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To cite this article: Pandri Pandiatmi et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 494 012061

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Bending Strength Optimization of Polyester Composite Strengthened By Coast Cottonwood Bark Fiber with Rice Husk Filler By Using Response Surface Method

Pandri Pandiatmi¹, Emmy Dyah, Sastriawan

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

*Corresponding author: pandri@unram.ac.id

Abstract. Composite is a material composed of more than two constituent elements; composites are heterogeneous on a macroscopic scale. Each composite material has different properties, and when combined in certain compositions new properties are formed. The study of coast cottonwood bark fiber composites aims to determine the optimum bending strength of polyester composites strengthened with fiber from coast cottonwood bark with rice husk fillers by using the response surface method. The method used was to alkalize the coast cottonwood bark fibers by soaking 5% NaOH per 1 liter of water for 2 hours. The test object was made using the Hand Lay-Up and Compaction method, the fiber ratio was 35.86%, 40%, 50%, 60% and 64.14% with fillers 0.76%, 2%, 5%, 8% and 9%, 24%. The bending test used the ASTM D790 standard and analyzed the data using the response surface method. The test results showed the best condition was at fiber volume fraction of 49.06% and filler volume fraction of 5.39% with bending strength values of 99.71 N / mm². Regression equations were suitable for the response of this study: y = 99.6100 – 1.4339 x₁ + 0.5107 x² – 8.6506 x₁² – 2.4756 x²² – 1.4325 x₁* x₂. Response surface method is an efficient method used to determine the independent variables levels that can optimize response.

Keywords: Coast cottonwood, Response Surface Method, Rice Husk, Composite, Resin.

1. Introduction
Green technology or environmentally friendly technologies are increasingly being developed by countries in the world today, making it a challenge that continues to be researched by experts to be able to support this technological progress. One of them is composite technology with natural fiber material [1]. Composites are two or more ingredients which are combined or mixed "macroscopically". The
macroscopic keyword distinguishes between composites and compounds which incorporate "microscopic" elements. Many materials that have two or more constituents are not considered composites if the unit of structure formed are more likely at the microscopic level than the macroscopic level. Thus, metal alloys and mixtures of polymers are usually not classified as composites [2]. Composites consist of matrices as binders and fillers as composite fillers. The use and utilization of composite materials is now growing. Composites have their own advantages compared to other alternative engineering materials. The advantages of using composite materials are very much compared to other materials such as metals, for example composite materials are more economical, corrosion resistant to a longer service life, lightweight material, reduce machining processes, are inexpensive and the manufacturing process is easy [2].

The use of natural fibers as strengthening ingredients for composite materials because natural fibers are easy to obtain, the price is cheap, the types and variations are many. Fibrous composite continues to be researched and developed to be an alternative material to substitute metal. This is due to the strong nature of fiber composites, and has a lighter weight compared to metal. The composition of the fiber composite consists of fibers and matrices as the binder. The nature of composite materials is strongly influenced by the nature and distribution of constituent elements, as well as the interaction between the two. Other important parameters that might affect the nature of composite materials are the shape, size, orientation and distribution of the reinforcement (filler) and various characteristics of the matrix. Mechanical properties are one of the properties of composite materials that are very important to learn. For structural applications, mechanical properties are determined by material selection. The properties of composites are very dependent on the properties of the forming phases, the relative number of each phase, the shape of the phase, the phase size, and the size distribution of the phases and their distribution [1, 3-5]. Rice husk has several advantages such as the ability to withstand moisture, is not easy to mold and does not smell. [6] Rice husk does not contain hard part and difficult to process, rice husks also do not experience shrinkage, do not conical, not twisted, bent, split or curved. Rice husk is also strong, stiff, straight and light [6, 7].

In this study an experimental design was performed to determine the optimum bending strength of a composite. The response surface method is a practical method for conducting experiments in determining the optimal point [8,9].

