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Characteristics of Abs and Pla Material in 3D Printing for Car Backseat Headrest Hanger/Hook Model

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Abstract: Additive manufacturing (AM) is known as the technology which enable using a layer wise in fabrication of a complex part directly from CAD files without using any specific tooling. This manufacturing techniques offers many strategic advantages which include design freedom for the build of complex part geometries which cannot be made in other way, the ability to build functional part in a small size for the end user customization and its ability to do improvement for the expensive part in aerospace and other industries. The aim of this research is to study the effect of process parameter such as layer thickness, infill density and object orientation to the accuracy of printed part measurement with CAD model, surface roughness and mechanical strength of PLA and ABS material. Therefore, it is important to find the optimum value of dimensional accuracy, surface roughness and mechanical strength for both materials. To achieve the optimum value of dimensional accuracy, surface roughness and mechanical strength for both materials, Taguchi method L4 orthogonal array is used to conduct this experiment and Minitab 18 software will analyze the result and shows the best optimum value. The result from ANOVA analysis shows that object orientation gives highest contribution to the dimensional accuracy and surface roughness for both materials. Meanwhile, for mechanical strength layer thickness highly contributed to the ABS material and object orientation for the PLA material. A Car Backseat Headrest Hanger/Hook model is fabricated by the best optimal combination and level of process parameter of mechanical strength.

Keywords: Additive manufacturing, fused deposition modelling, PLA, ABS, taguchi method

1. Introduction

3D printing or additive manufacturing is the process of create an object by layering technique which is the object will be manufactured layer by layer until the end of the manufacturing process [1]. Additive manufacturing becomes popular by numerous of industries in the early of 18th century due to the time saving and cost of its manufacturing process. 3D printing manufacturing technology has been applied in a numerous of sector such as industrial 3D printing, aviation industries, tissue engineering, medical industries and automotive industries [2].

There are wide variety of 3D printing process such as Stereolithography Apparatus (SLA), Selective Laser Sintering (SLS), Laminated Object Manufacturing (LOM), and Fused Deposition Modelling (FDM) which is used layer by layer technique to form a product [3]. Fused Deposition Modelling (FDM) produce layer by layer with depositing material in a form of filament. This process works is simple which is by creating the design of the object by the used of 3D modelling program such as Computer Aided Design (CAD) then it will be converted into Standard Tessellation Language file or also known as STL file format. The model will be sliced into hundreds or thousands of layers by some computer program or rapid prototyping machine [4].

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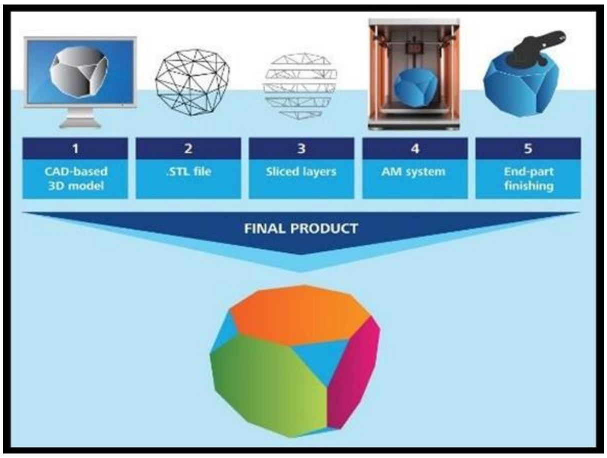

Fig. 1 - Additive manufacturing process [5]

2. Literature Review

Fused Deposition Modelling (FDM) is a process which is generally used for the application of modelling, prototyping and production. Scott Crump which is the founder of Stratasys is the one that firstly developed Fused Deposition Modelling processes in the late of 1980s then it was commercialized by Stratasys in the year of 1990 [6]. There were three steps in Fused Deposition Material (FDM) process which are pre-processing, production, and post-processing. In the pre- processing, a CAD model is being construct with SolidWorks software or any design software, then the CAD model will be converted into STL format to start the Fused Deposition (FDM) process. In production process, thermoplastic material is being heated to semi-liquid state then it will be extruded from extrusion head to build a part layer by layer according to the computer-controlled path. The extruder head is moved in X & Y direction while the working table is moved in Z direction. Next, the post-processing is a process of removing the support material of a printed part which is to do the cleaning process by the use of dental picks, needle-nose pliers, and diamond file.

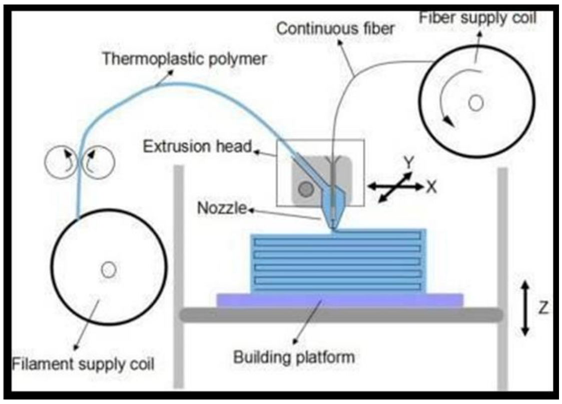

Fig. 2 - FDM schematic process

Fused Deposition Modelling (FDM) machines are using thermoplastics material in form of filament to do the process of extrusion and deposition. There were some properties of thermoplastic polymer to be used in Fused Deposition Modelling (FDM) process that allow this process to fabricate a tough part to be use as prototyping, installation and functional testing [8]. Materials can be divided into three categories which are mechanical performance, visual quality and process. Choosing material for the process is depend on the part to be print and it is based on these criteria such as ease of printing, visual quality, maximum stress, elongation at break, impact resistance, layer adhesion and heat resistance. Plastic materials that is commonly used for Fused Deposition Modelling process are Polylactic Acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) [9].

