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Physical Characterization of Onyx-Carbon Fiber Reinforced Material using Taguchi Method

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Abstract:- Fused deposition modeling (FDM) and continuous fiber fabrication (CFF) are methods of 3D printing technology. The Markforged Mark Two 3D printer is a 3D printer that utilizes both methods. In this study, the material used is a polymer matrix composite material, namely Onyx-Carbon Fiber Reinforced. The use of this material as a gripper, soft jaw, thread, jix and fixture, and bracket. However, the use of this material is still not optimal or overwhelming, because there is no physical characterization of this material. Therefore, this study is to obtain a characterization of Oyx-Carbon Fiber Reinforced material, especially tensile strength which will then be analyzed using the Taguchi Method. This research uses experimental method by varying several parameters. The parameters used are infill pattern and percentage density, with 3 levels each, namely triangular, rectangular, and hexagonal patterns with a density of 30%, 37%, and 44%. The results obtained that the significant parameter on tensile strength is percentage density, for the most optimal parameter configuration is to use a rectangular pattern with a density of 44% because it has the highest tensile strength of 33.002 MPa.

Keywords:- FDM, CFF, 3D Printing Technology, Onyx-Carbon Fiber Reinforced, Taguchi Metho.

I. INTRODUCTION

The Industrial Revolution 4.0 focuses on automation, aided by advances in technology and science in its application. The industrial revolution can of course change people's way of life. From the invention of wireless communication tools to the invention of cyber security to protect corporate information [1].

The Industrial Revolution 4.0 has five main pillars, including the Internet of Things, additive manufacturing, big data, artificial intelligence and cloud computing. One of the additive manufacturing technologies is 3D printing technology. 3D printing technology is increasingly entering areas that are believed to bring human progress and prosperity [2].

3D printing technology can also be used for rapid prototyping. In a rapid prototyping process, 3D printing technology requires only a 3D design created using software, which can then be printed directly on a 3D printer, making design validation quicker, easier and more efficient. It has several advantages. In addition to the rapid prototyping process, 3D printing technology is also used in product manufacturing [3].

The 3D printing method used in the rapid prototyping process usually uses thermoplastic materials such as acrylonitrile-butadiene-styrene (ABS), polylactic acid (PLA), modified polyethylene terephthalate glycol (PETG) and onyx which are relatively new materials. One of the advantages of using 3D printing technology is efficiency [4].

Onyx-Carbon Fiber Reinforced has stronger properties and can withstand deformation due to heat. However, in general, the price of these materials tends to be higher than other 3D printing materials [5]. The application of Onyx-Carbon Fiber Reinforced material in the industrial world, among others, as a raw material for making grippers, soft jaws, threads, threads, jix and fixtures, and brackets.

Fig 1. Jaw Gripper Made of Onyx-Carbon Fiber Reinforced

The purpose of this research is to identify the optimal parameter configuration and determine the physical strength properties of the composite so that it can be used in industrial applications.

Table 1. Geometry Reccomendations of ASTM D3039 [6]

Fiber Orientation	Width, mm [in.]	Overall Length, mm [in.]	Thickness, mm [in.]
0° unidirectional	15 [0.5]	250 [10.0]	1.0 [0.040]
90° unidirectional	25 [1.0]	175 [7.0]	2.0 [0.080]
balanced and symmetric	25 [1.0]	250 [10.0]	2.5 [0.100]
random-discontinuous	25 [1.0]	250 [10.0]	2.5 [0.100]
Fiber Orientation	Tab Length, mm [in.]	Tab Thickness, mm [in.]	Tab Bevel Angle, °
0° unidirectional	56 [2.25]	1.5 [0.062]	7 or 90
90° unidirectional	25 [1.0]	1.5 [0.062]	90
balanced and symmetric	emery cloth	-	-
random-discontinuous	emery cloth	-	-

