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The Effect of Fused Deposition Modelling Process Parameters on The Quality Of Abs Product

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Abstract: Fused Deposition Modelling is one of the widely used Additive Manufacturing techniques that are used to create functional end use part of Acrylonitrile Butadiene Styrene (ABS) plastic. The need to ensure that the parts have better dimensional accuracy, surface finish and better mechanical properties thus exist in order to create the good quality of functional end use of fabricated part. The aim of this research is to study the effect of process parameters on the quality of ABS product. In order to achieve the optimum performance of the part, Taguchi method have been implemented. In this project, orthogonal array of L_9 (3^3) was used and 9 pieces of samples were determined for 3 parameters namely: layer thickness, infill density and build orientation with 3 levels each. The sample used in this project is tensile specimen as per ASTM D638 type IV. The specimen was designed using SolidWorks and printed using UP Mini 3D Printer. The specimen was observed for dimensional accuracy, surface roughness and tensile strength. From the finding, it is found that the two most significant control factors for all of the output parameters are object orientation and infill density. Object orientation is the most significant control factor followed by infill density. It affects dimensional accuracy, surface roughness and the tensile strength of the printed specimen test the most compared to the control factor of layer thickness.

Keywords: ABS, rapid prototyping, fused deposition modelling, taguchi method, process parameters

1. Introduction

Rapid prototyping (RP) is belonged to additive manufacturing processes. The term of rapid prototyping was first used in mechanical engineering in the early 1980s [1]. Rapid prototyping is a new manufacturing technique that allow fast fabrication of computer models designed with three-dimension (3D) computer aided design software. It also allows fast realizations of ideas into functioning prototypes where it can shorten design time and can lead towards a very successful of final products. The fundamental process step in rapid prototyping are very easy to understand. Figure 1 shows the typical process chain of various rapid prototyping system [2]. A CAD model is designed by using software such as SolidWorks software for it to be created electronically in a CAD file. The CAD file is then converted into standard tessellation language file or also commonly known as STL file format. After it is converted into the STL file format, slicing process will be done by rapid prototyping machine or some computer program that will generate the object in layers electronically. From the layered "slice" file, the rapid prototyping machine will produce the model physically in layers [3].

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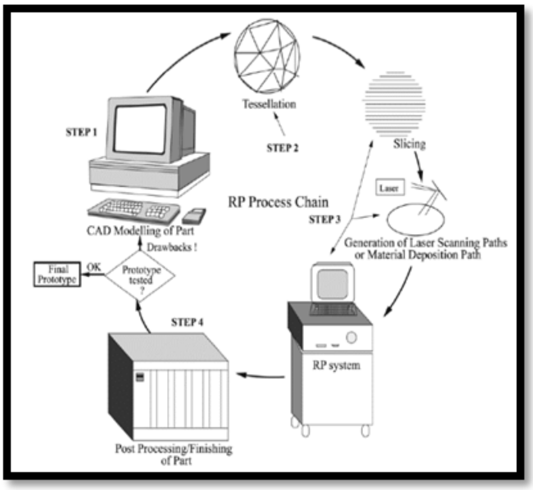

Fig. 1 - Fundamental Process of RP [3]

2. Literature Review

In FDM technology, by heating the thermoplastic material to a semi-liquid state, the part is built layer by layer according to the computer-controlled paths. Support structure may be generated during printing process if required [4]. By referring to Figure 2, small flattened strings of molten material are extruded to form layers to produce the model or part. The materials usually harden immediately after extrusion from nozzle. Materials filaments are fed to the print head from the 3D printer's material bay. The print head moves in X and Y coordinate. The material is deposited to complete each layer before the base moves down the Z axis and begin the next layer. When the part is completely built, the support material is breaks away [5].

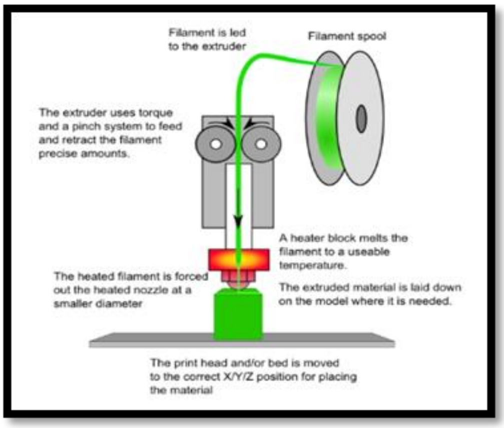

Fig. 2 - Principle of FDM process [5]

FDM can be categorized into three basic steps which is pre-processing, production and post-processing. The first step is pre-processing. In this step, a CAD model is constructed by using CAD software and then converted into STL file format. The second step is production. In production, the FDM machine will process the .STL file by creating sliced layers of the models to automatically prints the model layer by layer until completion of the model. The final step is post-processing. The model and any supports are removed by washing or stripping it away. Lastly the surface of the model will be cleaned [6].