Polylactic Acid (PLA) is made from the organic material which is sugarcane and corn starch which gives pleasant slightly sweet smell and it is environmentally plastic. The PLA plastic is more brittle but can resist UV light better. It usually can be print well at 180°C and 220°C and it does not release toxic fumes. PLA material is a biodegradable, bio-absorbable and renewable thermoplastic polyester and it has an excellent mechanical strength and process ability [10].

Acrylonitrile Butadiene Styrene (ABS) originated from an oil-based plastic. The printing temperature for the ABS plastic is slightly higher which is about 230 °C to 245 °C and it has the tendency to warp if cool while the printing process, and to overcome this problem ABS needs to be printed on a heated bed. This material is sufficiently resistant to heat, chemicals, and moisture and it is limited to extensive functional testing. It widely used to fabricate things such as musical instrument, Lego blocks, plastic car parts and mostly used by the industrial manufacturer due to its strength, flexibility, machinability and high temperature resistance [11].

2.1 Quality of Characteristics of Build Part by FDM Process

Since Fused Deposition Modelling (FDM) is a most popular technology, then the successful implementation of additive manufacturing process is the key so that there is an improvement can be made in terms of its surface quality, part strength, build time, accuracy and repeatability. An adjustment is needed to improve the function of various process related to the parameters which is by the properties of the build part of additive manufacturing process.

To find the optimal process parameter setting of the build part, there is three characteristics which is the most being measured which are surface roughness, dimensional accuracy and mechanical properties. Surface roughness significantly gives influence to the quality of Fused Deposition (FDM) model part especially in part functionality or assembly, mechanical properties testing, precision in dimension fit, tooling application, smoothness on mold pattern and other engineering application [12]. It is the one of the important role to a product such as wear resistance, coating and light reflection [13]. According to study by Mohammad S. Alsoufi (2018), the object building direction of 90° shows the excellent surface behavior and more accurate comparing to the ABS material [14].

Dimensional accuracy is an important characteristic to produce a part which is similar or accurate according to the CAD model in the software. According to Omar A. Mohamed, Syed H. Masood and Jahar L. Bhowmik (2015) states that build orientation and depositing thickness can affect surface quality of the build part and the result of deposition patterns is caused by the differences in dimensional accuracy [15]. Faiz Redza Ramli (2018) claims that the process parameter of layer thickness and infill density gives influence on the dimensional accuracy of slab features and its surface roughness instead of the machines performance [16].

For mechanical properties of 3D printed part is depending on different of variables. Md. Raf E Ul Shougat (2017) claims that angle of building orientation and suitable infiltrates has the effective influence and can improve the mechanical properties of the build part [17]. The study of Heechang Kim shows that different infill rate affect to the tensile strength result for the different material which is ABS material and PLA material, then it shows that PLA material is has better ultimate tensile strength than ABS material [18].

3. Methodology

This experiment is focused on the evaluation of the Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA) part produce on determine the dimensional accuracy in terms of its measurement and density of printed part, surface roughness and strength of part is being measured. The specimen model will be fabricated by using Fused Deposition Modelling (FDM) with Ultimaker 3 Extended 3D printing machine. The software used is Ultimaker Cura, an open source 3D printer software which slice the model file into layers according to desired setting and generate a G-Code. The G-Code is sent to the 3D printer to start the manufacturing process.

3.1 Experimental Plan

The fabrication of the specimen test is using PLA and ABS material with diameter of 2.85 mm. The process parameter that is being required in this project are layer thickness, part orientation, and infill density. The infill pattern that have been choose for both materials in this experiment is grid. There were various of setting parameter can be choose in the machine, however only two level of each factor chosen and being considered in this project. Table 1 shows the control factor and its value for each level.

Table 1 - Control parameter and its value for each level

Parameter	Level	
	1	2
Layer Thickness	0.2 mm	0.3 mm
Infill Density (%)	10	30
Part Orientation	X	Y

3.2 Specimen Test

The specimen test that was fabricated is according to the standard tensile test ASTM D638 specimen Type IV with overall length of 115mm, overall width is 19mm and 4mm thickness. This specimen will be use to evaluate the dimensional accuracy, surface roughness and also the mechanical strength. Figure 3 shows the geometry and dimensions of the specimen test.

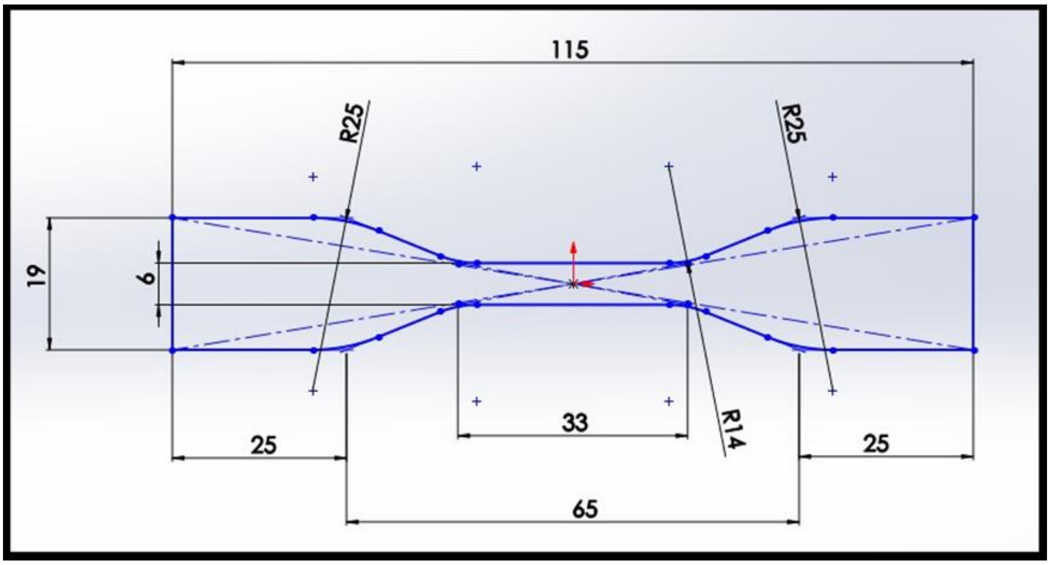

Fig. 3 - Geometry and dimension of ASTM D638 Type IV specimen test [19]