Response Surface Methodology (RSM) is a set of mathematical and statistical methods used in modeling and analysis, which aims to see the effect of several quantitative variables on a response variable and to optimize the response variable [10]. For example, you will find levels of temperature ($x_1$) and pressure ($x_2$) that can optimize a production result ($y$). The relationship of these variables can be written in an equation as follows:

$$y = (x_1 + x_2) + \varepsilon$$  \hspace{1cm} (1)

In which $\varepsilon$ is an observation error in response $y$. If the response expectation value is written $(y) = (x_1 + x_2) = \eta$, then $\eta = f(x_1 + x_2)$ represents a surface called the response surface.

If the form of the relationship is quadratic, then for the function approach a higher degree of polynomial is used, namely the second-order model

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} x_i^2 + \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon$$  \hspace{1cm} (2)

The response surface method has several advantages, namely minimizing observations using experimental design and optimization using estimating the resulting response equations, producing contour plots and surface plots where both plots can explain the relationship between the interaction of factors and responses produced so that the level of factors that provide optimum response [8]. For this reason, a research of bending strength optimization of polyester composites which strengthened by coast cottonwood bark fiber with rice husk filler which was performed using the response surface method.
2. Method
The research was performed by experiment. In making specimens for bending tests, then the experimental design used were factorial 2^k level and k factors (k = 2, namely fiber volume fraction and filler volume fraction). While the data analysis used to test the hypothesis was the response surface method. Data was analyzed using MINITAB 16 software. The main discussion was to find the optimum condition of composite bending strength using the response surface method. The data obtained from bending test results were then processed with mathematical models using the response surface method. The response surface method is a set of mathematical and statistical techniques that are useful for analyzing and optimizing models, in this study there were two independent variables which 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 two level (2^k) factorial designs.

Variable level selection:
1. Fiber volume fraction (% of coast cottonwood bark): low level (-1) = 40, middle level (0) = 50, high level (1) = 60
2. Filler volume fraction (% of rice husk): low level (-1) = 2, middle level (0) = 5, high level (1) = 8

2.1 Bending Testing
The test object was made by the Hand Lay-Up method. Bending testing refers to the ASTM D790 standard [11], with dimensions according to figure 1. In which on the upper side of the material the compressive force was obtained while the lower side obtained a tensile force.

![Figure 1. Bending Test Specimens for ASTM D790.](image)

3. Results and Discussion
Data on Bending Strength Test Results

| Volume fraction of Fiber (%) | Volume fraction of Filler (%) | $\sigma_b$ (Mpa) |
|-----------------------------|------------------------------|-----------------|
| 40                          | 2                            | 90,00           |
| 60                          | 2                            | 88,48           |
| 40                          | 8                            | 91,04           |
| 60                          | 8                            | 83,79           |
| 35,86                       | 5                            | 83,42           |
| 64,14                       | 5                            | 81,51           |
| 50                          | 0,76                         | 92,08           |
### Results of Bending Strength Regression Analysis

#### Table 2. Regression of the Bending Strength of the CCD Response Surface Method

**Response Surface Regression: Bending versus Fv Fiber; Fv Filler**

The analysis was done using coded units.

| Term                  | Coef  | SE   | Coef  | T     | P     |
|-----------------------|-------|------|-------|-------|-------|
| Constant              | 99,61 | 1,69 | 58,76 | 0,00  |       |
| Fv Fiber              | -1,43 | 1,34 | -1,07 | 0,32  |       |
| Fv Filler             | 0,51  | 1,34 | 0,38  | 0,71  |       |
| Fv Fibeer*Fv Fiber    | -8,65 | 1,43 | -6,02 | 0,00  |       |
| Fv Filler*Fv Filler   | -2,47 | 1,43 | -1,72 | 0,13  |       |
| Fv Serat*Fv Filler    | -1,43 | 1,89 | -0,75 | 0,47  |       |

S = 3,79025  
PRESS = 273,669  
R-Sq = 84,78%  
R-Sq(pred) = 58,58%  
R-Sq(adj) = 73,91%
From Table 2, it is known that as many as 84.78% of the response variations can be explained by this estimation. With the model obtained as in the table.

\[
\text{Bending strenght} = 99.6100 - 1.4339x_1 + 0.5107x_2 - 8.6506x_1^2 - 2.4756x_2^2 - 1.4325x_1x_2
\]

Simultaneous regression testing is seen from the regression constant in Table 2. For regression testing simultaneously obtained p-value = 0.009 or less than a significant degree = 5% this means that these variables have a significant effect on composite bending strength.

