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Bending properties of 3D printed coconut wood-PLA composite

S Kesavarma[1,2], C K Kong[1], M Samykano[1,3*], K Kadirgama[1,3] and A K Pandey[4]

[1]Department of Mechanical & Automotive Engineering, College of Engineering, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[2]Green Kingdom Solution Sdn. Bhd., 41100 Klang, Selangor
[3]Centre of Excellence for Advanced Research in Fluid Flow, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[4]Research Centre for Nano-Materials and Energy Technology (RCNMET), School of Science and Technology, Sunway University, Petaling Jaya, 47500 Selangor Darul Ehsan, Malaysia

*mahendran@ump.edu.my

Abstract. Fused Deposition Modelling (FDM) is an additive manufacturing technology that has been utilized in developing numerous components from various material for various application. However, in particular, the properties of PLA embedded with coconut wood are still limited. Coconut wood is well known for its environmentally friendly, biodegradable materials, thermal resistance and corrosion resistance. Therefore, the purpose of this research is to investigate the properties of Coconut wood-PLA at different infill percentage (25%, 50%, 75%) and infill pattern (Rectilinear, honeycomb, grid, concentric and octagram spiral) by using FDM technique. The infill percentage refers to the amount of material in percentage used to print corresponding infill patterns. The specimen is printed according to ASTM D790. After that, the bending test been carried out to investigate the mechanical properties. Two mechanical properties were analyzed which are flexural strength and flexural modulus. After the experiment, the results obtained are then further analyzed by using response surface methodology to determine which parameter gives significant effect to mechanical properties. Mathematical models of the mechanical properties were also introduced using response surface methodology which can be used to predict desired mechanical properties with varying infill percentage and infill pattern. The results show that concentric infill pattern and 75% infill percentage achieved maximum properties in bending testing. The optimum parameters combination is concentric infill pattern with 75% infill percentage. Its optimum mechanical property is 22.666MPa for flexural strength and 0.4823GPa for flexural modulus. ***Keywords:*** Fused Deposition Modelling (FDM), Flexural Test, Coconut Wood PLA, Infill pattern, Infill

1. Introduction

Generally, referring to the American Society for Testing and Materials (ASTM), additive manufacturing (AM) is a procedure that forms layers by layers to create three-dimensional (3D) solid objects from digital models, allowing creatives, engineers, architects and designers to make customized designs in the one-step process [1-3]. Additive manufacturing is widely used in the automotive sector, aerospace sector, manufacturing sector, medical sector, energy sector, and consumer products [4-8].

Basically, there are 6 types of additive manufacturing most commonly used in the world which are Material Extrusion, VAT polymerization, Powder Bed Fusion (Polymers), Material Jetting, Binder Jetting, and Powder Bed Fusion (Metals). Nowadays, the demand for the 3D printer application has escalated drastically. 3D printing which is known as three-dimensional printing is a technology that fabricates the products layer by layer under the control of the computer. Another term to describe 3D printing is additive manufacturing. Additive manufacturing technologies can optimize the usage of the based materials and reduces the waste and at the same time providing an accurate dimension of the final products. The great advantages of using additive manufacturing technologies are the time consuming and cost saving. Among all the additive manufacturing, fused deposition modeling (FDM) is widely used for the thermoplastic. FDM is a technology where the melted material filament is injected onto the building platform through the nozzle. Each layer printed was hardened before the subsequent layer is printed on it. The process cycle is repeated until the object designed in the computer is fully print. FDM process usually can provide high efficiency, higher accuracy products and most importantly the mechanical strength of the final products. Mechanical properties of the finished products rely on the printing parameters chosen by the user. Nowadays, there are many materials been used in the FDM process, such as wood particles filled filament, carbon fibers, ceramic, and so on. The usage of FDM technology has been escalated drastically in different kind of sectors all around the world. Compare with the old traditional method, FDM technology has brought great advantages in term of the time consuming, cost savings and the usage of the raw materials. The example of the old traditional method is injection molding, sand casting, and blow molding are used in the old time and the process is very time-consuming. Wood particles are one type of the natural particles which were used widely especially in the biomedical sectors. However, there is limited information for the mechanical properties of pure wood materials with a variety of printing parameters.

