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ANALYSIS ON THE IMPACT PROCESS PARAMETERS ON TENSILE STRENGTH USING 3D PRINTER REPETIER-HOST SOFTWARE

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ABSTRACT

RepRap (Replicating Rapid Prototyper) is an open-source 3D printer which current revolution from rapid prototyping technology. The technology has become well-known to the public and starting to widely commercialize in the market. The low cost and flexibility of the open-source 3D printer become the alternative for making three-dimensional parts. The advantage of using this technology is that the user has a complete freedom of controlling the process parameters of the fabricate product. Despite of being a low-cost 3D machine, there is no extensive study of the performance on this technology. This paper investigates the impact on process parameters for tensile strength using polylactic acid (PLA) material. Parts were printed using newly developed open-source 3D printer with Repetier-Host software by manipulating three parameters which were layer thickness, shell thickness and printing speed. The printed parts were tested under tensile test machine and the analysis from ANOVA shows that the shell thickness contributes higher significant impact on tensile strength.

Keywords: 3D printer, tensile strength, repetier-host software and process parameters.

INTRODUCTION

The technologies of Fused Deposition Modeling (FDM) or synonyms as 3D printing has emerged and widely spread all over the world since 1980s [1]. The demand on fabricating three-dimensional parts has increase year by year and thus making this technology becomes as one of the best options for 3D printing machine. The FDM was originally own by Stratasys Inc. and patented by Crump [2], can be said at the beginning of commercializing the 3D printing. The concept of FDM system where filament fed into the liquefier by the help of motor, and melted. The melted material will then deposited layer by layer until a complete part is finished [3]. The simple and flexible of FDM system making this technology popular among the users.

The era of open-source 3D printer begun after expiration of FDM patent where RepRap (Replicating Rapid Prototyper) was introduced with affordable price and the first RepRap has been sold on November 2008. There are two versions of RepRap in the beginning which are "Darwin" and the second version is "Mendel". The second version is approximately 50% lighter and cheaper compare to the first version. Unlike the commercial FDM technology, the ReRap technology give the user fully control over the built parts [4]. With the technology provide open-source system and freely available, the user have an option to fabricate three-dimensional parts in low cost.

There is a lot of research has been done regarding the performance of FDM technology by manipulating the process parameters to evaluate the impact on the mechanical properties. The parameters involve in the study include layer thickness, percentage infill, raster orientation and road width [5]–[8]. However, to date there is not so much study on the performance for low-cost 3D printer regarding the mechanical properties. Recently, research on evaluation on the mechanical properties using MakerBot Replicator 2 Desktop 3D printer has been done by manipulating layer thickness, per cent infill and print orientation [9]. Other study also studying the impact process parameters using Rep-Rap Prusa I3 3D printer by changing others parameters such as number of shell perimeters and factor infill orientation [10].

The present study investigates the impact process parameters on the mechanical properties by using a newly developed open-source 3D printer using Repetier-Host software. The research manipulating three parameters including layer thickness (mm), shell thickness (mm) as well as printing speed (mm/s) and the print parts will be tested under tensile test machine. All these parameters will be evaluated and the best parameters will be suggested as to have the highest significant impact on the tensile strength.

METHODOLOGY

3D printer machine

A new open-source 3D Printer has been developed in the lab comprises four stepper motors with three axes as shown in Figure-1. To gain more accuracy, the lead screw has been used for all the three axes movement. The maximum building parts for this machine is 190 mm (length) x 190 mm (width) x 150 mm (height).

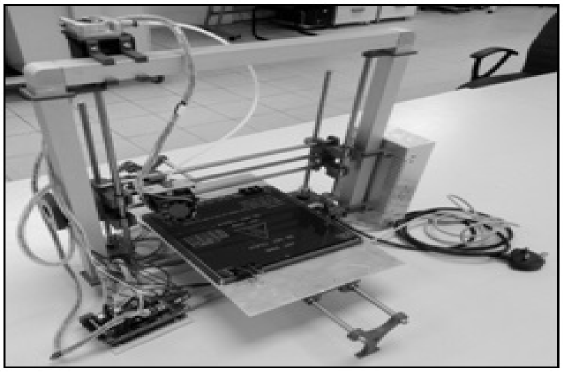

Figure-1. The new open source 3D printer.

Sample fabrication

Test samples were designed using an Autodesk Inventor Software (Autodesk, USA) and generally the dimension follow the ASTM test samples (ASTM D638-10 Standard Test Method for Tensile Properties of Plastics) as shown in Figure-2. The procedure of the sample fabrication follow the previous research [9].