While for the conformity test of the regression model, namely:

3.1.1 Hypothesis:

H0: Regression model is suitable (no lack of fit) and H1: Regression model is not suitable (there was lack of fit). The results show that from the Lack of Fit test to the model obtained p-value = 0.791 or greater than the degree of significance = 0.05 there was no lack of fit, so that it can be concluded that the regression model matches or accordingly.

Results of Analysis of Variance

(ANOVA)

| Source              | DF | Seq SS | Adj SS | Adj MS | F     | P     |
|---------------------|----|--------|--------|--------|-------|-------|
| Regression          | 5  | 560.169| 560.169| 112.034| 7.80  | 0.009 |
| Linear              | 2  | 18.535 | 18.535 | 9.268  | 0.65  | 0.553 |
| Fv Fiber            | 1  | 16.448 | 16.448 | 16.448 | 1.14  | 0.320 |
| Fv Filler           | 1  | 2.087  | 2.087  | 2.087  | 0.15  | 0.714 |
| Square              | 2  | 533.425| 533.425| 266.713| 18.57 | 0.002 |
| Fv Filler*Fv Fiber  | 1  | 490.791| 490.791| 490.791| 36.24 | 0.001 |
| Fv Filler*Fv Filler | 1  | 42.633 | 42.633 | 42.633 | 2.97  | 0.129 |
| Interaction         | 1  | 8.208  | 8.208  | 8.208  | 0.57  | 0.474 |
| Fv Filler*Fv Filler | 1  | 8.208  | 8.208  | 8.208  | 0.57  | 0.474 |
| Residual Error      | 7  | 100.562| 100.562| 14.366 |
| Lack-of-Fit         | 3  | 21.004 | 21.004 | 7.001  | 0.35  | 0.791 |
| Pure Error          | 4  | 79.558 | 79.558 | 19.890 |
| Total               | 12 | 660.731|        |        |

3.2 Results of testing residual assumptions

Testing of residual assumptions, namely to examine the adequacy of the model not only pay attention to the lack of fit, but also residual analysis must be performed.
3.2.1 Identity

![Residual Vs. Fitted Value Graph](image)

Figure 2. Residual Vs. Fitted Value Graph

In Figure 2 it can be seen that the plot of residual versus fitted value, the residuals are scattered randomly around the zero price and do not form a specific pattern. This shows that identical residual assumptions are fulfilled [9].

3.2.2 Normal Distribution

![Probability Plot of Bending](image)

Figure 3 Strength Normality Test

Mean 92.76
StDev 7.420
N 13
KS 0.127
P-Value >0.150
Strength normality assumption test was performed by Kolmogorov-Smirnov test. Test results with a degree of significance $\alpha = 0.05$ are shown in Figure 3. From the test results using the Kolmogorov Smirnov (KShitung) statistical value was 0.127, while Kolmogorov Smirnov’s value from Table (KStabel) for $\alpha = 0.05$ and number of observations 13 was 0.361. Because the KShitung < KS table then the square or quadratic regression model is accepted. This means that the model obtained has Normal distribution.

3.3 Optimization of Composite Composition Using the Response Surface Method

With the mathematical model of the response surface, it has identified the optimum composition of the composite to produce the best bending strength. Making composites with variations in fiber volume fraction (35.85%, 40%, 50%, 60% and 64.14%) with filler volume fractions (0.76%, 2%, 5%, 8% and 9.24%) which can affect the composite bending strength has been predicted using the response surface method. Contour prediction plot for bending strength of polyester composites reinforced with fiber from coast cottonwood bark with rice husk fillers as shown in figure 4 and 5.

