Scientific Research Journal,
Vol 22, special issue (2025) 135-149
https://doi.org/10.24191/srj.v22is.13289

An Optimum Combination of Filament Material and Slicing Software in Improving the Manufacturing Performance of 3D-printed Parts

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Received: 9 September 2024
Accepted: 4 October 2024
Online First: 25 January 2025

ABSTRACT

Additive manufacturing, or 3D printing, creating a layer of material to produce three-dimensional objects from computer models. Specifically for Fused Filament Fabrication (FFF) that uses filament material, different filament material varies in strength, flexibility, temperature resistance, etc. These factors impact 3D-printed part performance. Apart from filament material, various slicing software that available in the market also influence the manufacturing performance of 3D print parts. Therefore, selecting a correct filament material with suitable slicing software is important. Up to date, the relation between filament materials and slicing software on printed part quality and manufacturing performance is still unknown. Thus, it is necessary to study the manufacturing characteristics of 3D printed parts using different filament materials and slicing software to find the best combinations and parameters for reliable and efficient production of high-quality parts for various applications. This work evaluates relationship between filament and slicing software on the manufacturing performance of 3D printing parts. PLA, ABS, and Nylon as filament material is used. Meanwhile, Ultimaker Cura, PrusaSlicer, and Repetier-Host is used as slicing software. Printed parts are produced according to ASTM D638 Type 1 dimensions. The manufacturing performance were measured

based on accuracy of printing time prediction, dimensional accuracy, and surface quality. From the result, each slicing software have advantages and disadvantages when different material used. In general, when using Nylon as filament material, the printing time became shortest regardless slicing software (30.33 minute to 71.33 minute). However, the shortest time printing time can be produce using combination of Repetier-host as slicing software and Nylon as filament material where printing time taken is 30.33 minute. Meanwhile, by using combination of ABS material and Ultimaker Cura, printer will able to produced smoothest surface (2.792 μm). For dimensional accuracy, the most accurate combination was using Repetier-Host and PLA filament (0.03%).

Keywords: Fused Filament Fabrication (FFF); Filament Material; Slicing Software; Dimensional Accuracy; Surface Quality.

INTRODUCTION

Additive manufacturing also known as 3D printing has become an option to traditional subtractive manufacturing methods like milling, drilling and cutting process. With the capability to produce complex shape at optimum material usage, 3D printing has progress effectively in producing customize products. Over the years, many research has contributed to significantly progressing in 3D printing development. 3D printing technology such as Filament Fused Fabrication (FFF) [1-3] Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Stereolithography (SLA) and many more has rigorously developed and optimized.

Specifically, for FFF, there are many research and findings related to printing parameter optimization [3-6], design optimization, filament material, and slicing software. Recently, there are many developments on filament material that offers a bigger option across application. Example of available filament material such as Polyacrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polycarbonate (PC), Nylon, and polyamide (PA). ABS and PLA [4] are the most popular materials used [7,8]. ABS have low glass transition temperature (T_g) and high-quality processing features. It is categorizing as amorphous polymer due to lacks crystallite. Therefore, printing accuracy and dimensional consistency is high because

shrinkage ratio will be low throughout the cooling phase [9]. ABS also can withstand intense heat, cold, humidity, and sunlight because of its chemical and physical resilience [10]. PLA material has low melting point and hence low energy requirements for production. It adheres well to the substance and may be used without heating [11]. This material has huge economic potential effect due to positive characteristics such as glossiness, multicolor appearance and ease of printing [12].

On the other hand, development of slicing software also significantly increases over the years. There are many slicing software available in the market such as Ultimaker Cura [13,14], PrusaSlicer , Simply3D [13], Slic3r [13,15], OctoPrint, and Ideamaker. Abundance of slicing software make users overwhelmed, in deciding which software is the most ideal for their application. Therefore, this work is conducted to study the effect of filament material with combination of slicing software. The manufacturing performance of printed parts is evaluated based on accuracy of slicing software in predicting printing time, dimensional accuracy of printed dimensions in term of its length, width, and thickness, and finally measure the surface roughness to investigate surface quality from filament material used and its slicing software. Findings from this work may help manufacturer selecting the best material to be used with ideal slicing software for their application.

