THE EFFECT OF DIFFERENT SLICING SOFTWARE ON THE MANUFACTURING PERFORMANCE OF 3D PRINTED PARTS

Normariah Che Maideen[1]*, Muhammad Haziq Nazri[1], Salina Budin[1], Koay Mei Hyie[1], Hamid Yusoff[1], and Shuib Sahudin[2]

[1] Mechanical Engineering Studies, Universiti Teknologi MARA, Cawangan Pulau Pinang, Permatang Pauh Campus, 13500 Pulau Pinang, Malaysia

[2] Fakulti Kejuruteraan & Sains Hayat, Universiti Selangor, Jalan Timur Tambahan, 45600 Bistari Jaya, Selangor, Malaysia

*Corresponding email: normariah@uitm.edu.my

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ABSTRACT

Plastic 3D printing is currently in-trend for producing custom parts and products with intricate geometry. Fused Filament Fabrication (FFF) is one of the preferred technologies, as it requires a simple operation with affordable equipment setup. Previous studies have achieved many breakthroughs in using FFF. To successfully produce parts using the FFF machine, a slicing software is required to provide instructions to the machine. Currently, numerous slicing software are available in the market that can be integrated to the FFF machine. Each slicing software has a slightly different performance compared with others. Therefore, careful consideration should be taken when choosing the most suitable slicing software for the machine in use. In this work, three slicing software, namely, Ultimaker Cura 4.8.0, Cura 2.7.0, and PrusaSlicer have been chosen to investigate their effect on the manufacturing performance of 3D printed parts. The parameters for evaluating manufacturing performance were accuracy of the slicing software in predicting printing time, the dimensional accuracy of the printed parts, and the surface roughness of the printed parts. The effect of printing speed was also investigated at three levels, which were at 20, 40, and 60 mm/s. In this work, the 3D Espresso F220 machine was used. The geometry of the printed parts followed the ASTM D638 Type I geometry using polylactic acid (PLA) filament material. The results showed that Ultimaker Cura 4.8.0 can produce the best results, if the priority of the producer is to use a software with high accuracy in printing time prediction and better surface quality. However, if the priority of the process is to produce small dimensional errors (close tolerance to designed geometry), the characteristics of the dimension (length, width, or thickness) need to be identified. Ultimaker Cura 4.8.0 produced small errors when the critical dimension was width, but Cura 2.7.0 was good for length dimension, while PrusaSlicer was good for thickness dimension. The results also showed that printing speed can affect the time of completion of the printed parts and the surface quality. The lowest printing speed was able to produce parts with better surface quality; however, printing time can become longer.

Keywords: *Fused Filament Fabrication (FFF), slicing software, printing time, manufacturing performance, dimensional accuracy, surface roughness*

1.0 INTRODUCTION

3D printing is a straight-forward, additive manufacturing process. It is the inverse of subtractive manufacturing with high flexibility in producing geometry, just enough material usage, and

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minimum waste. The ASTM Standard F2792 [1] listed seven categories of 3D printing technologies, namely, binding jetting [2], material jetting [3], directed energy deposition [4], vat photopolymerization [2], power bed fusion [5, 6], sheet lamination [4], and material extrusion [7, 8]. This paper is focused on the material extrusion technology, known as Fused Filament Fabrication (FFF).

The process concept of FFF is to extrude melted polymer through a nozzle that builds patterns layer by layer to create the designed geometry. This process has progressively improved over the years [9]. Low-cost FFF 3D printers are widely available in a variety of choices [10, 11, 12]. The main components of the FFF 3D printer are the print bed, an extruder, and a hot end [13]. Apart from the printer, filament material also plays a significant role. It is possible to create 3D printed parts from thermoplastic filaments, such as polylactic acid (PLA) [14], acrylonitrile butadiene styrene (ABS) [15], polypropylene (PP), and polyethylene (PE). PLA is widely used in 3D printing because of its low temperature requirement in printing and it is biodegradable. It can be recycled and reused, as well as biocompatible with the human body [16].

In terms of a manufacturing process, 3D printing starts by creating a 3D geometry using the Computer Aided Design (CAD) software, followed by programming a process instruction using the slicing software, and finally producing the geometry by loading the programmed instructions to the FFF machine [12]. From these flow processes, many factors need to be considered to produce good quality printed parts. Many research studies have analysed the parameters and factors in FFF [13, 16, 17, 18, 19] and some of these studies have investigated the influence of the slicing software [20, 21, 22, 23, 24].