3.3 Experimental Design

Design of experiment Taguchi is used in this study. This method involves the analysis that reveals the factors that is most effective to reach goals and direction in which factors need to be adjusted to improve the result of dimensional accuracy, surface roughness and mechanical strength of PLA and ABS material. In this study, Taguchi method of L4 orthogonal array is applied to the experiment which is there are three parameters with two level for each parameter. Table 2 shows the experimental design using L4 orthogonal array.

Experiment Number	Control Parameter		
	Layer Thickness (mm)	Infill Density (%)	Object Orientation
1	0.2	10	X
2	0.3	30	X
3	0.2	30	Y
4	0.3	10	Y

3.3.1 Dimensional Accuracy

In this study, Kern Germany Vernier caliper is a precision tool to measure the length (L) of specimen test. Meanwhile, Mitutoyo Micrometer Screw Gauge is used to measure the width (W), reduce section width (RSW) and thickness (T) of the specimen test. In this experiment, the length, width, reduced section width, and thickness of the specimen is being measure for three times to get the average reading. Figure 4 and Figure 5 shows the measuring process for specimen test.

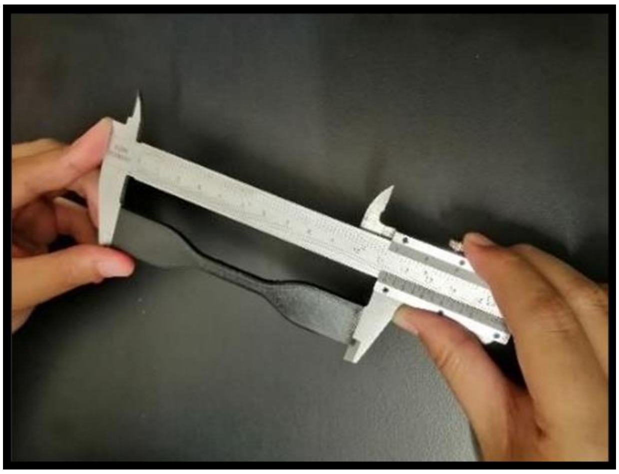

Fig. 4 - Measuring length of specimen test

Fig. 5 - Measuring reduced section width of specimen test

3.3.2 Surface Roughness

In this study, Mitutoyo SJ-410 Surface Roughness Tester will be used to measure surface roughness for PLA and ABS materials. The reading of surface roughness is taken 3 times and the reading will average. Figure 6 shows the measuring process for surface roughness of specimen test.

Fig. 6 - Measuring process for specimen test

3.3.3 Tensile Testing

In this study, Victor Universal testing machine is used to test the tensile strength. Three set of ASTM D638 Type IV tensile specimen is used to perform the process of tensile strength testing. Figure 7 shows the process of tensile testing for the specimen test. The speed of machine to control the testing is 300 mm/min.

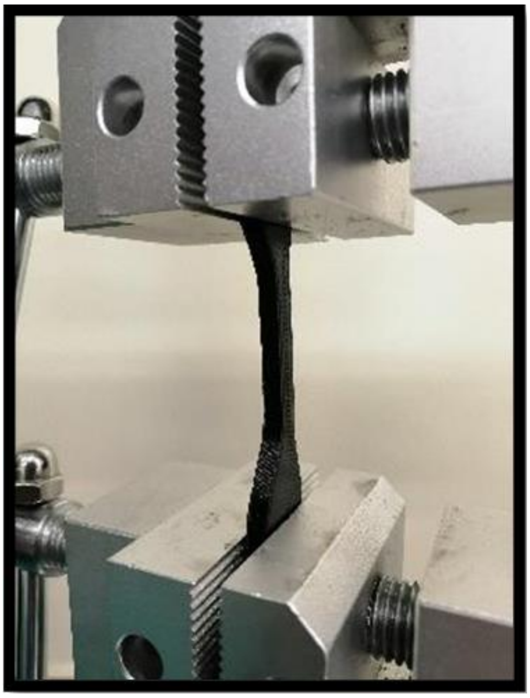

Fig. 7 - Tensile testing process

4. Tensile Testing

4.1 Dimensional Accuracy

Minitab 18 software is generated the result for the S/N (Signal to Noise) ratio of the measurement reading and percentage error that have been computed to the software. The S/N ratio applied to the dimensional accuracy is smaller-the-better to get the optimum number of errors for the accuracy of the specimen. The result of dimensional accuracy for PLA and ABS material will be categorized according to length (L), width (W), reduced section width (RSW) and thickness (T).

4.1.1 Polylactic Acid (PLA)

i. Length

Figure 8 shows the main effect plot of length. Graph shows the best parameter is the highest value level for each factor which is 0.2 mm of layer thickness, 30 % of infill density and object orientation of Y. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, layer thickness (91.05 %) is most significantly influences the dimensional accuracy of length followed by infill density (7.99 %), and object orientation (20.36 %). Therefore, according to the contribution percentage (%) it clearly shows that layer thickness is the most contribute process parameter to get the optimal measurement length for the specimen test.