To date, coconut wood particles are well known for their environmentally friendly, biodegradable materials, corrosion resistance, and thermal resistance. However, there is limited information regarding the mechanical behaviors of the coconut wood particles with variation in printing parameters. Printing parameters such as printing speed, layer thickness, printing pattern [9], melting temperature and fill density have significant effect on mechanical properties on final product [10-12]. The infill percentage refers to the amount of deposited material in overall on each surface layer and directly proportional to the strength of the printed components and inversely proportional to the printing time and amount of material used. There are a few studies focused on the effect of infill pattern towards mechanical behavior of FDM process [13]. Therefore, this research will emphasize on the mechanical properties of printed coconut wood with different kind of printing parameters. The infill percentage varied with 25%, 50%, 75% whereas the infill pattern varied with Concentric, Honeycomb, Grid, Rectilinear and Octagram-spiral.

2. Materials and methods

Wanhao Duplicator i3 Desktop 3D Printer with MK10 0.4mm nozzle diameter was used to fabricate the bending test specimen using 1.75 mm coconut wood PLA filament. All the dimensions of the specimens are following the ASTM D790. The width and thickness of the cross-section are 13 mm and 3.2 mm respectively. Repetier Host slicing software was used to generate G-code files. G-code is transferred into an SD card which can be inserted into the 3D printer. The parameters that varied were the infill pattern and infill percentage. There are few parameters were kept constant throughout the experimental work as shown in table 1. For the environmental factor, the humidity and the room temperature must be fulfilled before each of the printing process starts. The humidity surrounding must be between 70%-80% and the room temperature must be 20°C to 25°C.

Table 1. Parameters that kept constant during the printing process.

Num.	Parameters	Values (Kept Constant)
1	First layer height	0.3 mm
2	Layer height	0.3 mm
3	Horizontal Shell: solid layer	Top: 1 layer, Bottom: 1 layer
4	Nozzle diameter	0.4 mm
5	Filament diameter	1.75 mm (± 0.05 mm)
6	Extruder temperature	200 °C (± 2 °C)
7	Print bed temperature	60 °C (± 2 °C)
8	Printing speed	30mm/s

Table 2. Constant Printing Parameters.

Specimen	Infill pattern	Infill percentage (%)
1	Concentric	25
2	Grid	25
3	Honeycomb	25
4	Rectilinear	25
5	Octagram Spiral	25
6	Concentric	50
7	Grid	50
8	Honeycomb	50
9	Rectilinear	50
10	Octagram Spiral	50
11	Concentric	75
12	Grid	75
13	Honeycomb	75
14	Rectilinear	75
15	Octagram Spiral	75

2.1 Design of experiment (DOE)

The DOE is essential to allow us to carry out the experiment to study the effect of the parameters on the mechanical properties of the specimen printed. The parameters chosen for this research project have a higher impact on the mechanical properties of the specimens. The total number of specimens with a different combination of parameters as shown in table 2.

2.2 Fabrication of bending specimen

The bending specimen is designed by using SOLIDWORKS 2017 edition. All the dimensions were following ASTM D790 standard. The designed model is then saved as the .stl file to import in the slicing software. The slicing software used in this research project is Repetier Host. The parameters that varied were the infill pattern and infill percentage.

Besides the parameters mention above, printer setting, print setting, and also filament setting can be adjusted by using the slicing software. After finish setting all the parameters needed, the g-code generator will generate the g-code. After that, the g-code is transferred into an SD card which can be inserted into the 3D printer to carry on the printing process. To start the printing process, the selected g-code printed file must be select on the 3D printer. However, the heating bed must heat to a certain temperature before the printing process begins. During the whole printing process, the temperature of the nozzle and the bed temperature keep constant.