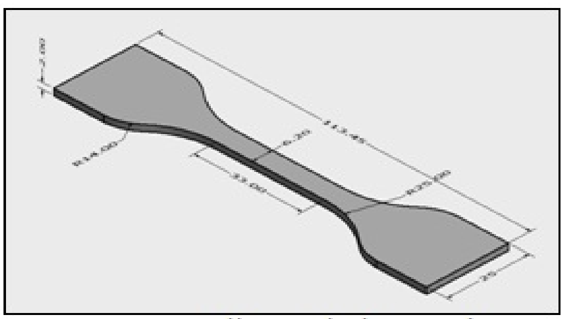

Figure-2. Tensile test design specimen.

Materials and method

The tensile test sample was printed with 1.75 mm diameter of Poly lactic acid (PLA) filament in white colour. All the parameters have been controlled using Repetier-Host Software (Hot-World GmbH & Co. KG, Germany). Design of experiment (DOE) has been performed using Minitab 16.0 (Minitab, USA) software. Taguchi's method has been performed in 3^3 and a total of nine samples has been printed and the parameters involve shown in Table-1. The parameters involve in this study are layer thickness (mm), shell thickness (mm) and printing speed (mm/s) as well which considered as variable parameters.

Table-1. Variable parameters for the experiment.

No.	Layer Thickness (mm)	Shell Thickness (mm)	Printing Speed (mm/s)
1	0.2	0.4	30
2	0.3	0.8	60
3	0.4	1.2	90

Fixed or constant parameters for the experiment are:

i. Printing temperature: 220 °C
ii. Bed temperature: 45 °C
iii. Air gap: 0
iv. Raster angle: 45° angle

The set up parameters was illustrated in Figure-3.

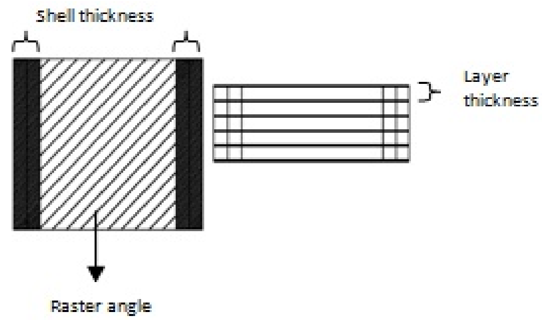

Figure-3. Set up parameters for the specimen.

The tensile test was performed using a tensile test machine Instron 3366 Dual Column Tabletop, Universal Testing System (Singapore) as shown in Figure-4. Software Bluehill®2 has been used as to set up the interface such as the specimen dimension and the overall process of the tensile test.

Figure-4. (a) Tensile test machine; (b) Sample ready to be tested.

RESULTS AND DISCUSSION

All the nine samples (refer to Figure-5) were fabricated using the 3D machine and tensile test was performed as shown in the Table-2. Figure-6 shows the graph load (N) versus extension (mm) indicate the maximum load applied to the specimen before the specimen breaks.

Table-2. Experimental results from tensile test.

No.	Layer Thickness (mm)	Shell Thickness (mm)	Printing Speed (mm/s)	Tensile Strength (MPa)
1	0.2	0.4	30	27.16
2	0.2	0.8	60	31.23
3	0.2	1.2	90	32.33
4	0.3	0.4	60	23.71
5	0.3	0.8	90	31.05
6	0.3	1.2	30	33.06
7	0.4	0.4	90	21.10
8	0.4	0.8	30	30.90
9	0.4	1.2	60	32.40

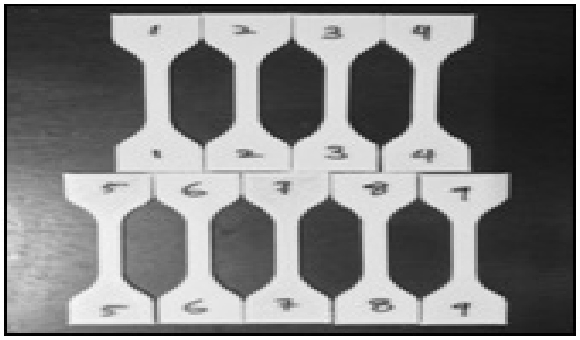

Figure-5. All nine printed parts for tensile test.

