Parameters optimization of bio composite manufacturing using experimental design

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Abstract. Indonesia is one of the banana producing countries that reaches millions of tons every year. With a huge number of banana production, the waste from banana trees, especially banana midribs, is also enormous. Banana midribs or pseudo-stem is known to have robust tensile strength and can be made miscellaneous products, such as composite materials. Composites are currently used in industry many times, especially in the construction industry as partitioning and ceiling material. The purpose of this study was to discover the optimal parameters in the manufacture of bio composite materials in an effort to utilize the pseudo-stem and environmental sustainability. This study began with conducting experiments, testing the tensile strength of composite materials, and calculating the experimental results. The method applied was the factorial experimental design to figure out the best parameters in the manufacture of composite materials. The results showed that from the 3 factors used, the fiber direction had the substantial contribution, followed by the pressing duration and the adhesive type. Meanwhile, the combination of factors and levels that produced the optimum parameters for tensile strength were by using the adhesive type on level 1, the fiber direction on level 1, and the pressing duration on level 2 which are polyvinyl acetate (PVAc), unidirectional, and 1 hour, respectively.

Keywords: ANOVA, banana pseudo-stem, bio composites, experimental design, tensile strength

1. Introduction
The Industrial Revolution 4.0 could be a hope and a challenge for the industry players, especially in the sector of environmental sustainability [1, 2]. Population growth, climate change, increased greenhouse gas emissions, and food and water needs are challenges in growing sustainability [3, 4]. Various industries are currently working to combine the principles of economics and biology in order to make effective and efficient existing raw materials for daily life and are known as bio-economic strategies [5-7]. Based on sustainable technology by utilizing biological resources, including organic waste, industrial products have begun to be produced with emphasis on protecting biodiversity and the environment [8, 9].

Banana is one of the biological resources in agriculture and plantation considerable potential for demand that shows an increasing trend over time [10]. Some parts of bananas can be used to fulfill the...
human needs today, but not with banana stem that are still rarely used and become waste. With a huge amount of banana production can imagine how much the amount of waste generated banana trees [11].

Based on several previous studies, banana stems are known to have a wide range advantages. Besides being an easily obtained and renewed material, in several studies it was also found that banana stem fiber has excellent tensile strength [12-15]. This study aimed to optimize the benefits of banana stems for producing composite materials that were environmentally friendly.

Various previous studies had been conducted on sustainable construction studies that use biological resources, including composites [16-18]. Composites had been used widely, especially in the construction industry, as well as the use of natural composites or bio composites [19-23]. Banana stems used as bio-composites also been studied previously with the analysis of several factors, including fiber and gluten [24-26]. However, until now still not found a study evaluating the use of banana stem as composites in partition material and optimization of influential factors.

Composites intended for partitions must have good tensile strength scores in order to withstand the load to be sustained [27, 28]. Therefore, this study had a score of tensile strength as the response variable represented the quality characteristics. By combining the waste of banana stems as a filler material (matrix) combined with certain reinforcing materials, it was expected to create an environmentally friendly bio-composite product for the sustainable of bio-economics.

2. Research Method

One way to improve quality is by engineering off-line quality using experimental designs [29]. In general, experiments are used to study the process and systems. In the experimental design there are various methods that can be used including simple random design, randomized complete block design, the latin square design, factorial design, taguchi and others. However, the method used in this study was factorial design.

Factorial design is an experimental method in which almost all levels of a particular factor are combined or crossed with almost all levels of each other factor in the experiment [30]. Aims to analyze alternatives both in terms of the production process and in terms of raw materials, so that it is expected to find the most optimal alternative parameters in order to fulfill the quality standards. Many experiments conducted involving two or more factors. In a factorial experiment, all possible combinations of factor levels are tested. The steps in conducting an experiment are shown in Figure 1.

![Figure 1. Experiment procedure.](image-url)

The initial phase was the identification of problems based on observations and theoretical relating to this study. The second phase was experimental planning of constructing research designs for
experiments. The third phase was the implementation of experiments and continued with a statistical analysis until drawing the conclusions and the recommendations.

2.1. Experimental Planning
This phase constructed a research design including the identification and quantification of the factors and levels, the selection of response variable and experimental design. Experiments were conducted by creating specimens and randomly selected as many as 10 pieces of test samples with various combinations of factors and factors levels used.

Based on the results of prior literature, there were several factors that are considered influential, such as the type of banana, type of adhesive, adhesive content, fiber direction, pressing time, and drying time. From these factors, three factors were chosen as independent variables or treatment factors in this study, i.e. the type of adhesive, the fiber direction, and the pressing duration. Other factors were not chosen because the results of the analysis of the foregoing studies had been discovered for the optimal conditions.