The slicing software is used to programme and compute the intersectional curves of models and slicing planes. Many slicing software are available in the market, such as Cura, MatterControl, KISSlicer, and Simplify 3D [25]. The STL file saved from the 3D software will be uploaded to the slicing software, where a process parameter will be set-up. Careful consideration should be given to all parameter setups because they will determine the quality of the geometry being printed, the printing time to complete the geometry, and the quantity of filament required to print the geometry. Therefore, it is expected that there will be variations of properties and characteristics of the printed parts due to the slicing software used [20, 21, 22].

Ariffin et al. [20] compared the dimensional accuracy of printed parts and surface visualisations obtained from using CuraEngine and Slicer software. Their study used an open-source 3D printer, and they reported CuraEngine as the best software in providing better accuracy with minimum filament usage. However, for products that have a lot of hanging structures, Slicer was reported as the best option to be used.

Sljivic et al. [21] compared the accuracy of three slicing software, which were Cura, Slicer, and Simplify 3D. A low-cost FFF 3D printer was used (Infitary M508). They proposed Simplify 3D as the best slicing tool that can provide better accuracy and quality support. As described by Selvaraj et al. [22], different software can produce different properties of a printed part after they compared two slicing software, namely, Replicator and Flashprint, using Wanhao Duplicator 4S-printer. The results showed that samples produced using Replicator were more consistent and have precise graphical patterns compared to samples produced using Flashprint software in terms of ultimate tensile strength and surface roughness. Sally et al. [24] used the 3D print Maker Gear to compare the effect of using three different slicing software, namely, Cura v 4.5.0, Ideamaker v 3.1.0, and Repetier Host v 2.1.6. The printed parts using these softwares were measured based on dimensional accuracy and surface roughness. From the results, they proposed Cura v 4.5.0 as the best slicer tool for the Maker Gear printing machine.

Previous research has shown that many slicing software are available worldwide for use with a variety of 3D printers and their own specifications. Careful consideration is important in selecting the best slicing software for a specific 3D printer. The aim of selecting the best slicing software is to produce good quality printed parts in the most economic environment (low cost, shorter time). Therefore, the scope of this work was to investigate the effect of different slicing software on the manufacturing performance of 3D printed parts. However, the concern was to choose the most compatible and suitable software for the 3D printer (Expresso F220). In this work, three slicing

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software, namely, Ultimaker Cura 4.8.0, Cura 2.7.0, and PrusaSlicer were used to investigate their effect on the manufacturing performance. Measurements of manufacturing performance included the accuracy of the slicing software in predicting printing time, the dimensional accuracy of printed parts, and the surface quality of printed parts, which was determined based on the value of surface roughness.

2.0 METHODOLOGY

This study was conducted based on three main processes, namely, 3D modelling using the CAD software, slicing using the slicing software, and FFF printing using the 3D Espresso F220 to produce printed parts. These printed parts were then measured based on their dimensional accuracy using a vernier calliper and surface roughness using the surface roughness tester, SURFTEST SJ-210.

2.1 3-Dimensional Model

The 3D geometric model selected for this work follows the ASTM D638 Type 1, as shown in Figure 1. Although FFF is known to produce complex models, this work selected a simple geometry for three reasons: 1) easy to compare findings from previous research that used this geometry; 2) easy to measure surface roughness and dimensional accuracy values, since this geometry allowed consistent measurements, and it was easy to handle and evaluate; and 3) the medium size range of this geometry was suitable with the work envelope of the machine used.

SolidWorks software is used to develop the 3D geometry model, as shown in Figure 2. This parametric software allowed easy modification of complex parts and detailed drawings. The developed design dimensions were later compared with the actual dimensions of the printed parts. The length (165 mm), width (19 mm), and thickness (3.2mm) of the printed parts were the selected dimensions for comparison.