In FDM process, there are basically two types of material usually used which are Acrylonitrile Butadiene Styrene (ABS) and Polylactic acid (PLA). ABS and PLA material may seem similar but both materials do have differences [7]. ABS material is a sturdy and strong plastic with main substance is oil-based. This plastic is not easy to print as it has high melting point and it has tendency to warp during printing. Therefore, ABS need to be printed on a heated bed at temperature 80℃ and the standard temperature for printing is 230℃. As for the PLA materials, it is a biodegradable thermoplastic. Since it is biodegradable, it makes PLA as the most environmentally friendly solution in the domain of 3D printing [8]. PLA material is tough, but a little brittle once it has cooled down. The standard temperature for printing PLA material is around 180℃ to 220℃ and it can be printed without a heated bed. Even though it can be printed without heated bed, it is strongly suggested to heat the bed at 60℃ [9].

FDM is a complex process that have much difficulty to determine the optimal parameters due to the large numbers of parameters that may influence the material properties and quality of the part produced [10]. In most 3D printer, the user used the default setting of printing process parameter provided by the manufacturer. Since there are several parameters that need to be considered before printing, the default values that has been set by the manufacturer do not guarantee quality of the printed part in term of its dimension error, surface quality or strength [11].

Figure 4 shows the fish bone diagram which gives an overview regarding the consideration that must be taken seriously to get the best quality and good mechanical properties of the printed part [12]. Based on the fish bone diagram, there are several working parameters which is air gap, raster angle, raster width, layer thickness, part fill style and contour width. Part build orientation is also one of the process parameters that need to be considered since each X, Y, and Z direction will highly affect the mechanical properties of the printed part. Apart from the mentioned parameters, there are also other parameters such as necking, shell, cusp height and speed of deposition [13].

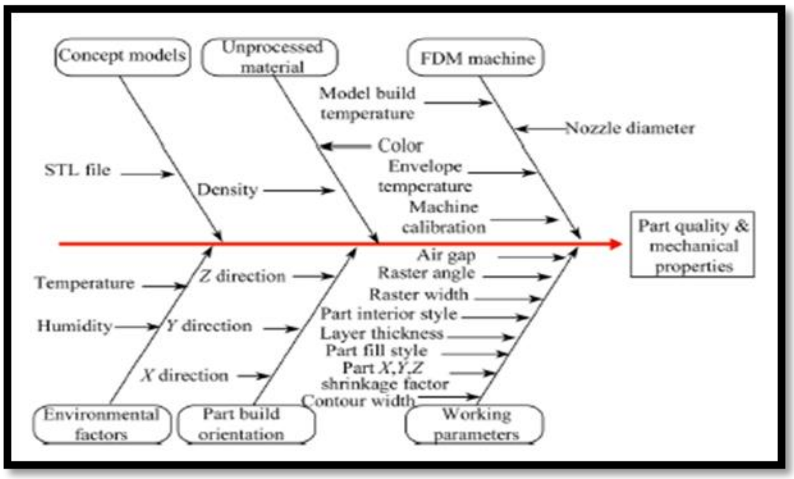

Fig. 3 - Fish Bone Diagram [13]

Different process parameters give different effects on the part quality of FDM built part. Since there are always need to adjust parameters for most parts to balance the exchange between production time, surface finish and dimensional accuracy, there are still no best optimal conditions for all type parts and materials. In order to improve the part quality and mechanical properties for FDM built parts, it is required to know the relationship between material properties and process parameters [14]. There are basically three characteristics that are mostly considered in FDM built part which is dimensional accuracy, surface roughness and mechanical strength characteristics [7]. Dimensional accuracy and surface quality of a manufactured part remains main issue in the manufacturing engineering process [15]. Sudin, Shamsudin, & Abdullah (2016) pointed out that the need to have a very accurate parts or features that resembles as close as possible to the original design is important as it will influence how the product will be fully accepted and approved for distribution to the end users [16]. According to A. Kumar, Ohdar, & Mahapatra (2009) part orientation is the parameters that plays main role in obtaining the dimensional accuracy of the printed part. The orientation of part as should be as low as possible because the coefficient of accuracy increases with lower orientation [17].