The factors that had been determined in this study for example were the types of bananas. The selected type was Kepok banana (Musa paradisiaca), because the banana fiber of that banana has good mechanical properties, which has an average tensile strength of 600 MPa [31, 32]. Glue levels were also not selected and the level of 20% was determined in this study, because these levels have impact strength and high hardness rates [33]. The drying time factor was considered as a noise factor, because relied on weather and sunlight. So that the composite was completely dry and ready for use, the specimen was allowed to stand for 1 night in this study.

The first factor used was the type of adhesive, A factor, using polyvinyl acetat (PVAc) glue and polyester resin as levels 1 and 2 [34-36]. The second factor was the banana stem gluing technique, B factor, including unidirectional and bidirectional as levels 1 and 2 as shown in Figure 2 [37-39]. The third factor was the duration of pressing, C factor, which were 30 minutes and 60 minutes as levels 1 and 2 [40, 41].

The nature of the composite material is strongly influenced by the nature of its constituent materials, which in this study are banana pseudo stem (stem). The role of banana stem in the composite material to be made is as a reinforcing fiber (filler). Fiber contribution largely affects the tensile strength of composite materials [42-44]. Therefore, the dependent variable or response used in this study was the tensile strength of composite materials to determine the effectiveness of banana stem as composite reinforcing fibers.

Replication calculation is one important step prior to the experiment because it can provide a better estimate of the average effect of a factor [45]. The formula used in the calculation of replication is shown in Eq. 1.

\[(t - 1)(r - 1) \geq 15\]  

Where \(t\) and \(r\) are the number of treatments and replications. From the calculation results obtained replication amount was greater than 9, so the number of specimens or replication to be performed in a single treatment combinations were as many as 10 times.

The final phase in experimental planning is the determination of experimental design type. In this study, factorial design methods \(2^3\) with 2 and 3 showed the number of levels of each factor and the number of factors used. This method was chosen because the experiment conducted was a new experiment that has never been done before. Meanwhile, the composite material of banana stem is a...
new material design that has never existed before. Therefore, the use of factorial design was very suitable for analyzing the bio composite material of banana stem.

The efficient experiments are experiments with a small number of factors and treatment combinations [46]. Determination of factor levels can be conducted by considering the level points that indicate extreme values, which are taken as many as 2 factor levels with the highest and lowest values [47].

Factorial design was used in this experiment to determine the effect of a combination of all factors on the response variable, so that more detailed results and data analysis were obtained. After obtaining several influential factors along with their factor level, then the treatment combination was determined. The various experimental treatment combinations performed are shown in Table 1. The total number of specimens to be made was 80 units which were divided into 8 types of treatment combinations.

| Factors                  | Fiber directions (B) |
|--------------------------|----------------------|
|                         | Unidirectional (B1)  | Bidirectional (B2) |
| Pressing duration (C)    | 30 min (C1)          | 60 min (C2)        |
| Adhesive type            |                      |                    |
| Polyvinyl acetate (A1)   | A1, B1, C1 (10 replication) | A1, B1, C2 (10 replication) |
| Resin polyester (A2)     | A2, B1, C1 (10 replication) | A2, B2, C1 (10 replication) |

2.2. Conducting The Experiments

In manufacturing bio composite materials, several things that be prepared were the tools and materials used. The materials required were dried banana stem, adhesives, molds, containers, and press machines. Bio composite material manufacturing consisted of several processes, starting from preparing experimental material, gluing, pressing, drying process, and specimen formation.

At the material preparing phase, obtained from the banana stem waste cleaned beforehand to obtain clean and well layers, then separated each page. The layers of banana stem or banana sheath used were already quite old and had turned slightly greenish (Fig. 3). Banana stems that had been separated and then dried through the drying process with the same light intensity and temperature of approximately 29°C Celsius and an average moisture content of 10%. The long drying time was approximately 2 days to get a dry banana stem to facilitate the gluing process. The dried banana fronds were cut according to the size of the specimen made and split to take the outer skin to obtain a solid composite specimen, so that the adhesive could function optimally.

![Figure 3. The composite manufacturing process: (a) Peeling, (b) Pressing, (c) Drying](image)
strength test aimed to determine the extent of the strength of the material against the tensile force applied to the material. Before testing, the specimen had been made according to ASTM D 638M-84M-1 which was composite test material testing standards for Tensile Properties of Plastics. The size and design of the specimen are shown in Table 2.

| Dimensions          | Length (mm) | Tolerance (mm) |
|---------------------|-------------|----------------|
| W: Width if narrow section | 13          | ± 0.5          |
| W0: width of overall      | 19          | ± 0.5          |
| Lo: length of overall    | 165         | No max         |
| G: gage length           | 50          | ± 0.25         |
| D: distance between grips| 115         | ± 0.5          |
| R: radius of fillet      | 76          | ± 1            |