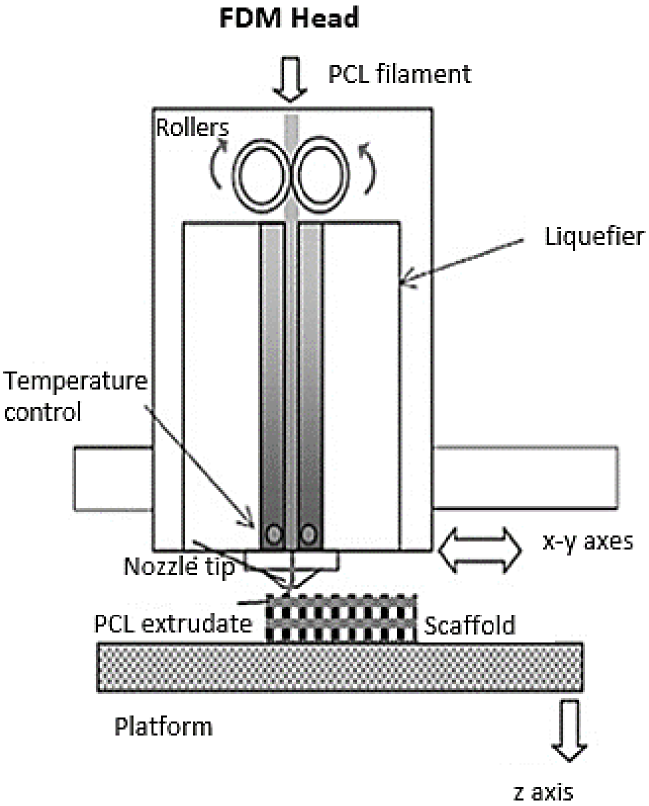

Figure 1. Fused deposition modelling working mechanism.

Figure 2. WANHAO Duplicator i3 Desktop 3D Printer.

The temperature of extruder is set at 205 °C to melt the coconut wood PLA filament. The working principle is illustrated in figure 1. A sample of rectilinear infill pattern with varied infill percentage of coconut wood bending test specimen is shown in figure 3.

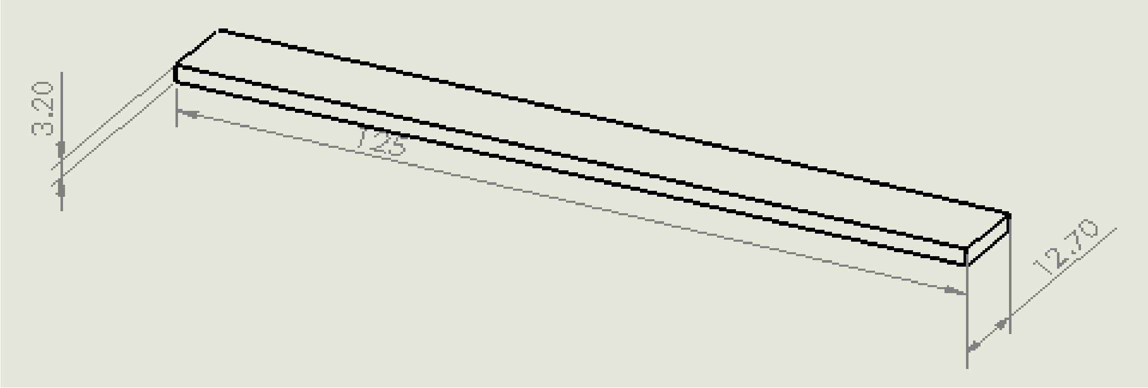

Figure 3(a). Dimension of test specimen.

Figure 3(b). 25% infill percentage Coconut Wood with Rectilinear infill pattern.

Figure 3(c). 50% infill percentage Coconut Wood with Rectilinear infill pattern.

Figure 3(d). 75% infill percentage Coconut Wood with Rectilinear infill.