METHODOLOGY

Four main steps involved in this work start with 3D modeling using Fusion 360 software, slicing the developed 3D model using various slicing software (Ultimaker Cura, Repetier-Host, and PrusaSlicer), print 3D model from all slicing program using different filament material (PLA, ABS, Nylon), and finally manufacturing performance measurement of printed part is evaluated from the accuracy of printing time prediction comparing calculated printing time by slicing software and actual printing time taken by printer, dimensional accuracy using digital vernier caliper, and surface quality using Mitutoyo SJ-410.

3D Model

Sample's geometry is following ASTM D638 Type 1. The model is developed using Fusion 360 software and saved in STL file format.

Slicing

After 3D model is developed and converted into STL file, the model is imported into slicing software and all printing parameter are programmed in selected slicing software. In this work, three slicing software were used which are Ultimaker Cura, Repetier-Host, and PrusaSlicer. Interface for all slicing software is shown in Figure 1. Printing parameters used in this work is tabulated in Table 1. Three filament materials are used which are PLA, ABS, and Nylon. All printing parameter is set constant in all slicing software except extruder temperature and bed temperature. This is because, extruder and bed temperature are differed between materials. The temperature used is based on manufacturer's recommendation. As suggested by manufacturer, PLA material requires lower temperature compared to ABS and Nylon. In total, there are nine programs created in this work that is based on three different slicing software that programmed for three different materials.

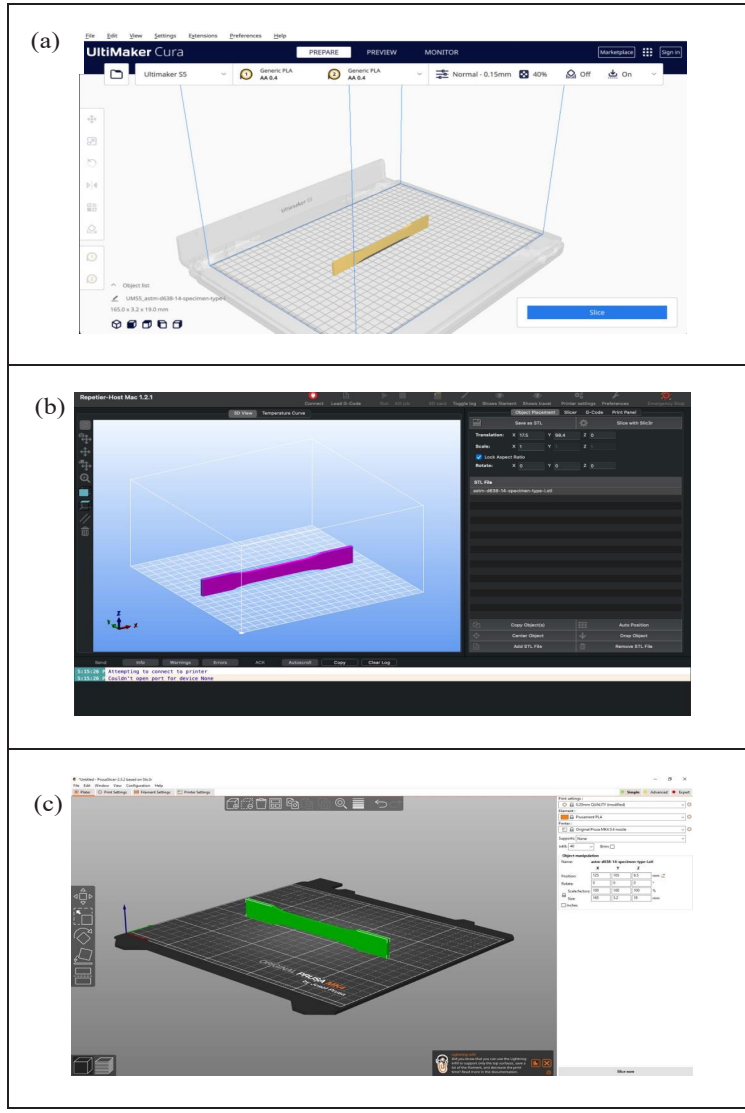

Figure 1: Interface of (a) Ultimaker Cura, (b) Repetier-Host, and (c) PrusaSlicer