II. RESEARCH METHODOLOGY

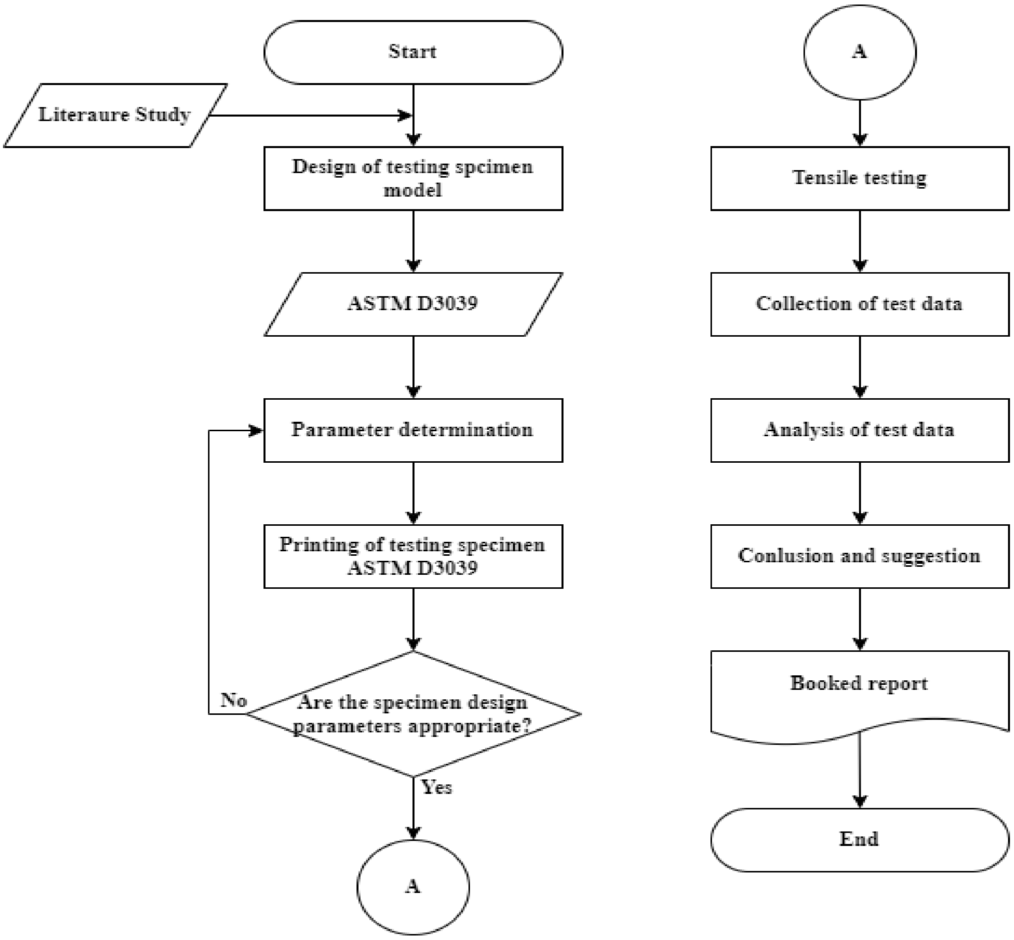

Fig 2. Flowchart

This study uses an experimental method that begins with the design of ASTM D3039 test specimens. After the design is complete, before printing the samples, the concentration parameters for each sample are determined. The infill pattern used in this study is a triangular pattern. hexagonal pattern and rectangular pattern. Density percentages are 30%, 37% and 44% respectively. After the parameter concentrations were set, the samples were printed using the Markforged Mark Two 3D printer. Then the specimens is adjusted to the software.

After conforming, the specimens results were tested for tensile using a universal testing machine, after which the data was processed and analyzed using the Taguchi method in Minitab software.

III. RESULT AND DISCUSSION

- *Refinement of parameter determination*

The parameters of this study were the infill pattern and density percentage, the selected patterns were triangles, rectangles and hexagonal, and the percentages used were 30%, 37% and 44%, with a triangular parameter of 37% as a comparison on Eiger.io.

Table 2. Factors and Levels

No	**Factor**	**Unit**	**Level**		
			1	**2**	**3**
1	Infill pattern		Triangles	Rectangles	Hexagonal
2	Density	%	30	37	44

- *Result of tensile test*

From the results of the ASTM D3039 tensile test, the ultimate tensile stress (UTS) was obtained using a tensile testing machine (UTM).

