Optimization for tensile strength of polyester composites reinforced by waru bark fiber with rice husk filler using response surface method

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Abstract. This research on the composite of Waru (Hibiscus tiliaceus) bark fibers aims to determine the optimum conditions for the tensile strength of polyester composites reinforced by Waru bark fiber with rice husk filler using the response surface method. The method used is to alkalize Waru bark by 5% NaOH soaking per 1 liter of water for 2 hours. The test object was made using the Hand Lay-Up and Compaction method, the ratio of fibers was 35.86%, 40%, 50%, 60% and 64.14% with filler 2.93%, 5%, 10%, 15% and 17.071 %. Tensile testing using standard ASTM D3039 and data analysis using response surface method. The test results show that the best conditions are at 57.131% fiber fraction and 10.73% filler volume fraction with a tensile strength value of 123.59 N mm⁻². The response surface method is an efficient method used to determine levels of independent variables that can optimize response.

Keywords: optimization, composite, fiber, Waru bark, response surface

1. Introduction
Composite or composite material is a material that is composed of more than two constituent elements. Composites are heterogeneous on a macroscopic scale. Each of these composites constituents has different properties, and when combined in a certain composition then new properties are formed which are adjusted to the wishes. Composite consists of a matrix as a binder and a filler as a composite filler. The advantages and benefits of composite materials are providing the best mechanical properties of the constituent components, light weight, corrosion resistance, economical, and insensitivity to chemicals [1].

The use of natural fibers as a reinforcing material for composite materials is because natural fibers are easy to obtain, inexpensive, and have many types and variations. Composites made of fiber (fibrous composite) are continuously researched and developed to become an alternative material to replace metal materials[2][3]. This is due to the nature of the fiber composite which is strong, and has a lighter weight than metal. The composition of the fiber composite consists of fibers and a matrix as the binding material. The properties of composite materials are strongly influenced by the properties and distribution of constituent elements, as well as the interactions between the two. Other important parameters that may influence the properties of the composite
material are the shape, size, orientation and distribution of the filler and various characteristics of the matrix. Mechanical properties are one of the most important properties of composite materials to study. For structural applications, the mechanical properties are determined by the choice of material. The mechanical properties of composite materials depend on the properties of the constituent materials [2]. The main role in fiber reinforced composites is to transfer stresses between fibers, provide resistance to adverse environments and protect the fiber surface from mechanical and chemical effects.

One of the natural fibers that can be used as composite reinforcement is the bark fiber of Waru tree. The bark fiber of the Waru tree (hibiscus tiliaceus) is a type of fiber derived from plants obtained from the bark of the Waru tree [2]. The bark fiber of the Waru tree is an alternative in making scientific composites, where the bark fiber of the Waru tree is known for its strength, and has good quality with a smooth surface. This fiber is also one of the natural fibers which availability is currently very abundant, but it is no longer used and disposed of as waste, even though the bark fiber of the Waru tree can still be used as an alternative natural fiber for composite materials.

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 [4,5]. The purpose of this study is to determine the optimum tensile strength conditions for the polyester composite of Waru bark fiber and rice husk filler using the response surface method.

2. Method
The research was conducted by experiment. In specimens making for tensile testing, the experimental design used was a factorial design of $2^k$ 2 levels and $k$ factor ($k = 2$, namely fiber volume fraction and filler volume fraction). While the data analysis used to test the hypothesis is the response surface method [5].

Materials used in the making of composites are polyester resin and catalyst, bark fiber of Waru tree, rice husk powder, NaOH solution with a concentration of 5% (wt%) NaOH.

2.1 Tensile testing
Tensile test is a mechanical stress-strain test which aims to determine the strength of the material against the tensile force or to obtain the modulus of elasticity of the fiber composites used in this study. The testing using the Universal testing Machine.

![Figure 1. Tensile Test specimens according to ASTM D3039 standard [6]](image)

2.2 Experimental design using response surface methodology (RSM)
The data obtained from the tensile test results are then processed with a mathematical model using the response surface method. The response surface method is a set of mathematical and statistical techniques that are useful for analyzing and optimizing the model. In this study there are two independent variables that are considered as variables that affect the tensile strength of
polyester composites, namely fiber volume fraction \((x_1)\) and filler volume fraction \((x_2)\). The experimental design used is a two-level \((2^k)\) factorial design. From the results of data processing using Minitab, the experimental data of tensile strength is obtained.

