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The Analysis of the Effect of Printing Orientation Parameter on the Surface Roughness of 3D Metal Printed Specimens

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ABSTRACT

Designing and manufacturing work related to the utilization of rapid prototyping and 3D CAD modeling is popular nowadays since this method is convenient compared to other traditional design and manufacturing methods. The investigation of the effect of 3D printing parameters on surface roughness is familiar since many types of 3D printing machines have been created at present. But for the Selective Laser Melting (SLM) 3D printing machine, the surface roughness experiments are difficult to execute as the SLM's specimens are using metal as the main material. Besides, there are limited studies of previous researchers that study the surface roughness of SLM specimens. Therefore, this paper will discuss the study of the effect of SLM 3D printing parameters on surface roughness using metal (Stainless steel) as the main material. The printing parameters were: the effect of surface area, the effect of height, and the effect of angle printing. Each parameter consists of 3 specimens with different dimensions and orientations. The result will determine which printing condition will give the best result of surface roughness.

Keywords: *Additive manufacturing method, Selective Laser Melting (SLM), Stainless steel powder, Surface Roughness*

1. INTRODUCTION

The additive manufacturing method (AM) is a manufacturing process that analyses the computer 3D CAD design files and manufactures 3D objects continuously in a layer-by-layer manner until the 3D object is created [1–4]. The application of AM machines mainly focuses on the industry that manufactures a complex design object where it is difficult to construct the object using a traditional method such as casting, milling, and turning process [5-6].

A Selective Laser Melting machine (SLM) is a machine that uses the same concept as the AM method where the material powder uses a laser in a layer-by-layer manner [7]. The application of SLM machines mainly focuses on heavy-duty type objects since they use metal powder as the main material of the printing process. The SLM machine has in common with direct metal laser sintering (DMLS) machines since they use metal as their main material. According to Rahman [8], the SLM and DMLS machine uses a variety of metal and metal alloys such as stainless steel, aluminum, titanium, and cobalt chrome. Each of the metal powders had its own different regularity parameter which is compatible with their material properties. Figure 1 below shows the working principle of the SLM machine by Nakano [9].

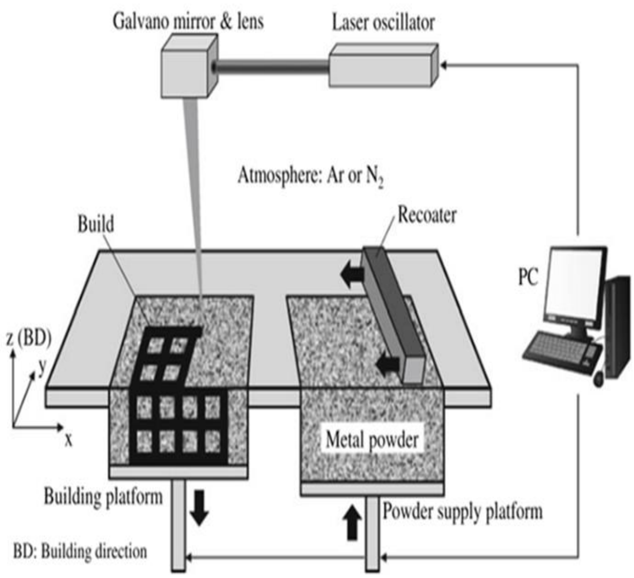


Figure 1. The Selective Laser Melting Machine (SLM) working principle by [9].

2. THEORETICAL BACKGROUND

The AM method is popular with a smooth surface condition after printing. There were also a lot of experiments that were executed by researchers that were related to surface roughness and AM method specimens. Based on Chand and Alsoufi experiments, the result of surface roughness is determined by the orientation of the printing condition [10][11]. By changing the orientation of the printing position, [10] determined which orientation of the printing position would produce the best result of surface roughness.

In addition, the experiments that were executed by Bintara and Y. Li study the effect of changing the machine parameter on the specimen surface roughness [12][13]. Most of them change the layer thickness, temperature of the nozzle and production bed then study the effect of that change. The researcher will determine which parameter provides the specimen with the best surface roughness result according to these variables.