Apart from getting accuracy, low orientations also can strengthen parts [17]. Surface roughness is considered as one of the most important characteristics in the FDM built parts and it is one big challenge for the researchers nowadays and they are currently looking for ways to produce product with less surface roughness [18]. Less surface roughness will benefit to the production of functional prototypes. Layer thickness and stair case effect are the disadvantages in layered manufacturing that can increase surface roughness of the prototypes [7]. The larger number of thickness result in non-smooth surface while the last picture shows that the smaller the number of thickness, the smoother the surface. According to Chacon & Caminero (2017) the strength of part fabricated by FDM process is depending on the bonding between the individual raster's [19]. Apart from that, it is also dependent on the orientation of the part. The density of the infill is also a main feature in determining the strength of built part. Moreover, the strength characteristics are also influenced by the type of fill used to fill the space of the part. It is related to the density of the part. Proper selection of process parameters are the main key of the success AM process [10].

3. Methodology

In this project, before the fabrication process begins, the CAD model of the specimen test was created by using SolidWorks 2017 software. The CAD model was first converted to STL file format before being import to UP Studio software. The software was used to make the selection variation of the processing parameter where each of the specimen have different value of parameters. The fabrication of the specimen test was done by using UP Mini 3D printer as shown in Figure 4.

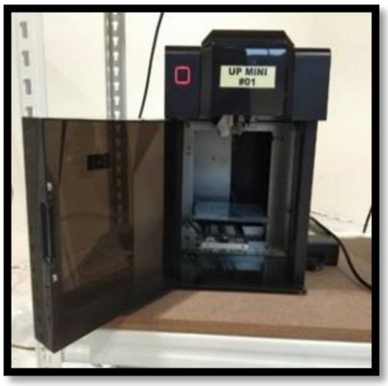

Fig. 4 - UP Mini 3D Printer

3.1 Experimental Plan

The material that is used for fabrication of specimen test is ABS with filament diameter 1.75 mm. There are various choice of layer thickness and infill density for the printer, but there are only three level of each factor chosen that is considered in this project as shown in Table 1. As for the infill type, diamond type has been chosen for this testing. Therefore, each specimen test is having the same infill type.

Table 1 - Experimental plan factors and its value for each level

Factor	Level 1	Level 2	Level 3
Object orientation	X	Y	Z
Infill density (%)	20	65	80
Layer thickness (mm)	0.20	0.25	0.35

3.2 Specimen Test

ASTM D638 type IV with overall length of 115 mm, overall width of 19 mm and 4 mm thickness is the most common standard used for tensile test. The geometry and dimensions of the specimen test were shown in Figure 5.

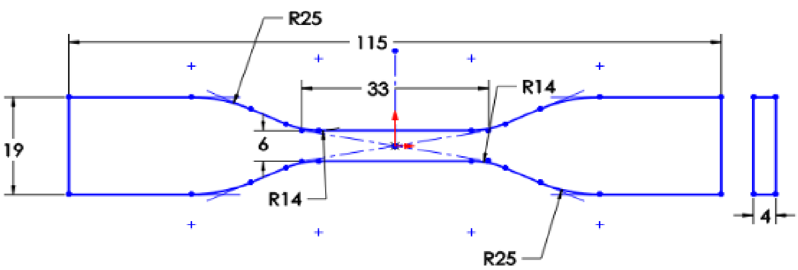

Fig. 5 - CAD model of tensile specimen as per ASTM D638 type IV [20]

3.3 Experimental Design

The Taguchi design of experiment was used in this study. It is used to estimate the chosen process parameters on the quality of ABS product in terms of dimension nal accuracy, surface roughness and also tensile strength of the specimen test. In this study, L9 orthogonal array which having 3 process parameters with 3 level each have been selected. The experimental design for this study is shown in Table 2.

Table 2 - Experimental design using orthogonal array

No.	Levels		
	Object orientation	Layer thickness (mm)	Infill density (%)
1	X	0.20	20
2	X	0.25	65
3	X	0.35	80
4	Y	0.20	65
5	Y	0.25	80
6	Y	0.35	20
7	Z	0.20	80
8	Z	0.25	20
9	Z	0.35	65

3.4 Dimensional Accuracy

In this study, Mitutoyo Digimatic Caliper was used to measure the length of the specimen test and Mitutoyo Micrometer was used to measure the width (W), reduce section width (RSW) and also the thickness (T) of the specimen test. The micrometer used can measured up to 25 mm with a precision of 0.01 mm. The reading of each specimen test is taken 3 times and then the reading is then average to get the end result reading for the specimen.