2.3. *Bending testing*

The bending test is conducted by using INSTRON 3367 machine. Bending test is a test used to identify the stiffness and the yield properties of the materials. The main parameters in this bending test support span, the velocity of the loading and the maximum deflection of the beam. The span-to-depth ratio is set as 16:1. INSTRON 3367 machine was used to conduct this bending testing. The ASTM standard used in bending testing is ASTM D790. ASTM D790 is designed to determine the flexural properties of the materials [14-16]. The test is stopped if the printed test specimen had reached 5% deflection or the specimen cracks before it reached 5%. The dimension of the test specimen is according to ASTM D790. First, the samples were 3D printed according to dimensions stated at ASTM D790 specifications. Then, depth, width and span length are determined and entered. According to the standard, span to depth ratio to conduct the test is 16:1. Rate of the crosshead motion is determined using equation (1) given from standard [17] and it was identified rate of crosshead motion to be used was 1.365 mm/min.

$$R = ZL^2 / 6d \tag{1}$$

R = Rate of crosshead motion, mm/min
L = Support span, mm
d = Depth of beam, mm
Z = Rate of straining of the outer fibre, mm/mm/min (constant = 0.01 mm/mm/min)

In figure 3a, the design of specimen geometry is shown. The printed specimen is shown in figure 3b, 3c and 3d.

3. Results and discussion

In the bending test results, flexural strength or also known as bend strength is the highest stress applied perpendicular to measure the rigidity of a material [18-19]. It can be calculated by the maximum load applied to divide by the area of the specimen. For the flexural modulus, it is known as the modulus elasticity of bending that used to determine the stiffness on the first stage of the bending process. All of the bending properties collected can be calculated from the raw data generated after testing conducted using the Bluehill software. The raw data consists of the load applied on the testing specimen and the extension length which can be used to calculate the stress and the strain respectively. The specimen after testing is shown in figure 4a, 4b and 4c.

Table 3. Bending Properties for each parameter combination of Coconut Wood PLA.

Infill Pattern	Infill Percentage (%)	Flexural Strength (MPa)	Flexural Modulus (GPa)
Octagram Spiral	25	7.137	0.2067
Rectilinear	25	7.500	0.2424
Honeycomb	25	9.070	0.3018
Grid	25	9.937	0.3128
Concentric	25	13.517	0.3586
Octagram Spiral	50	11.697	0.3112
Rectilinear	50	12.970	0.3235
Honeycomb	50	13.250	0.3547
Grid	50	16.063	0.3554
Concentric	50	19.187	0.3856
Octagram Spiral	75	13.950	0.3801
Rectilinear	75	17.063	0.3996
Honeycomb	75	17.090	0.4173
Grid	75	18.160	0.4277
Concentric	75	23.183	0.5151

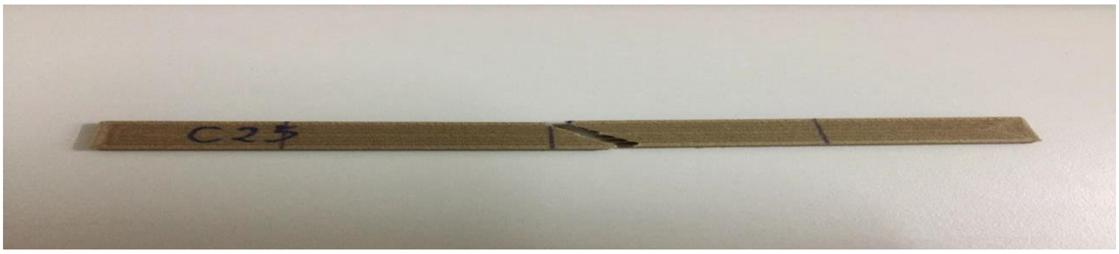

Figure 4(a). 25% infill percentage Coconut Wood with Concentric infill pattern.

Figure 4(b). 50% infill percentage Coconut Wood with Concentric infill pattern.