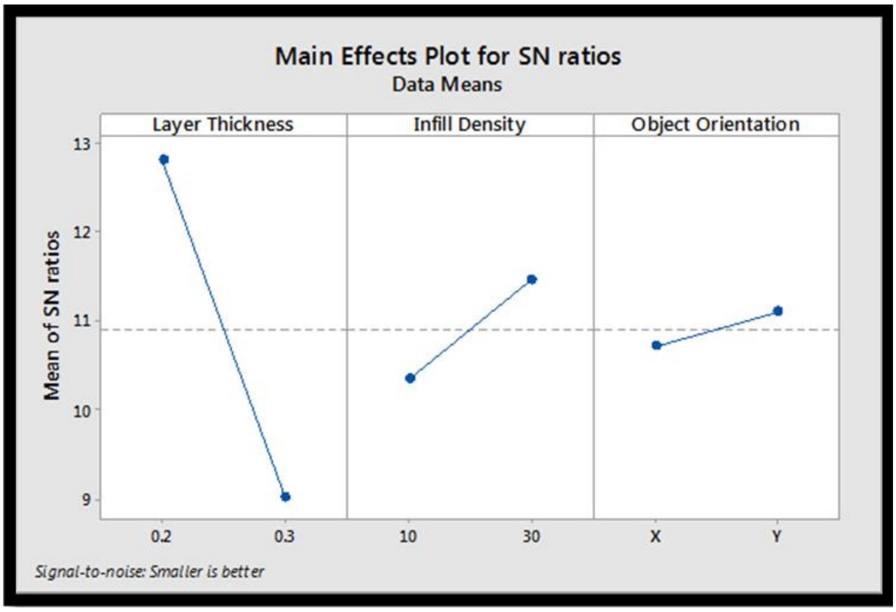

Fig. 8 - Main effect plot of PLA

ii. Width

Figure 9 shows the main effect plot of width. Graph shows the best parameter is the highest value level for each factor which is 0.2 mm of layer thickness, 30 % of infill density and object orientation of Y. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, object orientation (80.64 %) is most significantly influences the dimensional accuracy of length followed by layer thickness (12.68 %), and infill density (6.68 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement width for the specimen test.

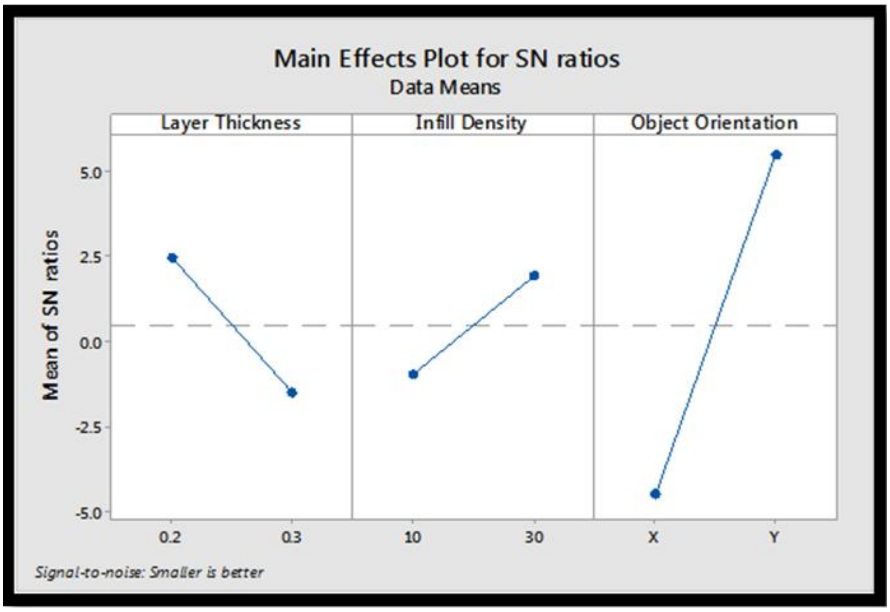

Fig. 9 - Main effect plot of width for PLA

iii. Reduced Section Width

Figure 10 shows the main effect plot of reduced section width. Graph shows the best parameter is the highest value level for each factor which is 0.3 mm of layer thickness, 10 % of infill density and object orientation of Y. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, object orientation (99.22 %) is most significantly influences the dimensional accuracy of length followed by infill density (0.72 %), and layer thickness (0.06 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement reduced section width for the specimen test.

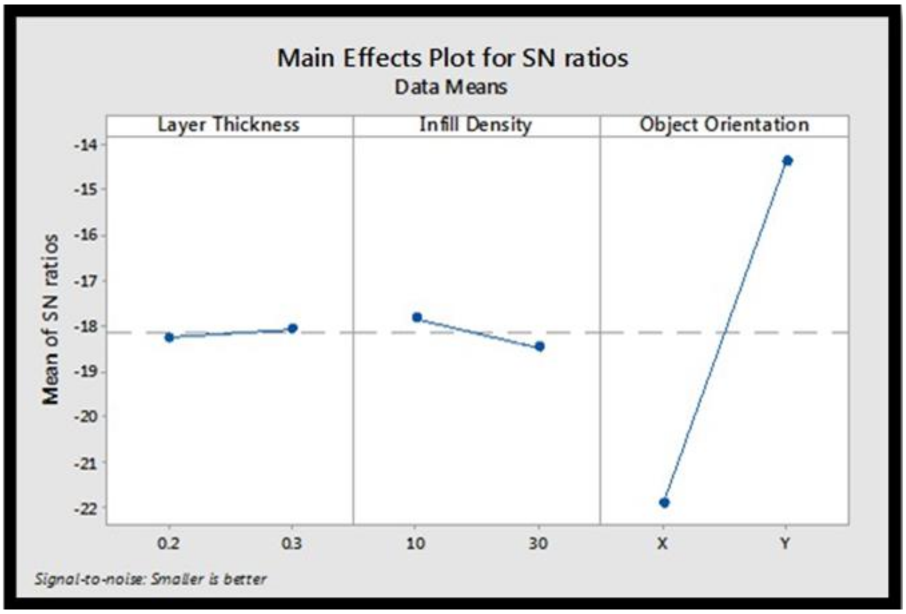

Fig. 10 - Main effect plot for reduced section width for PLA

iv. Thickness

Figure 11 shows the main effect plot of thickness. Graph shows the best parameter is the highest value level for each factor which is 0.3 mm of layer thickness, 30 % of infill density and object orientation of X. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, object orientation (78.60 %) is most significantly influences the dimensional accuracy of length followed by layer thickness (16.60 %), and infill density (4.80 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement of thickness for the specimen test.

