

PAPER • OPEN ACCESS

Polyester Composite Bending Strength Optimization Strengthened with Coastal Cottonwood Tree Bark Fiber and Fly Ash Filler

To cite this article: Pandri Pandiatmi *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **494** 012010

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

Polyester Composite Bending Strength Optimization Strengthened with Coastal Cottonwood Tree Bark Fiber and Fly Ash Filler

Pandri Pandiatmi*, Emmy Dyah, Samsul Watoni

Mechanical Engineering Department, Mataram University
JalanMajapahit, Mataram, Lombok, Indonesia

*Corresponding author: pandri@unram.ac.id

Abstract. Composite material is a combination of more than one type of material and is designed to get the best combination of characteristics from each constituent component. Composite materials have many advantages, including lighter weight, higher strength and durability, corrosion resistance and wear resistance. This study aims to determine the optimum conditions of polyester composites bending strength reinforced with Coastal Cottonwood bark fibers and fly ash fillers. The method used was alkalizing the fiber of coastal cottonwood tree bark by immersing 5% NaOH solution for 2 hours. The specimen was made by the Hand Lay-Up method, the fiber volume fraction was 35.8; 40; 50; 60 and 64.14% with filler 2,93; 5; 10; 15 and 17.071%. Bending testing used the ASTM D790 standard and data analysis used the response surface method with Central Composite Design. The optimization results showed the best conditions were in the fiber volume fraction of 52.79% and filler volume fraction of 9.73% with a bending strength of 101.05 N/ mm². The mathematical model obtained from the experiment is: $y = 100.296 + 5.009 x_1 - 2.710 x_2 - 10.285 x_1^2 - 3.006 x_2^2 - 1.415 x_1 * x_2$. Surface response method is an efficient method used to determine the levels of free change that can optimize response.

Keywords: Coastal Cottonwood, response surface method, fly ash, composite, resin.

1. Introduction

Composite material is a combination of more than one type of material and is designed to get the best combination of characteristics from each constituent component. Composite materials have many advantages, including lighter weight, higher strength and durability, corrosion resistance and wear resistance. The concept of using local natural fiber materials as a Composite amplifier to be applied to various products is a very noble thought [1] Composite materials have many advantages, including lighter weight, higher strength and durability, corrosion resistance and wear resistance [2-4] The mechanical properties of composite materials depend on the nature of the constituent materials.



The main role in fiber-reinforced composites is to move stress between fibers, providing resistance to the environment which is detrimental and preserves the fiber surface from mechanical and chemical effects [5,6]. Selection of skin fibers from Coastal Cottonwood trees (*Hibiscus tiliaceus*) as reinforcement on composites because Coastal Cottonwood leather fibers have a continuous fiber structure and strong natural webbing but their utilization is still very limited and usually people use them as a binder to climb coconut trees and livestock.

Fly ash is one of the residual materials from burning fuel, especially coal. Fly ash is not used and if stacked in a place can bring unfavorable effects on environmental sustainability. Fly ash can be used as an aluminum matrix composite amplifier. This can be proven by increasing mechanical properties (bending strength, hardness and wear resistance) along with increasing levels (weight fraction) of fly ash up to 5%. The mechanical properties of the aluminum matrix composite also increase with increasing sintering temperature to 550°C [7].

Based on the description above, the idea arises to analyze the optimization of the bending strength of polyester composites reinforced by Coastal Cottonwood bark fibers and fly ash filler with the aim to produce optimum values using response surface method. Where the response surface method has several advantages, namely minimizing observations using experimental designs [8] and optimizing using the resulting response equation estimation, generating *countur plot* and *surface plot* where these two plots can explain the relationship between the interaction of factors and responses produced so that they can be searched level of factors that provide optimum response [8,9].

2. Research method

2.1 Materials

The resin used is unsaturated polyester. The fiber used was Coastal Cottonwood bark fiber on a stem with a diameter of 5cm. The filler used was fly ash with 200mesh sieve. There was no special treatment for filler. The length of fiber used was 15cm. Specimen making was done by using Hand lay up.