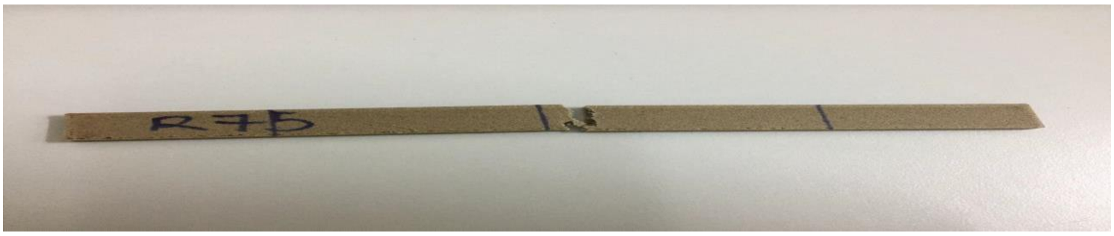

Figure 4(c). 75% infill percentage Coconut Wood with Rectilinear infill pattern.

3.1. Flexural strength

Referring to table 3 and figure 5, the highest flexural strength is the specimen with the 75% infill percentage with a concentric pattern which is 23.183 MPa. From the results obtained, it is clearly seen that at each infill pattern, the flexural strength will be increased when the infill percentage increases at the same time. Meanwhile, these results show that 75% infill percentage has the highest flexural strength followed by the 50% infill percentage and 25% infill percentage. For the comparison among the infill pattern, the specimen with concentric pattern has the highest flexural strength followed by the grid, honeycomb, rectilinear and lastly octagram spiral pattern.

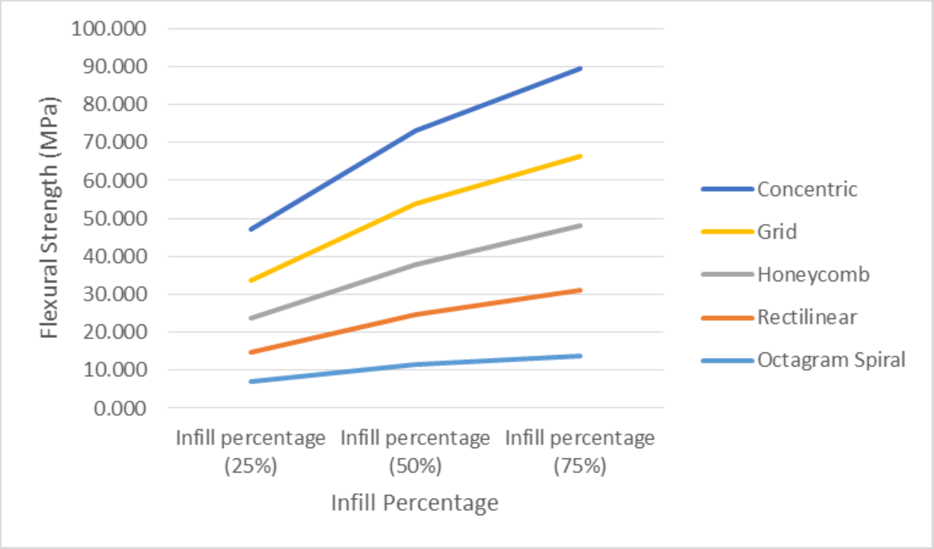

Figure 5. Graph of flexural strength against infill percentage.

3.2. *Flexural Modulus*

According to table 3 and figure 6, the highest flexural modulus is specimen with 75% infill percentage and concentric infill pattern which contributes 0.515 GPa among all the specimens. From figure 4.10 shown below, it is obviously shown that at each infill pattern, when the infill percentage increases, the value of the flexural modulus of the specimen is increasing too. This is proven in each infill pattern as the highest flexural modulus is achieved by the 75% infill percentage followed by the 50% infill percentage and lastly 25% infill percentage. However, for the comparison among the infill pattern, a specimen with concentric pattern has the highest flexural modulus in all the infill percentage followed by the grid, honeycomb, rectilinear and lastly octagram spiral pattern.