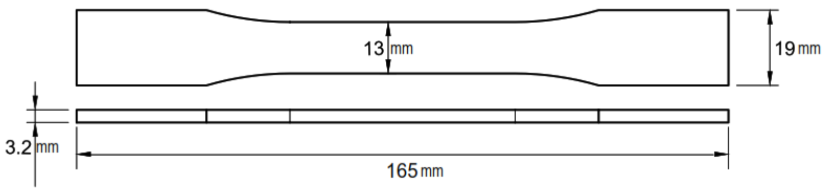

Figure 1: ASTM D638 dimension

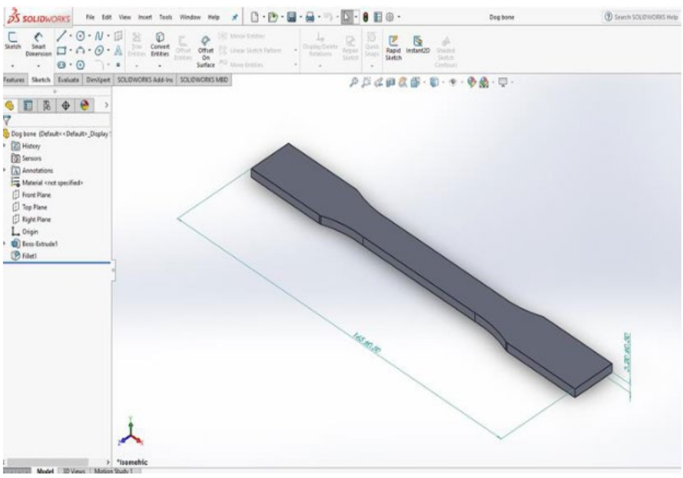

Figure 2: 3D model developed using SolidWorks software

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2.2 Slicing

The developed 3D model, as described in Section 2.1, was saved in STL file format. Then, a slicing software was used to set the appropriate printing parameters for the model. This work has utilised three slicing software, which were Ultimaker Cura 4.8.0, Cura 2.7.0, and PrusaSlicer. Figure 3 shows an interface of Ultimaker Cura 4.8.0, Figure 4 shows an interface of Ultimaker Cura 2.7.0, and Figure 5 shows an interface of PrusaSlicer.

Ultimaker Cura 4.8.0: This free, open-source software was designed by Ultimaker. It is a simple, yet powerful software that supports both 3D (e.g., 3MF, STL, and OBJ) and 2D (e.g., .JPG, .PNG, .BMP, and .GIF) file formats.

Cura 2.7.0: This is another free, open-source software by Ultimaker that was developed for their 3D desktop printers. However, its user-friendly features have attracted the attention of other 3D printer companies as well.

PrusaSlicer: This is a free, open-source software based on Slic3r by Alessandro Ranellucci. This software provides a clear and simple user interface that allows skip converting CAD models into an STL file. From a 3D model, a STEP file can be imported directly into the slicing software. It is known that a STEP file is interoperable among most CAD software, such as SolidWorks, Fusion 360, and CATIA.

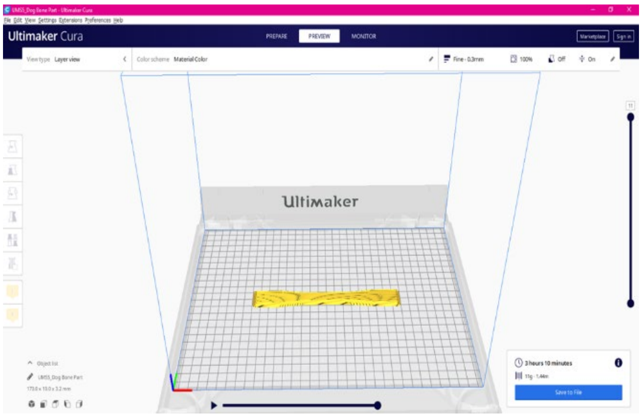

Figure 3: Interface of Ultimaker Cura 4.8.0

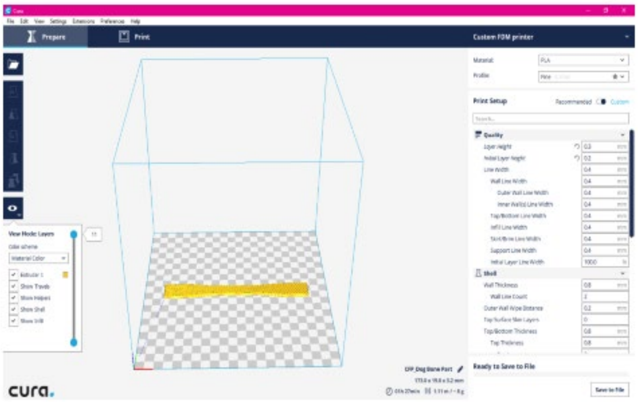

Figure 4: Interface of Ultimaker Cura 2.7.0

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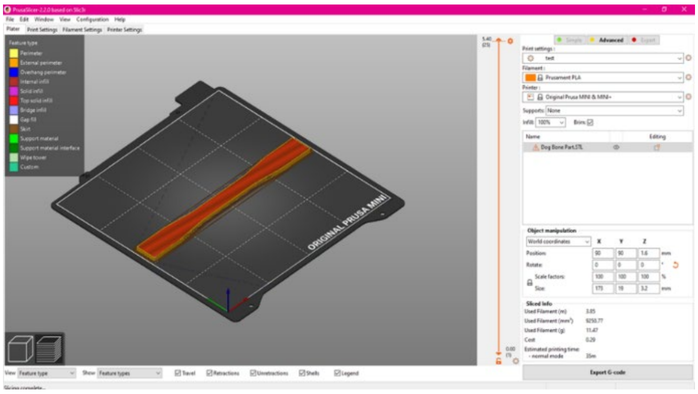