On the other hand, Dzienniak and Abdullah study the surface roughness result by comparing different types of material and machine brands [14][15]. Their study mostly categorized as the comparisons between 3D printer brands and mainly focused on which type of 3D printer brand gave the best performance and surface roughness result.

Lastly, Fountas and Oravcová study both machine parameters and the performance of different types of material on surface roughness results [16][17]. Their research focuses on which 3D printer machine parameter was appropriate with the material and resulted in the best surface roughness outcome by varying printing parameters such as layer thickness, nozzle temperature, and printing bed temperature.

In this study, the effect of different orientations of printing conditions on surface roughness results was chosen as the experiment parameter. The experiment was undergone 3 types of different printing conditions with 3 different specimens for each condition. For the SLM machine, the machine parameter must be suitable for the type of material that will be used. If the machine parameter can be changed with ease, it will increase the possibility of the printing process failing. Besides, it will take a lot of time and budget to execute the experiment with different materials. Therefore, this research will mainly focus on the effect of different printing orientations on surface roughness results.

3. METHODOLOGY

The experiment was executed under 3 types of conditions:

3.1. Effect of Surface Area (EOSA)

From this condition, the machine capability will be studied about what will happen to surface roughness results if the specimen's printing area becomes wider. The figure and table below show the specimen's figure in CAD printing software and the dimensions of the EOSA specimens.

Table 1 The dimensions of EOSA specimens

Specimen	Dimension
Specimen 1	20 mm × 20 mm × 2 mm
Specimen 2	30 mm × 30 mm × 2 mm
Specimen 3	40 mm × 40 mm × 2 mm

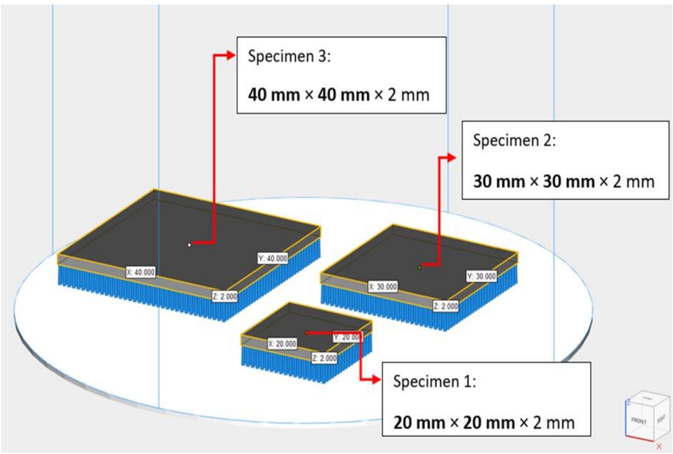


Figure 2. The effect of surface area (EOSA) experiment's specimens.

3.2. Effect of Height (EOH)

From this condition, the machine capability will be studied about what will happen to surface roughness results if the specimen's height becomes higher. The figure and table below show the specimen's figure in CAD printing software and the dimensions of the EOH specimens.

Table 2 The dimensions of EOH specimens

Specimen	Dimension
Specimen 1	20 mm × 20 mm × 6 mm
Specimen 2	20 mm × 20 mm × 8 mm
Specimen 3	20 mm × 20 mm × 10 mm

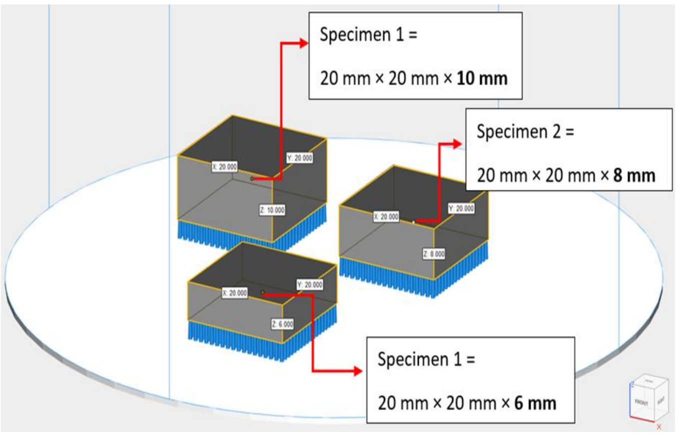


Figure 3. The effect of height (EOH) experiment's specimens.