Table 3. Result of Tensile Test

No.	**Pattern**	**ρ (%)**	$\bar{\varepsilon}$	$\bar{\sigma}_T$ **(MPa)**	$\bar{\sigma}_Y$ **(MPa)**	**E (GPa)**
1	Triangles	30	0.020	26.229	26.10	1.257
2	Triangles	37	0.016	27.309	27.25	1.560
3	Triangles	44	0.024	32.199	32.10	1.235
4	Rectangles	30	0.016	26.494	26.00	1.550
5	Rectangles	37	0.020	29.508	29.00	1.326
6	Rectangles	44	0028	33.002	32.90	1.133
7	Hexagonal	30	0.020	25.689	25.00	1.397
8	Hexagonal	37	0.030	26.421	26.00	1.004
9	Hexagonal	44	0.024	27.343	27.25	1.058

Based on the results of the maximum stress on the specimen, the following diagram can be made:

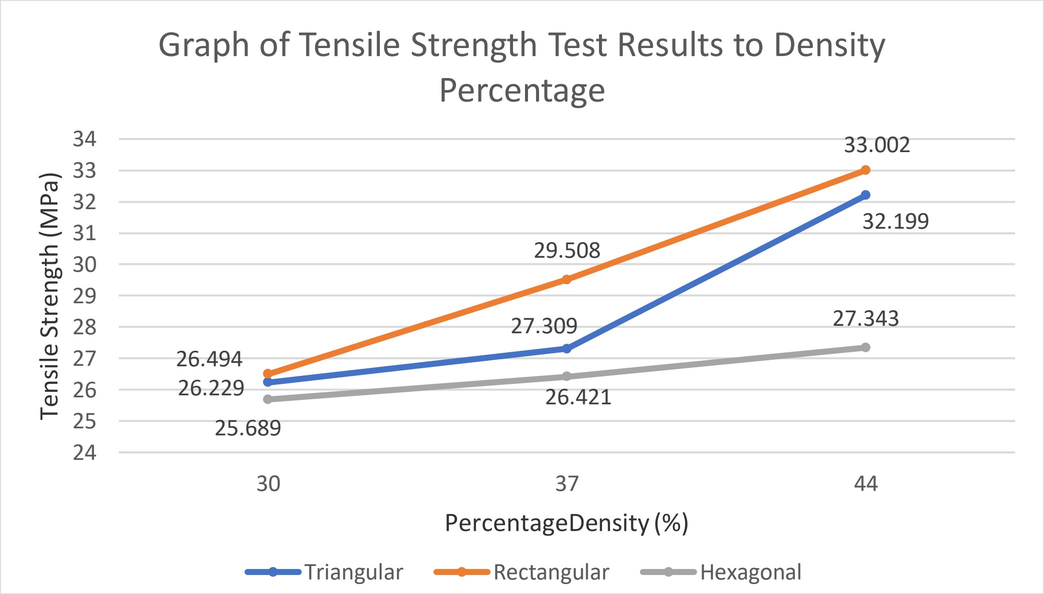

Fig 3. Graph of Tensile Strength Test Result to Density Percentage

- *Determine the orthogonal matrix*

An orthogonal matrix is a square matrix whose inverse is equal to the transpose result, the rows in an orthogonal matrix are unit vectors, where the product of two different rows is zero [7].

The calculation of the orthogonal matrix in this study is as follows

Orthogonal matrix = (number of factors) x (number of levels -1) (1)

Orthogonal Matrix = 2 x (3 – 1) = 4

So that the form of the orthogonal matrix is $L_4(3^2)$, then by reviewing the orthogonal matrix according to research standards and Minitab 21 software, the orthogonal matrix $L_{27}(3^2)$. is chosen. In the process of the tensile experiment, the data obtained is in the form of tensile strength. Then, from the tensile strength, the S/N ratio was calculated using Minitab 21 software. The orthogonal matrix design can be seen in Table 4.

Table 4. Orthogonal Matrix Design.

Experiment	**Parameter**		**Tensile Strength (MPa)**
	Infill Pattern	**Density Percentage**	
1	1	1	25.144
2	1	1	27.003
3	1	1	26.538
4	1	2	24.960
5	1	2	28.588
6	1	2	28.378
7	1	3	29.647
8	1	3	33.475
9	1	3	33.475
10	2	1	24.800
11	2	1	27.690

Experiment	Parameter		Tensile Strength (MPa)
	Infill Pattern	Density Percentage	
12	2	1	26.994
13	2	2	26.526
14	2	2	29.352
15	2	2	32.648
16	2	3	31.736
17	2	3	33.052
18	2	3	34.217
19	3	1	27.939
20	3	1	23.544
21	3	1	25.584
22	3	2	30.136
23	3	2	25.898
24	3	2	23.227
25	3	3	25.397
26	3	3	28.222
27	3	3	28.409