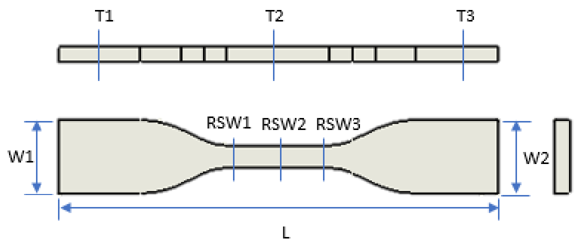

Fig. 6 - Location of measurement for dimensional accuracy

3.4 Surface Roughness

Mitutoyo Surface Roughness Tester SJ-410 as shown in Figure 7 was used in order to get the reading of the surface roughness of the specimen. The reading of surface roughness is taken 3 times and then the reading will average to get the end result reading.

Fig. 7 - Mitutoyo Surface Roughness Tester

3.5 Tensile Test

To evaluate the tensile strength of the FDM parts, the specimen was tested per ASTM D638-14 standards on Victor Universal Testing Machine as shown in Figure 8. The speed of the testing was controlled using speed 300 mm/min at room temperature.

Fig. 8 - Universal Testing Machine

4. Result And Discussion

4.1 Dimensional Accuracy

The reading of measurement, percentage error and the reading of the S/N (signal to noise) ratio for the length, width, reduced section width and thickness have been computed in the Taguchi analysis method. For dimensional accuracy section, the S/N ratio applied is the-smaller-the-better since the aim is to get the minimum number of errors in accuracy. Based on data in Table 3, the S/N response diagram can be constructed as shown in Figure 9. By referring to the graph of main effect plot for length, the optimize parameter to get accurate length is by combining level 1 object orientation which is X, second level of layer thickness which is 0.25 mm and lastly the highest infill density which is level 3, 80 %.

Table 3 - Dimensional accuracy for length results

Exp No.	Length (mm)	Error (%)	(S/N) ratio
1	115.03	0.03	30.46
2	115.02	0.02	33.98
3	114.99	-0.01	40.00
4	115.04	0.04	27.96
5	115.01	0.01	40.00
6	115.04	0.04	27.96

7	115.16	0.14	17.08
8	115.13	0.11	19.17
9	115.16	0.14	17.08

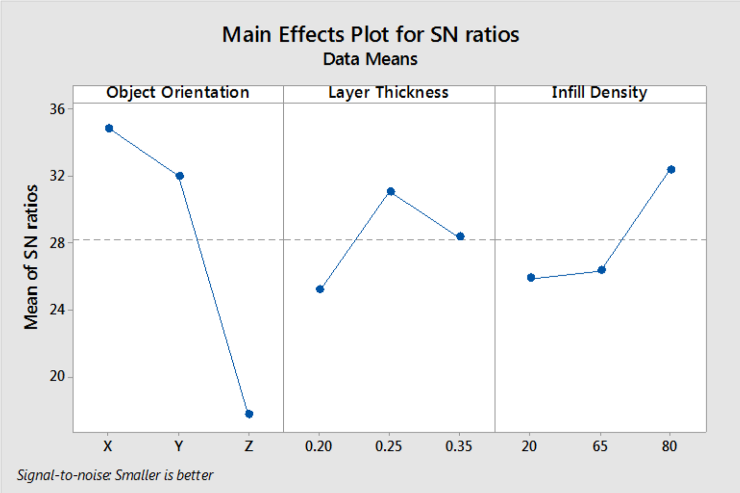

Fig. 9 - Main effect plot for length

Table 4 shows the response table for the S/N ratio. It demonstrates that the most significant factor on the accuracy of the length dimension are object orientation, followed by infill density and lastly layer thickness. Table 5 present the analysis of variance (ANOVA) which DF is degree of freedom, Seq SS is sequential sums of squares, Adj MS is adjusted mean square, F-value is the test statistic used to determine whether the term is associated with the response and P-value is a probability that measures the evidence against the null hypothesis. The percentage (%) contribution shown in the last column in Table 5 signifies the importance of the process parameters. Based on the table, object orientation contributes about 77.38 %, layer thickness contributes about 8.06 % and infill density is about 12.18 %. From the percentage (%) of contribution, it shows that object orientation process parameter is the most contributing process parameter in order to obtain optimal length measurement of the specimen test.