Table 1: Printing parameter

Parameter	Value
Filament material	PLA, ABS, Nylon
Filament diameter	1.75mm
Extruder temperature	220°C (PLA), 235°C (ABS), 235°C (Nylon)
Bed temperature	60°C (PLA), 80°C (ABS), 80°C (Nylon)
Printing speed	40mm/s
Layer thickness	0.3mm
Infill density	40%
Infill pattern	Grid

3D Printing

After 3D model is programmed and sliced using slicing software, the program is loaded into the 3D printer and samples are produced. Figure 2 shows a printer used which are Ender 3 Pro. Three replications for each parameter, 27 samples have been produced (Figure 3).

Figure 2: 3D printer (Ender 3 Pro)

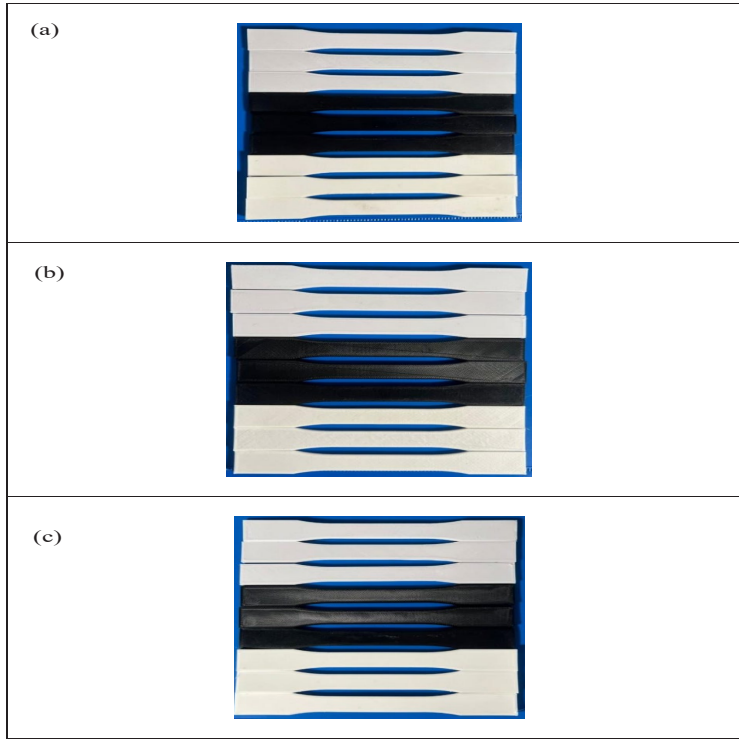

Figure 3: Printed samples using (a) Ultimaker Cura, (b) Repetier-Host, and (c) PrusaSlicer software

Manufacturing Performance of 3D Print Methodology

After the samples have been fabricated, the quality of parts is measured. In this work, three measurement is taken to determine the quality of the printed parts which are accuracy of printing time prediction, dimensional accuracy, and surface quality. Accuracy of printing time prediction is calculated based on Eq. (1).

Eq. (1) is measuring the percentage error on actual time taken to print the part compared to prediction time generated from slicing software. The lowest percentage of error indicate the most accurate slicing software in predicting the printing time.

For dimensional accuracy, firstly, the dimension of length, width, and thickness of printed parts is measured using vernier caliper. The dimensions are then compared with designed 3D model dimension. The most accurate dimension is known from the lowest error percentage calculated by using Eq. (2). For surface quality, the surface roughness value is taken using Mitutoyo SJ-410.

$$\left|\frac{A_t - P_t}{A_t}\right| \times 100 \quad (1)$$

Where; A_t = Actual time, P_t= Prediction time,

$$\left|\frac{d-p}{d}\right| \times 100 \quad (2)$$

Where; d = Designed dimension, p = printed dimension.