The equation used in the tensile strength test in this study was written in Eq. (2) where $F_t$, $P$, $B$, and $H$ were the tensile strength, maximum load, width, and height of the specimen.

$$F_t = \frac{P}{B \times H} \text{(MPa)}$$ \hspace{1cm} (2)

3. Results and Discussion
The results of the tensile strength test of the material were gathered for further analysis. Calculating the average score and analysis of variance (ANOVA) performed in this analysis. Table 3 represents data for the results of tensile strength test for banana stem as bio-composite materials in Mpa that had been calculated using Eq. (2).

| Factors                  | Fiber Direction (B) |
|--------------------------|---------------------|
| Pressing Duration (C)    | Unidirectional (B1) | Bidirectional (B2) |
|                          | 30 min (C1) | 60 min (C2) | 30 min (C1) | 60 min (C2) |
| Adhesive type (A)        | PVAc (A1)     |              |              |              |
|                          |              |              |              |              |
|                          | 54.81        | 63.70        | 44.44        | 55.56        |
|                          | 57.04        | 59.26        | 45.93        | 52.59        |
|                          | 54.81        | 60.74        | 44.44        | 53.33        |
|                          | 57.04        | 66.67        | 45.93        | 51.85        |
|                          | 59.26        | 62.22        | 48.89        | 56.30        |
|                          | 56.30        | 62.22        | 53.33        | 57.04        |
|                          | 55.56        | 55.56        | 48.89        | 54.07        |
|                          | 55.56        | 57.78        | 47.41        | 51.85        |
|                          | 56.30        | 61.48        | 47.41        | 50.37        |
|                          | 58.52        | 60.74        | 45.93        | 55.56        |
| Resin polyester (A2)    |              |              |              |              |
|                          | 54.07        | 62.96        | 41.48        | 48.15        |
|                          | 55.56        | 59.26        | 42.22        | 47.41        |
|                          | 53.33        | 56.30        | 38.52        | 48.89        |
|                          | 52.59        | 58.52        | 40.00        | 51.85        |
|                          | 54.81        | 62.22        | 39.26        | 48.15        |
|                          | 53.33        | 55.56        | 42.22        | 48.89        |
|                          | 52.59        | 57.04        | 40.74        | 49.63        |
|                          | 52.59        | 57.04        | 39.26        | 48.15        |
|                          | 57.78        | 62.22        | 41.48        | 44.44        |
|                          | 53.33        | 58.52        | 40.74        | 45.93        |

The results of the average calculation indicated which level of factors was more influential on the response variable. Table 4 is the average calculation result for both the factor and factor level.
Table 4. Response For Experimental Average Score

| Level | Factor | A     | B     | C     |
|-------|--------|-------|-------|-------|
| 1     |        | 54.67 Mpa | 57.63 Mpa | 49.59 Mpa |
| 2     |        | 50.43 Mpa | 47.46 Mpa | 55.50 Mpa |
| Deviation |  | 4.24 | 10.17 | 5.91 |
| Ranking | | 3    | 1    | 2    |

Furthermore, the ANOVA calculated to determine the factors that influenced the response variable. Through this calculation, it could also be discovered the percentage contribution each factor and the influence of interactions between factors on the response variable. ANOVA results can be seen in Table 5.

Table 5. ANOVA Result

| Source of Variation | SS    | df | MS    | SS'   | Rho % | F     | Ftable | Conclusion |
|---------------------|-------|----|-------|-------|-------|-------|--------|------------|
| A                   | 359.68| 1  | 359.68| 354.78| 9.90  | 73.39 | 3.97   | Rejected H0 |
| B                   | 2,067.22 | 1 | 2,067.22 | 2,062.32 | 57.55  | 421.80 | 3.97   | Rejected H0 |
| AB                  | 75.62 | 1  | 75.62 | 70.72 | 1.97  | 15.43 | 3.97   | Rejected H0 |
| C                   | 697.95 | 1  | 697.95 | 693.05 | 19.34 | 142.41 | 3.97   | Rejected H0 |
| AC                  | 2.48 | 1  | 2.48 | -2.42 | -0.07 | 0.51  | 3.97   | Accepted H0 |
| BC                  | 27.22 | 1  | 27.22 | 22.32 | 0.62  | 5.55  | 3.97   | Rejected H0 |
| ABC                 | 0.34 | 1  | 0.34 | -4.56 | -0.13 | 0.07  | 3.97   | Accepted H0 |
| Error               | 352.87 | 72 | 4.90 | 387.17 | 10.8  |       |        |            |
| Mean                | 220,889.06 | 1 | 220,889.06 | 220,889.06 | 100   |        |        |            |
| Total               | 224,472.43 | 80 |       |       |       |        |        |            |

ANOVA and the average score of the bio composite experimental data were then performed to determine the effect of the three types of factors used along with the influence of each factor on the response variable. The ANOVA results for the hypotheses are explained as follows.