3.3. Effect of Angle Positioning (EOAP)

From this condition, the machine capability will be studied about what will happen to surface roughness results if the angle of printing position of the specimen changes. The figure and table below show the specimen's figure in CAD printing software and the dimensions of the EOAP specimens.

Table 3 The angle position of EOAP specimens.

Specimen	Dimension
Specimen 1	20°
Specimen 2	30°
Specimen 3	40°

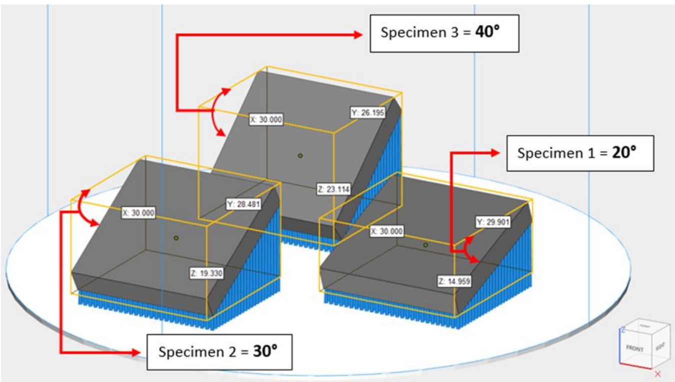


Figure 4. The effect of angle positioning (EOAP) experiment's specimens.

3.4 Scanning Range

Figure 5 shows the scanning range of the 3D Non-Contact Profilometer for surface roughness result, Ra:

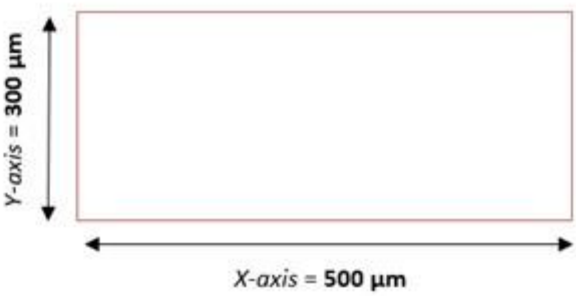


Figure 5. The scanning area of the 3D Non-Contact Profilometer.

3.4.1 Scanning Area for EOSA's Specimens

The coordinate area of scanning the specimen for EOSA's specimens for the surface roughness experiment is at the center of the top surface of the specimen. Figure 6 below shows the scanning area of EOSA's specimens.

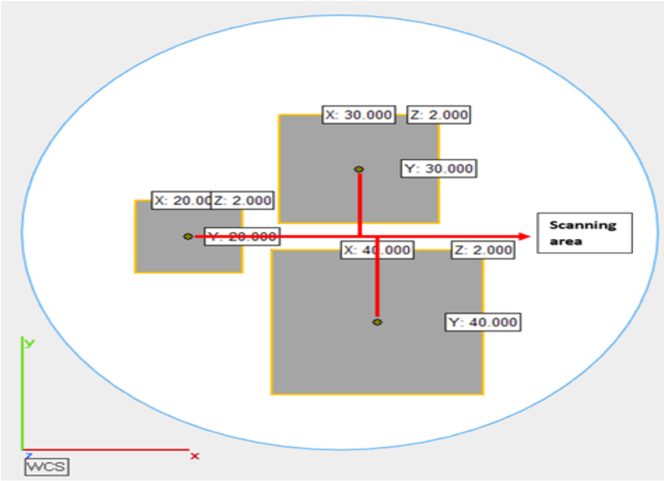


Figure 6. The scanning area of EOSA's specimens.

3.4.2 Scanning Area for EOH's Specimens

The coordinate area of scanning the specimen for EOH's specimens for the surface roughness experiment is at the center of the left side surface of the specimen. Figure 7 below shows the scanning area of EOH's specimens.