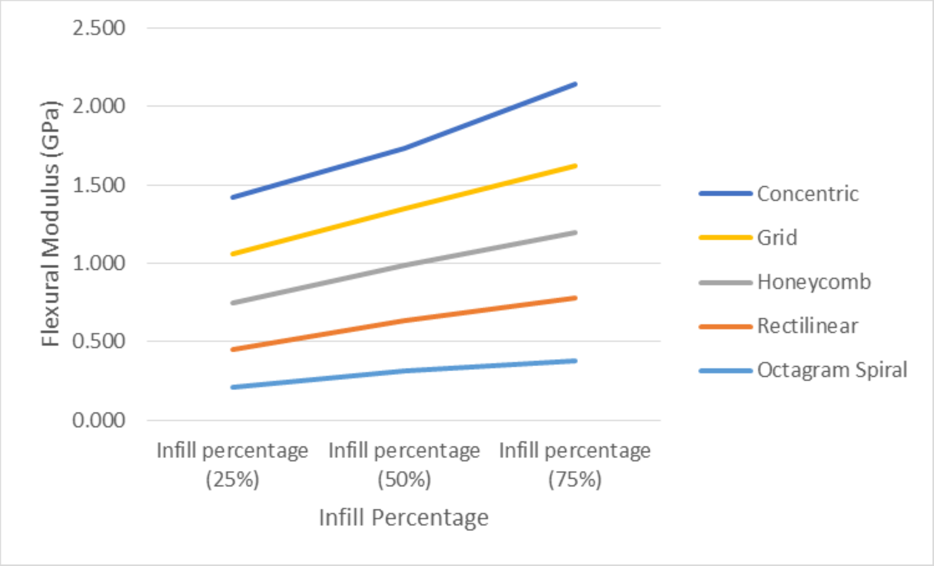

Figure 6. Graph of Flexural Modulus against infill percentage

3.3. Optimization by Response Surface Methodology

In this research project, the DOE was done by using response surface methodology. The software that used to do analyzation is MINITAB 18. The main purpose of using this software is to perform the statistical evaluation on the effect of the printing parameters against the mechanical properties of the printed coconut wood PLA. The significant of the effect of the infill pattern and infill percentage was determined by this analysis with 95% confidence interval. In other words, it means that the α (alpha value) is 0.05. Other than that, this response surface methodology can be used to create modelling and analyzing the problems and at the same time to optimize the results through the model generated. In overall, the optimization is conducted to determine the most suitable parameter combination that will give the maximum mechanical properties, for example, flexural strength and flexural modulus. For flexural strength, the optimization response indicates that concentric infill pattern and 75% infill percentage gives maximum properties. The same infill pattern and infill percentage also gives maximum properties to the flexural modulus. The value of the maximum flexural strength and flexural modulus are 22.666 MPa and 0.4823 GPa respectively. The comparison suggests that the combination of concentric infill pattern and 75% infill percentage is the most suitable parameter to give maximized overall bending properties. Table 4 shows the comparison between the experimental and predicted value obtain from the experiment. The percentage error between the experimental and predicted is calculated.

Table 4. Comparison between the experimental and predicted value of overall optimized properties of the specimen with concentric infill pattern and 75% infill percentage.

Bending Properties	Predicted Value	Experimental Value	Error (%)
Flexural strength	22.666 MPa	23.183 MPa	2.28
Flexural modulus	0.4823 GPa	0.5151 GPa	6.80

4. Conclusion

The bending properties of the coconut wood PLA 3D printed were obtained from the raw data obtained. For the bending test results show that infill percentage and infill pattern give significant effect for flexural modulus whereas infill pattern, infill percentage and second order term of infill pattern shows a significant effect on the flexural strength. All the highest bending properties are achieved by concentric infill pattern and 75% infill percentage.

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