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A Tensile Strength Analysis of *Hibiscus cannabinus* L. Fiber and Corn Silk Reinforced Polyester Resin Matrix Hybrid Composite and Optimization of Design Parameters Using Response Surface Methodology

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Abstract. The increasing demand for materials for manufacturing products needs to be met with the development of new materials. This research aimed at developing a composite of *Hibiscus cannabinus* L. fiber, corn silk, and polyester resin. In the first stage of this research, a composite of a variety of mass fractions and fiber length was made. The mass fraction used in the *Hibiscus cannabinus* L. fiber : corn silk was (10%: 10%), (12.5%: 7.5%), and (15%: 5%). The fiber lengths of *Hibiscus cannabinus* L. fiber and corn silk were 30, 60, and 90 mm. The method used to make composite materials was the hand lay-up method using molds. In the second stage, the composite material was tested with a tensile test. The standard used was ASTM D 638M-84 M-1. The third stage was to optimize tensile test results by using the Response Surface Methodology (RSM). The result of RSM optimization was *Hibiscus cannabinus* L. fiber : corn silk composition (16%: 4%) with the fiber length of 102.4 mm, having a tensile strength of 3.65 Kg/mm².

Keywords: Tensile strength, composite, response surface methodology, *Hibiscus cannabinus* L.

1. Introduction

The material requirements for the manufacturing process of a product are certainly balanced by the development of various types of material. Material technology demands that when the high strength properties and low density are combined with binder or matrix materials such as resin polymers will have their own material properties [1]. The use of composite materials is one of the steps to find alternative materials that are superior in mechanical properties and low density so that the material is more environmentally friendly. The composite materials can be found in various products such as car bodies, boat bodies, bumpers, dashboards, etc. [2].

Materials that come from nature are solutions that can be used in addition to being environmentally friendly and reducing the amount of waste that exists [3, 4]. One alternative that can be used to replace glass fiber or carbon fiber is *Hibiscus cannabinus* L. fiber [5-10]. Referring to previous research conducted by Akil *et al.* [11], one *Hibiscus cannabinus* L. fiber has mechanical properties such as tensile



strength of 11.9 GPa and modulus young of 60 GPa. *Hibiscus cannabinus* L. fiber is a fiber-producing plant that is quite good compared to other plant fibers. *Hibiscus cannabinus* L. fiber has outstanding strength, so it has the opportunity to be used as a reinforcing material on the composite.

One of the components that have been rarely used and have the potential as a fiber in a composite is a waste of corn silk. Corn silk waste is difficult to destroy even if it is buried in the soil for a long time. This gives a fact, how strong corn silk is on acids, corrosive solutions, and moisture. Therefore, corn silk waste has a great potential to be used in engineering, especially as a composite material reinforcement. In the use of corn fiber in the composite, there is a tendency for the fiber to pull out because of the outer layer of hair that blocks the bond. Therefore, it needs to be given a chemical treatment of fiber; one of them with NaOH treatment before using it as an amplifier in the composite so that it can improve mechanical bonding between and matrix [12]. Seeing from the results of these studies, the strength of corn silk and *Hibiscus cannabinus* L. fiber can be used as alternative materials. If the fiber is combined with a resin matrix, it will certainly have particular strength and tenacity. This certainly can be used as a reference in making a new material with determined strength.

2. Methods

2.1. Material

The fiber used was corn silk with the temperature of 60 °C and *Hibiscus cannabinus* L. fiber which had been dried at 110 °C for one hour. The treatment of corn silk used NaOH concentration of 1%, and for *Hibiscus cannabinus* L. fiber used a concentration of 6% NaOH or 6 moles. The corn silk used was silk in hybrid corn that is 125 days old during harvest. The *Hibiscus cannabinus* L. fiber used was the Karangploso 11 (KR 11) with a harvest period of 140 days. This study does not discuss the chemical processes that occurred in resins against materials. The binding media employed Polyester and Yukalac 157 BQTN-EX resin with hardener CAT-Mepoxe. The catalyst used was Methyl Ethyl Kaeton Peroxide (MEKPO) with a composition of 2% of the total resin or matrix. The arrangement of fibers used the continuous three-layer method. The analysis of tensile strength for composite materials with ASTM D638 standard is shown in Figure 1, where independent variables were optimized with Response Surface Methodology (RSM).