Figure 5: Interface of PrusaSlicer

Each slicing software uses a similar value for each parameter, as tabulated in Table 1. This table shows that all parameters are made constant, except printing speed that has three speeds (20, 40, and 60 mm/s). Printing speed was made a variable because the literature review has highlighted its significant influence on the surface roughness of printed parts and printing cycle time. Therefore, in this work, the characteristics of surface roughness and printing cycle time of the printed parts using the selected slicing software were observed.

Table 1: Printing parameter setting in a slicing software.

Parameter	Value
PLA filament (diameter)	1.75 mm
Extruder temperature, bed temperature	230 °C, 50 °C
Infill percentage, infill pattern	50%, line
Layer thickness	0.3 mm
Printing orientation	X, Y, Z
Printing speed	20, 40, 60 mm/s

2.3 FFF printing and measurement

FFF printing is performed using the 3D Espresso F220, as shown in Figure 6. This low-cost printer is capable of producing a medium-sized geometry with a broad range of materials for printing. Printing is performed according to the setting listed in Table 1. All setting parameters have been set as constant, except printing speed with three variations (20, 40, and 60 mm/s). In this work, each parameter was measured in quadruplicate. Therefore, a total of 36 samples were produced. The printing bed was cleaned after the completion of each sample before the new sample was printed. This procedure was repeated until all samples have been completed.

Data collection was conducted by taking measurements of time, surface roughness, and dimensions. The prediction accuracy of each slicing software was analysed based on the difference between the estimated time given by the slicing software and the actual FFF printing time. To measure dimensional accuracy, the length of each printed part was measured using a height gauge, while its width and thickness were measured using a vernier calliper. Then, the measured dimensions were compared with the design dimensions. To measure surface quality, surface roughness was measured using the SURFTEST SJ-210.

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Figure 6: 3D Espresso F220

3.0 RESULTS AND DISCUSSION

3.1 Prediction time accuracy

Table 2 shows the accuracy of the prediction time by each slicing software. The results showed that Ultimaker Cura 4.8.0 can predict more accurately compared to Cura 2.7.0 and PrusaSlicer. This can be seen from the lowest difference in the percentage of error between the prediction time calculated by each software and the actual time taken for the printer to print. PrusaSlicer came in second, while the prediction time given by Cura 2.7.0 was further from the actual time taken to complete the printing. A bigger error is indicative of a less effective software. In this work, the most accurate software (Ultimaker Cura 4.8.0) could contribute towards producing an accurate process plan, where the process cycle time and cost estimation would be closer to the actual time and cost.

Based on Table 3, as predicted, the slower the printing speed, the longer time is needed to complete the process. These predictions were aligned with all software that produced similar trends. As shown in Table 2, Ultimaker Cura 4.8.0 is the most accurate software in predicting the printing time regardless of the printing speed, followed by PrusaSlicer. Although Cura 2.7.0 has the least accurate prediction of printing time, it recorded the fastest printing process for all slicing speeds. The longest time taken for a sample to be sliced was by Ultimaker Cura 4.8.0. Therefore, if the shortest printing time is an important factor for the user, Cura 2.7.0 is the best software to be used compared to PrusaSlicer and Ultimaker Cura 4.8.0.

Table 2: Results of prediction time accuracy at 60 mm/s printing speed

Software	Prediction time	Actual time	% Error
Ultimaker Cura 4.8.0	35 min	34 min and 40 s	0.95
Cura 2.7.0	21 min	32 min and 20 s	53.97
PrusaSlicer	29 min	32 min and 20 s	11.49

Table 3: Effect of printing speed on prediction time accuracy

	Ultimaker Cura 4.8.0			Cura 2.7.0			PrusaSlicer		
Printing speed (mm/s)	Prediction time	Actual time	% Error	Prediction time	Actual time	% Error	Prediction time	Actual time	% Error
60	35 min	34 min and 40 s	0.95	21 min	32 min and 20 s	53.97	29 min	32 min and 20 s	11.49

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40	49 min	50 min and 2 s	2.11	22 min	31 min and 20 s	42.42	32 min	35 min and 11 s	9.95
20	93 min	92 min and 20 s	0.36	25 min	33 min and 57 s	35.80	41 min	41 min and 29 s	1.18

3.2 Dimensional accuracy

Table 4 shows the results of dimensional accuracy for all three software. In terms of printing parts with accurate length, Cura 2.7.0 produced the most accurate length compared to the other two software. In terms of the width, Ultimaker Cura 4.8.0 produced more accurate results, while in terms of thickness, PrusaSlicer was better compared to the other two software. Based on these results, manufacturers can select the most critical dimension to control during printing prior to selecting the best-fit slicing software.