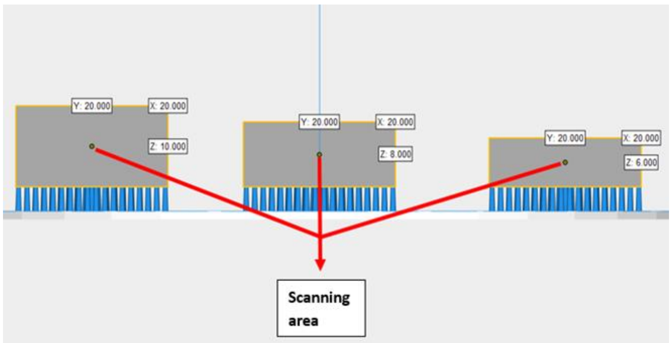


Figure 7. The scanning area of EOH's specimens.

3.4.3 Scanning Area for EOAP's Specimens

The coordinate area of scanning the specimen for EOAP's specimens for the surface roughness experiment is at the center of the top surface of the specimen. Figure 8 below shows the scanning area of EOAP's specimens.

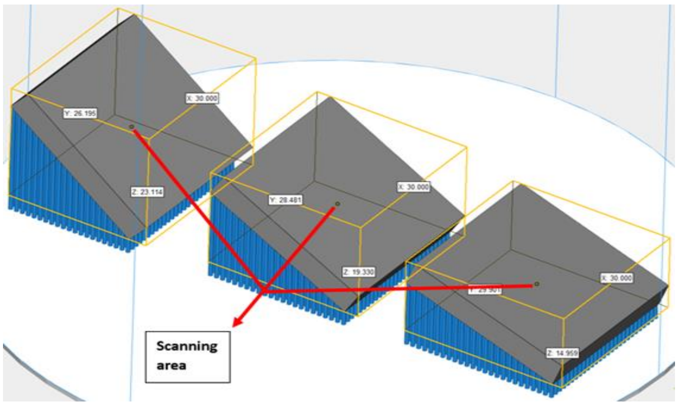


Figure 8. The scanning area of EOSA's specimens.

3.5 Material

The material used in this experiment is Spherical Ermak S 316 L-A11 (Stainless steel powder) by ERMAKSAN.

3.6 Machine

The AM machine used to print the specimen is ERMAKSAN, ENAVISION 120 SLM 3D printing machine. Table 4 bshows the machine parameters that were implemented to manufacture the specimens.

Table 4 The machine parameters used to print the specimens

Parameter	Value
Scanning speed	1000.0000 mm/s
Laser power	240. 0000 W
Laser diameter	0.075 mm
Powder Increment	0.06 mm
Production Increment	0.04 mm
Hatch offset	0.01 mm
Hatch distance	0.1 mm

3.7 Measuring Equipment

After all of the experiment specimens are printed using SLM 3D printing machine, the specimens will undergo the surface roughness test using a 3D non-Contact Profilometer. Figure 7 below shows the 3D Non-Contact Profilometer that is located in Universiti Teknikal Malaysia Melaka (UTeM) Tribology Lab (Faculty of Mechanical Engineering). Unlike other 3D printers that use composites and plastic as their main material such as Selective laser sintering (SLS), Fused Deposition Modelling (FDM), Digital Light Processing (DLP), and Stereolithography (SLA), fresh print SLM's specimen surface is seen rougher to others 3D printing machines since it used metal as their main material. So, using other direct-contact profilometer testers will yield less accurate data as well as damaging the profilometer's probe.

Figure 9. The 3D non-Contact Profilometer.

4. DATA COLLECTION AND ANALYSIS

The information below shows the surface topography and surface roughness, Ra result for each specimen based on its particular conditions. It requires 5 separate Ra profiles for each specimen to provide the variation.