2.2 Mold making

Mold making was made by using steel plates with a thickness of 6 mm mold with the size of the specimen refers to the ASTM D790 bending test standard [10].

2.3 Experiment Design

The data obtained from the bending test results were then processed with a mathematical model using the response surface method and added with Central Composite Design (CCD). Surface response method is a set of mathematical and statistical techniques that are useful for analyzing and optimizing models [11], in this study there are two independent variables that are considered as variables that affect the bending strength of polyester composites, namely fiber volume fraction and filler volume fraction. The experimental design used was a two-level factorial design. The data analysis used was with the help of Minitab16 software.

- Fiber Volume Fraction ($\times 1$) = 40 (- 1); 60 (+1)
- Filler Volume Fraction ($\times 2$) = 5 (- 1); 15 (+1)

Experimental levels in each independent variable were then encoded so that the low level corresponds to -1 and the high level corresponds to 1 to facilitate calculation. The CCD design in the experiment used 2 independent variables, so that the rotability value was ± 1.41421 including the value used for coding.

Table 1. Level codes with level values

Level Code	-1,41421	-1	0	1	1,41421
X1	35,86	40	50	60	64,14
X2	2,93	5	10	15	17,071

Table 2. Experimental Design

Run	Volume fraction of fiber (%)	Volume fraction of filler (%)	Y Bending
1	40	5	Y1
2	60	5	Y2
3	40	15	Y3
4	60	15	Y4
5	35,86	10	Y5
6	64,14	10	Y6
7	50	2,93	Y7
8	50	17,071	Y8
9	50	10	Y9
10	50	10	Y10
11	50	10	Y11
12	50	10	Y12
13	50	10	Y13

3. Results and discussions

3.1 Regression

Table 3. Regression Analysis Result

Response Surface Regression: Bending versus FV Fiber; FV Filler					
Estimated Regression Coefficients for Bending					
Term	Coef	SECoef	T	P	
Constant	100,296	1,600	62,682	0,000	
FV Fiber	5,009	1,265	3,960	0,005	
FV Filler	-2,710	1,265	-2,142	0,069	
FV Fiber*FV Fiber	-10,285	1,357	-7,582	0,000	
FV Filler*FV Filler	-3,006	1,357	-2,216	0,062	
FV Fiber*FV Filler	-1,415	1,789	-0,791	0,455	
S=3,57789 PRES = 188,378					
R-Sq=91,95% R-Sq(pred)=83,07% R-Sq(adj) =86,19%					

From the data processing using the Minitab 16 software, the result showed in Table 3 shows 91.95% of the response variations can be explained by this estimation. From this table we also get the estimated parameters of the model. Based on the results of the analysis, the following models were obtained:

$$\text{Bending strength} = 100,296 + 5,009 x_1 - 2,710 x_2 - 10,285 x_1^2 - 3,006 x_2^2 - 1,415 x_1 x_2 \quad (1)$$

3.2 Analysis of Variance (ANOVA)

Tabel 4. Output ANOVA Minitab 16

Analysis of Variance for Bending						
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	5	1022,98	1022,98	204,596	15,98	0,001
Linear	2	259,44	259,44	129,718	10,13	0,009
FV Fiber	1	200,69	200,69	200,695	15,68	0,005
FV Filler	1	58,74	58,74	58,742	4,59	0,069
Square	2	755,53	755,53	377,767	29,51	0,000
FV Fiber *FV Fiber	1	692,70	735,94	735,941	57,49	0,000
FV Filler*FV Filler	1	62,84	62,84	62,838	4,91	0,062
Interaction	1	8,01	8,01	8,009	0,63	0,455
FV Fiber *FV Filler	1	8,01	8,01	8,009	0,63	0,455
Residual Error	7	89,61	89,61	12,801		
Lack-of-Fit	3	8,72	8,72	2,905	0,14	0,929
Pure Error	4	80,89	80,89	20,223		
Total	12	1112,59				

From the data processing using the Minitab 16 software, the results shown in Table 4 are obtained from the ANOVA output, it can be concluded that the right model for this case is the second order model (Square). To examine the significance of the second-order model, we can see the p-value of Regression in the table. The p-value = 0.001 was smaller than the significance level = 5%, this means that the independent variables have a significant influence on the bending strength of the composite and make a meaningful contribution to the model. The testing procedure that was also carried out is:

3.3 Test the suitability of the regression model (Lack of Fit)

Hypothesis:

H0: There is no lack of fit

H1: There is a lack of fit

From the Lack of Fit test, the model obtained $p\text{-value} = 0.929$ or greater than the significance level of $\alpha = 0.05$, there was no lack of fit, so it can be concluded that the regression model is suitable or appropriate [8,9]

3.4 Residual assumption test results

The residual assumption test is to check the adequacy of the model not only to pay attention to the lack of fit, but also to do residual analysis.

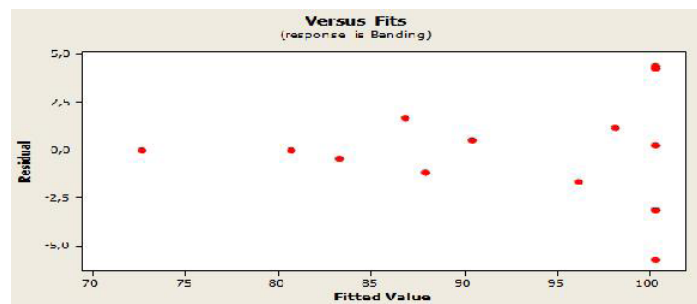


Figure 1. Residual Vs Fitted Value Graph

In Figure 1 it can be seen that the residual versus fitted value plot, the residuals are scattered randomly around zero prices and do not form a specific pattern. This indicates that the assumption of identical residuals is fulfilled (Gapsari, 2018).

3.5 Normality Test

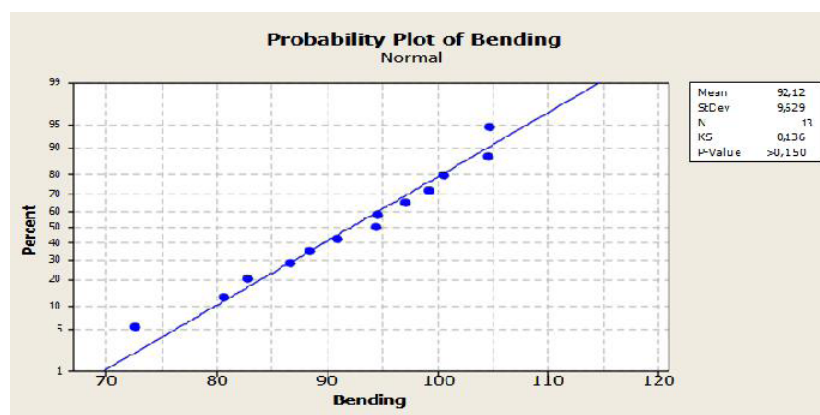


Figure 2. Normality Strenght Test

The assumption of residual normality was done by the Kolmogorov-Smirnov test.

The test results with a significance level of $\alpha = 0.05$ are shown in Figure 4.2.

Hypothesis:

H0: Residual regression model is normally distributed

H1: Residual regression models are not normally distributed

From the test results using the Kolmogorov Smirnov statistic value (KShitung) is 0.136, while the Kolmogorov-Smirnov value from the table (KStabel) for $\alpha = 0.05$ and the observations number 13 is 0.361. Because $KShitung < KStabel$, then H0 is accepted. This means that the residuals from the model obtained

have normal distribution

3.6 Composite Composition Optimization Using Respond Surface Method

With a mathematical model of the response surface has identified the optimum composition of the composite to produce the best bending strength. Composite manufacturing with variance of contraction weight (35.85%, 40%, 50%, 60% and 64.14%) and filler volume fractions (2.93%, 5%, 10%, 15%, and 17.071%) which can influence composite bending strength have been predicted using the response surface method. Contour plot predictions for bending strength of polyester composites are reinforced by Coastal Cottonwood bark fibers with fly ash filler as shown in Figures 3 and 4