- *S/N Ratio calculation*

$$S/NRatio\ (Larger\ is\ Better) = -10Log\left[\frac{1}{n}\sum_{i=1}^{n}\left(\frac{1}{{y_1}^2}\right)\right] \quad (2)$$

Description:
S/NR = Signal to Noise Ratio (Larger is Better)
n = Number of Experiment
y_i = Observation data
S/NR calculation for experiment 1 [8]:

$$S/NR = -10Log\left[\frac{1}{1}\left(\frac{1}{25.144^2}\right)\right] = 28.009$$

Then the results of the above calculations are sought averaged to determine the effect of levels on each research factor [9]. Calculation of the value of S/N Ratio to tensile strength through a combination of levels of each factor can be seen below:

$$p_1 = \frac{28.009+28.628+28.447+27.945+29.124+29.060+29.440+30.494+30.494}{9}$$

$= 29.07$

- *Analysis of response to tensile strength*

After all the settings are as needed, the Taguchi Method can take place. Following are the results of the analysis of the tensile strength parameters using the Taguchi Method [9].

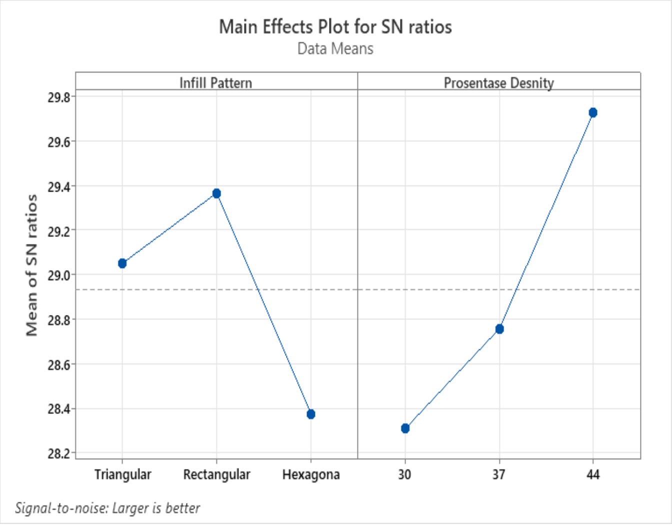

Fig 4. Graph of S/N Ratio to Tensile Strength

By looking at Figure 4 it can be seen that the magnitude of the influence of each parameter at each level on the tensile strength of the material. From the graph it can be seen that the parameters that have a certain influence are indicated by the difference in the distance between the highest and lowest points, the farther the distance between the highest and lowest points, the parameter has a significant effect, conversely the smaller the distance between the highest and lowest points, the parameter does not have a significant effect [10].

It can also be seen in Figure 4, the Hexagonal pattern has the lowest tensile strength because it is located at the bottom between the Triangular and Rectangular patterns. While the density percentage of 30% is the weakest between 37% and 44%. The results of data analysis with the Taguchi Method can be formed using the response table from the S/N Ratio.

Table 5. Response S/N Ratio to Tensile Strength

Level	Infill Pattern	Density Percentage
1	29.07	28.33
2	29.40	28.82
3	28.43	29.74
Delta	0.97	1.41
Rank	2	1

Based on the above results, it can be seen that the optimal parameter configuration for tensile strength is as follows:
Fill pattern: Rectangle
Density percentage: 44%

In this research, it has been known that the most optimal tensile strength parameters when carrying out the 3D printing process using Onyx-Carbon Fiber Reinforced material.

IV. CONCLUSION AND SUGGESTION

The conclusion that can be drawn from this study is the parameter that has the most significant effect is the percentage density, because based on the analysis of the Taguchi Method which has been carried out delta the largest response value between levels is the percentage of density compared to the infill pattern. The most optimal parameter configuration for this experiment is to use a rectangular pattern with a density percentage of 44%, because it has an average of tensile strength that is higher than the other parameters of 33.002 MPa, while for parameter configurations that has an smallest average of tensile strength is the hexagonal pattern with a density of percentage of 30% which have a value of 25.689 MPa.

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