Table 4 - Response Table for Signal to Noise Ratios (length)

Level	Object Orientation	Layer Thickness (mm)	Infill Density (%)
1	34.81	25.16	25.86
2	31.97	31.05	26.34
3	17.78	28.35	32.36
Delta	17.04	5.89	6.50
Rank	1	3	2

Table 5 - Analysis of Variance for SN ratios (length)

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Object Orientation	2	499.86	249.93	32.46	0.03	77.38
Layer Thickness	2	52.08	26.04	3.38	0.23	8.06
Infill Density	2	78.68	39.34	5.11	0.16	12.18
Residual Error	2	15.40	7.70			2.38
Total	8	646.02				100

Based on data in Table 6, the S/N response diagram can be constructed as shown in Figure 10. By referring to the graph of main effect plot for width, the optimize parameter in order to get accurate width is by combining third level of object orientation which is Z, first level of layer thickness which is 0.20 mm and lastly the highest infill density which is level 2, 65 %.

Table 6 - Dimensional accuracy for width results

Exp No.	Width (mm)	Error (%)	(S/N) ratio
1	19.07	0.37	8.64
2	19.06	0.32	9.89
3	19.11	0.58	4.73
4	18.99	-0.05	26.02
5	18.89	-0.58	4.73
6	19.40	2.11	-6.49
7	18.95	-0.26	11.70
8	18.97	-0.16	15.92
9	18.99	0.05	26.02

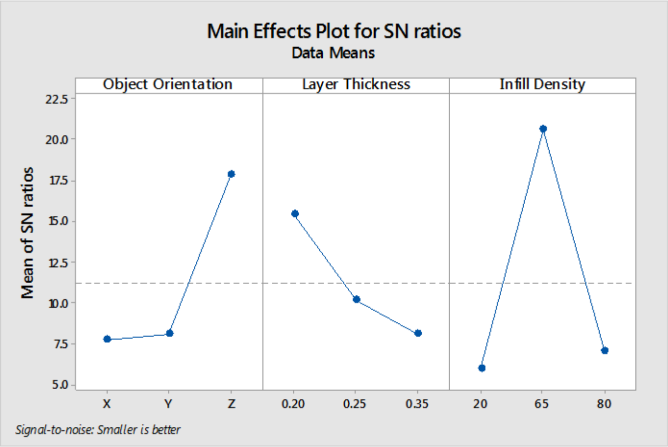

Fig. 10 - Main effect plot for width

Table 7 shows the response table for the S/N ratio. It demonstrates that the most significant factor on the accuracy of the width dimension are infill density, followed by object orientation and lastly layer thickness. The percentage (%) contribution shown in the last column in Table 8 signifies the importance of the process parameters. Based on the table, object orientation contributes about 22.91 %, layer thickness contributes about 9.97 % and infill density is about 46.12 %. From the percentage (%) of contribution, it shows that infill density process parameter is the most contributing process parameter in order to obtain optimal width measurement of the specimen test.

Table 7 - Response Table for Signal to Nois Ratios (width)

Level	Object Orientation	Layer Thickness (mm)	Infill Density (%)
1	7.75	15.45	6.02
2	8.09	10.18	20.65
3	17.88	8.09	7.05
Delta	10.12	7.36	14.62
Rank	2	3	1

Table 8 - Analysis of Variance for SN ratios (width)

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Object Orientation	2	198.48	99.24	1.09	0.48	22.91
Layer Thickness	2	86.38	43.19	0.47	0.68	9.97
Infill Density	2	399.64	199.82	2.20	0.31	46.12
Residual Error	2	182.03	91.01			21.00
Total	8	866.53				100

Based on data in Table 9, the S/N response diagram can be constructed as shown in Figure 11. By referring to the graph of main effect plot for reduced section width, the optimize parameter in order to get accurate reduced section width is by combining third level of object orientation which is Z and the second highest infill density which is level 2, 65 %. Layer thickness seem to be less or no effect on the accuracy of the reduced section width.