The independent variables in this study are fiber volume fraction (Waru bark) and filler volume fraction (rice husk). The experimental levels on each of the independent variables are coded such that the low level corresponds to -1 and the high level corresponds to 1 to make computation easier.

The dependent variable in this research is tensile strength with a fiber volume fraction of 35.86%, 40%, 50%, 60%, and 64.14%. The filler volume fraction are 2.93%, 5%, 10%, 15%, and 17.071%. The experimental design was carried out in accordance with the Design of Experiment with RSM CCD optimization. The level of the study is shown in Table 1.

### Table 1. Level code vs level value

| Level Code | -14142 | -1 | 0 | 1 | 1.4142 |
|------------|--------|----|---|---|--------|
| Fiber volume fraction | 35.85 | 40 | 50 | 60 | 64.14 |
| Filler volume fraction | 2.93 | 5 | 10 | 15 | 17.071 |

3. Result and discussions

The experimental results can be seen in Table 2. The experimental results testing with RSM was carried out by statistical testing of the experimental data obtained. The test is a residual test, normal distribution.

### Table 2. Data from the calculation of the composite tensile strength

| Fiber volume fraction (%) | Filler volume fraction (%) | \(\sigma t\) (Mpa) |
|--------------------------|---------------------------|------------------|
| 60                       | 15                        | 117.52           |
| 60                       | 5                         | 119.52           |
| 40                       | 15                        | 84.75            |
| 40                       | 5                         | 73.43            |
| 50                       | 10                        | 129.14           |
| 50                       | 10                        | 113.05           |
| 50                       | 10                        | 122.37           |
| 50                       | 10                        | 121.35           |
| 50                       | 10                        | 103.31           |
| 64.14                    | 10                        | 115.23           |
| 50                       | 17.0710                   | 112.25           |
| 35.86                    | 10                        | 65.35            |
| 50                       | 2.93                      | 95.57            |

3.1 Residual assumption testing

Testing of residual assumption, namely to check the adequacy of the model, not only takes into account the lack of fit, but also requires a residual analysis. The residual assumption consists of
two testing models, including identification testing and normality testing. This test is also a test that must be performed to find out whether the data used fulfills these two assumptions in conducting the test. The residual identities assumption checking, this test is performed to see whether the residuals fulfill the identical assumptions. A data is said to be identical if the residual plot spreads randomly and does not form a certain pattern [9].

![Residual test](image)

**Figure 2.** Residual test

Figure 2 showing the results of the Minitab, it can be seen that the red dots is a plot of the residuals versus fitted value of each specimen, the residuals are spread randomly around zero values and do not form a certain pattern. This situation indicates that the assumptions of the residual assumptions have been fulfilled.

### 3.2 Normal distribution

Testing the strength normality assumption is performed by Kolmogorov Smirnov test. The test results with a significance level of $\alpha = 0.05$ are shown in Figure 3. From the test results using the Kolmogorov Smirnov statistical value (KS count) is 0.985, while the Kolmogorov Smirnov value from the table (KS table) for $\alpha = 0.05$ and the number of observations 13 is 0.361. Because calculated $\text{KS} > \text{KS table}$, a square or quadratic regression model is accepted. This means that the model obtained has a normal distribution.

![Normality testing](image)

**Figure 3.** Strength normality testing

Testing the strength normality assumption is carried out by the Kolmogorov Smirnov test. The test results with a significance degree of $\alpha = 0.05$ are shown in Figure 4. From the test results using
the Kolmogorov Smirnov statistical value (KS count) is 0.985, while the Kolmogorov Smirnov value from the table (KS table) is for $\alpha = 0.05$ and the number of observations 13 is 0.361. Because calculated $KS > KS$ table, a square or quadratic regression model is accepted. This means that the model obtained is normally distributed.