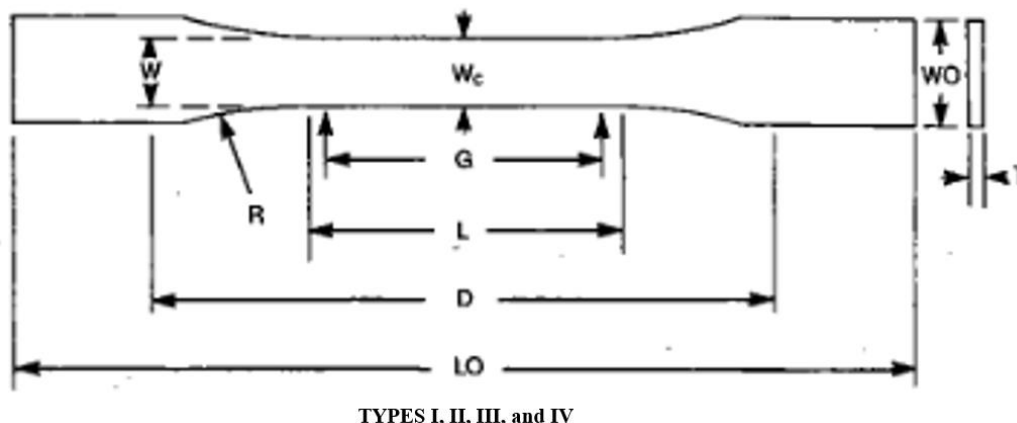


Figure 1. Design of tensile strength measurement using ASTM D638 standard

2.2. RSM (Response Surface Methodology)

Surface response method (Response Surface Methodology) or RSM is a method that can be used to see the influence of several variables together. RSM can study the relationship between a set of variables with the output of a system or response. Practically, Central Composite Design (CCD) is a very suitable design for obtaining a second-order mathematical model.

The second-order polynomial model equation is a mathematical equation used to find the relationship between independent variables and dependent variables/responses. The independent variables used in this study were a mass fraction of *Hibiscus cannabinus* L. fiber : corn silk of (10%: 10%), (12.5%: 7.5%), (15%: 5%) and fiber length (30, 60, 90 mm). Using two factors and three levels resulted in the following mathematical models:

$$Y = \beta_0 + \sum_{i=1}^k \beta_i X_i + \sum_{i=1}^k \beta_{ii} X_i^2 + \sum_{i < j} \beta_{ij} X_i X_j + \varepsilon \quad (1)$$

where y is the predicted response, X_i and X_j are the codes of the independent variables, β_0 is the regression term at the center point, β_i is the linear coefficient, β_{ii} is the quadratic coefficient, and β_{ij} is the interaction coefficient between 2 factors. The experiment levels on variables were encoded, where the low levels were encoded with numbers -1 and the high levels were encoded with numbers 1. The calculation of statistics on the CCD to determine the relationship between the dimensionless code values of the independent variables and the actual values are as follows:

$$x_i = \frac{X_i - (X_{i,high} + X_{i,low})/2}{(X_{i,high} - X_{i,low})/2} \quad (2)$$

where $X_{i,low}$ and $X_{i,high}$ is the actual value of the independent variable at the low and high levels. The above equation obtained the coding values for variables X_1 , X_2 , and X_3 presented in Table 1.

Table 1. Coded variables of experimental design

Standard run	Symbol	Range and Level				
		$-\alpha$ (-1,41421)	-1	0	1	$+\alpha$ (1,41421)
Fiber Length	X_1	18 mm	30 mm	60mm	90mm	102 mm
Mass Fraction (<i>Hibiscus cannabinus</i> L. Fiber and Corn Silk)	X_2	9%; 11%	10%; 10%	12.5%; 7.5%	15%; 5%	16%; 4%

3. Results and Discussion

Tensile testing was carried out to determine the mechanical properties of corn fiber hair composite material and polyester resin *Hibiscus cannabinus* L. fiber as test material in this study. The data generated from the tensile test with two experimental design factors, three levels, and the addition of four axial points are shown in Table 2. The data that have been obtained from the tensile test results of the composite material was done using RSM with the CCD method.