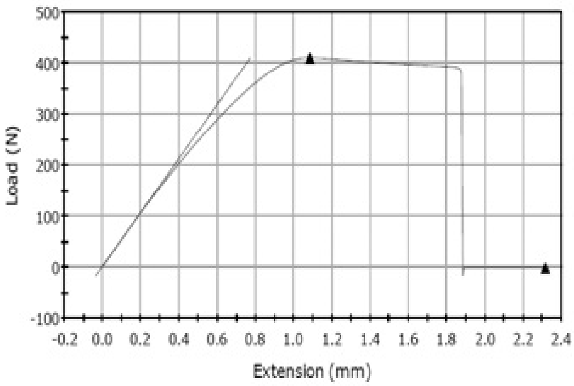

Figure-6. Maximum load applies to the specimen before the specimen break.

ANOVA analysis

Analysis of variance (ANOVA) was used to verify normality and constant variance. Normal probability plot of residuals is to determine the normal distribution and the residual versus fits show the random pattern as shown in Figure-7 and Figure-8.

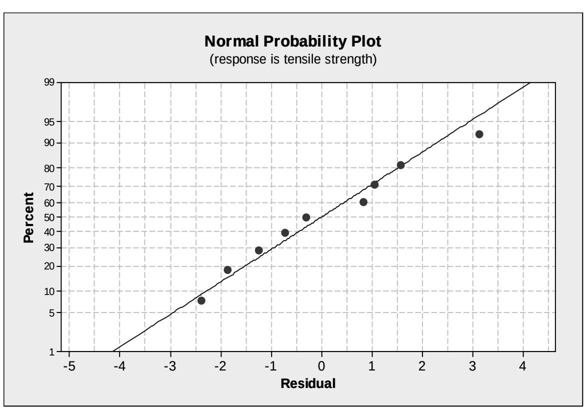

Figure-7. Normal probability plot of residuals.

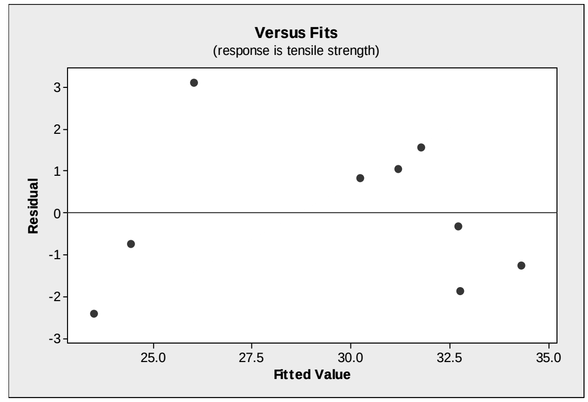

Figure-8. Residual versus fits.

Referring to Figure-7, a straight line was drawn to curve fit the results and it shows that the plot is normally distributed. While Figure-8 for residual versus fits shows the data is scattered and there is no obvious pattern in the plot.

Table-3. Experimental result from the tensile test.

Source	DF	SS	MS	F	*p*-value
Layer Thickness	2	6.672	3.336	1.39	0.418
Shell Thickness	2	126.421	63.210	26.39	0.037
Printing Speed	2	7.395	3.698	1.54	0.393
Error	2	4.791	2.396		
Total	8	145.279			

Result from the ANOVA in Table-3 shows that the shell thickness gives significant effect (p=0.037) which dominantly affect the tensile strength. Meanwhile, for the printing speed (p=0.393) and layer thickness (p=0.418) shows no significant effect on the tensile strength. It is evident that from the Figure-9 with an increase in shell thickness from 0.4 mm to 1.2 mm thus it will increase the tensile strength of the specimen. Even though the other two factors are not significantly contribute to the result, however consideration need to take into account for the improvement of the tensile strength for the specimen

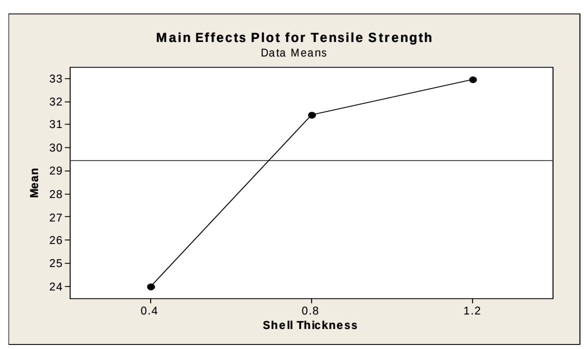

Figure-9. Main effects plot for shell thickness.