4.1. Effect of Surface Area (EOSA) Experiment Data

Table 5 The EOSA's specimens 3D surface topography at the scanning area

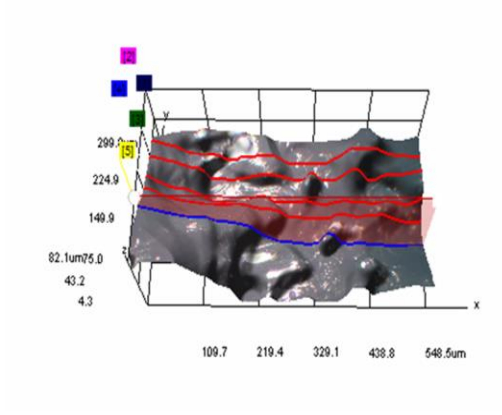
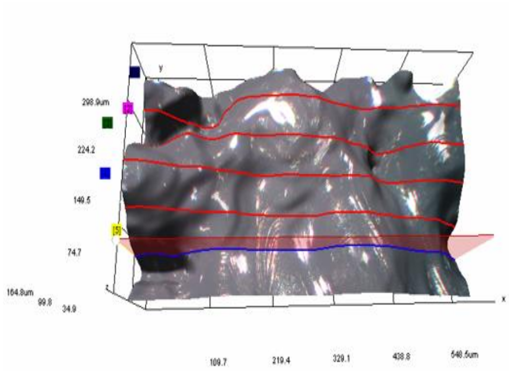
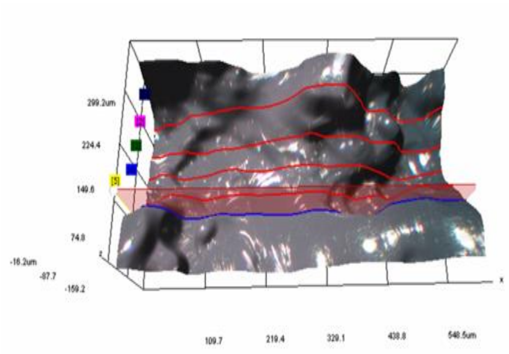
	The EOSA specimen's surface topography in 3D view
Specimen 1	
Specimen 2	
Specimen 3	

Table 6 The result of surface roughness (Ra) of EOSA's specimens

Name	Surface Roughness Ra [µm]		
	Specimen 1	Specimen 2	Specimen 3
Profile 1	5.3	13.8	14.5
Profile 2	4.8	9.4	9.2
Profile 3	3.7	4	9.4
Profile 4	3.4	5.9	8.6
Profile 5	4.1	7.5	10.8

4.2. Effect of Height (EOH) Experiment Data

Table 7 The EOH's specimens 3D surface topography at the scanning area

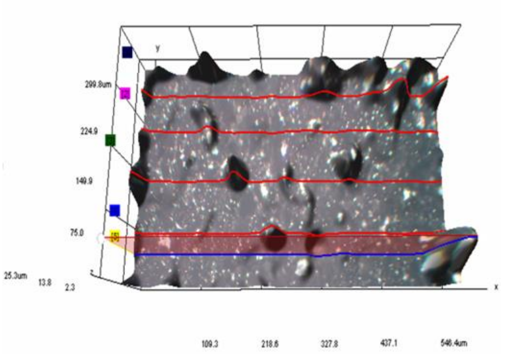
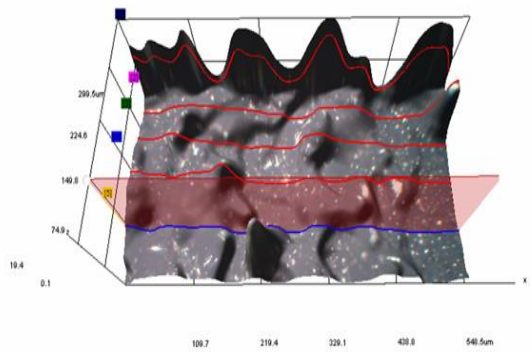
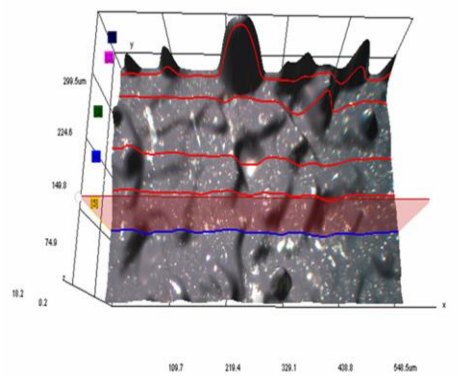
	The EOH specimen's surface topography in 3D view
Specimen 1	
Specimen 2	
Specimen 3	