RESULT AND DISCUSSION

There are three performance indicators to evaluate the manufacturing performance of 3D print based on criteria mentioned in methodology section. There are accuracy of printing time prediction, dimensional accuracy, and surface quality.

Accuracy of Printing Time Prediction Methodology

Based on Eq.(1), accuracy of printing time prediction is calculated. Table 2 shows the accuracy of printing time prediction for all (9) printing programs. From the result, for the prediction time, across all software, the predicted printing time is same regardless any filament material used. However, the actual printing time recorded has small variation between materials. Printing 3D part using Nylon require shortest time (30.33 min to 71.33min) compared to printing PLA and ABS. PLA and ABS recorded almost similar printing time regardless any slicing software used.

Table 2: Accuracy of printing time prediction

Slicing Software	Filament Material	Prediction Time (min)	Actual Time (min)	Accuracy (%)
Ultimaker Cura	PLA	64	71.67	11
	ABS		73.00	12
	Nylon		71.33	10
PrusaSlicer	PLA	47	52.33	10
	ABS		52.33	10
	Nylon		51.33	8
Repetier-host	PLA	21	31.00	32
	ABS		31.00	32
	Nylon		30.33	31

In term of performance of slicing software, PrusaSlicer performed the best in predicting printing time compared to Ultimaker Cura and Repetier-host. Even though slicing program from Repetier-host recorded highest error that resulting less accurate in predicting printing time, it is the program that completing printing in shortest time compared to Ultimaker Cura and PrusaSlicer. Therefore, if the shortest cycle time is a concern over an accuracy of prediction time, the manufacturer may decide to use Repetier-host compared to the other two software. However, if the accuracy of printing time prediction is significant over printing time, PrusaSlicer should be used as slicing software because it is recording the lowest error percentage (between 8 – 10%) which indicate most accurate slicing software over various filament material.

Dimensional Accuracy

Figure 4 until Figure 6 shows the result of dimensional accuracy using different material and various slicing software to produce printed parts. Lowest dimensional error value recorded in Figure 4 indicates better dimensional accuracy. From the result, in producing an accurate 3D part, it is important to do material selection and identify critical dimension. If selected material is PLA and it is critical to control length dimension, the best slicing software is Repetier-Host. This is because, by using programmed by Repetier-host, the part produced most accurate dimension (0.03%) compared to Ultimaker Cura and PrusaSlicer. However, if critical dimension is width

and thickness, PrusaSlicer would be the best software to use (Figure 3).

On the other hand, if ABS material is choosen, the best software to be used is Repetier-Host regardless length, width and thickness as critical dimension. Meanwhile, if Nylon material is chosen, PrusaSlicer is the best choice to be used as slicing software.

Figure 4: Dimensional accuracy (%) of 3D printed part using PLA material with various slicing software

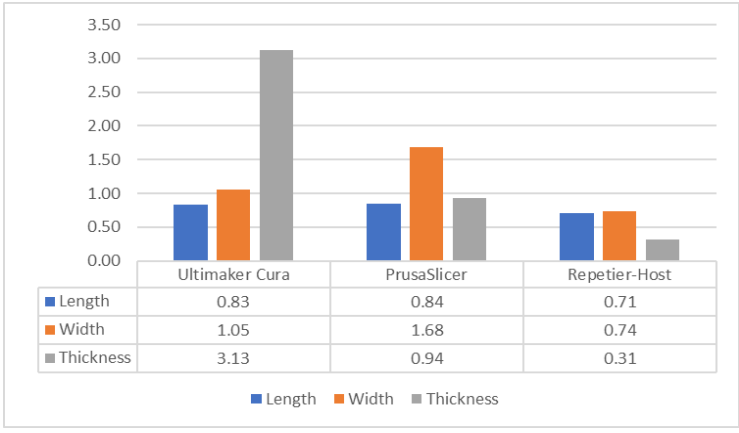

Figure 5: Dimensional accuracy (%) of 3D printed part using ABS material with various slicing software