Table 4: Results of dimensional accuracy at 60 mm/s printing speed

Measurement	Design model (mm)	Ultimaker Cura 4.8.0 (mm)	% Error	Cura 2.7.0 (mm)	% Error	PrusaSlicer (mm)	% Error
Length	165	163.86	0.69	164.22	0.48	163.97	0.63
Width	3.2	3.07	0.92	3.55	10.78	3.31	3.28
Thickness	19	18.83	4.22	19.14	0.74	18.95	0.29

3.3 Surface roughness

Figure 7 shows the results of surface roughness for all software. Surface roughness was measured to determine the surface quality of the samples produced from a programme using three different slicing software (Ultimaker Cura 4.8.0, Cura 2.7.0, and PrusaSlicer). This work has only considered printed parts with 0.3 mm of thickness at three different speeds (60, 40, and 20 mm/s). Selvaraj et al. [9] concluded that ReplicatorG has a better consistency compared to Flashprint, in terms of the effect of different slicing software on printed parts with 0.1, 0.2, and 0.3 mm of thickness.

Based on the results of this work, the slicing programme by Ultimaker Cura 4.8.0 was able to produce better surface roughness compared to the other two software, regardless of the printing speed. At printing speeds of 60 and 40 mm/s, Cura 2.7.0 has produced better surface roughness compared to PrusaSlicer. However, at the lowest speed of 20 mm/s, PrusaSlicer produced smoother surfaces compared to Cura 2.7.0. Thus, the higher the printing speed, the rougher the surface produced. Since 3D printers can be categorised as lightweight machines, higher printing speeds can cause the printing bed to vibrate more and consequently, disrupts the alignment of the nozzle with the printing bed during printing, which affects the quality of the printed surface.

Surface quality also has a close relationship with printing speed. The results showed that to produce smoother or better surface roughness, the lowest printing speed (20 mm/s) would be favourable. However, the lowest printing speed will require longer printing time. This will affect the productivity rate, which will indirectly reflect on the operation cost. Therefore, proper consideration is required when selecting the best practice during process planning.

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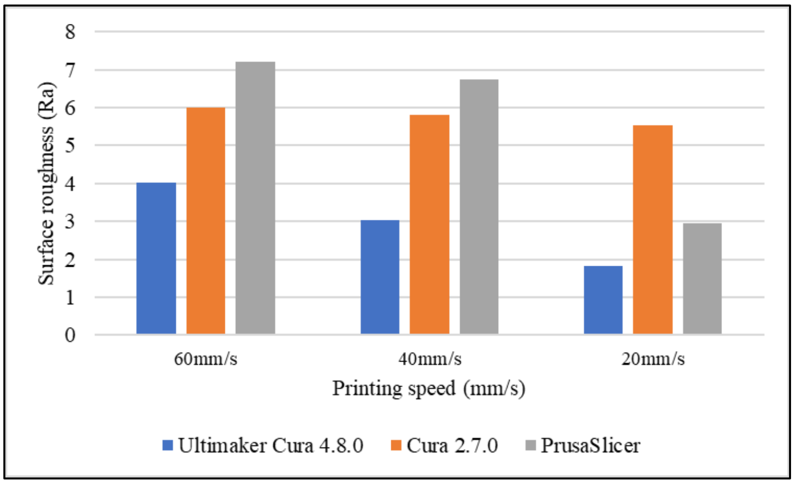

Figure 7: Results of surface roughness

4.0 CONCLUSION

In general, the results have shown that Ultimaker Cura 4.8.0 was the best slicing software, as it can accurately predict printing time and produced better surface quality compared to Cura 2.7.0 and PrusaSlicer. However, based on their dimensional accuracy performance, all three software showed a fair accuracy. Producers may select a slicing software according to critical dimensions that need to be precisely printed. On the other hand, if surface quality is the top priority, the best-fit slicing software and printing speed are crucial. Therefore, this work would recommend Ultimaker Cura 4.8.0 software at 20 mm/s printing speed. Additionally, if producers need to meet all three performance parameters (prediction time, dimensional accuracy, and surface quality), Ultimaker Cura 4.8.0 would be the best slicing software to be used.

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