From the ANOVA results in Table 3, it shows that the main factor that influenced the tensile strength of the material was fiber length with a contribution percentage of 51.4%. Then, it is followed by a *Hibiscus cannabinus* L. fiber and corn silk mass fraction of 22.5%, fiber length*fiber length of 13.4%, *Hibiscus cannabinus* L. fiber* *Hibiscus cannabinus* L. fiber by 3.4%, and fiber length* *Hibiscus cannabinus* L. fiber by 2.4%. There was a small error of around 6.9% due to fabrication defects. The P value of the model was 0.001, where the model had a significant influence. If the P value is less than 0.05, then the model is significant. In this case, the fiber length, *Hibiscus cannabinus* L. fiber, and fiber length*fiber length are significant models. Meanwhile, *Hibiscus cannabinus* L. fiber* *Hibiscus cannabinus* L. fiber, the fiber Length* *Hibiscus cannabinus* L. fiber is an insignificant model. The results of the analysis obtained the following model.

$$Y = 2.3 + 0.2138 X_1 + 0.1413 X_2 + 0.1169 X_1 * X_1 + 0.0594 X_2 * X_2 + 0.0650 X_1 * X_2 \quad (3)$$

where Y is the estimated value for the tensile test response, X_1 is the fiber length, and X_2 is the mass fraction of *Hibiscus cannabinus* L. fiber.

Table 2. Composite Material Tensile Test Results with Fiber and Mass Length Fraction Variations

Run	Sample Code	Independent Variable					Dependent Variable/Response		
		X1		X2			Tensile Strength (kgf/mm ²)		
		Fiber Length (mm)	Coded	<i>Hibiscus cannabinus</i> L. fiber (%)	Corn Silk (%)	Coded	Actual	Predicted	
1	KO1	30	-1	10	10	-1	Factorial Design	2.14	2.19
2	KO2	30	-1	15	5	1		2.54	2.49
3	KO3	90	1	10	10	-1		2.37	2.34
4	KO4	90	1	15	5	1		3.03	2.89
5	KO5	60	0	9	1	-1.41	Axial Points	2.26	2.23
6	KO6	60	0	16	4	+1.41		2.72	2.84
7	KO7	28	-1.41	12.5	7.5	0		2.23	2.22
8	KO8	102	+1.41	12.5	7.5	0	Center Points	2.52	2.62
9	KO9	60	0	12.5	7.5	0		2.31	2.30
10	KO10	60	0	12.5	7.5	0		2.30	2.30
11	KO11	60	0	12.5	7.5	0		2.32	2.30
12	KO12	60	0	12.5	7.5	0		2.29	2.30
13	KO13	60	0	12.5	7.5	0		2.28	2.30

Table 3. Minitab ANOVA Output

Source	DF	Adj SS	Adj MS	F-Value	P-Value	% Confidence Level
Model	5	0.651096	0.130219	18.5	0.001	
Linear	2	0.52539	0.262695	37.32	0.000	
Fiber Length	1	0.365743	0.365743	51.96	0.000	51.4%
<i>Hibiscus cannabinus</i> L. Fiber	1	0.159647	0.159647	22.68	0.002	22.5%
Square	2	0.108807	0.054403	7.73	0.017	
Fiber Length*Fiber Length	1	0.095024	0.095024	13.5	0.008	13.4%
<i>Hibiscus cannabinus</i> L. fiber*	1	0.024524	0.024524	3.48	0.104	3.4%
<i>Hibiscus cannabinus</i> L. fiber 2-Way Interaction	1	0.0169	0.0169	2.4	0.165	
Fibre Length* <i>Hibiscus cannabinus</i> L. fiber	1	0.0169	0.0169	2.4	0.165	2.4%
Error	7	0.049273	0.007039			6.9%
Total	12	0.700369				

S = 0.0838987

 $R^2 = 92.26\%$ R^2 (adj) = 87.94%

The R^2 value of the original model was 92.26% (0.92) which showed that there was a real relationship between the independent variable and the response. R^2 value is said to be good if the value is close to 100% or 1, where there was a strong influence from the independent variable on the response variable.