Table 9 - Dimensional accuracy for reduces section width results

Exp No.	RSW (mm)	Error (%)	(S/N) ratio
1	6.23	3.69	-11.34
2	6.17	2.83	-9.04
3	6.18	2.91	-9.28
4	6.14	2.33	-7.35
5	6.15	2.50	-7.96
6	6.20	3.33	-10.45
7	6.01	0.17	15.39
8	5.97	-0.50	6.02
9	6.01	0.17	15.39

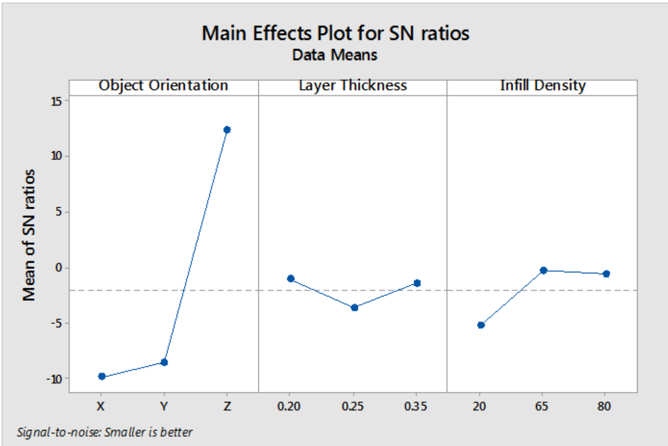

Fig. 11 - Main effect plot for reduces section width

Table 10 shows the response table for the S/N ratio. It demonstrates that the most significant factor on the accuracy of the reduced section width dimension are object orientation, followed by infill density and lastly layer thickness. The percentage (%) contribution shown in the last column in Table 11 signifies the importance of the process parameters. Based on the table, object orientation contributes about 93.25 %, layer thickness contributes about 1.16 % and infill density is about 4.61 %. From the percentage (%) of contribution, it shows that object orientation process parameter is the most contributing process parameter for improvise reduced section width measurement of the specimen test.

Table 10. Response Table for Signal to Noise Ratio (RSW)

Level	Object Orientation	Layer Thickness (mm)	Infill Density (%)
1	-9.88	-1.09	-5.26
2	-8.58	-3.66	-0.33
3	12.27	-1.44	-0.62
Delta	22.15	2.56	4.93
Rank	1	3	2

Table 11. Analysis of Variance for SN ratios (RSW)

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Object Orientation	2	927.24	463.62	95.63	0.01	93.25
Layer Thickness	2	11.57	5.78	1.19	0.46	1.16
Infill Density	2	45.88	22.94	4.73	0.18	4.61
Residual Error	2	9.70	4.85			0.98

Total	8	994.38				100

Based on data in Table 12, the S/N response diagram can be constructed as shown in Figure 11. By referring to the graph of main effect plot for thickness, the optimize parameter in order to get accurate thickness is by combining first level of object orientation which is X, first level of layer thickness which is 0.20 mm and lastly the level 2 of infill density which is 65 %.

Table 12 - Dimensional accuracy for thickness results

Exp No.	Thickness (mm)	Error (%)	(S/N) ratio
1	4.02	0.50	6.02
2	4.03	0.75	2.50
3	4.08	2.00	-6.02
4	4.28	7.00	-16.90
5	4.26	6.50	-16.26
6	4.20	5.00	-13.98
7	4.30	7.50	-17.50
8	4.23	5.75	-15.19
9	4.53	13.25	-22.44

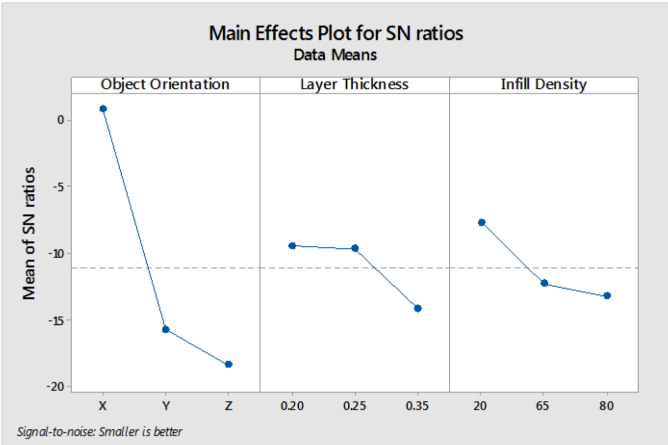

Fig. 12 - Main effect plot for thickness

Table 13 shows the response table for the S/N ratio. It demonstrates that the most significant factor or the factor that gives the most impact on the accuracy of the thickness dimension are object orientation, followed by infill density and lastly layer thickness. The percentage (%) contribution shown in the last column in Table 14 signifies the importance of the process parameters in order of their influence. Based on the table, object orientation contributes about 85.66 %, layer thickness contributes about 5.57 % and infill density is about 6.92 %. From the percentage (%) of contribution, it shows that object orientation process parameter is the most contributing process parameter in order to obtain optimal length of the specimen test.