Table 8 The result of surface roughness (Ra) of EOH's specimens

Name	**Surface Roughness Ra [µm]**		
	Specimen 1	**Specimen 2**	**Specimen 3**
Profile 1	1	4	5.5
Profile 2	0.4	1.6	2.7
Profile 3	0.8	1.6	1.8
Profile 4	0.7	1.1	1.9
Profile 5	1.7	1.1	1.5

4.3. Effect of Angle Positioning (EOAP) Experiment Data

Table 9 The EOAP's specimens 3D surface topography at the scanning area.

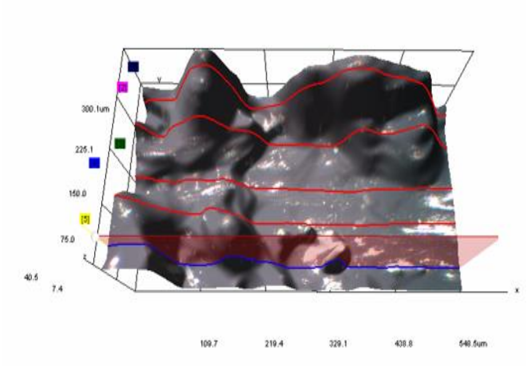
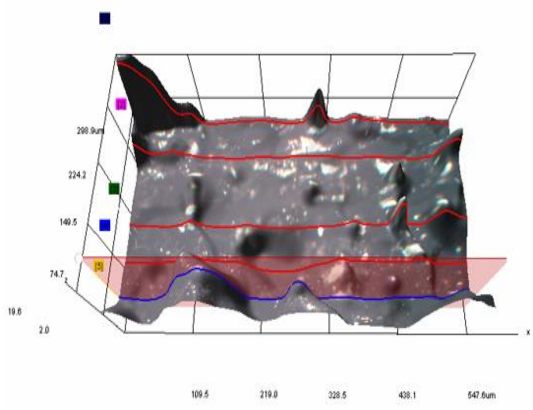
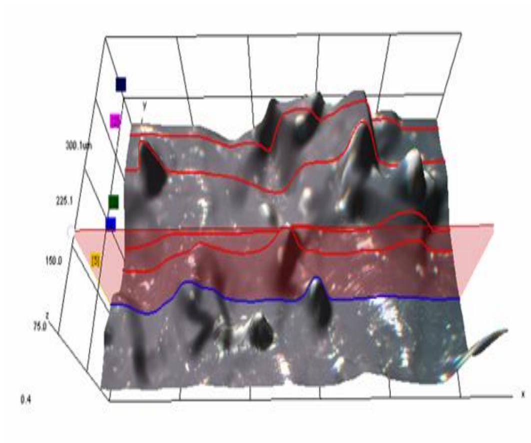
	The EOAP specimen's surface topography in 3D view
Specimen 1	
Specimen 2	
Specimen 3	

Table 10 The result of surface roughness (Ra) of EOAP's specimens

Name	Surface Roughness Ra [µm]		
	Specimen 1	Specimen 2	Specimen 3
Profile 1	12.3	7.1	3
Profile 2	8.4	4.5	3
Profile 3	2.7	2.2	1.6
Profile 4	4.1	2.1	2.2
Profile 5	6.8	4.7	2.1

5. RESULTS AND DISCUSSION

5.1. Effect of Surface Area (EOSA)

Figure 10 and 11 and Table 11 show the EOSA graphic view from 5 profiles, the EOSA graphic view of the average result, and the comparison of the EOSA specimen's average surface roughness data. The EOSA data below shows that specimen 1 has better Ra results compared to other specimens. The Ra result of specimen 1 achieved better than other specimens because the area of the laser plasma firing on specimen 1 is smaller than other specimens. According to Kostadinov [18], the large power density of laser plasma that firing on the metal powder are the main reason why the surface profile of the specimen leads to various surface defect such as local accumulations, pores, protrusions, fracture, etc., which decrease the quality of the product. Besides, Król [19] states that laser plasma also creates spark containing half-molten powder form a non-uniform thin layer on the specimen's surface, leading to a bad result of Ra and surface topography. The wider the laser plasma area, the more spark is created during printing. Therefore, from EOSA condition data, it can be concluded that if the surface area of the specimen increases, the surface roughness of the specimen becomes rougher.