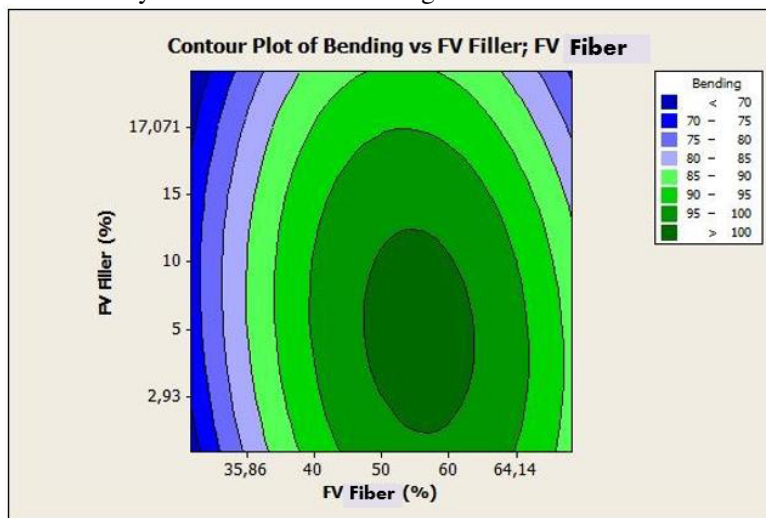


Figure 3. Plot Optimization of Response Surface Method from the Strength of Bending vs. Fiber Volume Fraction, Filler Volume Fraction

From Figure 3, it can be seen that the fiber volume fraction (35.86%, 40%, 50%, 60% and 64.14%) of the filler volume fraction (2.93%, 5%, 10%, 15% and 17.071%) then from the plot of the response surface method optimization from bending strength vs. fiber volume fraction, filler volume fraction, it can be seen that the bending strength value > 100 fractions of fiber volume can be started from 50% to 60%. While the bending strength value > 100, for the filler volume fraction will be obtained at the point with filler starting from 2.93% continues to increase to a point of 15%.

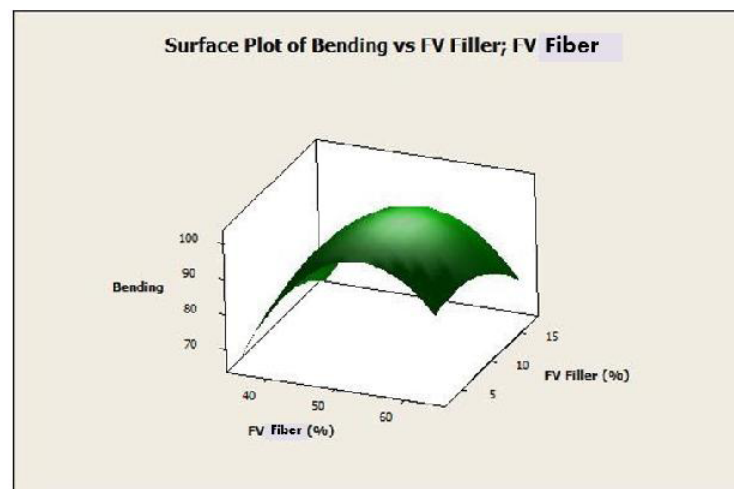


Figure 4. Surface Response Streight Bending vs. Fiber Volume Fractions, Filler Volume Fraction

From visual observations in Figures 3 and 4 it can be seen in the fiber volume fraction (40%, 50% and 60%) and the filler volume fraction (5%, 10%, 15%) respectively that the optimal volume fraction variation on bending strength was obtained at the fiber volume fraction is 50% while for the filler volume fraction variation decreases from 15% volume fraction. From the research results on the effect of fiber volume fraction and filler volume fraction, the largest bending strength was obtained at 50% fiber volume fraction where bending strength increased with increasing fiber volume fraction level and filler volume fraction level but at 60% fiber volume fraction decreased bending strength, this was due to the resin is not able to completely wet the fiber so that the bond between resin and fiber becomes weak.