Table 13 - Response Table for Signal to Noise Ratio (thickness)

Level	Object Orientation	Layer Thickness (mm)	Infill Density (%)
1	0.83	-9.46	-7.72
2	-15.71	-9.65	-12.28
3	-18.38	-14.15	-13.26
Delta	19.21	4.69	5.54
Rank	1	3	2

Table 14 - Analysis of Variance for SN ratios (thickness)

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Object Orientation	2	650.01	325.00	46.19	0.02	85.66

Layer Thickness	2	42.23	21.12	3.00	0.25	5.57
Infill Density	2	52.52	26.26	3.73	0.21	6.92
Residual Error	2	14.07	7.04			1.85
Total	8	758.83				100

4.2 Surface Roughness

The reading of surface roughness and S/N (signal to noise) ratio for each set of the specimen test is computed in the Taguchi analysis method. For surface roughness section, the S/N ratio applied is the-smaller-the-better since the better surface quality is the one with smoother surface. Based on data in Table 15, the S/N response diagram can be constructed as shown in Figure 13. The result to get the optimize parameter to get accurate thickness is by combining first level of object orientation which is X, the level 1 of infill density which is 20 %. Layer thickness seem to be less or no effect on the surface roughness of the specimen.

Table 15 - Surface roughness results

Exp No.	Ra (μm)	(S/N) Ratio
1	0.61	4.34
2	0.78	2.16
3	0.78	2.12
4	1.67	-4.45
5	1.60	-4.07
6	1.32	-2.43
7	2.10	-6.45
8	1.80	-5.12
9	1.74	-4.83

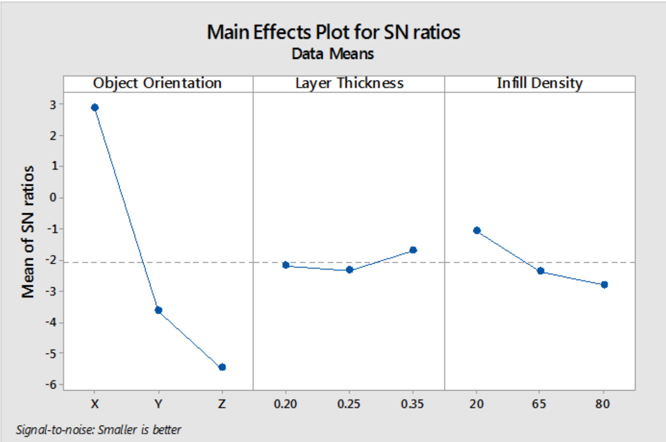

Fig. 13 - Main effect plot for surface roughness

Table 16 shows the response table for the S/N ratio. It demonstrates that the most significant factor on the surface roughness of the specimen test are object orientation, followed by infill density and lastly layer thickness. The percentage (%) contribution shown in the last column of the Table 17 signifies the importance of the process parameters. All of the parameters which is object orientation and also infill density having a significant effect on the surface roughness of the specimen test except layer thickness which only contributes 0.54 %. Based on the table, object orientation contributes about 94.27 %, infill density is about 3.96 %. while the relative percentage of the layer thickness is less than 1 %. From the percentage (%) of contribution, it shows that object orientation process parameter is the most contributing process parameter to obtain optimal surface roughness of the specimen test.

Table 16 - Response Table for Signal to Noise Ratios

Level	Object Orientation	Layer Thickness (mm)	Infill Density (%)

1	2.87	-2.19	-1.07
2	-3.65	-2.34	-2.37
3	-5.47	-1.71	-2.80
Delta	8.34	0.63	1.72
Rank	1	3	2

Table 17 - Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Object Orientation	2	115.43	57.71	76.16	0.01	94.27
Layer Thickness	2	0.65	0.33	0.43	0.70	0.54
Infill Density	2	4.85	2.42	3.20	0.24	3.96
Residual Error	2	1.52	0.76			1.24
Total	8	122.45				100

4.3 Tensile Strength

The reading of tensile strength and S/N (signal to noise) ratio for each set of the specimen test is computed in the Taguchi analysis method. For tensile strength section, the S/N ratio applied is the-bigger-the-better better since good mechanical properties is the one with highest strength value. Based on data in Table 18, the S/N response diagram can be constructed as shown in Figure 14. By referring to the graph of main effect plot for tensile strength, it can be seen that the best set of parameters to be combined is the highest value for each factor. Therefore, the result to get the optimize parameter is by combining second level of object orientation which is Y, the third level of infill density which is 80 %. Layer thickness seem to be less or no effect on the strength of the specimen test.