![Contour Plot of Bending vs Fv Filler; Fv Fiber](image)

**Figure 4.** Optimization Plots of Response Surface Methods from Bending Strength vs. Fiber Volume Fraction, Filler Volume Fraction

From figure 4, it can be seen that fiber volume fraction is (40%, 50% and 60%) the filler volume fraction (2%, 5%, 8%) with code level -1, 0, 1 sequentially, then from the response surface method optimization plot from the bending strength vs. fiber volume fraction, filler volume fraction, it can be seen that the bending strength value > 95 is between the points with the code of fiber volume fraction levels ranging from -0.5 to 0.5. While the value of bending strength > 95, for the volume fraction is located at the point with filler starting from code level -1 continues to increase to point 0.
8

From the visual observations in Figures 4 and 5 it can be seen that the variation of the optimal volume fraction against bending strength was obtained at the fiber volume fraction of 50% while the variation of the volume fraction decreases from the volume fraction 8%.

From the results of the study on the effect of fiber volume fraction and filler volume fraction obtained the greatest bending strength at 50% fiber volume fraction where bending strength increases with increasing fiber volume fraction and filler volume fraction but at the 60% of fiber volume fraction, the bending strength decreases; this is because the resin is not able to wet the fiber completely so that the bond between resin and fiber becomes weak.

Finding the optimum point using a quadratic model that has been stated according to the data and coding as the bending strength model obtained from regression testing, namely:

\[ Bending \ test = 99.6100 - 1.4339x_1 + 0.5107x_2 - 8.6506x_1^2 - 2.4756x_2^2 - 1.4325x_1x_2(4) \]

4. Conclusions

From the analyzed data, the appropriate regression equation is obtained for the experimental response, namely:

\[ y = 99.6100 - 1.4339x_1 + 0.5107x_2 - 8.6506x_1^2 - 2.4756x_2^2 - 1.4325x_1x_2 \]

Based on the analysis results using response surfaces, the best condition is obtained at 49.06% fiber volume fraction and 5.39% filler volume fraction with bending strength 99.71 N/mm². Response Surface method is an efficient method used to determine the levels of independent variables that can optimize response.
5. References

[1] X. Li, L. G. Tabil, and S. Panigrahi. 2007. Chemical treatments of natural fiber for use in natural fiber-reinforced composites: a review. Journal of Polymers and the Environment. 15 (1) 25–33.

[2] K.K. Chawla. 1998. Composite Materials. Springer Science and Media. New York.

[3] Q. Mu, C. Wei, and S. Feng. 2009. Studies on mechanical properties of sisal fiber/phenol formaldehyde resin in-situ composites. Polymer Composites. 30 (2) 131–137.

[4] N. Reddy and Y. Yang. 200. Preparation and characterization of long natural cellulose fibers from wheat straw. Journal of Agricultural and Food Chemistry. 55 (21) 8570–8575.

[5] Akil, H. M., Omar, M. F., & Mazuki, A. A. M. 2011. Kenaf fiber reinforced composites: A review. Materials & Design, 32 4107–4121.

[6] N. Liu, K. Huo, M.T. McDowell, J. Zhao, Y. Cuii. 2013. Rice husks as a sustainable source of nanostructured silicon for high performance Li-ion battery anodes. Scientific Reports. 3.

[7] Sun, L. & Gong, K. 2001. Silicon-based materials from rice husks and their applications. Ind. Eng. Chem. Res. 40 5861–5877.

[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. Suprapto, W. Suprapto. 2018. Minimization of corrosion rate using response surface methodology. Engineering Review. 38 (1).

[10] Montgomery., Myers., Raymond, H., Douglas C., Christine, M., Anderson., Cook., 2010. Response Surface Methodology Process and Product Optimization Using Designed Experiments. THIRDEDITION.

[11] ASTM. D 790 Standart Test Methods for Flexural Properties Of Unreinforced Plastics and Electrical Insulating Material. Philadelphia, PA : American Society for testing and materials.