Figure 10. The EOSA's 5 profiles Surface Roughness result.

Figure 11. The EOSA Average Surface Roughness result.

Table 11 The comparison of average surface roughness results of the EOSA specimen

Specimen	Dimension
Specimen 1	4.3
Specimen 2	8.1
Specimen 3	10.5

5.2. Effect of Height (EOH)

Figure 12 and 13 and Table 12 show the EOH graphic view from 5 profiles, the EOH graphic view of the average result, and the comparison of the EOH specimen's average surface roughness data. From the EOH result data below, specimen 1 has better results compared to other specimens since the data of Ra at specimen 1 outdo other specimens. This does not imply that the Ra results for the other specimen are subpar, they also fall within the 0.5 to 3 μm range which is relatively smooth for metal specimens according to the Ra range values reported in Dashti [20]. The rationale behind the result of specimen 1 outdoing other specimens because the support cannot handle the pressure of the material which leads to a wavy surface topography. Furthermore, based on research executed by Morton and Kamarudin indicates that the selection support for the printing process needs to be chosen carefully, particularly for tall and large specimens to prevent any defection on the specimens which leads to bad Ra results [21-22]. In addition, the results of the research conducted by Kamarudin also proved that the taller specimen leads to rough surface profile results [22]. Therefore, from EOH condition data, it can be concluded that if the height of the specimen increases, the surface roughness of the specimen becomes rougher.

Figure 12. The EOH's 5 profiles Surface Roughness result.

Figure 13. The EOH Average Surface Roughness result.

Table 12 The comparison of average surface roughness results of the EOH's specimens

Specimen	Dimension
Specimen 1	1
Specimen 2	1.9
Specimen 3	2.7

5.3. Effect of Angle Positioning (EOAP)

Figure 14 and 15 and Table 13 show the EOAP graphic view from 5 profiles, the EOAP graphic view of the average result, and the comparison of the EOAP specimen's average surface roughness data. From the EOAP result data below, specimen 3 shows better results compared to other specimens since the data of Ra on specimen 3 is smoother than other specimens. This is due to specimen 3 having a smaller area exposed to the laser plasma's spark during the printing process according to Foudzi [23]. Like the EOSA specimen's result, the bigger the area exposed to laser plasma's spark resulted in a non-uniform and rough surface topography. Since specimen 3's angle position at 40° had a smaller exposed surface area compared to other specimens, it generated better Ra results compared to 20° and 30° angle positioning. Plus, based on the experiment that was conducted by Kozior where printed the specimens with 3 different angle which is 0°, 45°, and 90° orientation [24-25]. According to Kozior experiment results, the specimen that printed with high angle orientation produced better compared to the lower angle orientation [24-25]. Therefore, from EOAP condition data, it can be concluded that if the angle of printing position of the specimen increases, the surface roughness of the specimen becomes smoother.

Figure 14. The EOAP's 5 profiles Surface Roughness result.

Figure 15. The EOAP Average Surface Roughness result.

Table 13 The comparison of average surface roughness results of the EOAP specimen

Specimen	Dimension
Specimen 1	6.8
Specimen 2	4.2
Specimen 3	2.3

6. CONCLUSION

Based on the result above, it can be concluded that the positioning of the specimen in the production chamber is crucial and needs to be prioritized to ensure the best result of Ra can be achieved. In addition, to secure a smoother surface on the specimen, the arrangement of the area exposed to the laser plasma's spark needed to be as small as possible. The Ra result of EOSA and EOAP proved that the specimen with a larger printing area possesses a rougher surface compared to the others. Moreover, to secure the best Ra result for tall specimens like EOH, a proper design of support that is thicker and sturdier and can withstand the pressure of printed materials needs to be appointed prior to the printing process.

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