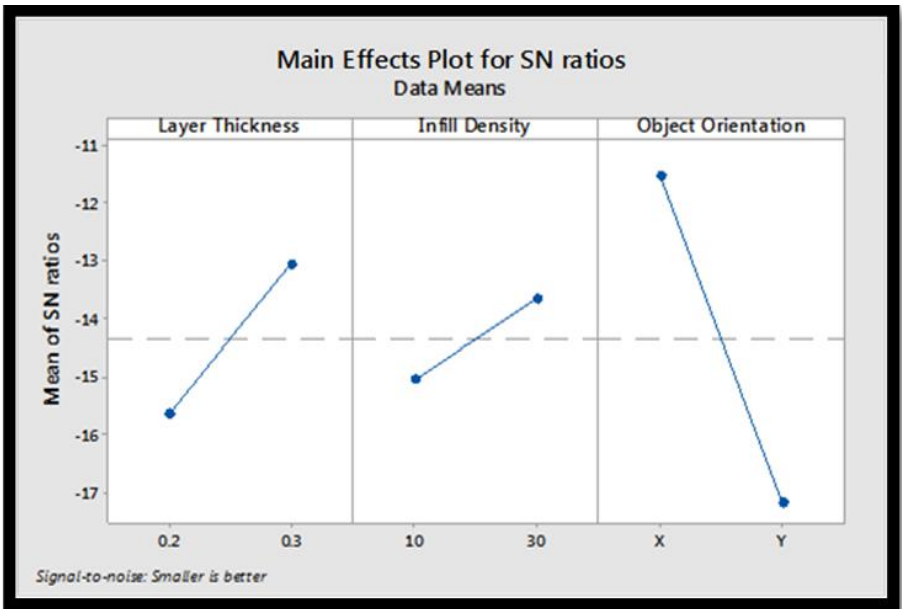

Fig. 11 - Main effect plot of thickness for PLA

4.1.2 Acrylonitrile Butadiene Styrene (ABS)

i. Length

Figure 12 shows the main effect plot of length. Graph shows the best parameter is the highest value level for each factor which is 0.2 mm of layer thickness, 30 % of infill density and object orientation of X. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, object orientation (93.49 %) is most significantly influences the dimensional accuracy of length followed by layer thickness (4.59 %), and infill density (1.92 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement length for the specimen test.

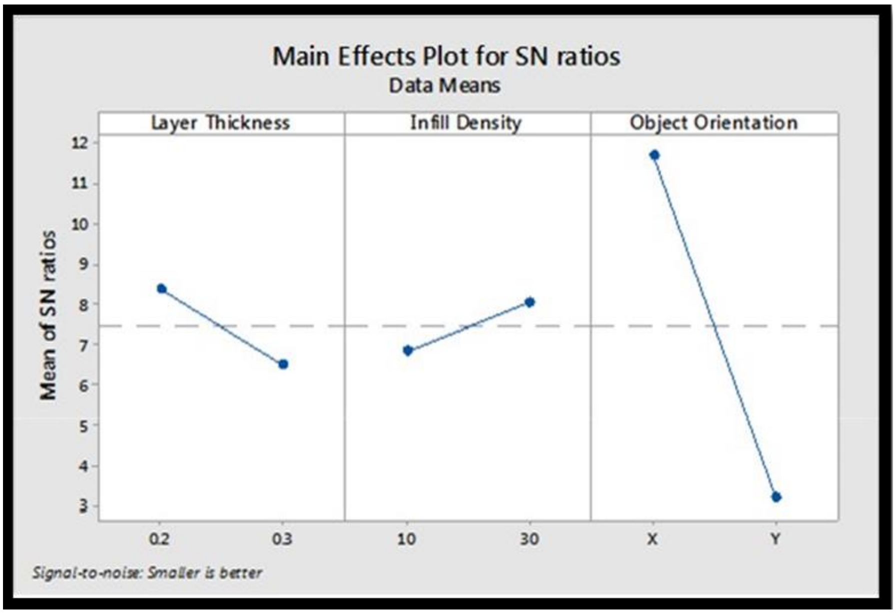

Fig. 12 - Main effect plot of length for ABS

ii. Width

Figure 13 shows the main effect plot of width. Graph shows the best parameter is the highest value level for each factor which is 0.3 mm of layer thickness, 10 % of infill density and object orientation of Y. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, object orientation (49.70 %) is most significantly influences the dimensional accuracy of length followed by infill density (29.06 %), and layer thickness (21.24 %). Therefore, according the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement width for the specimen test.

