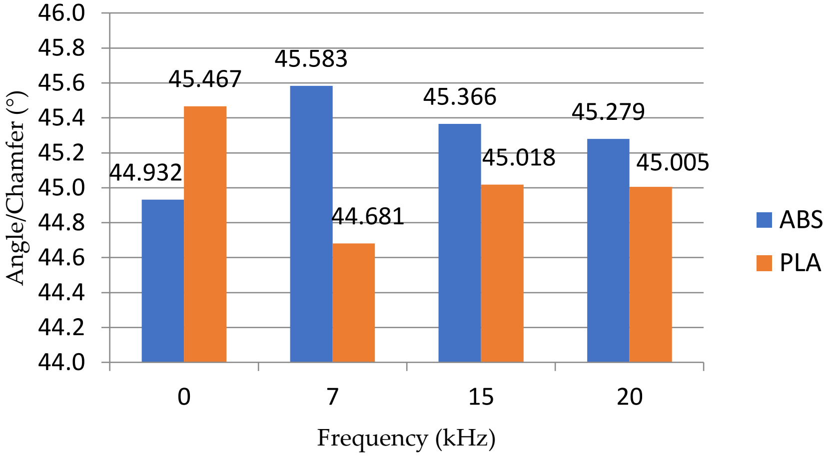

Figure 8: Graph for chamfer vs frequency of ABS and PLA

3.5 Result of Perpendicularity Measurement

Figure 9 shows the graph for the perpendicularity vs frequency of ABS and PLA. It can be seen that the measurement for both ABS and PLA at 0 kHz has an almost equal value which is 89.718° and 89.747° respectively. The 0 kHz specimen of ABS shows the nearest to 90° compared to other ABS specimens. PLA 20 kHz displayed the nearest to 90° with about 0.38% of increment in accuracy compared to the 0 kHz specimen.

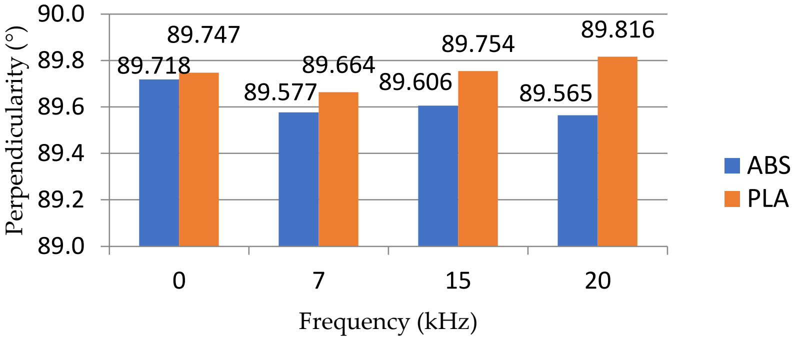

Figure 9: Graph for perpendicularity vs frequency of ABS and PLA

3.6 Result of Corner Radius Measurement

Figure 10 exhibits the graph for the corner radius vs frequency of ABS and PLA specimens. The desired measurement is 10 mm. The specimen that produced the nearest dimension to 10 mm is ABS 20 kHz followed by PLA 20 kHz. For the 20 kHz ABS, the application of ultrasound frequency has improved the accuracy by 5.53% from the 0 kHz. The dimensional accuracy for the 20 kHz PLA specimen had also improved by 5.09% from the standard specimen.

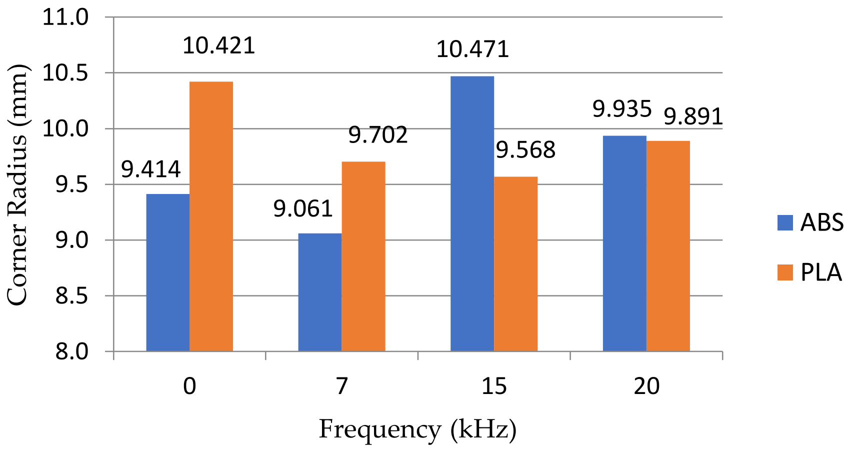

Figure 10: Graph for corner radius vs frequency of ABS and PLA

3.7 Result of Width Measurement

Figure 11 shows the graph for the width vs frequency of ABS and PLA specimens. The width of the specimens varies significantly. However, it can be seen that the specimen with the closest reading to the desired value for ABS material is printed with a 7 kHz ultrasound frequency. The dimensional accuracy improves by 0.43%. The width for the overall specimens of PLA is quite precise; nevertheless, the specimen with the best measurement of width is also printed with a 7 kHz ultrasound frequency. The accuracy of the width of the specimen had improved by 0.02% from the one printed without any ultrasound.

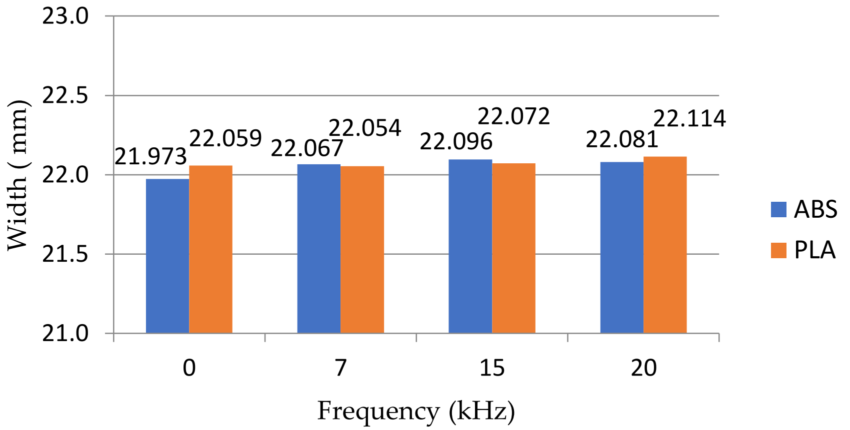

Figure 11: Graph for width vs frequency of ABS and PLA

4.0 CONCLUSION

Based on the results, it can be concluded that PLA specimens are more likely to be affected by the addition of ultrasound frequency while printing the test specimens. When the frequency was set to 20 kHz, the dimensional accuracy of the PLA specimen improves drastically. Most of the desired dimensions tested resulted in a high accuracy reading. It can be concluded that 20 kHz is the optimum frequency parameter to be applied when using a 3D printer and printing PLA specimens. On the other hand, for ABS specimens, it can be seen that the addition of ultrasound frequency (7 kHz and 15 kHz) improved only the thickness of the specimens. However, all other geometries measured were too far from the desired value. The application of ultrasound does not result in any significant changes in the dimensional accuracy of the 3D printed specimens for ABS material compared to PLA. This study shows that the factors which affect the dimensional accuracy are the geometries and materials used. However, in this study, the design was kept constant, and the main difference is the material and the addition of ultrasound frequencies.

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