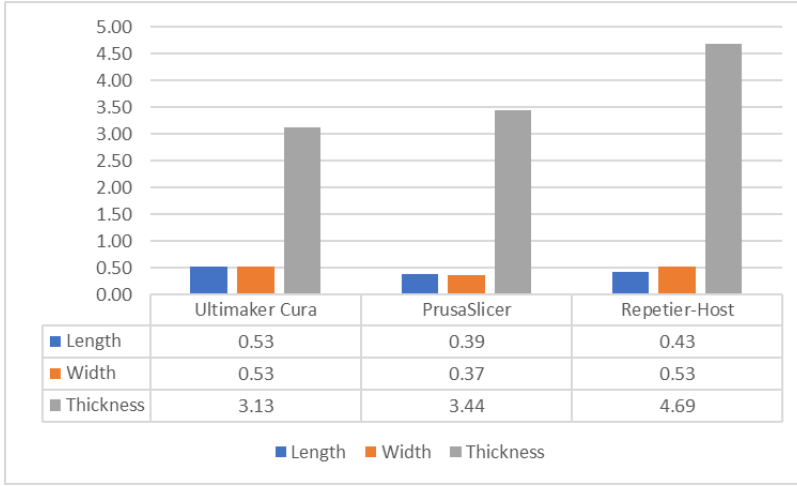

Figure 6: Dimensional accuracy (%) of 3D printed part using Nylon material with various slicing software

Surface Quality

Figure 7 shows the result of surface roughness value for the printed parts. The lower the surface roughness value indicate smooth surface which exhibit good surface quality. From the result, surface roughness value is highly dependent on filament material and slicing software used. For all filament material, the result is depended on slicing software used. The lowest surface roughness value gathers from program sliced by Ultimaker Cura printed using ABS filament (2.792 µm). On the other hand, the highest surface roughness value gathers from program sliced by PrusaSlicer and printed using ABS filament (16.891 µm). In comparison of slicing software, PrusaSlicer is recommended to be used for slicing the program because from the result, the software able to produced lower surface roughness value when printing 3D parts using PLA and Nylon. However, when printing ABS, PrusaSlicer tend to produce rougher part.

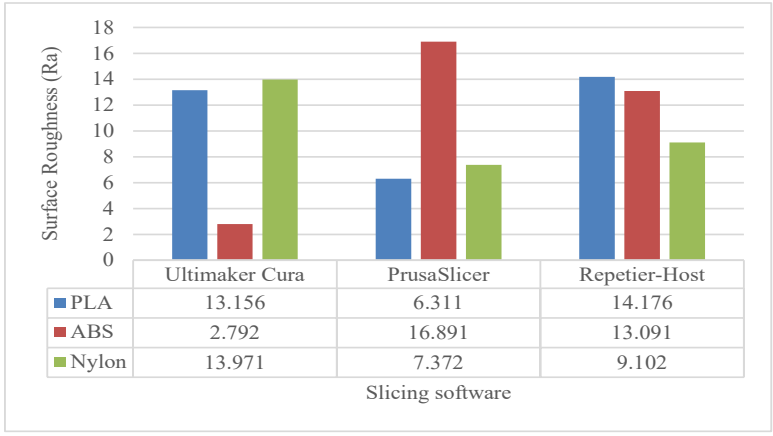

Figure 7: Surface roughness of different filament materials using various slicing software

CONCLUSION

From the findings of this work, it can be concluded that filament material did affect the selection of slicing software. A clear effect of filament material in 3D printing is found from the measurement of manufacturing performance that is based on accuracy in predicting printing time, dimensional accuracy and surface quality. Therefore, the findings offer and insight to the manufacturer to select what is the best for them in term of filament material and slicing software to be used. Some recommendations are;

1. Most accurate slicing software in predicting printing time is PrusaSlicer.
2. Shortest printing time recorded when Repetier-Host software is used.
3. Nylon filament material require shortest time to produced compared to ABS and PLA.
4. Filament material does affect dimensional accuracy of printed part. Incorporation with slicing software, when using PLA and Nylon material,
5. PrusaSlicer is the best slicing software to use. Meanwhile, for ABS material Repetier-Host is recommended to be used.

ACKNOWLEDGEMENTS

Authors would like to acknowledgment Universiti Teknology MARA, Cawangan Pulau Pinang for the equipment support to this research.

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