Figure-10 shows the different in shell thickness which contribute to the variation on the tensile strength. To be more clear, the effect of shell thickness was observed by imaging with a scanning electron microscope (Hitachi SU1510, Japan) as shown in Figure-11.

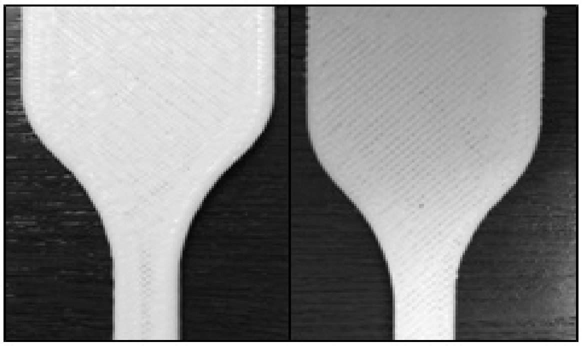

Figure-10. The different on 1.2 mm (left) and 0.4 mm (right) shell thickness.

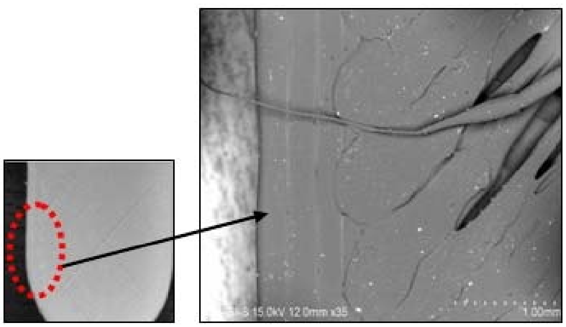

Figure-11. Scanning electron microscopy image of 1.2 mm shell thickness.

By referring to Figure-12, the interaction of shell thickness and layer thickness somehow give some evident that the lower layer thickness gives better tensile strength. The effect on the printing speed can be seen in Figure-13 where the highest printing speed contributes lower tensile strength which mean controlling the printing speed in the optimum level can affect the mechanical properties of the printed parts as well.

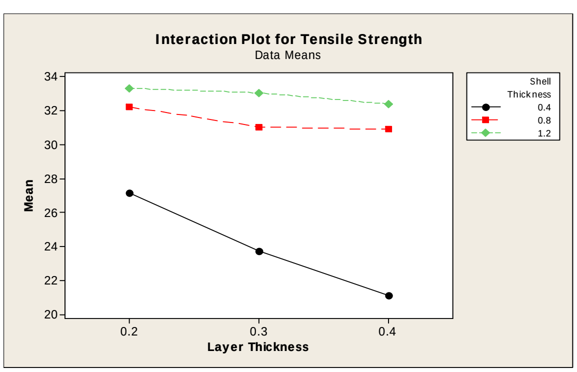

Figure-12. Interaction plot of layer thickness.

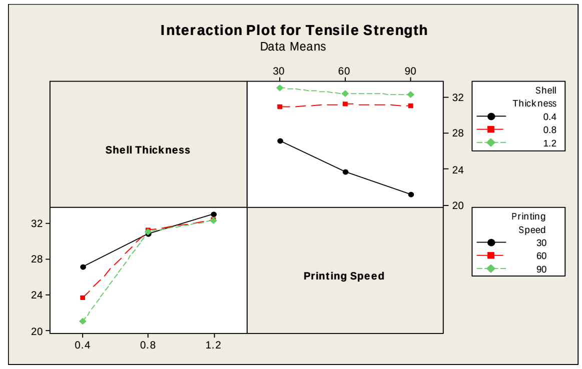

Figure-13. Interaction plot of shell thickness and printing speed.

Analysis optimum parameters

Three parameters have been analyzed using ANOVA analysis and shell thickness shows the dominant compare the other two parameters. To have optimum setting parameters for the 3D printer machine, these three parameters must be combine together and analyzed which combination will contribute the most optimum parameters. From the Table-2, the specimen number 6 gives the highest tensile strength with value of 33.06 MPa. These results confirm that the combination of shell thickness (dominant factor) and printing speed contribute the highest value of tensile strength. However, for the layer thickness, 0.3 mm is not the optimum setting as Figure-12 shows that the lowest layer thickness somehow affects the tensile strength. Reduce the layer thickness to 0.2 mm can improve the mechanical properties of the printed parts. The combination of higher layer thickness (0.4 mm), lower shell thickness (0.4mm) and highest printing speed (90 mm/s) contribute the most lowest tensile strength (21.10 MPa) shown in Figure-14.