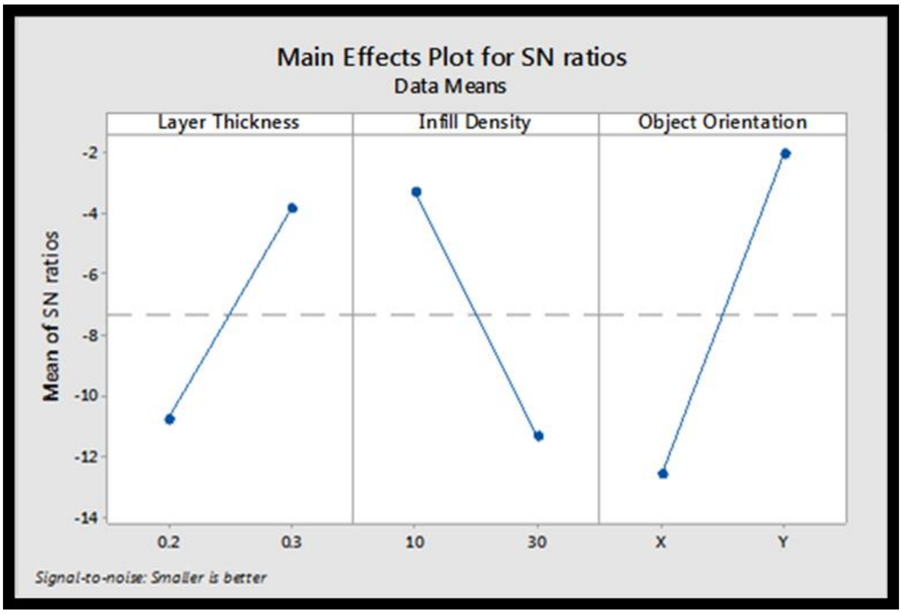

Fig. 13 - Main effect plot of width for ABS

iii. Reduced Section Width

Figure 14 shows the main effect plot of reduced section width. Graph shows the best parameter is the highest value level for each factor which is 0.2 mm of layer thickness, 30 % of infill density and object orientation of Y. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, object orientation (95.41 %) is most significantly influences the dimensional accuracy of length followed by infill density (2.53 %), and layer thickness (2.06 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement reduced section width for the specimen test.

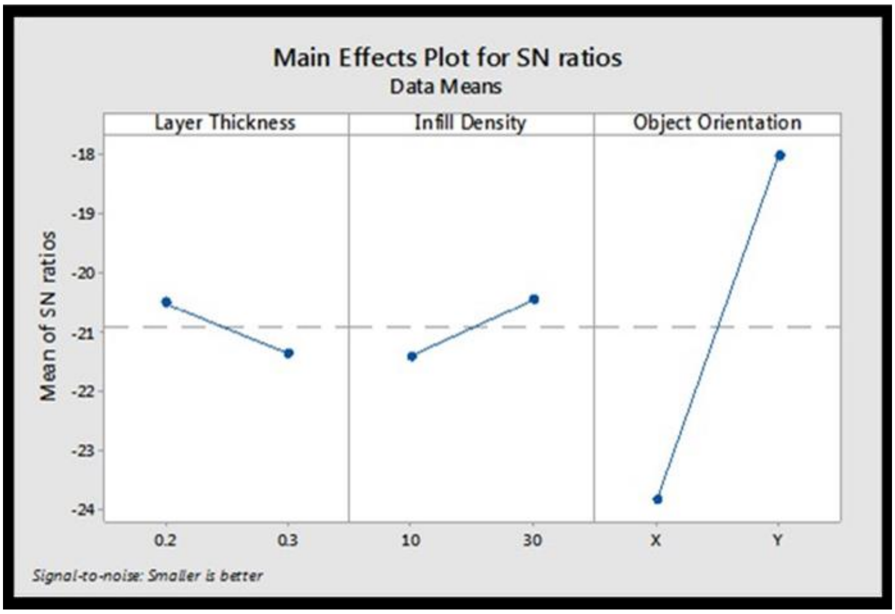

Fig. 14 - Main effect plot of reduced section width for ABS

iv. Thickness

Figure 15 shows the main effect plot of thickness. Graph shows the best parameter is the highest value level for each factor which is 0.3 mm of layer thickness, 30 % of infill density and object orientation of X. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio shows that object orientation (53.97 %) is most significantly influences the dimensional accuracy of length followed by infill density (36.70 %), and layer thickness (9.33 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement of thickness for the specimen test.

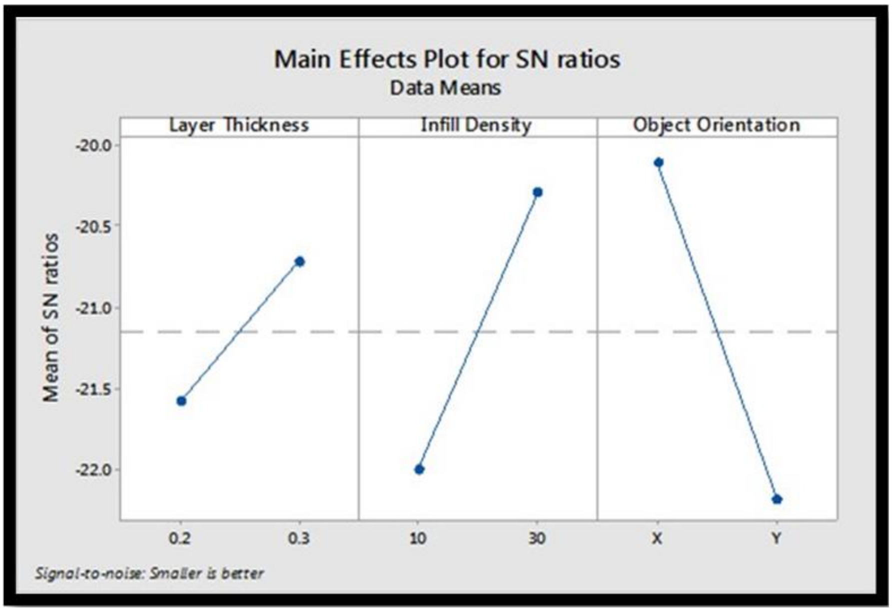

Fig. 15 - Main effect plot of thickness for ABS

4.2 Surface Roughness

Surface roughness of PLA and ABS material is using the same specimen which is ASTM D638 Type IV and all of the measurement taken will be average to get the fixed value. The S/N ratio applied to the surface roughness is smaller-the-better to get the optimum value for the surface quality of the specimen.