Table 18 - Tensile strength results

Exp No.	Tensile strength (MPa)	(S/N) Ratio
1	21.57	26.68
2	22.18	26.92
3	24.62	27.83
4	25.17	28.02
5	26.95	28.61
6	23.88	27.56
7	16.79	24.50
8	14.12	23.00
9	15.70	23.92

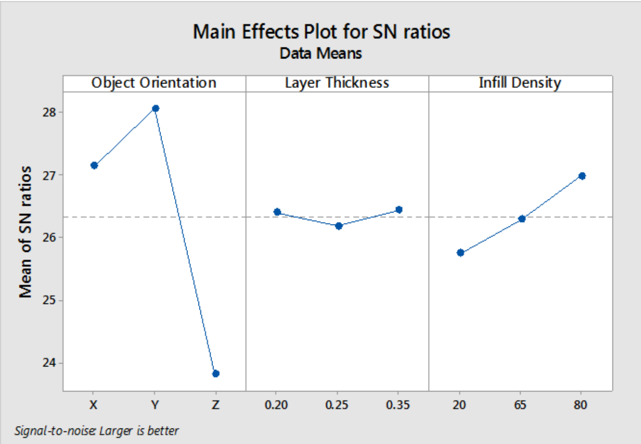

Fig. 14 - Main effect plot for tensile strength

Table 19 shows the response table for the S/N ratio. It demonstrates that the most significant factor on the tensile strength of the specimen test are object orientation, followed by infill density and lastly layer thickness. The percentage (%) contribution shown in the last column of the Table 20 signifies the importance of the process parameters. All of the parameters which is object orientation and also infill density having a significant effect on the surface roughness of the specimen test except layer thickness which only contributes 0.36 %. Based on the table, object orientation contributes about 95.51 %, infill density is about 7.06 % while the relative percentage of the layer thickness is less than 1 %. From the percentage (%) of contribution, it shows that object orientation process parameter is the most contributing process parameter in order to obtain optimal tensile strength of the specimen test.

Table 19 - Response Table for Signal to Noise Ratios

Level	Object Orientation	Layer Thickness (mm)	Infill Density (%)
1	27.14	26.40	25.74
2	28.06	26.18	26.28
3	23.81	26.43	26.98
Delta	4.26	0.26	1.23
Rank	1	3	2

Table 20 - Analysis of Variance for SN ratios

Source	DF	Seq SS	Adj MS	F	P	Contribution (%)
Object Orientation	2	30.11	30.11	1324.61	0.00	92.51
Layer Thickness	2	0.12	0.12	5.20	0.16	0.36
Infill Density	2	2.30	2.30	101.11	0.01	7.06
Residual Error	2	0.02	0.02			0.07
Total	8	32.54				100

5. Conclusion

As a conclusion, this study examines the effect of three FDM process parameters on the final parts characteristics. The study examines the effect of object orientation, layer thickness and infill density on the quality of ABS product in term of surface roughness, dimensional accuracy and also tensile strength of ABS product. In this project, the significant parameter and optimum value of surface roughness, dimensional accuracy and tensile strength have been identified by using Taguchi method and analysis of variance (ANOVA). The optimum value of surface roughness, dimensional accuracy and tensile strength was identified. The two most significant control factor for dimensional accuracy, surface roughness and tensile strength are object orientation and infill density. This both control factor is most affected the dimensional accuracy, surface roughness and tensile strength of the printed specimen test compared to the of layer thickness.

The result from this study will help another researcher to make further work regarding the study on the effect of Fused Deposition Modelling process parameters on the quality of ABS product. From this research, some recommendation is made:

- Comparison using ABS material provided by different manufacturer. It can help researcher to determine if the material used does affect the result obtained and it can help in determining the best material from certain manufacturer to be used.
- Another mechanical properties analysis for ABS materials such as for bending test, flexural test and also impact test should also be carried out.

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