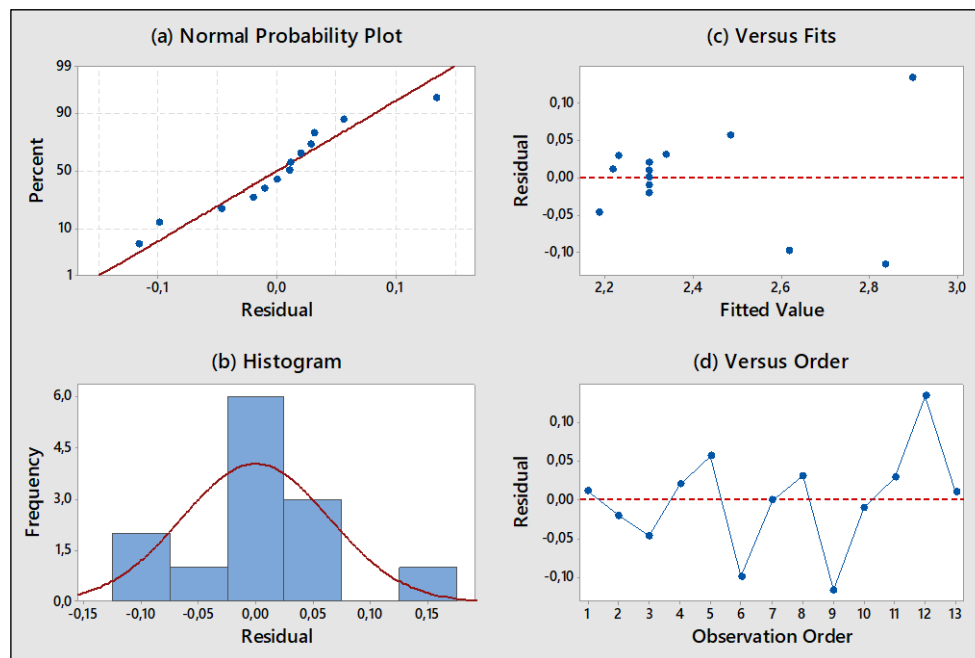


Figure 2. The Graphs of (a) Normal Probability Plot (b) Histogram (c) Versus Fits (d) Versus Order

Besides that, to check the adequacy of the model, the residual analysis contained in Figure 2 could be done. Regression model can be considered to fulfill the assumption of normality if residual obtained from the regression model are distributed normally. The hypothesis used in this test were H_0 as a residual distribution distributed normally and H_1 as a residual distribution which was not distributed normally. Figure 2 (a) shows normal probability plot graph finding that the observation data were around the diagonal line and according to the histogram in Figure 2 (b) the bar chart followed the normal curve formed. Thus, according to two tests, it can be decided that H_0 was accepted, which means that the residual distribution was distributed normally.

Residual Versus Order was used to determine the independence assumption, whether the residual values with the sequence of the trial run were mutually independent or not. The effect of time or sequence of data collection could be observed by using this plot. This plot also could be used to determine the abnormal data. According to Figure 2 (c), it can be seen that the independence assumption was fulfilled due to the residual value distributed randomly around number 0 and there were no visible patterns which indicated a violation of independence assumption.

Figure 2 (d) is a versus order graph used to test heteroscedasticity to understand whether the regression model had the same residual variance or not. A good regression model is a model that has the same residual variety (homogeneous). The hypothesis used was H_0 as a homogeneous residual variety and H_1 as a non-homogeneous residual variety. The way to test it was to observe the plot graph between the predictive value of the dependent variable and its residual. According to Figure 2 (d), it can be seen that there is no clear pattern or points distributed above and below zero number on the Y-axis so that H_0 was accepted (homogeneous residual variety).

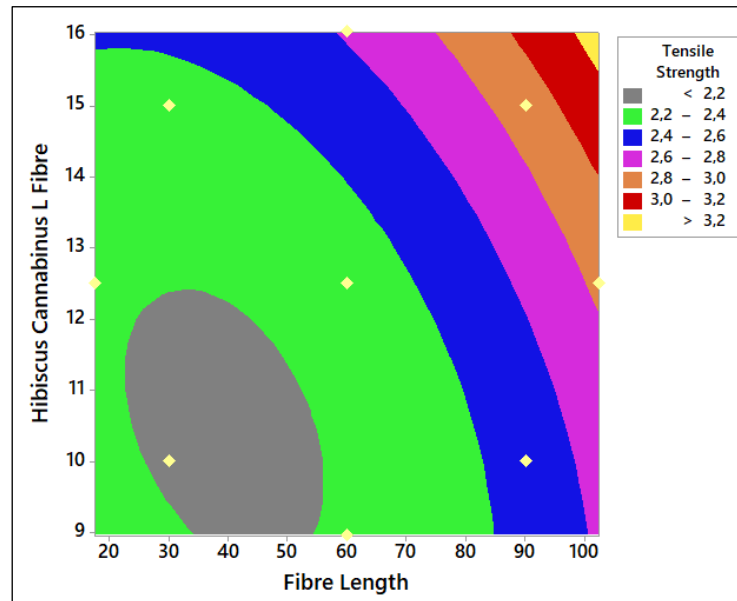


Figure 3. Contour Plot Tensile Response

Contour plot shows how a variable response relates to both independent variables according to the model. The contour plot shows the functional relationship between responses with independent variables in two dimensions. Based on Figure 3, it can be understood that the longer the fiber length and the higher the mass fraction of kenaf fiber against corn silk fiber, the tensile strength of the composite would be higher, which was more than 3.2 kgf/mm² indicated with yellow contours. The shorter the fiber length and the lower the mass fraction of kenaf fiber, the tensile strength of the composite would be lower, that was less than 2.2 kgf/mm² indicated with gray contours.