4.2.1 Polylactic Acid (PLA)

Figure 16 shows the main effect plot of surface roughness. Graph shows the best parameter is the highest value level for each factor which is 0.3 mm of layer thickness, 30 % of infill density and object orientation of X. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, object orientation (98.90 %) is most significantly influences the surface roughness followed by layer thickness (1.02 %), and infill density (0.08 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement surface roughness for the specimen test.

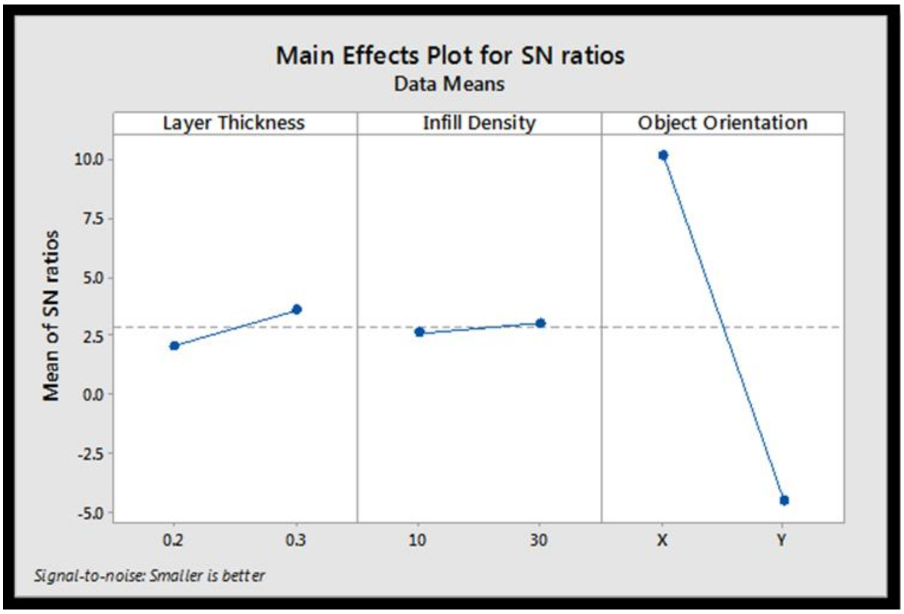

Fig. 16 - Main effect plot for S/N ratios of surface roughess for PLA

4.2.2 Acrylonitrile Butadiene Styrene

Figure 17 shows the main effect plot of surface roughness. Graph shows the best parameter is the highest value level for each factor which is 0.3 mm of layer thickness, 10 % of infill density and object orientation of X. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio shows that object orientation (98.32 %) is most significantly influences the surface roughness followed by layer thickness (1.68 %), and infill density (0.01 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement surface roughness for the specimen test

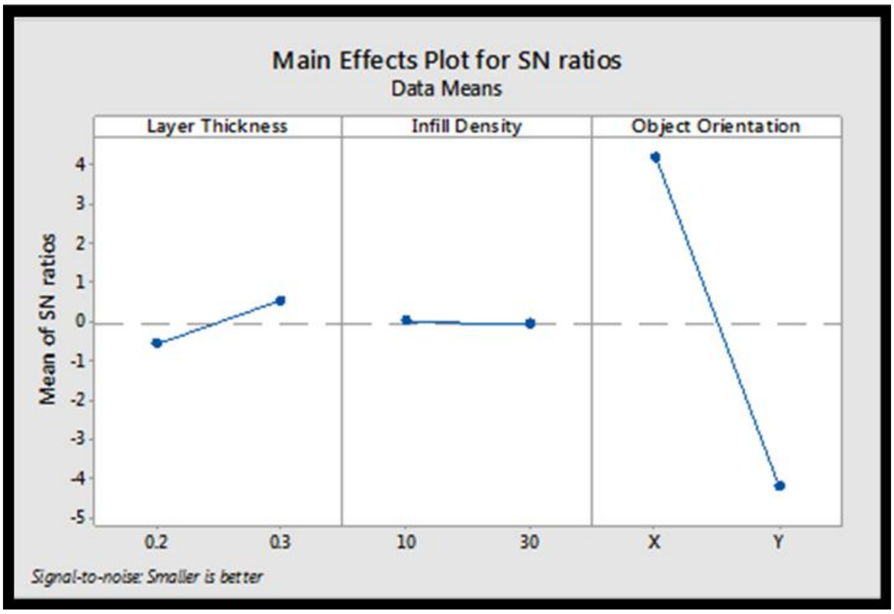

Fig. 17 - Main effect plot for S/N ratios surface roughness for ABS

4.3 Mechanical Strength

The mechanical characteristics of the product is depending on the manufacturing parameters. The S/N ratio applied to the mechanical strength is larger the-better criteria were used for computing S/N ratio due to the prime objective of maximization of strength.

4.3.1 Polylactic Acid

Figure 18 shows the main effect plot of tensile strength. Graph shows the best parameter is the highest value level for each factor which is 0.2 mm of layer thickness, 30 % of infill density and object orientation of X. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, object orientation (57.27 %) is most significantly influences the surface roughness followed by layer thickness (36.02 %), and infill density (6.70 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement tensile strength for the specimen test.