The hypothesis test disclosed that A, B, C, AB and BC factors have a F calculated > F table indicating that there was a significant influence on the tensile strength of bio composite materials. As for AC and ABC factors, it had a F calculated < F table, so it concluded that of the two there was no significant effect on the tensile strength of composite materials. Based on the percent contribution (Rho %), B factor, the fiber direction, had the highest contribution percentage which was 57.55%, then C and A factors, pressing duration and adhesive type, were 19.34% and 9.90%. Therefore, the fiber direction had the most significant influence on the tensile strength of bio composite materials compared to other factors.

Furthermore, if based on the average tensile strength score for the bio composite materials in Table 3, each factor had been ranked and the average response score calculated to find a more dominant level. For the factor of adhesive type, the level that produced a greater tensile strength score was PVAc, while for the fiber direction was unidirectional, and the pressing duration is for 1 hour. The best combination to make a bio composite material from banana stem obtained in this study was to use a type of adhesive, fiber direction, and pressing duration which were PVAc, unidirectional, and 1 hour, respectively.

The adhesive factor was an important element in manufacturing composites, because it is one of the constituent components (matrix). The type of adhesive used directly impacts the mechanical strength of the material. Rigid nature is needed to withstand all work loads, whereas composites are generally thin, so they require stiffness [51]. In this study, PVAc and polyester resin were used as adhesives. Both are actually commonly used in wood gluing processes and have good characteristics as adhesives, but the results of experimental tests showed that PVAc had better tensile strength than polyester resins. PVAc is a polymer that has a very strong adhesiveness and often used as a basic
material for making fabric, paper and wood glue. PVAc has odorless, non-flammable, and solid properties [52]. In addition, PVAc is also a material that is friendly and safe for the environment, because it does not contain formaldehyde.

Banana stem fiber was also an important factor in this experiment. Banana stem fibers are relatively thin, but has a strong endurance, so it serves as a reinforcing fiber. The main role in the composite fiber is to move the tension or stress between the fibers, provides resistance to adverse environments and keeping the fiber surface from mechanical effects [53]. In general, fiber orientation or direction is divided into unidirectional and bidirectional which were also applied in this experiment [54]. The experimental test results found that the composition of the unidirectional of fiber direction structure had a stronger material appeal than bidirectional. This was because the mechanical properties of composites globally would change if the direction of the lamina layer reinforcement fibers changed, so if the direction of the fibers was arranged bidirectionally, it caused lower tensile strength compared to unidirectional.

The pressing duration was the last factor observed in this study. The pressing time can increase the bending and tensile strength of the composite, but decrease the impact strength of the composite. Determination of the factor level on the pressing time factor considered the extreme value that used in the pressing time of the board and bamboo laminating producing process, which was 30 and 60 minutes. The experimental test results showed that the pressing time for 60 minutes was better than 30 minutes. This was because the longer pressing time makes the banana stem material and glue that had been arranged more sticky, so the material had a denser texture and gave a more optimal tensile test score.

The results of this study were expected to be used as a basis for the implementation of future work where there will be more involvement of factors and level of factors in the experiment. In addition, the quality criteria for composite materials are known not only to be measured based on the tensile strength characteristics, but also other quality criteria such as physical and mechanical tests. Enhanced studies on environmentally friendly materials or bio materials that combine economic and biological principles in order to make effective and efficient existing raw materials for daily life are expected to be a bio-economic sustainability strategy.

4. Summary

The factors used in experiments for the manufacture of bio composite materials made from banana stem were obtained through observation and literature review. Three kinds of factors selected were adhesive type, fiber direction and pressing duration.

Through Anova and the average score obtained the best combination or the optimal setting parameter of three factors used. First on factor A, the adhesive type, PVAc was used. The calculation of the average score of the response variable, tensile strength, showed PVAc had an average score greater than polyester resin, which was 54.67 MPa. For factor B, the fiber direction, the setting level of the more dominant factor was located at level 1, which was in the unidirectional with an average score of 57.63 MPa. As for factor C, the pressing duration, obtained level 2, 1 hour, as the most optimal level with an average response score of 55.50 MPa.

The results of factorial experimental design $2^3$ also showed that the largest percent contribution to the average response score was B factor, the fiber direction, by 57.55%, followed by C and A factors, the pressing duration and the adhesive type, by 19.34% and 9.90%, respectively. Therefore, it could be concluded that the most influential factor on the tensile strength score of the banana stem composite material was fiber direction.

Future work will be conducted further study with the addition of factors or factors levels in order to obtain a more diverse combination of factors. In addition, it will be also made more diverse tests in order to obtain more detailed data on the strength of bio composite materials.

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