Finding the optimum point using the quadratic model that has been stated according to the data and coding as the bending strength model obtained from regression testing as in equation 1. Value of the optimal bending strength of the model that has been obtained

$$\begin{aligned}
 \text{Bending strength} &= 100,296 + 5,009 x_1 - 2,710 x_2 - 10,285 x_1^2 - 3,006 x_2^2 - 1,415 x_1 * x_2 \\
 &= 100,296 + 5,009 (0,2793) - 2,710 (-0,0535) - 10,285 (0,2793)^2 - 3,006 (-0,0535)^2 - 1,415 \\
 &\quad (0,2793 * -0,0535) \\
 &= 101.05 \text{ N/mm}^2
 \end{aligned}$$

While the results of bending testing with optimal point values which using a fiber volume fraction of 52.79% and a volume of filler volume of 9.37%. There is bending strength as in table 4.6.

From the results of optimal value testing based on the response surface method at 52.79% fiber volume fraction and 9.37% volume filler fraction the bending strength is equal to 101.23 N/mm². The results of these optimal conditions are then tested to have a difference of 0.2%.

4. Conclusions

From the research results, testing and the test results discussion that have been carried out, therefore conclusions can be drawn as follows:

1. From the data analyzed using Minitab 16 output the p-value > of (5%) means that all factors are statistically significant. The model obtained from the experiment is:

$$y = 100.296 + 5,009 x_1 - 2.710 x_2 - 10.285 x_1^2 - 3.006 x_2^2 - 1.415 x_1 * x_2$$
2. Based on the analysis results using the response surface method, the best conditions were found at 52.79% fiber volume fraction and 9.73% filler volume fraction with a bending strength of 100.05N / mm².
3. By carrying out direct testing on the results of the optimal conditions of the response surface method

and bending strength of 101.23 N/mm². The optimal condition is a difference of 0.2%.

5. References

- [1] WW Raharjo, RSoenoko, YS Irawan, ASuprpto. The influence of chemical treatments on cantala fiber properties and interfacial bonding of cantala Fiber/Recycled High Density Polyethylene (rHDPE). *Journal of Natural Fibers*. **15** (1). 98-111.
- [2] Jones, R. M., 1999. *Mechanics of Composites Materials*. International Student Edition. Mc Graw-Hill ogakusha. Ltd.
- [3] ES Zaini, MD Azaman, MS Jamali, KA Ismail. 2018. Synthesis and characterization of natural fiber reinforced polymer composites as core for honeycomb core structure: A review. *Journal of Sandwich Structures & Materials*.
- [4] Bismarck, A., Askargorta, I.A., Lamphe, T., Wielaye, B., Stamboulis, A., Skenderovich, I., Limbach, H.H., 2002, *Surface Characterization of Flax, Hemp and Cellulose Fibres: Surface Properties and The Water Uptake Behaviour, Polymer Composites*. **23** (5).
- [5] L. Mohammed, M. N. M. Ansari, Grace Pua, Mohammad Jawaid, M. Saiful Islam. 2015. A Review on Natural Fiber Reinforced Polymer Composite and Its Applications. *International Journal of Polymer Science*.
- [6] M. M. Kabir, H. Wang, K. T. Lau, and F. Cardona. 2012. Chemical treatments on plant-based natural fibre reinforced polymer composites: an overview. *Composites Part B: Engineering*. **43**(7) 2883–2892.
- [7] M. O. Bodunrin, K.K Alaneme, L.H. Chown. 2015. Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. *Journal of Materials Research and Technology*. **4**434–445.
- [8] S. Wahyudi, F. Gapsari, H. Awali. 2014. Corrosion Rate of Sulfuric Acid Resistant Alloy Metal (SARAMET) Using Response Surface Methodology. *Jurnal Internasional- Advances in Applied Mechanic and Materials*. 493.
- [9] F. Gapsari, R. Soenoko, A. Suprpto, W. Suprpto. 2018. Minimization of corrosion rate using response surface methodology. *Engineering Review*. **38** (1).
- [10] ASTM. D 790 *Standard Test Methods for Flexural Properties Of Unreinforced Plastics and Electrical Insulating Material*. Philadelphia, PA : American Society for testing and materials.
- [11] Montgomery., Myers., Raymond, H., Douglas C., Christine, M., Anderson., Cook., 2010. *Response Surface Methodology Process and Product Optimization Using Designed Experiments*. THIRD EDITION.