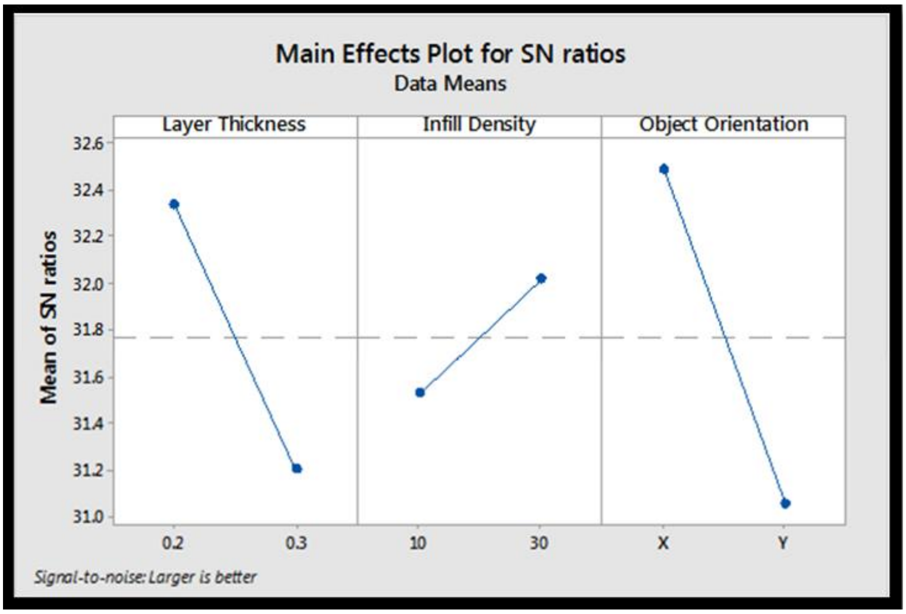

Fig. 18 - Main effect plot for S/N ratios of tensile strength of PLA

4.3.2 Acrylonitrile Butadiene Styrene

Figure 19 shows the main effect plot of tensile strength. Graph shows the best parameter is the highest value level for each factor which is 0.2 mm of layer thickness, 10% of infill density and object orientation of Y. The analysis of variance for S/N ratio is to determine the most significant factor affecting the optimum combination of process parameters on the output quality and characteristic. Based on analysis of variance for S/N ratio, layer thickness (52.89 %) is most significantly influences the tensile strength followed by object orientation (43.80 %), and infill density (3.31 %). Therefore, according to the contribution percentage (%) it clearly shows that object orientation is the most contribute process parameter to get the optimal measurement tensile strength for the specimen test

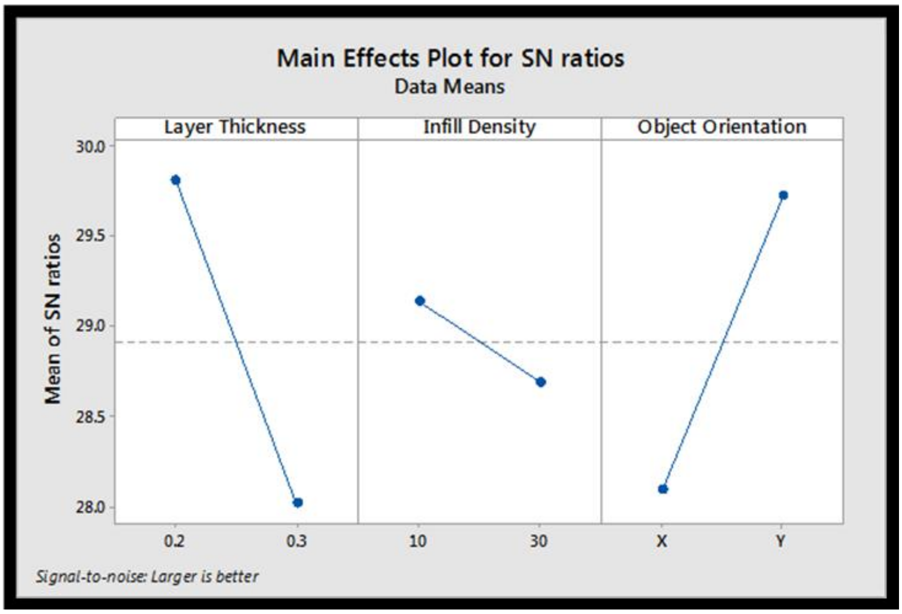

Fig. 19 - Main effect plot for S/N ratios of tensile strentgh of ABS

5. Conclusion

This experiment is studied on the influence of manufacturing parameters of an FDM process on the dimensional accuracy, surface roughness and mechanical properties of two materials that the most widely used in additive manufacturing which is PLA and ABS material. The process parameters that is being studied are layer thickness, infill density, and object orientation. Dimensional accuracy for PLA material shows that layer thickness highly effects on length, then followed by infill density and object orientation. Meanwhile, for dimensional accuracy for ABS material, the most effects on length is object orientation, then followed by layer thickness and infill density. Results for width, reduced section width and thickness for PLA and ABS material shows that the process parameter of object orientation is most contribute to the dimensional accuracy. Next, process parameter of object orientation gives highest contributions which is about 98.90 % for PLA material and 98.32 % for ABS material to the surface roughness. Meanwhile, infill density is less contributed to surface roughness which is 0.08 % for PLA material and 0.01 % for ABS material. For mechanical strength, object orientation had a highest effect to the tensile strength of PLA material with the contribution of 57.27 %. Meanwhile, for ABS material, layer thickness with contribution of 52.89 % has the highest effect on tensile strength. Lastly, once the optimal combination and level of process parameter had been obtained, a Car Backseat Headrest Hanger/Hook will be fabricated by using the result of mechanical strength for both PLA material and ABS material.

In order to improve this study for the future works, the model of a Car Backseat Headrest Hanger/Hook needs to be validated to verify the optimal process parameter obtained from the parameter design and generate a simulation on Finite Element Analysis (FEA) of mechanical strength to compared the experimental results with simulation. Furthermore, the number of control parameter has to be increased together with its level so that the results can be more reliable. The properties of the material such as colour and processing temperature also can be compared to identify its mechanical behavior.

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