3.3 Optimization of Composite Composition Using the Response Surface Method
The mathematical model of the response surface has identified the optimum composition of the composite to produce the best tensile strength. Composites making with variations in fiber volume fraction (35.85%, 40%, 50%, 60% and 64.14%) with filler volume fractions (2.93%, 5%, 10%, 15%, and 17.07%) which can affect the tensile strength of the composite has been predicted using the response surface method. The predictive contour plot for the tensile strength of polyester composites reinforced by the Waru bark with rice husk filler is shown in Figures 4 and 5.

![Contour Plot of Tensile Strength vs Fv fiber Fv filler](image)

**Figure 4.** Optimization plot of response surface method from tensile strength vs fiber volume fraction, filler volume fraction

![Surface Plot of Tensile Strength vs Fv Fiber : Fv Filler](image)

**Figure 5.** Surface plot response

Figure 4 shows a counter plot of tensile strength with a fiber volume fraction, namely (40%, 50% and 60%) the filler volume fraction, namely (5%, 10%, 15%) with a code level of -1, 0, 1, it can
be seen that the tensile strength value of each contour color has been predicted the value of its tensile strength. For the greatest tensile strength is > 120 between the points with the fiber volume fraction level code ranging from 0.5 to 1.0. While the tensile strength value > 120 Mpa, for the filler volume fraction will be obtained at the point where the filler starts from the code level-0.5 continues to increase until the point 0.5. Figure 5 shows Surface Plot of Tensile Strength Response Vs Fiber Volume Fraction, Filler Volume Fraction

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

To find out for the optimum point using a quadratic model that has been stated in accordance with the data and coding as the tensile strength model obtained from regression testing, namely

$$Tensile\,\,Strength= 116.620+18.686\,c_1 + 4.125 \, c_2 - 12.744 \, c_1 \, c_2 \, - 5.934 \, c_2^2 \, - 3.352 \, c_1 \, c_2$$

(1)

In which:

- $c_1$ = The value of the fiber volume fraction matrix
- $c_2$ = The value of the filler volume fraction matrix

Then the values of $c_1$ and $c_2$ are added into the quadratic mathematical model for optimal tensile strength, according to the optimal tensile strength values from the model that have been obtained as follows:

$$Tensile\,\,Strength = 116.620+18.686\,c_1 + 4.125 \, c_2 - 12.744 \, c_1 \, c_2 \, - 5.934 \, c_2^2 \, - 3.352 \, c_1 \, c_2$$

$$= 116.620+18.686(0.7131)+4.125(0.14605) -12.744(0.7131)(0.14605) -5.934(0.14605)^2$$

$$-3.352(0.7131*0.14605)$$

$$=123.17 \, N/mm^2$$

For the value of the optimal point obtained from the response surface using a fiber volume fraction of 57.131% with a filler volume fraction of 10.73%, a tensile test was carried out with the composition resulting in a tensile strength of 123.355 N/mm2. This value is close to the value in the calculation of tensile strength using the response surface method is 123.59 N/mm2. The results of the calculation of the tensile strength optimization are shown in Table 3.

Table 3. Value of optimal tensile strength test results with a fiber volume fraction of 57.131% and a filler volume fraction of 10.73%.

| Tensile strength (N/mm²) | average tensile strength (N/mm²) | STDEV |
|--------------------------|----------------------------------|-------|
| 123.56                   | 123.355                          | 0.28991378 |
| 123.15                   |                                  |       |

4. Conclusion
The regression equation that is suitable for the response to this research is:

$$y = 116.620+18.686\, c_1 + 4.125 \, c_2 - 12.744 \, c_1 \, c_2 \, - 5.934 \, c_2^2 \, - 3.352 \, c_1 \, c_2$$

Based on the results of the analysis using the response surface, it was found that the best conditions are the fiber volume fraction of 57.131% and the filler volume fraction of 10.73% with a tensile strength of 123.59 N/mm2. The response surface method is an efficient method used to
determine levels of independent variables that can optimize response. In this study, a CCD (Central Composite Design) was used. The CCD design is an experimental design consisting of a 2k factorial design with the addition of several center runs and axial runs.

5. References

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