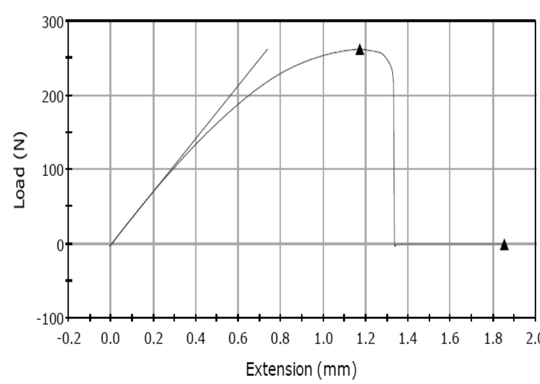

Figure-14. The lowest tensile stress for specimen No. 7.

Highest printing speed can decrease the consistency of the extrusion process because the temperature of the filament inside the liquefier keep changing the and difficult to keeps it constant [11]. Print head moves fast regardless that the filament inside the

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liquefier either has in fully melt or not. Figure-15 shows the effect of highest printing speed under the SEM microscopy.

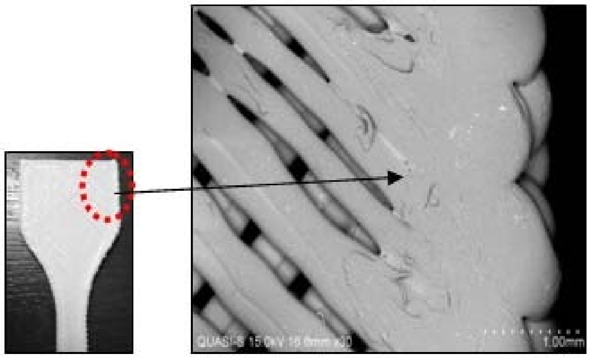

Figure-15. The effect of the high printing speed on sample part.

The effect of inconsistency will lead to ductile fracture and has been observed under SEM microscopy in Figure-16. Due to that, each layer not bond perfectly together with variation of road width (refer Figure-17) and also some of the printed parts was undeformed and over deposited.

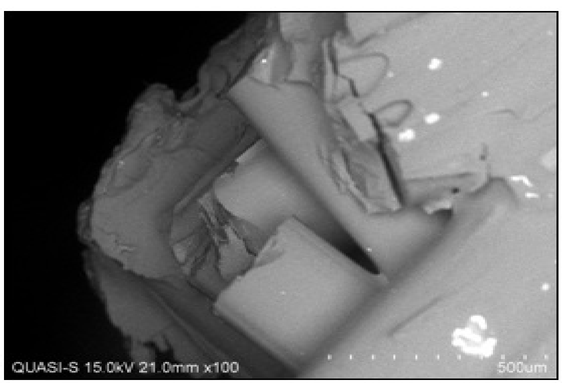

Figure-16. Ductile fracture due to high printing speed.

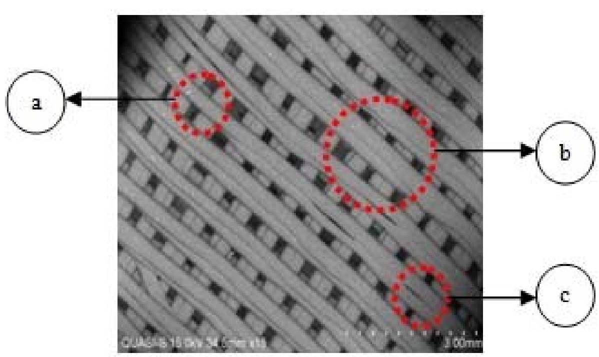

Figure-17. Some defects due to high printing speed

*Notes: a: Underposited layer thickness; b: Inconsistent road width; c: Overdeposited

CONCLUSIONS

Tensile test was performed on all nine printed samples using PLA material by manipulating three different parameters which are layer thickness (mm), shell thickness (mm) and printing speed as well (mm/s). Based on the ANOVA analysis, it shows that shell thickness gives highest significant impact on the tensile strength. Printing speed and layer thickness, however have slightly lower influence compare the other two parameters. From this study, it can be concluded that to increase the tensile strength of the printed parts, shell thickness should be increased, printing speed should be set lower and layer thickness should be set low value as it also affects the bonding arrangement between the layer.

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