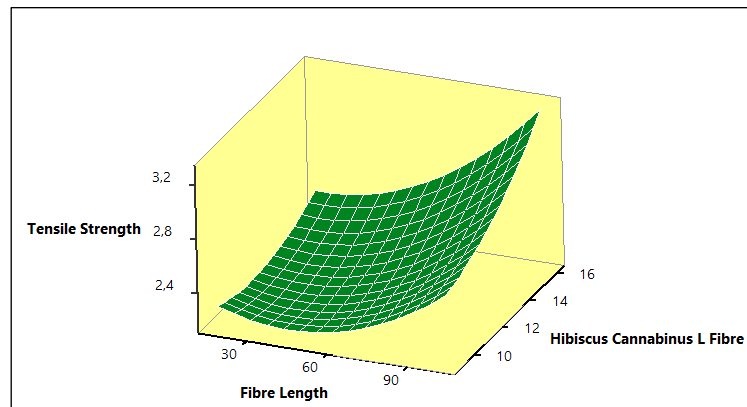


Figure 4. Surface Plot Tensile Response

As for the surface, the response of tensile strength to the variation of fiber length and mass fraction is shown in Figure 4. The figure shows that the fiber length and the mass fraction affected the tensile strength of the material. The longer the fiber and the amount of *Hibiscus cannabinus* L. fiber used could strengthen the material, so the use of corn silk not too significantly contributed to the tensile strength. This is due to the debonding mechanism, where the bonding of the interface between matrix and fiber is released due to excessive loading so that the fiber peels off the matrix. The bond is peeled off due to the weak matrix and fiber bond conditions when given a pull load before perfectly distributing the load to the core. The prevention that can be done to reduce debonding in composite materials requires a strong adhesion to the surface of the composite constituent so that debonding does not occur.

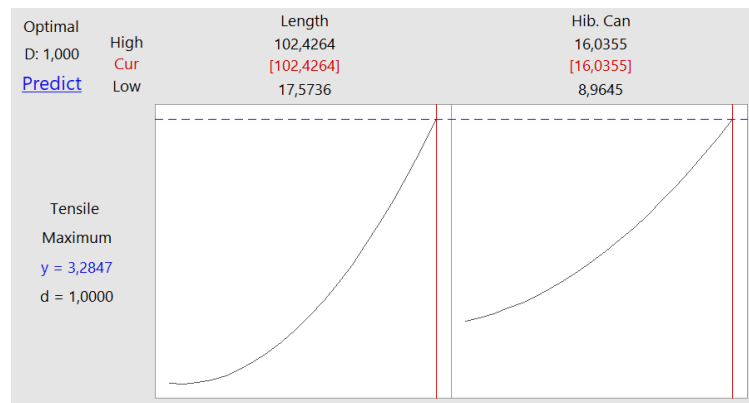


Figure 5. Optimization Response between Fiber Length and Mass Fraction

The optimum response of tensile strength in composite materials with the variations of fiber length and mass fraction can be seen in Figure 5. The figure shows the optimum parameter value of the fiber length was 102.4264 mm, *Hibiscus cannabinus* L. fiber mass fraction was 16.0355% and corn silk was 3.9645%, so the tensile strength result was 3.65 Kg/mm². This result was consistent with the study result conducted by previous work [10] reporting that hybridization had a significant effect on the mechanical properties of composites. The results of these studies indicated that composites that use kenaf fiber and banana fiber provide the highest tensile strength when compared to single fibers (without hybridization).

4. Conclusion

Based on the ANOVA analysis and regression contained in the Response Surface Methodology, it shows that the independent variables had a significant effect on the results of tensile strength. The results of the Response Surface Methodology optimization indicated that the optimum parameter values were 16.0355% mass fraction of *Hibiscus cannabinus* L. fiber, 3.9645% of corn silk fiber and 102.4264 mm of fiber length, that resulted in the tensile strength of 3.65 Kg/mm².

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